ECOLOGICAL STUDY OF BRAHMAPUTRA RIVER FLOODPLAIN IN SELECTED AREAS OF MAJULI AND KAMRUP AND POTENTIAL BIORESOURCE UTILIZATION PERSPECTIVES

by

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Requirements for the Degree of

DOCTOR OF PHILOSOPHY

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DECLARATION

It is to declare that the matter embodied in this thesis entitled ***"Ecological study of Brahmaputra river floodplain in selected areas of Majuli and Kamrup and potential bioresource utilization perspectives"*** is the result of investigations carried out by me under the supervision of **Dr. Utpal Bora, Department of Biotechnology** and **Professor Chandan Mahanta**, **Department of Civil Engineering** and is submitted to the Indian Institute of Technology Guwahati, Guwahati-781039, Assam, India for the award of degree of Doctor of Philosophy in Biotechnology. This work has not been submitted elsewhere for any degree or diploma of any institute or university to the best of my knowledge and belief.

In keeping with the general practice of reporting scientific observations, due acknowledgements have been made wherever the work of other investigators are referred, and copyright licenses have been taken from respective publishers.

Guwahati **NAYANMONI GOGOI**

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CERTIFICATE

It is to certify that the matter embodied in this thesis entitled ***"Ecological study of Brahmaputra river floodplain in selected areas of Majuli and Kamrup and potential bioresource utilization perspectives"*** is the result of investigations carried out by **Ms. Nayanmoni Gogoi** (Roll No.: 09615201) under my supervision, and is submitted to the Indian Institute of Technology Guwahati Guwahati-781039, Assam, India for the award of degree of Doctor of Philosophy. This work has not been submitted elsewhere for a degree.

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DEDICATION

मातृ देवो भव:

Honor thy mother as God

पितृ देवो भव:

Honor thy father as God

आचार्य देवो भव:

Honor thy teacher as God

Dedicated to

my mother Smt. Lily Gogoi

my father Sri. Satyendra Nath Gogoi

and

all my teachers

Nayanmoni Gogoi

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My thesis would not have been complete without the blessings of my ***"parents,"*** my family members and ***best friends***. I am indebted to my parents for protecting me in the tough times of sample collection in Majuli River Island. I owe my well – being to the affection and blessings of my ***elder brothers***, ***sister - in - laws*** and eternal love of my nieces – ***Arni*** and ***Aishani***. I appreciate my friends for making my life joyful, productive and memorable in IITG.

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July, 2014 ***Nayanmoni Gogoi***

Synopsis

A primary objective of ecological monitoring programs is to detect changes in ecosystem functions and processes. Healthy ecosystem functions are the key components to balanced ecosystem services. The value of ecological resources may be determined from primarily two perspectives – the value to humans and the value to ecological entities. Land forms and water bodies are the foundations of ecological services in the form of food, shelter, breeding areas, migratory pathways, movement corridors, etc. Assessment of ecological status is necessary to find out the fate of ecological entities and their response to the changing environmental conditions. Rapid urbanization and landuse activities provide an impending challenge to sustenance of a healthy ecosystem. Under increasing episodes of environmental degradation, ecological resilience seems to be ineffective. In this context, proper ecological monitoring, best management practices and sustainable use of ecosystem services would be helpful in reducing natural and man – made stress to the ecological components.

In this study, two ecologically sensitive areas were taken into consideration, Majuli River Island and Kamrup (Amingaon and Umananda River Island), in Brahmaputra floodplain, Assam, India. Majuli is one of the world's largest river islands having rich natural and cultural heritage and characteristics of a mainland as well as an isolated island ecosystem. It acts as a microcosm floodplain unique of its kind. Majuli is a highly flood inundated area, the productivity of wetlands and adjoining areas was evaluated as a major component of ecosystem function with special emphasis on water, soil and vegetation component. The productivity factor in Majuli lying in the upper – middle region of Brahmaputra floodplain was compared to the productivity scenario in Kamrup (Amingaon and Umananda River Island) lying in the lower Brahmaputra floodplain. Amingaon is a mainland with high urbanization and industrialization events

at the bank of Brahmaputra River. On the other hand, Umananda River Island represents a comparatively small island ecosystem in comparison to Majuli River Island with concurrence of high pilgrimage activities. The gradient of Brahmaputra River combined with topography differentiates the ecological properties of Majuli from Amingaon and Umananda in Kamrup. Thus depending on the topography and geographical separation, floodplain characteristics of Majuli River Island was studied as a comparative consideration with those of Amingaon and Umananda River Island. The research investigations were divided into two sections:

Part A – *Ecosystem functions* redefining the ecological processes under ecosystem ecology. This section included monitoring of water and soil quality. Soil productivity in terms of CNP stoichiometry, microbial population, microbial biomass and soil enzyme activities was assessed in Majuli, Amingaon and Umananda in Kamrup. Furthermore, pollution indexing was performed to assess the impact of metal concentration in the environment. Finally comparative assessment of the investigated parameters and in connection to that, existence of spatial variability and its influence on geochemical parameters was studied.

Part B – *Bioresource utilization* aiming at green synthesis of gold and silver nanoparticles from plant extracts obtained from endemic plant resources in Brahmaputra River floodplain. This section demonstrated a sustainable and environmental friendly method of bioresource utilization from some indigenous plants having traditional medicinal importance. Green synthesis or biologically mediated gold and silver nanoparticle synthesis included two important requirements, a) reducing capability and b) capping efficiency, due to presence of phytochemicals. Silver nanoparticles recognize extensive utilization in designing filters that are based on

triggering the major water contaminants (coliform and disease causing bacteria). In this context, antimicrobial activity was checked against *Escherichia coli* MTCC 443, with green synthesized and biofunctionalized silver naoparticles.

It has been observed that wetlands in Majuli River Island are vulnerable to flood, erosion, sediment deposition, tourism and occupational activities. Similarly industrialization and urbanization activities in Amingaon and frequent tourism events in Umananda seem to render the water and soil unfit for human habitation as well as existence of other living organisms. Assessment of the status of ecological parameters will enable us to establish a baseline for further research and its implementation in decision making processes. Evaluation of pollution indices will provide a better understanding of ecological risk due to high metal concentration in water and soil. Geostatistical analysis will further focus on the spatial attributes amalgamated with soil properties to assess the variability of parameters among the study areas. Moreover, Brahmaputra River floodplain represents a huge consortium of plant genetic resources of high endemic origin and ethnobotanical values. Considering the outputs of prevalent conventional methods of bioresource utilization, green synthesis of nanoparticles has been prioritized based on literature review, the medicinal value of plants and the occurrence of pathogenic bacteria in the environment.

Ecological studies of riverine ecosystem have been successfully assessed all around the world to meet the demands and adversities of nature and human interventions, adopt mitigation strategies for developing a better and sustainable way for living with the available resources. To accomplish the same, the research work was finalized into two sections as aforementioned and subdivided into four main objectives. The details are given below:

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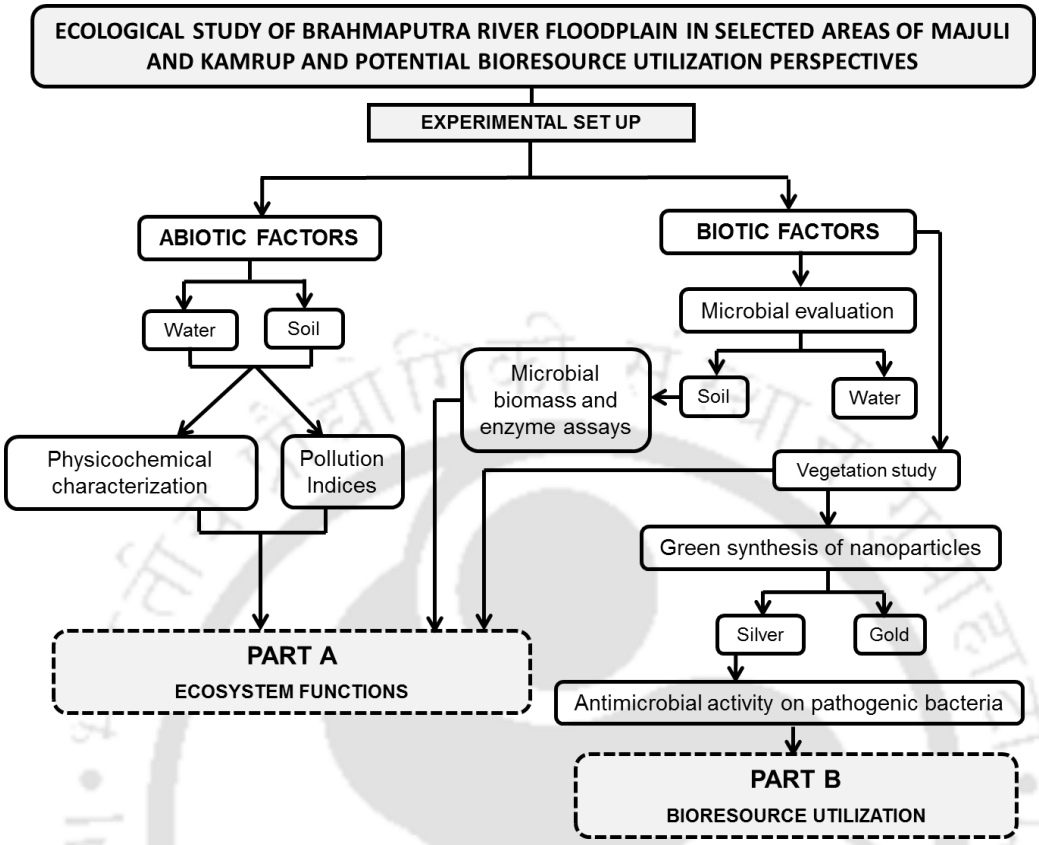

Figure 1 *Flow chart showing the objectives based on the concept of evaluation of ecological status and bioresource utilization, in Brahmaputra River floodplain*

Part A: Ecosystem functions

1. Analysis of floodplain characteristics vis-à-vis ecosystem support mechanism and evaluation of soil productivity as a function of nutrient cycling
2. Assessment of metal status and pollution indices in water and soil in Brahmaputra River floodplain
3. Comparative assessment of geochemical parameters in two soil typologies i.e. Majuli in the middle stretch and Kamrup in the lower stretch of Brahmaputra River floodplain

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Part B: Bioresource utilization

4. Green synthesis of gold and silver nanoparticles using plant extracts from indigenous plants in Majuli and Kamrup and antimicrobial studies of silver nanoparticles obtained by green synthesis

Based on the above mentioned objectives the thesis outline was prepared as follows:

TITLE: ***Ecological study of Brahmaputra river floodplain in selected areas of Majuli and Kamrup and potential bioresource utilization perspectives***

Chapter 1: Introduction and review of literature

Part A: Ecosystem Functions

Chapter 2: Analysis of floodplain characteristics vis-à-vis ecosystem support mechanism and evaluation of soil productivity as a function of nutrient cycling

Chapter 3: Assessment of metal status and pollution indices in water and soil in Brahmaputra River floodplain

Chapter 4: Comparative assessment of geochemical parameters in two soil typologies i.e. Majuli in the middle stretch and Kamrup in the lower stretch of Brahmaputra River floodplain

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Part B: Bioresource Utilization

Chapter 5: Green synthesis of gold and silver nanoparticles using plant extracts from indigenous plants in Majuli and Kamrup and antimicrobial studies of silver nanoparticles obtained by green synthesis

Chapter 6: Summary and future prospects

Chapter 1 gave a brief introduction of the concept of ecosystem functions and its significance in a riverine floodplain. Assessment of ecological status of riverine floodplain is necessary to find out the association between biological indicators and immediate surroundings for balanced ecosystem services. Review of literature focused on the present status of ecological study in the study areas, Majuli River Island and Kamrup in Brahmaputra River floodplain. Studies on geomorphological and geophysical aspects of Majuli River Island have been reported by a few workers. Most of the findings are available as online articles. Majority of the outcomes at the grass root level have not been reported, however developmental activities have been conveyed by Block Development reports, Department of Agriculture, Brahmaputra Board and local people in Majuli. Available literature showed that research in Kamrup is focussed on biodiversity, water and soil health. A huge survey on ethnobotanical properties plant species has been carried out in different regions of Kamrup. Socioeconomic studies have also been prioritised in Kamrup.

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Part A: Ecosystem functions

Chapter 2 involved the physical, chemical and biological components in Majuli River Island in two study periods, pre-monsoon (April, 2011) and monsoon (August, 2011). 20 water samples and 12 soil samples were collected in each season. Water samples were collected form 12 wetlands, 2 water bodies, 4 ground water samples and 2 river water samples (Brahmaputra River at two banks). Samples were further grouped as – a) residential area, b) grassland, c) agricultural field, d) ground water and e) surface water based on land use activities and geomorphic origin. 12 soil samples were collected from the water sampling sites including 2 bank sediments. Wetland soil samples were collected at 5 depths i.e. from surface to 100 cm excluding the bank sediments. Soil samples were also grouped as – a) residential areas, b) grasslands and c) agricultural fields and d) river banks. Soil sampling in Kamrup (Amingaon and Umananda) was performed in the following year, in pre-monsoon (April, 2012) and monsoon (August, 2012). Soil samples were grouped as – a) disturbed, b) undisturbed and c) bank sediments depending on similar criteria adopted in Majuli sampling procedure.

Physiochemical and geochemical characterization of water and soil samples were performed according to standard operating procedures and methods previously reported by researchers (ASTM and APHA). Microbial component was evaluated as Most Probable Number (MPN) of coliform bacterial cells in water samples, soil microbial colony forming unit (bacterial and fungal) and soil microbial biomass (CNP) in soil. Soil analysis included additional characterization as soil enzymatic assays, moisture content, particle size distribution, Cation Exchange Capacity (CEC), metal detection by EDX and soil digestion for analysis of trace elements. Vegetation study

included quadrat sampling method where abundance and frequency of occurrence of plants species was estimated. High abundance of *Hemarthria* sp. (grass) followed by *Cynodon dactylon* was observed in most of the wetlands. Vegetation in Kamrup (Amingaon and Umananda) was similar to Majuli River Island. Statistical analyses included regression and correlation studies.

Results showed that physicochemical and geochemical parameters in Majuli were within the permissible limits given by BIS, ICMR and WHO except in a few samples where turbidity and fluoride were remarkable. Microbial evaluation gave an overview of coliform species in water samples and bacterial and fungal population in soil samples. Among water samples, residential and ground water samples showed considerable levels of physicochemical parameters. Particle size distribution provided the sandy clay loam nature of soils in Majuli as well as in Kamrup (Amingaon and Umananda) pertaining to sediment transport and natural geomorphology. Soil organic matter was significantly higher in Kamrup and soil microbial biomass in each study area was in the range of 2 – 10%. Overall CNP stoichiometry was higher in Kamrup soil samples. In addition to CNP status, soil enzyme activities revealed a similar trend of incidence in Kamrup followed by Majuli. The activities of enzyme in ascending order followed a trend, cellulase > amylase > invertase > urease > protease > dehydrogenase > phosphatases in Majuli and Kamrup. Correlation studies and regression analyses projected SOM and MB as two dependent variables having functional relationship. Fertility and productivity in terms of CNP status, microbial population, microbial biomass and soil enzyme activities, was prominent in terrestrial sediments and inconspicuous in river bank sediments. Depthwise variation (0 – 100

cm) was evident in Majuli soil samples. Group C (agricultural fields) in Majuli and Group A (undisturbed area) in Kamrup showed significant activity as a response to physicochemical and geochemical characterization of ecological parameters. Seasonal variance was minimal but effective in the study areas. Overall experimental analyses summarized Kamrup as more productive ecosystem in comparison to Majuli.

Chapter 3 covered the outputs of assessment of metal status in Brahmaputra floodplain extensively highlighting the pollution potential and ecological risk assessment. Single pollution indices included Relative abundance (RA), Contamination Factor (C_f), and Geoaccumulation Index (I_{geo}). Integrated pollution indices involved Contamination Degree (C_d), Pollution Load Index (PLI), Nemerow's Pollution Index (NPI) and Potential Ecological Risk Index (PERI).

In Majuli River Island total Fe, Mn, Cu and Pb were evident in water samples. In soil samples, RA was higher for total Fe at all the sampling depths followed by Cu or Mn. Presence of total Fe, Cd and Pb was conspicuous in Kamrup. Depthwise variation of metal concentration in Majuli soil samples was possibly connected to discrepancy of CNP stoichiometry status with increasing depth (discussed in Chapter 2). C_f and I_{geo} in all cases were low except for Cu and total Fe. PLI and C_d showed optimum to moderate values in both the sampling periods. NPI revealed that water samples were moderately polluted owing to high turbidity in pre-monsoon season. PERI indicated low potential risk due to presence of metals in soil samples. A generalized conclusion drawn from the investigation indicated that enriched metal concentration was significant in Kamrup, however Umananda soil samples showed lower concentration of total Fe. Bank sediments in each study area presented low metal

concentration except Ni in Majuli. Overall analysis suggested that pollution indices were remarkable in samples collected from agricultural fields followed by residential areas in Majuli. While in Kamrup disturbed and undisturbed samples had almost equivalent metal concentration. Total Fe, Mn, Cu, Cd and Pb were prominent in pre-monsoon and monsoon seasons respectively.

Chapter 4 provided a comparative assessment of Brahmaputra River floodplain characteristics based on geochemical parameters analysed in both Majuli and Kamrup. Physicochemical, geochemical and biological analyses were performed in soil samples from Amingaon and Umananda River Island in Kamrup as a different soil typology. Methods of analysis included measurement of frequency distribution and dispersion; co-efficient of variation (CV) (%); Principal Component Analysis (PCA); variance between upland and lowland soil parameters by semivariograms based on Nugget to Sill ratios or degree of spatial dependence (DSD) (%) run by a semivariogram spherical model run in Arc GIS 9.2 (Geo Analyst tool pack); and documentation of spatial variability by kriging and generation of coloured contour maps in Arc GIS 9.2.

Skewness and kurtosis confirmed the asymmetrical nature of experimental data in Majuli as well in Kamrup. Mean values and corresponding standard deviation incidences of geochemical parameters were higher in Umananda and Amingaon in Kamrup. CV (%) indicated a link between skewed nature of data and some kind of spatial variability among geochemical parameters in Majuli, Amingaon and Umananda. Quartile distribution supported the results obtained from frequency distribution statistics. Principal Component Analysis (PCA) gave an overview on the variability among the sampling location based on geochemical parameters and prevailing soil

properties. Geostatistical analysis involving semivariogram spherical model showed significant DSD (%) of geochemical parameters depending on spatial variability in the study areas. Comparative analysis indicated a clear difference between the two soil typologies lying in the upper – middle and low lying regions in Brahmaputra River floodplain respectively.

Part B: Bioresource utilization

Chapter 5 included screening of native plants from Majuli River Island and Kamrup to synthesize gold and silver nanoparticles as a major initiative towards logical bioresource utilization trend. The main objective was to synthesize stable nanoparticles from the local indigenous by an eco-friendly, cost effective and sustainable method and check the antibacterial activity of silver nanoparticles against pathogenic coliform bacteria. In this context, synthesis, characterization and applicability of gold and silver nanoparticles in antibacterial activities were studied in detail. Gold and silver nanoparticles were synthesized from local plants of medicinal importance. *Nyctanthes arbortristis* flower extract and *Amaranthus spinosus* leaf extract were employed to synthesize gold nanoparticles and *N. arbortristis* flower extract was utilized in synthesizing silver nanoparticles. UV – visible spectroscopy and Transmission electron microscopy (TEM) confirmed the successful reduction of metallic ions to nanoparticles. Crystalline nature of the nanoparticles was determined by X – Ray Diffraction (XRD) analysis. Phytochemicals present in the EFE were adsorbed on the surface of the nanoparticles, evident as distinct Infra – Red bands in the Fourier Transform Infra – Red (FTIR) spectrum. TEM micrographs showed that gold nanoparticles synthesized from extracts of *N. arbortristis* and *A. spinosus* were around

19.8 nm and 10.74 nm respectively and silver nanoparticles synthesized from *N. arbortristis* flower extract were approximately 9.5 nm. Smaller size range of gold and silver nanoparticles makes them desirable for most of the therapeutic applications and water treatment processes. Finally silver nanoparticles were checked for antibacterial activity against pathogenic strain of *Escherichia coli* MTCC 443. Results showed positive antimicrobial activity with silver nanoparticles synthesized by green synthesis method.

Chapter 6 described an overall summary of the investigations carried out and provided a scope for further research. Majuli River Island represented a pristine ecosystem when compared to Kamrup lying in the lower Brahmaputra floodplain, from productivity and pollution perspective. Wetland and ground water quality were found within the permissible limits set by BIS, ICMR and WHO except turbidity, fluoride, total Fe and Mn.

The mean altitude from sea level is 85 – 90 m in Majuli and 35 – 55 m in Kamrup, this variation in altitude explained the gradient of Brahmaputra River amalgamated with topography that directs its downstream flow. Thus river flow dynamics indicated a differential sediment deposition event in the study areas i.e. Majuli and Kamrup (Amingaon and Umananda). In view of the nutrient discrepancy in upstream floodplain in Majuli and downstream floodplain in Kamrup, the soil typologies in these two places were anticipated to differ in terms of soil properties, fertility, productivity and pollution load corresponding to the steepness of the river. Keeping this in consideration, analysis performed as an essential requirement of ecosystem functions revealed that at a global scale Majuli and Kamrup (Amingaon and

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Umananda) were moderately productive zones, soil quality was however less productive in Majuli than the lower Brahmaputra zone. Outcomes of pollution risk assessment was variable in the two study areas. I_{geo} for Cu and total Fe was higher in Majuli as well as in Kamrup. Furthermore Kamrup showed relatively higher values of C_d, PLI, NPI and PERI than Majuli.

In bioresource utilization section, two medicinally important plants – *N. arbortristis* and *A. spinosus* were employed to synthesize gold and silver nanoparticles. Characterization of gold and silver nanoparticles was performed according to standard methods of assessment of optical and physical properties of nanoparticles. Silver nanoparticles synthesized from *N. arbortristis* flower extract showed effective antibacterial results.

There is a possibility for further research on ecological perspective in Majuli and Kamrup (Amingaon and Umananda). The soil microfauna contributing to wetland productivity can be screened for metagenomics. Experimental findings in Majuli River Island and Kamrup showed activities of some important enzymes as cellulase, phosphatase, amylase, dehydrogenase, invertase, protease and urease. The bioresource utilization areas have a scope for further secreening of indigenous plants for green synthesis of nanoparticles and check their antimicrobial activities.

The research work presented has been peer reviewed and resulted in the following publications:

Synopsis

Publications

1. **Gogoi N**, Babu PJ, Mahanta C, Bora U* (2014) Green synthesis and characterization of silver nanoparticles using alcoholic flower extract of *Nyctanthes arbortristis* and in vitro investigation of their antibacterial and cytotoxic activities. Materials Science & Engineering C. 46(1): 463–469

2. Das RK, **Gogoi N**, Babu PJ, Sharma P, Mahanta C, Bora U* (2012) The Synthesis of gold nanoparticles using *Amaranthus spinosus* leaf extract and study of their optical properties. Advances in Materials Physics and Chemistry. 2:275-281 (Equal contribution)

3. Das RK, **Gogoi N**, Bora U* (2010) Green synthesis of gold nanoparticles using *Nyctanthes arbortristis* flower extract, Bioprocess and Biosystems Engineering. 34(5):615-9 (Equal contribution)

Other publications

1. Das RK, Babu PJ, **Gogoi N**, Sharma P, Bora U* (2012) Microwave mediated rapid synthesis of gold nanoparticles using *Calotropis procera* latex and study of optical properties. ISRN Nanomaterials. 2012:1 – 6

Manuscripts in communication

1. **Gogoi N**, Talukdar NC, Mahanta C, Bora U*. Nutrient cycling and enzyme activities as a function of soil productivity in wetland ecosystems in Brahmaputra river floodplain-a case study in Majuli River Island, Assam, India (Research Article)

Manuscripts under preparation

2. **Gogoi N**, Talukdar NC, Mahanta C, Bora U*. Assessment of metal status and pollution indices in water and soil for evaluation of ecological risk in wetlands in Majuli River Island, Assam, India (Research Article)

3. **Gogoi N**, Talukdar NC, Mahanta C, Bora U*. Geochemical parameters as a function of soil productivity and fertility in an industrial area and a river island in lower Brahmaputra floodplain (Research Article)

Abbreviations

PM	:	Pre – monsoon
M	:	Monsoon
Kmb	:	Kamalabari
Nim	:	Nimatighat
AB	:	Amingaon Bank
U Bank	:	Umananda Bank
K Bank	:	Kachari Bank
DO	:	Dissolved oxygen
EC	:	Electrical Conductivity
COD	:	Chemical Oxygen Demand
SAR	:	Sodium Absorption Ratio
SSP	:	Soluble Sodium Percentage
KR	:	Kelly's Ratio
MPN	:	Most Probable Number
TOC	:	Total Organic Carbon
OC	:	Organic Carbon
SOM	:	Soil Organic Matter
OM	:	Organic Matter
CEC	:	Cation Exchange Capacity
TN	:	Total Nitrogen
MB	:	Microbial Biomass
MBC	:	Microbial Biomass Carbon
MBN	:	Microbial Biomass Nitrogen
MBP	:	Microbial Biomass Phosphorus
CNP	:	Carbon Nitrogen Phosphorus
CFU	:	Colony Forming Unit
BCFU	:	Bacterial Colony Forming Unit
FCFU	:	Fungal Colony Forming Unit
TP	:	Total Phosphorus

Abbreviations

ACP	:	Acid Phosphatase
ACP_T	:	Acid Phosphatase (with toluene)
AKP	:	Alkaline Phosphatase
AKP_T	:	Alkaline Phosphatase (with toluene)
Cell	:	Cellulase
Cell_T	:	Cellulase (with toluene)
Amy	:	Amylase
Amy_T	:	Amylase (with toluene)
Deh	:	Dehydrogenase
Deh_T	:	Dehydrogenase (with toluene)
Inv	:	Invertase
Inv_T	:	Invertase (with toluene)
Pro	:	Protease
Pro_T	:	Protease (with toluene)
Urea	:	Urease
Urea_T	:	Urease (with toluene)
EDX	:	Energy – Dispersive X-ray spectroscopy
FESEM	:	Field Emission Scanning Electron Microscopy
RA	:	Relative Abundance
$\mathbf{C_f}$	:	Contamination Factor
$\mathbf{I_{geo}}$	:	Geoaccumulation Index
PLI	:	Pollution Load Index
$\mathbf{C_d}$	:	Contamination Degree
NPI	:	Nemerow's Pollution Index
ER	:	Ecological Risk
PERI	:	Potential Ecological Risk Index
PCA	:	Principal Component Analysis
PC	:	Principal Component
FESEM	:	Field Emission Scanning Electron Microscopy

Abbreviations

TEM	:	Transmission Electron Microscopy
FTIR	:	Fourier Transform Infrared spectroscopy
XRD	:	X-Ray Diffraction spectroscopy
EDX	:	Energy-dispersive X-ray spectroscopy
NMR	:	Nuclear Magnetic Resonance spectroscopy
EFE	:	Ethanolic Flower Extract
NP	:	Nanoparticle
AuNP	:	Gold Nanoparticle
AgNP	:	Silver Nanoparticle
MH	:	Mueller Hinton
MHA	:	Mueller Hinton Agar
ROS	:	Reactive Oxygen Species

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CHAPTER 1

Introduction

&

Review of Literature

1.1 ECOLOGICAL STUDY OF RIVERINE FLOODPLAIN

Floodplain ecosystems are considered to be the most affected ecosystems worldwide due to human preference for suitable habitat and ecosystem services (Calow et al., 1992; Tockner et al., 2002). Ecological status of riverine ecosystems is affected by natural fluvial dynamics leading to flood-controlled disturbances, thereby favouring geomorphic processes and successional patterns (Amoros et al., 1988; Junk et al., 1989). From time immemorial, historic civilizations have taken shelter in riverine floodplains exploiting soil fertility and rich natural resources. The Harappa and Mohenjodaro cultures flourished along the banks of Indus River (Ali et al., 1987). Pre-historic data on management of water resources abridged a huge cultural influence on tropical rivers in Asia (Dudgeon, 1992). Since then, rapid landuse, urbanization and industrialization have led to alteration of natural functions of the river systems (Tockner et al., 2002). Human activities have induced longitudinal and lateral fragmentation of large river systems, considered to be one of the major threats to running water ecosystems (Dynesius et al., 1994; Schiemer, 1999). Assessment of ecological status of riverine floodplain is necessary to find out the requirements for balanced ecosystem activities between abiotic and biotic components and for maintaining ecosystem productivity and its contribution towards ecosystem processes.

Major rivers in the world are ecologically valued because of the mosaics of aquatic and terrestrial habitats assembling the biodiversity of a region. Consequently, there has been an increasing scientific interest in the link between biodiversity and the provision of ecosystem services (Wall, 2012). Large riverine ecosystems like Brahmaputra floodplain provide a wide range of ecosystem services that contribute to

human well-being enlisting fish and fiber, water, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and growing tourism industry. The biotic and abiotic components in such ecosystems are strongly intertwined. The change in level and quality of water and soil affect the biological components that in turn affect the ecosystem services. The value of ecological resources may be determined from basically two approaches, the value to humans and the value to ecological entities.

1.1.1 Concept of ecology

Ecological study basically includes two components of nature organisms and their environment (Sharma, 2009). It revolves around all natural and artificial processes that interweave the organisms with their immediate environment. Ecological study is an interdisciplinary study. Cain (1968) defines ecology as "***the science of interrelations-if natural resources are to be wisely managed and an environment of quality maintained or restored***." Ecological studies are based on observations and experimental results obtained from field study. Ecology deals with innumerable relationships between organisms and their surroundings (Sharma, 2009).

The term ***"ecology"*** was coined by Ernst Haeckel in 1869 (Tansley, 1935; Sharma, 2009; Kumar, 1995). Stanley (1998) describes ecology as the study of relationships, distribution and abundance of organisms or group of organisms in an environment. According to Fenchel (1987), ecology is a rather diffuse science that differs from most of the science in lacking a central core of concepts, methods and goals on which anyone can agree (Kumar, 1995). Charles Elton (1927) identified ecological science as scientific natural history. E. P. Odum (1963) interpreted ecology

as the study of the structure and function of nature. According to C. J. Krebs (1972), ecology is the scientific study of the interactions that determine the distribution and abundance of organisms.

1.1.2 Types of ecological study

Based on the definitions and theories, ecology identifies an array of themes suggested by scientists based on scientific observations. It is difficult to label ecology as different ecologists have various perspectives of ecological definition. Ecologists presented different perspectives of ecology and subdivided ecology into the following sub disciplines:

a) ***Landscape ecology*:** The pattern of land use or natural land forms
b) ***Ecosystem ecology***: The direct interrelation between the organisms and the surroundings
c) ***Physiologist ecology***: The impact of surroundings, environment and climate on the growth and development of organisms
d) ***Behavioural ecology***: The behaviour of organisms as a response to surrounding and developmental processes in organisms
e) ***Population ecology***: The structure and processes of populations an ecosystem
f) ***Community ecology***: The community of organisms surviving in an ecosystem
g) ***Evolutionary ecology***: The change of a community over time due to changes in characteristics such as form, physiology or behaviour
h) ***Applied ecology***: The applications of different kinds of ecology that give rise sub-disciplinary ecological aspects. Example: ***Industrial ecology*** (Frosch, 1992)

involving the network of all industrial processes using materials and energy from the ecosystems

Ecology is also defined by the kind of organisms, their habitat and application. Some of the examples put forward by Tansley (1935) are:

a) ***Ecology by concept***: Landscape, physiological, population, behavioural, community, etc.
b) ***Ecology by organism***: Plant, animal, microbe, zooplankton, human, deer, tree, etc.
c) ***Ecology by habitat***: Terrestrial, lakes and streams (limnology), marine (oceanography), arctic, rain forest, benthic thermal vents, urban, etc.
d) ***Ecology by application***: Theoretical, conservation, agricultural, public policy, academic, management, restoration, etc.

Ecological study of floodplain ecosystem is associated with ***"ecosystem ecology." Ecosystem ecology*** mainly deals with the flow of energy and matter through organisms and their environment (Carpenter, 1992). According to Stanley et al (1997), "***ecosystem ecology"*** in general may be classified as ***"fundamental"*** or ***"applied."*** Fundamental aspects deal with the core disciplinary concerns like nutrient cycling and productivity. Applied aspect focuses on practical issues like global climate change and new environmental issues. The broader aspects of ecology are demarcated by the ecosystem function and their proper management to avail sustainable ecosystem services. Tools in ecological studies provide a smooth drifting of field level studies to verification at the molecular levels.

In general, experimental analyses in ecological studies of riverine floodplain are based on fundamental aspects of floodplain ecosystem like water quality, soil productivity and quality, and their relationship with the existing biotic components. The essential components of an ecosystem are a) biotic components and b) abiotic components. Tansley (1935) stated that ***"organisms and their physical-chemical environment could be studied in an integrated ways as ecosystems."*** Water and soil are two important elements of an ecosystem. Soil fertility and productivity form the foundation of biogeochemistry where essential elements are made available to the plants and animals through the biogeochemical cycles. A part of the hydrological cycle associated with the soil system plays an important role in leaching of these elements in to the water bodies. The biogeochemical cycles are concerned with flow of materials and energy in the various trophic levels of an ecosystem. Microorganisms play an essential role in the biogeochemical transformations by taking part in processes like humification, nitrogen fixation, bioremediation, etc.

1.1.3 Ecological study of riverine floodplain all over the world

Assessment of ecological status and biodiversity of riverine floodplains have been a very hot topic since the last century. Important resolutions have been taken worldwide aimed at the protection and preservation of the ecosystems and biodiversities of river basins (Gómez-Pompa et al., 2004; Kearns et al., 2010; Ramsar Convention Secretariat, 2010). Environmental issues were given prominence at the United Nations Conference on Environment and Development (UNCED) held in Rio in 1992 and a number of targets relating specifically to biodiversity and ecosystem protection were incorporated into the Convention on Biological Diversity (CBD). A detailed discussion was

documented in the freshwater Chapter 18 of Agenda 21, which devotes a Programme Area to the Protection of Water Resources, Water Quality and Aquatic Ecosystems. In 1998, the World Water Council had set up a commission to produce a 'Vision' for the world's water, towards the end of a decade that had seen rapid growth in awareness of freshwater resources management as a global environmental issue. The primary contribution on environmental aspects was the World Vision for Water and Nature (IUCN, 2000), based on the understanding that the protection of ecosystems, that must remain central to sustainable development because "***environmental security, social well-being and economic security***" are intricately intertwined and fundamentally interdependent.

In this context, principles of transboundary co – operation within river basins were laid down in a convention under international law, the 1992 UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention). The Convention aims to achieve a good status for waters and related ecosystems, taking into account the specificity of river basins. This assessment includes 140 transboundary rivers (most of them with a basin area over 1,000 km^2) and 30 transboundary lakes in the European and Asian parts of the UNECE region, as well as 70 transboundary aquifers in South-Eastern Europe, the Caucasus and Central Asia (UNEC, Report). Some of the acclaimed ecological assessments of rivers worldwide is discussed below:

1.1.3.1 Asian countries

In Asia, a holistic approach has been seen towards the ecological status of some of the major rivers. The Environment (Protection) Act enacted in 1986, last amended in 1991 with the objective of providing for the protection and improvement of the environment include 12 environmental problems of which one is the ***"loss of ecology."*** In India, Brahmaputra Board Act, 1980 deals with planning implementation of measures for the control of flood and bank erosion in Brahmaputra Valley. While in other parts of India ecological assessment and restoration activities in lakes and rivers are widely surveyed. In North Eastern India, ecological assessment in terms of faunal biodiversity has been procured in Kameng, Subansiri, Dikrong, Pachin, lranga, Siang, Dibang, Lohit, Noadhing, Buridhing and Tirap (Nath, 2000). There is a huge record on biological and physicochemical monitoring of Brahmaputra River and its adjoining tributaries (Girija, 2007; Das et al. 2012; Baruah, 2013; Kalita 2013). Ecological status of Yamuna River, Kali River and some stretches of Ganga River has been evaluated. Other rivers include Periyar River, Cauvery River and several small water bodies in Bhopal (Gupta et al., 2006). Restoration of Lake Anasagar was reported in Rajasthan, restoration measures included forests, soil, watersheds, green infrastructure and vegetation with sand dunes (Pandey, 2013). Bahukhandi et al (2013) reported development of a building-block methodology assisted knowledge-based system for e-flow assessment and management for Suswa River of Dehradun district. Backwaters of South west coast of India cover a total area of 46128.94 ha, most of the region is under agricultural and urbanization stress, current status and modification of biodiversity have been monitored by researchers (Nandan, 2008). Ecologists have evaluated the environmental impact

assessment of the national large solar telescope project and its ecological impact on Pangong Lake in Merak area (CES, IISC, 2011). Zutshi et al (1980) broadly evaluated the limnological status of Surinsar Lake, Mansar Lake, Manasbal Lake, Nilnag Lake, Trigam Lake, Alipather Lake, Anchar Lake and Naranbagh Lake in Jammu and Kashmir.

Diversion and containment of rivers is a centuries-old tradition and had challenged the ecological integrity of river systems. The Kauvery Delta canals in India (2^{nd} century A.D.); Ifugao rice terraces of the Philippines (the 4000 year-old); Barrai irrigation dam in Burma (10^{th} century A.D); the Dujiangyan irrigation system (250 B.C.), the Linqu Canal (214 B.C.) and the Grand Canal (6^{th} century A.D.) are some the examples of man-made structures contributing to ecological stress in some major rivers of Asian domain. The Yellow River and the Mekong River Basin have been extensively studied (Yang et al., 2007, Mekong River Commission, 2003). Kummu and researchers (2014) studied water balance analysis for the Tonle Sap Lake floodplain system as an essential component of ecological assessment in Cambodia. Dudgeon (1992) described the pollution status of some of the large rivers in Asia as Chenab, Indus, Luni, Narmada, Brahmaputra, Ganges, Mahanadi, Godavari, Krishna, Cauvery, Yangtze (Chang Jiang), Salween, Mekong, Irrawaddy, Chao Phraya, Mae Nam Yom, Red River, Pearl River, DongtingLake (Yangtze River), Poyang Lake (Yangtze River), MinJiang; Perok, Tulangbawang, Cimanuk, Mas or Surabaya, Fly and Sepik. The pollution intensities in the rivers were correlated to ecological entities inhabiting the river waters.

1.1.3.2 European countries

Around 162 streams in Europe were sampled in the year 2003-2004 under European funded projects after the implementation of the Water Framework Directive. The ecological status of Mediterranean Rivers (Vicenete et al., 2004), Alcantara River (Gugliandolo et al, 2009), Meuse River (Looy, 2008) and Danube River (Fischer-Antze et al, 2004) has been monitored. Lake Myvatn and the outflowing River Laxá has been ecologically examined based on spatial and temporal variations (Einarsson et al., 2004). Long term changes in the ecological structure of Lake Myvat, basically eutrophication status and abundance of littoral planktons and invertebrates have been studied by Gardarsson et al (1988). Gerbersdorf et al (2011) provided a detailed report on the ecotoxicological aspects of Danube River, where he highlighted the state-of-the-art methods within the disciplines of concern related to contaminated sediments, ranging from ecotoxicological test systems, microbiological/molecular approaches to unravel changes of microbial ecosystems, up to the modelling of sediment transport and sorption/desorption of associated pollutants known as the "triad plus x" approach. Ecological importance and anthropogenic change of subaquatic springs in ancient Lake Ohrid has been assessed in Macedonia (Jordanoska et al., 2013). Kachvoryan et al (2008) studied the biodiversity of zoobenthos in riverine ecosystems of Lake Sevan Basin's Rivers in Armenia. Biomonitoring of large European rivers for invertebrate biodiversity and related environmental impacts were also studied in details (van Dijk et al., 2003). In this perspective, it was observed that Wye river (U.K.), the Upper Loire, the Aube and the Ardeche rivers (all three in France) and the Upper part of the Duero basin (Spain) represented almost natural rivers, whereas the Vistula river and the Warta

river (Poland), and the Elbe river (before 1992, Germany) represented heavily impacted rivers in terms of water quality parameters.

1.1.3.3 Australian countries

The Murray-Darling River system drains over 1000000 km^2, approximately one seventh of the Australian continent (Douglas, 1995). In Murray-Darling Basin (Gehrke et al., 2003), studies on the floodplains of the Alligator Rivers and the continuous wetland system associated with the Mary River and Adelaide River floodplains have been reported (Department of Natural Resources, Environment, Australia, 2007). Kingsford et al (2004) found that Lowbidgee floodplain is the Murrumbidgee River's major wetland in south eastern Australia in relation to destruction of wetlands and waterbird populations by dams and irrigation. Reformation of management criteria based on environmental flows associated with the hydrology, geomorphology and ecology for smooth ecosystem function was observed in Lachlan River, New South Wales (Hillman et al., 2010). Biodiversity and ecological assessment was evaluated specially on abundance and pattern of distribution of fish species in Warrego River in the Murray Darling Basin by Balcombe et al., (2006). Fish biodiversity was also reported in Cooper Creek, an arid-zone floodplain river (Arthington, 2001). Paroo River also witnessed similar fish biodiversity assessment in the in the Murray-Darling River Basin (Gehrke, 1995).

1.1.3.4 African countries

In African countries, the Nature Conservation Research Division is associated with the conservation of South African Rivers. Rivers were seen primarily as ecosystem

components that upholds a set of larger values. Ecological assessment of rivers as Orange River, Zambezi River, Palala River, Buffalo River, etc. was one of the initiatives taken towards conservation riverine ecosystems. In Calabar River, ecological impact assessment and limnological characterization in the intertidal region was emphasized (Andem, 2013). Everard et al (2002a, 2002b) studied the biodiversity of and flowed ecological management activities towards sustainable development of Lake Naivasha, Ramsar site in Nigeria. Odadaa et al (2002) studied the environmental assessment of the East African Rift Valley Lakes. Species richness of fishes in different habitat and hydrologic variables were studied in Nile (flowing into the Mediterranean waters) Senegal, Gambia, Tomine, Konkour, Kolente, Jong, Sewa, Moa, Manu, Loffa, St. Paul, Nipoue, Cavally, Dodo, Nero, San Pedro, Sassandra, Boubo, Bandama, Agnebe, Me, Comoe, Bia, Volta, Mono, Oueme, Ogun, Niger, Cross, Mungo, Wouri, Sanaga, Nyong, Lobe, Ntem, Ogowe, Niari and Zaire (Hugueny, 1989)

1.1.3.5 American countries

The most thoroughly studied rivers in American territories are the Mississippi and the Amazon Rivers. Sedimentation is the most critical ecological problems of the Upper Mississippi River System (UMRS). Lateral flooding in Orinoco River and its geological features have been reported in Venezuela. Scientists have evaluated the physical status of the river to identify its impact on the floodplain ecosystems (Hamilton et al., 1990). The Great Lakes in America namely, Lake Ontario, Lake Superior, Lake Huron, Lake Michigan and Lake Erie forms one of the largest groups of fresh water ecosystem in the world. Biodiversity and ecosystem of the Great Lakes have extensively reported. Kline et al (1985) focussed on the impact of pollution on

fresh water organisms in relation to toxicity of wide range of pollutants on the vertebrates and invertebrates. Ecosystem restoration studies have been observed in the floodplain ecosystem under potential impacts of damming of Rio Grande River in Mexico (Molles, 1998). Benke (1990) considered Yellowstone River as an exception for hydropower generation in terms of water quality. Graf (2006) discussed the downstream hydrologic and geomorphic effects of large dams on American rivers at a continental scale, outlining the general physical changes that play an important role in the riparian ecosystems and ultimately disturb the wildlife populations. According to Dawdy (1991), researchers have been studying the impacts of dam functioning on hydrological regime and ecological aspects of Colorado River. Similar studies were concentrated on Connecticut River watershed (Magilligan et al., 2001). Ecological implications were broadly studied in some of the dam affected river as Hudson River in New York; Platte River in Nebraska; Lower Missouri River in Missouri, Kansas, Nebraska, and Iowa; Upper Missouri River in Nebraska, South Dakota, North Dakota, and Montana; Gila River in New Mexico and Arizona; Yakima River in Washington and Willamette River in Oregon (Benke, 1990).

1.1.3.6 The Arctic and the Antarctic circles

The Arctic and Antarctic Circle remains frozen for most part of the year, however, some lakes as Char Lake, Toolik Lake, Anguissaq Lake, Burton Lake, etc. were studied (Vincent et al., 2008). Management of terrestrial ecosystems in Arctic Tundra has been considered as a necessity to conserve vegetation as a thermal barrier to permafrost melt and prevent loss of wildlife habitats (Bliss, 1973). Yenisey, Lena, Ob', Mackenzie and

Yukon are a few Atlantic rivers evaluated for nutrient status more specifically the organic carbon pool in the river ecosystems (Raymond, 2007).

Borja et al (2007) worked on the benthic ecological status assessment in the North Atlantic ecoregion. Williams (1996) provided a detailed report on the Antarctic microbial diversity, the basis of polar ecosystem processes and role of microorganisms in degradation of organic substrates in ice covered regions. Fish biodiversity as an ecological indicator was studied in Northeast Cape Fear River, Lumber River and Neuse Rivers in the Atlantic region (Kwak, 2006).

1.2 Ecological study of Brahmaputra River floodplain

Brahmaputra River originates from the holy Kailash Mansarovar in Tibet at an elevation of 5300 m above sea level. The river flows downwards through the hilly terrain of Tibet as Yarlang Tsangpo and fertile plains of Arunachal Pradesh as Siang, major part of Assam as Brahmaputra and Bangladesh floodplains as Jamuna, covering a distance of around 2900 km (Mahanta et al., 2002; Goswami et al., 1998; NIH Roorkee). The total length of the river in Bangladesh is around 240 km (Phukan, 2012). The river stretches over an area of 560000 km^2 that recounts to 50.5% in China, 33.6% in India, 8.1% in Bangladesh and 7.8% in Bhutan. The Brahmaputra basin in India is shared by 6 states in India. It traverses through Arunachal Pradesh (41.9%), Assam (36.3%), Meghalaya (6.1%), Nagaland (5.6%), Sikkim (3.8%) and finally West Bengal (6.3%) (NIH, Roorkee) before flowing into Bay of Bengal

Brahmaputra is one of the largest rivers in the world and second highest in sediment discharge after the Yellow River i.e. 1128 tons $km^{-2}yr^{-1}$ (Goswami, 1997;

Phukan, 2012). Brahmaputra basin is broadly divided into four macroclimatic zones: a) North bank Plain (NBPZ), b) Upper Brahmaputra Valley (UBVZ), c) Central Brahmaputra Valley Zone (CBVZ) and d) Lower Brahmaputra Valley Zone (LBVZ). Climate of Brahmaputra basin is humid subtropical characterized by high rainfall and humidity, mainly influenced by the south west monsoon from Bay of Bengal and surrounding hills of Assam, lower Himalayas and Assam plateau.

Total precipitation varies between 60-70% of the total annual rainfall. Brahmaputra basin receives heavy rainfall from the passage of south west Indian monsoon from June to September each year. The average normal rainfall in the valley is 2340 mm/year with a variation from 1210 mm/year to 4,590 mm/year (Kalita, 1984). The average minimum temperature of the region is about 10ºC in December/January and maximum of 32°C in July/August. The mean annual temperatures of the eastern, western and middle regions are 23.5°C, 24.5°C and 24°C, respectively. The relative humidity on an average exceeds 80% for the entire basin even in dry months of the winter season the average relative humidity does not fall below 75%. The alluvium derived soils of Brahmaputra valley have been grouped into new and old alluvium and forest soils according to conventional system of soil classification. The major groups of soil are Entisols, Inceptisols and Alfisols (Singh et al., 2004). High population density in the Brahmaputra plains is recorded as 340 persons km^{-2} (Census, 2001; Mahanta et al., 2002).

A portion of the Brahmaputra valley lies in Eastern Himalaya biodiversity hotspot region. The Brahmaputra basin has a great diversity of flora and fauna with their enormous variation in both vertical and horizontal distributions. It provides unique

habitat for a wide range of animals and plants, many of which rare and endangered species. Among the animals, great indian one-horned rhinoceros, pygmy hog, hispid hare, asiatic elephant, clouded leopard, marble cat, golden cat, binturong, hoolock gibbon, white-winged wood duck, bengal florican, etc. are highly endangered. The forest areas both explored and unexplored represents a huge consortium of plants species native to Assam. Satellite surveys specified that overall Brahmaputra basin, has a forest cover of about 14.5%, grasslands occupying approximately 44%, agricultural lands occupying about 14%, cropland and natural vegetation covering 12.8% and barren or sparsely vegetated land spreading over 2.5%. Besides, water bodies contain 1.8%, snow and ice cover 11%, urban land 0.02% and permanent wetlands cover 0.05% of flora (Goswami et al., 1998).

Majority of the plants occurring in this region has remarkable ethnobotanical importance. Researchers have been exploring the properties of indigenous plants to obtain productive outputs like energy production, medicinal evaluation, tissue culture, transgenic studies, animal feed, green synthesis of nanoparticles, biopesticides, manure, textile synthesis, carbon sequestration, bioremediation, green design, landscape design, ornaments, etc. The scientific domain of explorable plants is very large and requires proper knowledge of utilization techniques.

1.2.1 Majuli River Island

Majuli River Island located in the heart of Brahmaputra River in the upper-central Assam, has been designated as one of the world's largest river island. Majuli has recently been a proposed nomination to world heritage site under UNESCO because of its richness in cultural and ecological values. Majuli is situated in the north of Jorhat

between 93°30' to 94°35'E longitude and 26°50' to 27°10'N latitude. Majuli extends from north to south direction with an altitude of 85 – 90 m above the mean sea level (Misra, 2013; Dutta et al., 2012). Initially Majuli was a narrow lane known as "Majali" or "Mojali" between the river Brahmaputra and its tributary Dihing in the early 1600 century. It took a finite shape in the course of time as a result of several geographic changes. Genesis of the river island could not be traced exactly though there are evidences that earthquakes (1661-1696) and frequent floods caused the separation of the landmasses from the main track. The Brahmaputra separates Majuli sub division from the mainland on the northern side of Jorhat district in North Eastern India. Initially the land area of Majuli was 1246 km^2 till 1950, it has now reduced progressively to 925 km^2 in 1971 under the stress of regular flooding and bank erosion (Space Application Centre and Brahmaputra Board 1996; Mani et al., 2003; Kotoky et al., 2003; Dutta et al., 2010).

Land area of Majuli has been comprehensively discussed and various statistics were provided by researchers. Based on satellite imagery data, the land area of Majuli has been reported as 706.14 km^2, 578.38 km^2 and 484.34 km^2 in the time period 1966-1975, 1998 and 2008 respectively (Dutta et al., 2010; Dutta et al., 2012). Total land mass of 50 km^2 has been lost in the time period 1969 to 1994 (NBSS and LUP, ICAR, 2006). Out of this, the eroded area due to Subansiri river is 3.91 km^2 (0.42% of total area) as against 46.36 km^2 (5.43% of total area) eroded by the Brahmaputra river (Singh, 2011). The river island is an isolated and closed system characteristic of fluvial geomorphology. Majuli being an inherent part of the Brahmaputra River system experiences wet monsoon type of climate. The mean annual rainfall is high and more

than 90% of the rainfall is received in the months of April, May, June, July, August, September and October. Rainfall in December and January is less than 20%. Mean temperature is 24.1°C with a range of 7° to 37°C whereas mean summer temperature is 26.8°C and winter temperature is 7.3°C (NBSS and LUP, ICAR, 2006). Majuli is an agriculture based region depending mostly on paddy cultivation, with a cropping intensity of 102% (NBSS and LUP, ICAR, 2006). Fishing is another practised occupation for livelihood. Flooding is a phenomenal and seasonal process in Majuli strongly linked to bank erosion and submergence of chars and smaller sand bars. Soils of the Jorhat district as well as Majuli vary from sandy loam to clay loam (Singh, 2011).

Majuli is composed of 12 Gram Panchayats covering an area of 37670 .98 hectares. The population of Majuli is 81731 with a density of 2.16 persons per hectare (Majuli Block Development Office, 2011). The land forms of island include seven important geomorphic units- 1) Active Floodplains, 2) Sand Bars with grass covers, 3) Sand Bars, 4) Swamps, 5) Old Floodplains, 6) Channel Fills and 7) Natural Leeves (NBSS and LUP, ICAR, 2006). Majuli is rich is wetland resource. A total of 112 wetlands covering an area of 20.13 km^2 were reported in 1917 and 50 wetlands covering an area of 17.88 km^2 were reported in 1966 to 1972 (Sarma et al., 2004). 64 wetlands are under Majuli Development Block, 61 wetlands are under Ujani Majuli Development Block, 6 wetlands are under Assam Fisheries development Corporation (AFDC) and 9 wetlands are under Revenue Bils (wetlands) (Nath, 2009). Technically wetlands are classified into six basic types (Keddy, 2010):

1) ***Swamp***: Dominated by trees rooted in hydric soils, but not in peat. Example: mangroves
2) ***Marsh***: Dominated by herbaceous plants that are emergent through water and rooted in hydric soils, but not in peat. Example: Marshes around the Great lakes and reed beds around the Baltic Sea
3) ***Bog***: Dominated by mosses, sedges, shrubs or evergreen trees rooted in deep peat of low pH around 5. Example: peatlands
4) ***Fen***: Dominated by sedges and grasses rooted in shallow peat with or without ground water movement with a pH of around 6. Most of them occur on calcareous rocks having brown mosses. Example: peatlands of northern Canada and Russia
5) ***Wet meadow***: Dominated by herbaceous plants rooted in occasionally flooded soils. Such vegetation during temporary flooding do not include terrestrial plants and swamp plants, but drier growing seasons may produce plant communities typical of moist soils. These wetlands are generally produced due to periodic flooding. Example: wet prairies along floodplains or herbaceous meadows on lakes
6) ***Shallow water***: Dominated by aquatic plants submerged in water upto a level of 25 cm. Example: littoral zones of lakes

Depending on the classification given by Keddy (2010), wetlands studied in Majuli are characterized as ***marshes***, a few ***wet meadows*** and ***shallow water*** dominated by herbaceous plants and drained by monsoon floods. The wetlands areas in Majuli are vulnerable to exploitation (fishery, agriculture, transportation and recreational activities) and contamination due to huge tourism rush and increasing population density.

1.2.1.1 Status of work done in Majuli

Classical ecological study is lacking in Majuli, however biodiversity and geophysical properties of the river island as key components of ecological study have been reported by a few researchers (Mani et al., 2003; Kotoky et al., 2003; Sarma et al., 2004; Sankhua et al., 2005; NBSS and LUP, ICAR, 2006; Singh, 2011; Hazarika, 2012; Nath, 2012; Sarkar et al., 2012; Dutta et al., 2010; Dutta et al., 2012; Bhaskar et al., 2013; Bhaskar et al., 2007; Barman et al,. 2013). The overall study in Majuli River Island is represented in Table 1.1, most of the findings are available as online articles. Majority of the outcomes at the grass root level may have not been reported, though developmental activities have been conveyed by Block Development reports, Department of agriculture, Brahmaputra boards and local people in Majuli.

Table 1.1 *Details of online articles based on different ecological study components in Majuli, Assam, India*

Type of online articles	Flood and erosion	Development	Demography	Cultural studies	Geochemistry	Biodiversity	Agriculture
Research papers	12	Nil	2	1	2	7	7
Conference proceedings	3	Nil	Nil	Nil	Nil	Nil	Nil
Reports	12	11	Nil	2	2	3	3

Majuli is though rich in biodiversity, lack of proper documentation of the available species of flora and fauna has generated a breach between ground level and observatory data. Majuli has a rich floral and faunal diversity. The biodiversity of Majuli is under major threat to natural geophysical processes (Nath, 2011), and to some

extent anthropogenic activities. As soon as educational institutions have started developing and research and development activities have become centralized, researchers from various places have shown their keen interest in exploring and detailing the biodiversity of Majuli. Among the floral species, the medicinal values and their ethnobotanical importance have been reported (Bora et al., 2012a, 2012b). A survey a total no. of 23 plant species belonging to15 family have been recorded and use of parts of different plants in diverse localities have been informed (Bora et al., 2012). Study of faunal species involved exploration of fishes and amphibians in Majuli. A thorough study on fish species in Kakarikata beel and Kharjan beel (wetlands) in Majuli enlisted a total number of 82 species belonging to 10 orders, 54 genera of 23 families. Among all, Cyprinidae family was dominant with 32 species followed by Bagridae and Channidae with 7 and 5 species respectively. 6 species were endangered, one critically endangered, 19 species vulnerable, one data deficient and status of 34 species in lower risk category (Das et al., 2012). Fishes were categorized on the basis economic uses into food fish (96.4%), ornamental fish (74.4%) and commercially important fishes (40.3%). 32% of fish species were found in threatened category and 49% of fish species were lotic fishes whereas rest of the species were lentic (Das et al., 2012).

From the articles available online and from local offices, is was observed that a bulk of the research activities has been focussed on flooding, erosion and agricultural activities in Majuli. Flooding, erosion and deposition of sediment are perpetual processes in Majuli River Island. In the flooding history, the most active years

recounted in Majuli are 1951, 1962, 1966, 1969, 1970, 1974, 1977, 1988, 1991, 1993, 1995, 1998 and 2008 (Nath, 2012).

Under the conditions of extremities of flooding and erosion-deposition, the suitability of soil and its physico chemical properties for paddy cultivation has been finely explained by Bhaskar and Sarkar (2013). Being a flood inundated island, two major components pertaining to ecological balance have been identified in Majuli. These components are recounted as flooding erosion and sedimentation among the natural drive and crop management activities under man made adaptations.

1.2.1.2 Influence of flooding, erosion and sedimentation

Flooding in general deposits a huge amount of silt and at the same time, strong water currents aggravates the bankline erosion. These processes resulting in erosion are further boosted by the braiding nature of the Brahmaputra River (Akhtar et al. 2011). Erosion is not only confined to banks in Majuli, surface erosion due to rainfall and land use is inevitable (Barman et al., 2013). Natural and to some extent man induced processes have been extensively studied in the last three decades (Nath, 2012; Akhtar et al., 2011; Singh, 2011; Sarkar et al., 2012; Sarma, 2013; Sankhua et al., 2005; Sarma et al., 2004; Mani et al., 2003; Kotoky et al., 2003). Researchers have explained the root causes of erosion-sedimentation processes, results of such findings have simplified our approach pertaining to the massive loss of land and biodiversity in Majuli. Reports on average annual rate of erosion in the time period 1917 to 2001 gives an account of the extent of bank erosion, loss of area of 1.77 km_2 in 1917 to 1972, 1.84 km^2 in 1972 to 1996 and 6.42 km^2 in 1996 to 2001 was approved (Sarma et al., 2004). Sarkar et al. (2012) demarcated the range of bankline erosion in selected two reaches of Majuli,

analyzing satellite images of Indian Remote Sensing (IRS) from 1990 to 2008, they have identified the North Bank and South bank erosion and deposition profiles delineating Majuli (near Bessamora) and upstream Majuli (near Sibsagar). Some other reports indicate total erosion of 32.79 km^2 and total deposition of 9.07 km^2 in the South bank and total erosion of 64.27 km^2 and total deposition of 0.73 km^2 in the North Bank of Brahmaputra River (Department of Water Resources Development and Management IIT Roorkee 2012). Satellite imageary revealed that Majuli land area has reduced from initially 1245 km^2 till 1950 to 577.65 km^2 and finally to 376.93 km^2 in 2002 under the strong circumstances of flooding and erosion (Kotoky et al., 2003; Sankhua et al., 2005). Similar data were published by Space Application Centre, Ahmedabad and Brahmaputra Board (SAC), they have reported a reduction of land area from 1250 km^2 in to 925 km^2 in 1971. Mani et al., 2003 described relevant figures specifying loss of land area in the time period 1991 to 1997, erosion in 1900 ha and deposition of sediment in 700 ha of land respectively. Remote sensing analyses of satellite images by Sankhua et al (2005) showed that the area of Majuli has declined by 39.30 km^2 in the time period 1990 to 2002. Barman and researchers (2013) have detailed the loss of soil or surface erosion directly correlated to land use processes or vegetation cover and average rainfall of 2048.62 mm, documented in the time period 1970 to 2008. Remote sensing and model output data quantified the annual loss of soil from 7.53 to 8.39 km m^{-2} and reduction in vegetation cover from 237.69 m^2 to 86.21 m^2 in the time period of 1975 to 2008.

Flooding and erosion-deposition processes influence land cover/land use undertakings, alter and disturb normally growing flora and fauna. Submergence of

small islands and chars has immensely affected the livelihood and economic condition of the inhabitants in Majuli. Huge deposition of silt and fine sand has put the farmers under a bitter experience of loss of assets and economic commodities. Flooding leads to anoxic conditions in submerged soils that deprive plants and microorganisms from oxygen (Unger et al., 2009). Every year flood deposits a layer of silt over land cover and vegetation, the nutrient status of land is disturbed and growth of microorganism in the topsoil and subsurface soil are suppressed due to lack of oxygen and moisture and thereafter rate of transformation and decomposition of organic matter is slowed down (Fifield, 2004). Vegetation is a necessity because it keeps the nutrient content intact in soil and enhances microbial activities. Deposition of silt and fine sand renders the agricultural land productive for a long term (Nath, 2012), from previous information it was found that 116.2 km of fertile agricultural land of have been covered by barren sand leading to loss of productivity of the area (Sarma, 1998). The entire ecosystem of Majuli is distressed and ecological disturbances have a direct link with the biodiversity of the places affected. Several species of plants, migratory birds and river dolphins have diminished in course of time, results were prominent in Bongaon and Kamalabari in the southern part of the island and a few places in the northern eroded part of Subansiri River (Hazarika, 2012).

1.2.1.3 Influence of crop management activities

Agriculture, horticulture, animal husbandry and fishery are the chief practices adopted by local farmers under Majuli Development Block and Ujani Majuli Development Block (Block Development Report, Majuli 2011). Utiliztion of modern techniques and introduction of high yielding varieties and fertilizers in cropping system in Majuli has

taken a better form in the recent decades. Paddy cultivation is main agricultural practice in Majuli. Wetlands provide a good platform fulfilling the water and nutrient requirement for paddy cultivation. Other crops cultivated in Majuli are mustard potato, lentil, cowpea, vegetable crops and a few cereals. The inclusion of crop management activities has left an influential effect on the microbial communities in the soil. However the application of weedicides and pesticides has been reported as minimal when surveyed among the local inhabitants. In addition to it literature review on use of weedicides and pesticides showed passive results (ICAR Proceedings, 2011).

The areas cultivated for crops are mostly active floodplains, old floodplains and channel fills (NBSS and LUP, 2006 and Bhaskar et al., 2013). These flood inundated land forms are characterized by deposition of sediments differentiated into silt and fine sand with mineral composition like tourmaline, rutile, zircon, epidote, kyanite, silimanite, staurolite, micas (biotite and chlorite), hornblende, zoisite and opaque minerals and clay content containing mineral as illite, kaolinite and chlorite (Singh, 2011). Deposition of flood driven sediments and its role in cropping activities can be directly correlated to the microbial abundance in the soil (Unger et al., 2009).

1.2.2 Kamrup: Amingaon and Umananda River Island

Kamrup lies between 25°46'0"N to 26°49'0"N latitude and 90°48'0"E to 91°50'0"E longitude. Kamrup district occupies an area of around 4345 km^2, divided into two sub-divisions, Guwahati and Rangia. Guwahati sub-division includes 8 revenue circles and Rangia sub-division covers 3 revenue circles. Kamrup has 15 development blocks that consider 162 Gaon Panchayats each comprising of villages governed by local-self bodies. Udalguri and Baksa districts are situated on the northern part and Meghalaya

guards the southern part of Kamrup district. Darrang and Kamrup (Metro) shares the eastern border and Goalpara and Nalbari shares the western boundary of Kamrup district. Brahmaputra River floodplain in Kamrup is characterized by hilly terrain inundated with alluvial soils known as inselbergs comprising of mostly precambric gneissic rocks. Scattered hillocks with discontinuous plains are observed in the outskirt region extending upto Shillong Plateau on the southern boundary.

Topography of the region is a combination of hilly undulating landscape as well plain landmass. Meghalaya on the southern part is a continuation of the patchy hilly terrain dispersed by a few plain landscapes that gradually converge into a flat terrain towards Brahmaputra River in Kamrup. The hilly terrain bears small hills to residual hillocks. The steepness deceases towards the plains with a land slop less than 10 mkm^{-1} areas and land slop is from 300-600 mkm^{-1} in the hilly areas.

Some important rivers in Kamrup district are Brahmaputra and its smaller tributaries like Puthimari, Bornoi, Nona, Kulshi, Pagladia and Kalajal. Flooding is popular in low lying areas during May to August every year whereas late floods occasionally occur in later part of the year in September and October. Inflow of flood waters is contributed by Brahmaputra River and its adjoining tributaries in Kamrup. Soil varies in places depending upon topography, bedrock composition and sediment transport activities by the rivers. Main soil type of the district contrasts from sandy loam, loam, sandy clay and clay loam. The overall organic carbon and nitrogen contents are reportedly high due to the downstream river driven alluvium. The plains contain comparatively higher pH values than hills. (State Level Nodal Agency, IWMP, Guwahati, 2014).

Average annual rainfall in the area is about 1738 mm since the last ten years. Metrological data indicates approximately 90% of rainfall occur between April and September with maximum occurrence in June, July and August. The driest month of the year is January with an average rainfall of 5.46 mm since last ten years. The highest temperature is recorded at 33°C in the month of July and August and lowest temperature at 10.82°C in the month of January. Climate is hot humid in summer with maximum relative humidity of 90%. High humidity is experienced in the month of January. Kamrup district is under High Risk Zone-V of earthquakes incidents, where a maximum intensity of IX can be expected. Occurrence of flood events leads to bankline erosion by the Brahmaputra river (Guwahati City Disaster Management & Response Plan 2014).

Amingaon is located on the mainland near the bank of Brahmaputra River in the north of Guwahati and Umananda River Island or Peacock Island is located on the north east of Guwahati separated by the Brahmaputra River. Amingaon and Umananda River Island are two economically important sites in Kamrup experiencing a tropical wet monsoon climate, at an altitude of 31-55 m above mean sea level, predominantly depending on the terrain. Amingaon is an industrial area lying between 26°11′0.5″N latitude and 91°40′1.2″E longitude. A few of the industries located in Amingaon are vanaspati plant, a mini steel plant, tea dry port, tea godown, ware house, pharma manufacturing units, cosmetic manufacturing and bottling plant, bamboo processing and manufacturing unit, pvc plastic manufacturing unit etc. Umananda is a highly visited tourism and pilgrimage site located between 26°11′47.76″N latitude and 91°44′43.44″E longitude. Umananda River Island is home to the endemic species,

Golden langur (*Trachypithecus geei*). Geomorphological features are characterized by flood driven fertile alluvium. Major floods are inconspicuous, however flash floods are frequently witnessed during the monsoon downpour.

1.2.2.1. Status of work done in Kamrup

Research in Kamrup is focussed on biodiversity, water and soil health. A huge survey on ethnobotanical properties plant species have been carried out in different regions of Kamrup (Sharma et al., 2012; Barua et al., 1989; Gogoi et al,. 2013; Rao et al., 1979; Choudhury et al., 2011; Sharma et al,. 2010; Das et al., 2013). Among the faunal population, a total of 62 ornamental fish species belonging to 41 genera, 18 families and 7 orders have been estimated (Kalita et al., 2013). In Silsakho wetland, Baruah and others (2013) reported 24 species of ornamental fish species. Among these, 18 have been classified as ornamental fish and others 6 were non-classified as ornamental fishes. Turtles as *Pangshura sylhetensis*, *Chitra indica* and *Nilssonia nigricans*, considered as some of the endangered species of turtles in the world, were reported in the islands (chars) of Brahmaputra River. Awareness camps were successfully organized to spread the message of saving turtles through education programmes, highlighting necessary conservation aspects. In – situ turtle egg conservation strategies and methods were also discussed by most of the scientists (Baruah et al., 2010).

Deka et al (2011) studied the landuse pattern in Muktapur village in Kamrup and found that agricultural practices are the major landuse undertakings. The team described a representative agro-ecological framework of Brahmaputra valley. Winter rice, autumn rice, ahu rice and bau rice were cultivated in the lowlands that meet the water requirements. Kharif crops and rabi crops are two seasonal cropping patterns that

include rice as the main cereal and vegetables as key crops. Cropping pattern in Kamrup gave an overview of the agricultural activities flourishing in the alluvial floodplain of Brahmaputra River in its lower stretch.

1.2.2.2 Influence of urbanization and landuse activities

Kamrup has a forest area of approximately 1,16,694 ha. Amchang Wildlife Sanctuary and Deepor Beel Wildlife Sanctuary are examples of forest covered ecologically sensitive zones in Kamrup. Rapid urbanization and extensive land use activities have rendered the animals homeless, an excellent example of man animal conflict is the notorious activities of elephants and monkeys in Deepor beel wetland areas in the northern part of Kamrup. Human settlements have destroyed natural habitats of most of the wild animals living in that region. Numerous species of indigenous fishes, amphibians, birds and aquatic animals have undergone threat to extinct as an outcome of massive environmental pollution events. Devi et al (2008) highlighted one such event in Jalukbari, Kamrup where the incidences of homeless monkeys counteracting human activities have been troublesome since a long period of time.

Ecological assessment in Kamrup has been previously studied as evaluation of physicochemical and geochemical parameters of water and soil samples at several places along the floodplains of Brahmaputra River. Soil properties and the consequences of Jhum cultivation in Amingaon watershed, has been broadly discussed by researchers (Shougrakpam et al., 2012). They demonstrated that soil macroporosity have a wide range of applications in the region, some of them are water quality monitoring and groundwater pollution assessment due to preferential leaching of solutes and pesticides. In their research findings, they found low soil macroporosity in

areas of previously practised Jhum cultivation, such areas showed disconnected subsoil macropores, not desirable for proper water infiltration in soils, possibly indicate occurrence of flash floods in the long run. In contrast, undisturbed forest areas showed high soil macroporosity. Chakrabarty and others (2011) discussed about fluoride geochemistry of groundwater in Kamrup. Metals like Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn were reported in the urban soils of Guwahati City (Mahanta et al., 2011). It was observed that metals concentrated in the urban pockets of Kamrup district where commercial activities and population density were high. Metal accumulation can be linked maximum human intervention in the market areas of Guwahati city in Kamrup. Deka et al (2011) studied the impact of oil spillage on soil metal accumualtion in the popular Noonmati refinery. Zn, Pb, Fe and Mn were highly concentrated in the soils of industrial, commercial and residential areas. Cd, Zn, and Pb primarily enriched in areas of a 3 year old abandoned dumpsite of municipal solid waste MSW in Guwahati (Choudhury et al. 2013).

Socioeconomic studies have also been popularized in Kamrup. Das et al (2003) briefly recounted the educational pattern explaining the trend of privatization of tutorial classes, especially mathematics. There are several ground level studies on wild life conservation in Amchang Wild Life Sanctuary and Deepor Beel Wildlife Sanctuary that has been conducted by students for attainment of institute degrees and have not been communicated. The proper bridging of knowledge through scientific techniques would generate the information in a better way for implementation in decision making processes and baseline development.

1.3 Ecological assessment of floodplain characteristics

Ecological assessment includes evaluation of quality of ecological parameters in relation to ecosystem support in a particular region. Physicochemical characterization of water and geochemical characterization of soil samples are recognized as essential methods in ecological assessment that checks impacts of human activities, climate change and extensive land use activities (Whitehead et al., 2009). Natural geophysical events concerned with ecosystem health are flooding, sedimentation, landslides, earthquakes and drought. Water and soil quality monitoring programmes keep a record of the ecological status of riverine floodplains as an important feature of environmental monitoring techniques (Aremu et al., 2011; Ahiarakwem et al., 2012). Essential water parameters like dissolved oxygen and nutrient content determine the longitudinal as well as vertical stratification of river waters (Effler, 1983). Thus influx and outflow of water affect the biological components. Likewise, soil quality determines the productivity and fertility of soil that promotes plant growth, agricultural activities and flourishes soil microorganisms. The fresh water species as well the soil flora and fauna are highly susceptible to contamination and over exploitation. Soil organic matter, moisture content and soil microbial activities indicate the soil health. Monitoring of water and soil quality in wetlands is intended to keep track of the level of contamination in an ecosystem.

1.3.1 Physicochemical characterization of water samples

Water is a “universal solvent” as well as a “health determinant” (Bernier et al., 2009). Water is recognized as a reservoir of nutrients for widespread ecosystem support and as an important vector of transmission of some widespread and debilitating diseases that

afflict humanity (Reiff et al., 1996). According to Drangert (1993), ***"Water quality is a concept that includes taste, odour, colour, appearance, softness, temperature, as well as bacteriological and chemical properties."*** Water resources are vulnerable to contamination, the sources of water pollution may be differentiated as point sources and non-point sources depending on origin of waste generation. Point sources include industrial effluents and municipal waste discharges (Sibanda et al., 2013). Non-point sources include defective septic systems, storm water drainage systems and runoff from animal feedlots. In general, it may be concluded that environmental waters originate from agricultural sources, wild and domesticated animals, urban development and effluent treatment facilities such as on-site wastewater treatment systems (Kelsey et al., 2004). Polluted waters are characterized by presence of faecal colonies (Ahmed et al., 2010), as they are rich in organic and inorganic matter essential for growth of water borne micro- and macro-organisms. Eutrophication is a primary indicator of water pollution observed in most of the water bodies featured with low level of dissolved oxygen, high biochemical oxygen demand and densely populated phytoplanktonic and zooplanktonic species.

Brahmaputra River floodplain represents a fresh water ecosystem, productivity of floodplain ecosystems and wetlands are comparatively lower than the marine ecosystems worldwide. Brahmaputra and Ganga jointly known as the Ganges Brahmaputra Basin experience a tropical wet monsoon climate. Fluctuation of water levels in the rivers, adjoining tributaries and wetlands directly respond to climate induced rainfall. Nutrients from the sediments are leached into water as well as

infiltrated deeper into the ground water aquifers in flood affected areas (Minor et al., 2014).

Physiochemical composition of water is a function of hydrogeochemical processes in rivers and lakes (Matthieu et al., 2005; USEPA, 1983). Management of water bodies is essential prior to application in domestic and industrial undertakings, irrigation plants, transportation, recreation and development of fisheries (Abel, 1996). Assessment of nutrient status and physicochemical characterization of water from rivers and lakes has been prioritized all over the world (Table A 1.1, Appendix 1).

Physiochemical analysis in general include evaluation of pH, electrical conductivity (EC), turbidity, nitrate (NO_3^-), sulphate (SO_4^{2-}), ammonia (NH_3), nitrite (NO_2^-), fluoride (F^-), chloride (Cl^-), total alkalinity (TA), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD) of water samples, trace elements, etc. and water quality indexing as Sodium Absorption ration (SAR), Soluble Sodium Percentage (%) and Kelly's ratio (KR), etc.. Physicochemical characteristics and its ecological implications in most of the rivers and lakes have been highly reported in India followed by Nigeria, China, some of the American and European territories. Water quality monitoring under the influence of climate change has also been studied in ice covered lakes in the Northern and the Southern Hemispheres respectively. In India, Chambal River (Saksena et al., 2008), Chandola Lake (Verma et al., 2012), Gorewada Lake (Puri, 2010), Kotitirtha Lake, New Palace Lake and Lakshatirth Lake (Pawar, 2012), Katraj Lake (Shaikh et al., 2013), Lakes in Bangalore (Jumbe et al., 2008), Lidder River (Rashid et al., 2013), Lotus Lake (Patil et al., 2013), Mansar Lake (Al-Mikhlafi et al., 2003; Kumar et al., 2006), Mansar Lake

and Surinsar Lake (Singh et al., 2013; Anuradha et al., 2013; Singh et al., 2007), Tsokar Lake, Tsomoriri Lake, Renuka Lake (Singh et al., 2013; Singh et al., 2007), Dal Lake (Singh et al., 2007), Musi River (Cheepi, 2012), Periyar Lake (Krishanan, 2013); Manasbal Lake (Sarah et al., 2011); Porur Lake and Vihar Lake (Chandra et al., 2012), Pushkar Lake (Sharma et al., 2011), Ganges – Brahmaputra River Basin (including Yamuna River sub – basin), Indus River (including Satluj and Beas River sub-basins), Godavari River, Krishna River, Mahanadi River, Narmada River, Cauvery River, Brahmini River (including Baitarni sub-basin), Tapi River, Mahi River, Pennar River and Sabarmati River (Central Water Commission, 2011), Saptakosi River, Saptagandaki River and Karnali River (Sharma et al., 2005), Sawanga Lake (Wankhade et al., 2013), Shahpura Lake (Trivedi et al., 2012), Small Lake (Tandel et al., 2011), Futala Lake, Ambazari Lake and Gandhisagar Lake (Puri et al., 2011), Upper Lake (Rahul et al., 2013), Vrishabavathi River and Byramangala Lake (Madhukar et al. 2013) and Wular Lake (Shah et al., 2012) have been extensively monitored for ecological parameters by evaluation of physicochemical parameters.

1.3.2 Physicochemical characterization of soil samples

Like water quality evaluation, sediments from river floodplains have been characterized for texture, grain size, geochemical parameters and nutrient composition globally. Soil characterization includes evaluation of basic parameters as pH, EC, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), SO_4^{2-}, NH_3, NO_3^-, NO_2^-, Cl^-, Na, K, Mg, Ca, and trace elements as Fe, Mn, Cu, Pb, Zn, Cd, Cr, Ni, As, etc. Geochemical characterization is highly reported in the lakes and rivers in American countries followed by India, Nigeria and most of the European unions. In India,

sediment characterization for ecological assessment has been carried out in Mansar Lake (Chandrakiran et al., 2013), Jhelum River (Hussain Mir et al., 2013), Dal Lake (Jeelani et al., 2006), Nainital Lake, Bhimtal Lake, Sattal Lake, Naukuchiatal Lake, Mansar lake, Dal Lake, lakes in Sagar and Bhopal (Singh et al., 2007), Sagar Lake (Singh et al., 2009), Kasardi River (Lokhande et al., 2011; Lokhande et al. 2011), Vasai Creek (Singare et al., 2011), Thane Creek (Singare et al., 2011), lakes located at and around Thane City, Mumbai, India (Singare et el., 2010), Kukshet Lakes of Nerul (Singare et al., 2011), Gomti River (Singh et al., 2005), Mansagar Lake (Sahni et al., 2012), Sawanga Lake (Wankhade et al., 2013), Mahanadi Basin (Sundaray et al., 2011), Brahmaputra River (Kotoky et al., 2006), Dhansiri River (Kotoky et al., 2011), Sundarban mangroves River (Rajkumar et al., 2012), Ahiran River (Dhanesh et al., 2014) and Gosthani River (Ganesh et al., 2013). It was observed that apart from assessment of nutrient status, productivity and geochemical characterization, researchers have also focussed on sediment deposition, accretion, and subsidence processes in course of time as in Louisiana (Hatton et al., 1983), sediment processes in the upper Yuba River (Curtis et al., 2005) and sediment removal activities in Illinois River (Marlin, 2002).

1.3.3 Microbial evaluation of water and soil samples

Microbial population in water and soil is often interpreted discretely depending on the nature and pathogenicity of microorganisms. Water and the soil system collectively contain useful as well as harmful microorganisms. Monitoring of water and soil samples from riverine floodplains provide an overview of the health hazards linked to harmful microorganisms in a region. Most of the useful microorganisms are isolated

from their immediate environment for beneficiary uses like the thermophiles from hot springs (Inskeep et al., 2010), psychrophiles from cold regions (Cavicchioli et al., 2011), or in other words, extremophiles are screened for their enzymatic activities and utilized in several industrial purposes by the scientists (Cardoso et al.2011). The new era of metagenomics, i.e. isolating DNA directly from environmental samples and cloning the 16rDNA using vectors to obtain an organism with similar activities have widened the scientific domain of microbiological assessment.

Temperature profile and nutrient status in water determine growth of microorganisms that may change turbidity, odour and taste of waters. Presence of microorganisms significantly correlates to the DO in water and hence the fluctuating levels of BOD and COD. Plate count methods, use of selective media and Most Probable Number (MPN) estimation for coliform species are the basic methods of speculating presence of specific microorganisms or faecal coliforms in water. Standard methods of isolation of bacteria include extraction of bacteria from sample including a suitable media and enumeration of single colonies by plate culture method. Cells are lysed and DNA is purified for 16SrRNA sequencing to obtain the similarity of isolated strain to an already existing species. Most of the common pathogenic microorganisms reported in water samples from rivers, lakes, ponds and streams in India are *Staphylococcus aureus* (Kumar et al., 2013), *Pseudomonas* sp. (Kumar et al., 2013; Sharma et al., 2013; Lyngdoh et al., 2012; Manivannan et al., 2013; Sati et al., 2011), *Proteus vulgaris* (Kumar et al., 2013), *Clostridium tetani* (Kumar et al., 2013), *Alcaligenes faecalis* (Kumar et al., 2013, *Shigella* sp. (Kumar et al., 2013; Manivannan et al., 2013), *Salmonella* sp. (Kumar et al., 2013; Manivannan et al. 2013), *Micrococcus*

sp. (Kumar et al., 2013; Usharani et al., 2010), *Enterobacter* sp. (Sharma et al., 2013; Manivannan et al., 2013), *Aeromonas* sp. (Sati et al., 2011) *Enterococci* sp. (Srivastava, 2012; Lyngdoh et al. 2012), *Escherichia coli* (Kumar et al., 2013; Sharma et al., 2013; Chatterjee et al., 2010; Srivastava, 2012; Lyngdoh et al., 2012; Suneela et al. 2007; Usharani et al., 2010), *Bacillus* sp. (Usharani et al., 2010), *Klebsiella* sp. (Lyngdoh et al. 2012; Manivannan et al., 2013; Sati et al., 2011), *Staphylococcus* sp. (Lyngdoh et al., 2012; Usharani et al., 2010), *Vibrio* sp. (Manivannan et al., 2013; Sati et al., 2011), *Citrobacter* sp. (Manivannan et al., 2013) and *Streptococcus* sp. (Chatterjee et al., 2010; Srivastava 2012; Manivannan et al., 2013; Usharani et al., 2010). Water in rivers, lakes, estuaries and wetlands are contaminated by three important sources: a) industrial effluents, b) household sewage and c) agricultural effluents. These wastes generated are rich in nutrient content generally observed with eutrophication events. However industrial and agricultural effluents indicate a lesser contribution as compared to household chores (EPA 2009).

In soil samples, presence of useful microorganisms however determines productivity connected to agricultural activities. Soil is a complex system comprising of several biochemical and physical processes under the influence of environmental factors in a particular ecosystem. Soil contains nutrients, chelates, microorganisms, air and moisture upholding the most important components of a terrestrial ecosystem (Bakshi et al., 2011). According to Hawsworth (2002), one billion bacteria are found in 1 gram of soil, fewer than 1 % have been discovered and named, and for fungi, out of 1.5 million species with only 5% have studied upon. Useful bacteria from soil

rhizosphere are often isolated for their importance in significant enzyme activities and implementation in several industrial purposes.

Microbial evaluation for harmful bacterial species has been considered as vital investigation worldwide. Drinking water sources basically water from rivers, lakes, wetlands and streams have assessed for existence of coliform bacteria. Some of the important rivers and lakes studied for microbiological assessment in India are Kaushalya River (Aggarwal et al., 2012), Kallada River (Ashiq et al., 2012), Achal Taal, Lal Taal and Laal Diggi ponds in Aligarh (Ayub et al., 2011), Muttukadu Back Waters, East Coast of Tamil Nadu (Baheerathi, 2012), Koel River (Burh, 2011), Damodar River (Chatterjee et al., 2010), Datte – Da – Talab in Birpur, Jammu and Kashmir (Sharma et al., 2013), Vedvyas River and Koel River (Srivastava, 2012), Pamba River (Jalal et al., 2013), barmouths and lagoons in Chennai (Jayakumar et al., 2013), Bathu – da – Mandir and Beas River Dehra (Kumar et al., 2012), Umiam Lake (Lyngdoh et al., 2012), Ranganathapuram Lake, Chinthamani Lake, Vedapatti Lake, Pannimadai Lake, Vallan Lake (Manivannan et al., 2013), Indus River (Shafiq et al., 2011), Dal Lake (Saleem et al., 2011), Bhagirathi River and Alaknanda River (Sati et al., 2011), Manasbal Lake (Shafi et al., 2013), Udaipur Lakes (Sharma et al., 2008), Narmada River (Soni et al., 2013), Hussain Nagar Lake in Hyderabad (Suneela et al., 2007) and Noyyal River (Usharani et al., 2010). Apart from microbiological assessment in rivers and lakes, genotoxicity studies have been carried out as in Danube River (Kolarević et al., 2011). Yeasts species as *Aureobasidium pullulans* and *Candida krusei* have been isolated from Doce River Basin in Brazil (Medeiros et al., 2012). A detailed

microbiological assessment of rivers and lakes all over the world is given in Table A 1.2, Appendix 1.

In case of soil microorganisms, methods of isolation are similar to isolation of bacteria from water samples. Use of selective media enables initial screening of the type of organisms and their pathogenicity. Soil microorganisms especially monitoring of bacteria, fungi and actinomycetes have been reported. Some of the microorganisms isolated from soils and sediments of rivers, lakes, salt marshes, etc. are bacteria as *Pseudomonas* sp. in Indus River, India (Praveen et al., 2011), *Escherichia coli* in Hussain Nagar Lake, Andhra Pradesh (Suneela et al., 2007), sulphur oxidizing bacteria as *Micrococcus* sp., *Bacillus* sp., *Pseudomonas* sp. and *Klebsiella* sp. from mangrove soil of Mahanadi River Delta (Behera et al., 2014), *Corynebacterium* sp., *Bacillus* sp., *Enterobacter* sp., *Klebsiella* sp., *Staphylococcus* sp., *Micrococcus* sp., *Acinetobacter* sp., *Pseudomonas* sp., *Aeromonas* sp., *Salmonella* sp., *Streptococcus* sp., *Proteus* sp. and *Erwinia* sp. in Foma River, Nigeria (Agbabiaka et al. 2012), *Escherichia coli* in Awba Lake, Nigeria (Tijani et al., 2005), bacteria from the phyla *Proteobacteria*, *Firmicutes*, *Planctomycetes*, and *Bacteroidetes* in Pearl River Delta (Yang et al., 2013), diatoms as *Achnanthes*, *Amphora*, *Cocconeis*, *Cymatopleura*, *Cymbella*, *Diatoma*, *Fragilaria*, *Gomphonema*, *Gyrosigma*, *Navicula*, *Nitzschia*, *Pinnularia*, *Rhoicosphenia* (abbreviata) and *Surirella* in Rhine River (Yang et al., 2013), *Actinobacteria* from mangrove soils of Bhitarkanika in the estuarine region of Brahmani and Baitarani, Odhisa (Kishore, 2011), *Actinobacteria*, *Thermomicrobia*, *Clostridium*, *Intrasporangium*, *Propionibacterium*, *Rubrobacter* from Samoylov Island, Lena Delta, Siberia (Liebner et al., 2008), *Proteobacteria* in Mediterranean Temporary Rivers

(Amalfitano et al., 2008), *Proteobacteria*, thermophilic species of *Bacillus* and *Azotobacter* in Inuvik on the on the East Channel of Mackenzie River (Boyd et al., 1990), Psychrotolerant species closely related to *Pseudomonas* and mesophilic *Burkholderia cepacia* in low temperature Arctic soils (Master et al., 1998) and *Clostridium* spores in Reno River Watershed, Italy (Ferronato et al., 2013).

Among these, bacterial species as *Escherichia coli*, *Micrococcus*, *Bacillus*, *Pseudomonas* (a few species), *Salmonella*, *Streptococcus* and *Klebsiella* have been clinically proven harmful to human beings imparting health related hazards and are frequently transmitted from soil to organisms through the food chain. Ecological assessment in sensitive areas likes permafrost in the polar ice caps in the Northern and Southern hemispheres have revealed a wide spectrum of economically useful bacteria. These include methanogen from order *Methanococcales* and *Methanomicrobiales* form Canadian High Arctic (Allan et al., 2014), *Methanomicrobiales* from Siberian Arctic and Antarctica soils, bacteria belonging to the family *Methanomicrobiaceae*, *Methanosarcinaceae* and *Methanosaetaceae* from Laptev Sea coast, Siberian Arctic were reported (Ganzert et al., 2007). Other bacteria belonged to phyla *Actinobacteria* and *Proteobacteria* with a few species of *Proteobacteria* related to the order Rhizobiales (*Alphaproteobacteria*), more closely matching with *Rhizobium*, *Mesorhizobium* and *Bradyrhizobium*, some species belonged to *Arthrobacter* and *Cryobacterium* in Northeast Greenland (Ganzert et al., 2014) and *β-Proteobacteria*, species showed similarity with *Iodobacter fluviatilis*, *Polaromonas vacuolata*, *Rhodoferax* sp. in the cold environments of Southern Hemisphere Glaciers.

Actinomycetes as species of *Intrasporangium* were reported in Samoylov Island, Lena Delta, Siberia (Liebner et al., 2008). Fungi as *Curvularia*, *Aspergillus*, *Penicillium*, *Saccharomyces*, *Cladosporium*, *Geotrichum*, *Trichoderma*, *Mucor*, *Rhizopus*, *Fusarium* and *Mortierella* were isolated in Foma River, Nigeria (Agbabiaka et al., 2012). Details of similar isolates recovered from soil and sediments at a global scale are detailed in Table 1.3, Appendix 1.

1.3.4 Vegetation study

Vegetation study in an ecosystem is an essential part of ***"vegetation ecology"*** which means study of the plant cover and its relationships with the environment, also known as synecology (van der Maarel, 2005). Vegetation cover and plant species composition are two of the most commonly used groups of indicators in many terrestrial ecosystems (Niemi et al., 2004). These indicators have been correlated with a large number of ecosystem services including biodiversity, soil and water conservation, habitat for wildlife, food and fiber production (Millenium Ecosystem Assessment, 2003). Vegetation depends on the site of study, forest vegetation may include canopy cover whereas a grassland or agroecosystem may involve foliar cover (Bonham, 1989). The most widely used and common methods of vegetation study are quadrat methods and line transect methods (Godinez-Alvarez et al., 2009). Quadrat method is preferable over smaller areas of study like grasslands whereas line transect method is appropriate for large study area like forests.

Quadrat sampling is recognized as one of the most suitable methods of studying vegetation in plain topography. A good overview on design of quadrat sampling procedures has been given by Goldsmith et al (1986). The size of quadrats is an

important element and depends on the approximate cover of vegetation (Gleason, 1920). According to Mosley et al (1989), dense vegetation required larger quadrats. More than one quadrat size may be required for several species with varying plant sizes, distributions, and densities to be measured (Smith et al., 1987). Data obtained by quadrat methods are used to measure spatial pattern along with vegetation cover and make a quantitative analysis (Cottam et al., 1953). Quadrats are reliable samples of the true plant populations (Anderson,. 1955). Quadrat sampling involves counting all the individuals within a known area (or volume). Since density (D) and population size (N) are related, as N = D x Area (A), the density for the sample can be estimated and total population can thus be computed. The calculations are based on an assumption that the area the population occupies is finite and known. For plant communities, plot sizes involved are 0.1 to 1 m^2 for herbaceous vegetation, 10-20 m^2 for shrubs or saplings up to 3m height, and 100 m^2 for forest trees. The number of plots sampled, as a minimum, must be sufficient to turn up the bulk of small plant as well as large trees present.

1.3.5 Soil microbial biomass characterization

The productivity of an ecosystem is governed directly by the nutrients present in a soil system, the process of humification and nutrient mineralization takes place in soil progressively (Nannipieri et al., 1996; Insam, 1996; Sinsabaugh et al., 1991, Caldwell, 2005). Among the active pool of nutrients present in the soil, the most important ones are Carbon, Nitrogen, Phosphorus and Sulphur. The biogeochemical cycles circulating these elements make the nutrients available to the living organisms through the producer plants. The labile components of soil, commonly the minerals are fixed and made available to the living organisms through degradation processes by the organisms

existing in the soil mostly importantly bacteria, fungi and actinomycetes (Waldrop et al., 2000). Almost all ecological processes required to sustain life through dissimilative reactions to gain energy by decomposing organic matter and nutrient cycling are dependent on microorganisms. Biodegradation of organic matter in soil may refer to microbial transformation (Nannipieri, 1996). Nutrients in the soil are mineralized by microorganisms and a minor but significant quantity is retained by the microorganisms as microbial biomass (Figure 1.1). Microbial biomass manages the fertility of soil and help in tracing contaminants in soil (Hargreaves et al., 2003; Broos et al., 2007). Around 2-10% of the nutrient is confined as microbial biomass (Kujur et al., 2012). Microbial biomass has played an essential role in the field of agriculture, it functions as an indicator of nutrient content in the soil (Griffiths et al., 2012; Kujur et al., 2012). It has several purposes including stabilization of soil aggregates and acting indicator of pollutants in soil (Brookes, 2007).

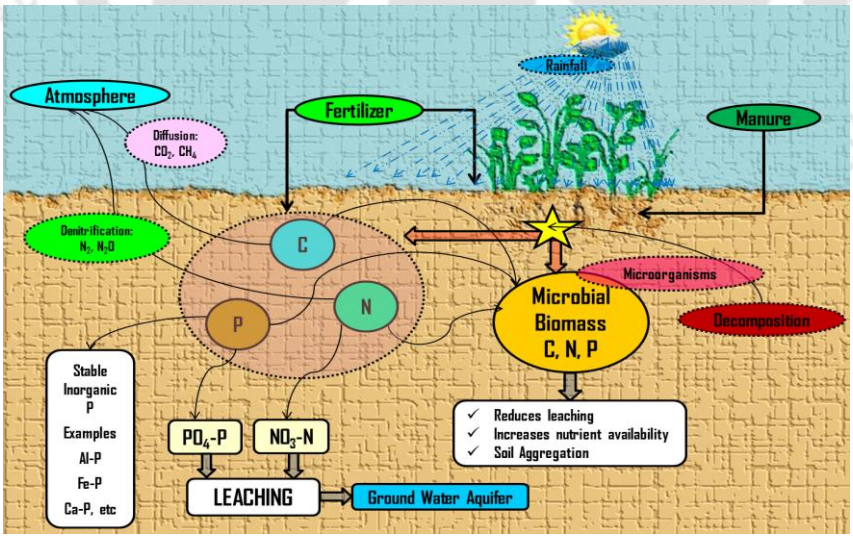


Figure 1.1 *Diagrammatic representation of the processes nutrient mineralization and formation of microbial biomass (adapted from Nagaoka et al., 2014)*

Soil microbial estimation is carried out by classical method of chloroform-fumigation-incubation (CFI) proposed by Jenkinson and Powlson (1976). Chloroform act as a fumigant and biocide releasing the cellular component of soil microorganisms not solubilize non-microbial soil organic matter (Vance et al., 1987). The fumigated soil is extracted with K_2SO_4 followed by treatment on an oscillating shaker for 30 min or 24 hours. The extract is filtered and analysed for CNP concentrations. The difference between the values of CNP in fumigated and non-fumigated soil is microbial biomass content. Vance and others (1987) demonstrated the deviance of values among variables and variance among a defined set of variables for microbial biomass estimation based on which a correction factor of 2.64 for microbial biomass carbon and 0.45 for microbial biomass nitrogen and phosphorus respectively. Other methods of soil microbial biomass estimation include microwave irradiation to destroy microbial cells in short time period and most of the researchers showed a positive approach towards microwave irradiation method comparable to CFI method (Hendricks et al. 1988; Islam et al., 1998). Soil microbial estimation is advantageous over soil microbial characterization because this method includes both the culturable and unculturable microorganism present in soil and releases the nutrient components of the entire soil microflora by decomposing the microbial organic matter only.

Researchers follow organic or inorganic amendment technologies in soil to determine the direct involvement of soil organic matter in increasing the soil microbial biomass aided by enzymatic activities (Goyal et al. 1999). Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties

under tropical conditions. Previous studies indicate that enzyme activities directly correlate to such amendments but the increase or decrease of soil microbial biomass in undefined (Albiach et al., 2000; Araújo et al., 2010). Brookes (2001) explained that microbial biomass turnover responds positively to fertilizer inputs in soil, the nutrients are taken up by the microorganisms, released gradually and taken up more efficiently by the crops in agricultural fields. Microbial biomass and significant rates of bacterial productivity in soil is low governed by the geochemical parameters (Trasar-Cepeda et al., 1997). Alongi (1988) suggested that high microbial biomass in Mangrove soils in Australia depends on the presence of bacterial consumers under tidal influence. In case of high bacterial growth followed by their consumption by protozoans, the nutrient (Carbon) level may be high in microbial biomass and hence less available for higher organisms. Microbial biomass depends on litter decomposition in a particular area, forest ecosystems logically have high soil microbial biomass followed by grasslands. Grasslands studied in temperate region showed accumulation of soil microbial biomass in undisturbed high litter grasslands as compared to grassland having low metabolic quotients in terms of low litter diversity (Bardgett et al., 1999). Apart from organic amendment activities and influence of environmental parameters, major factor affecting the soil microbial biomass is the land use activities (Yao et al. 2000). Celik (2005) reports that forest and grassland soils in highlands of southern Mediterranean Turkey showed change in soil physical properties as result of crop management activities. Tillage results in significant fluctuations in soil microbial biomass and soil productivity as the cultivation disintegrates the soil aggregates exposing the previously inaccessible organic matter to microbial attack and hence accelerates the decomposition and mineralization of organic matter in soil (Franzluebbers, 1999). Other factors as natural

calamities like too influence soil microbial biomass (Jia et al., 2005). Forest fires are intended to increase the nutrient levels but the intensity of heat kills most of the microorganisms in the topsoil and somewhat subsurface soils imparting a sterilizing effect. Recurrence of microbial biomass depends on plant recolonisation (Certini 2005). However Fu and others (2012) found that a short-term warming experiment in alpine meadow on the Tibetan Plateau had no obvious effect on the decrease or increase of soil microbial biomass. Natural process like forest succession in Europe showed that microbial biomass was promoted by forest succession in abandoned arable sites upto a level of mature forest (Susyan et al., 2011). Long term succession on post-mining similarly showed increase in the concentration of microbial biomass in soil (Frouz et al., 2005). Microbial biomass also accumulates in municipal solid wastes as reported in Erriadh city of Beja (Fourti et al., 2011).

The CNP stoichiometry, the complexity and spatial heterogeneity have been broadly discussed by Cleveland and Liptzin (2011), it was observed that a Redfield like tend to exist in soil as well soil microbial biomass. Analytical results revealed the element concentrations of CNP in individual phylogenetic groups within the soil microbial community on average shows atomic C:N:P ratios in soil in the ratio of 186:13:1 and the soil microbial biomass in the ratio of 60:7:1 at a global scale. The ratio of soil microbial biomass to soil organic matter is strongly influenced by agricultural activities. Emmerling and others (2001) found that there was a gradual increase in the ratio of soil microbial biomass to soil organic matter on shifting from conventional agricultural practices to integrated agricultural management system.

Similar observations of increase of increase of soil microbial towards long-term organic fertilization were observed by Esperschutz and others (2007).

Soil microbial biomass has been adopted as important tool is soil productivity analysis, significantly correlated to the soil physicochemical and biological parameters. Role of microbial biomass in nutrient mineralization is often studied and established as function of soil enzymatic activities in an agroecosystem and urban ecosystems.

1.3.6 Soil enzymatic activities

Soil related activities are dependent on a major attribute of the soil system, ***"the soil enzyme profile"***. Soil is the major platform for several enzymatic activities of higher organisms as well microorganisms. Plant and animal remains provide a pool of nutrients and biomolecules that are acted upon by enzymes in the soil (Holt et al., 1998; Kourtev et al., 2002; Egamberdieva et al., 2011). The nutrient mineralization has also been studied as function of enzymatic activities in soil (Schimel et al., 2003). According to Tate (1995), soil enzyme activities can be used as measures of microbial activities, soil fertility and productivity and effects of pollutants. Enzymes act as vital activators in life processes and help in maintaining soil ecology, physical and chemical properties, fertility, and soil health (Shukla et al., 2011). Enzymes in soil are important mediators of all the activities like organic matter degradation (Sinsabaugh et al., 1991), mineralization and nutrient cycling taking place in the soil system (Dick, 1998). Soils and sediments contain a large variety of organic materials ranging from simple sugars and carbohydrates to the more complex proteins, fats, waxes, and organic acids (Kiss et al., 1978). Factors as vegetation (Dinesh et al., 2004), fertilizers, pesticides (Gundi et al., 2007), soil management (Shukla, 2011) and crop rotation activities influence the

enzyme activity in soil. The origin of soil enzymatic activities is dependent on several sources, the most important ones are classified as extracellular enzymes from different sources like plants or animal origin and intracellular enzymes confined to microorganisms (James et al., 1991; Richmond, 1991). As described in the literature some of the important enzymes in the soil are cellulase, cellobiohydrolases, ß-glucosidases amylase, oxidases, peroxidase, peptidases, proteases, invertase, nitrogenases, phosphatases, phosphomonoesterases, lipases, urease and dehydrogenase (Caldwell 2005; Pancholy et al., 1973; Shukla, 2011). The source of enzymes in soil exists as intercellular i.e. from microorganisms or extracellular i.e. from microbial or any other origin. This confusion to some extent is frequently ruled out by addition of toluene or similar fumigant to release the enzymes from cellular components (Tabatabhai et al., 1972 The enzymatic activities found in the soil are vital function of the microorganisms present in soil as well the plants associated with the same (Dick, 1997). Addition of toluene is known to delineate the cellular and extracellular enzymes in soil. Toluene has a differential effect on the activity of different enzymes. It leads to plasmolysis of the cellular components of microorganisms present in the soil, releases the enzymes and increases the enzyme activity (Conrad, 1940; Skujins, 1967 and Nannipieri et al., 2011). Many researchers have described that toluene have no intense effect on the growth inhibition of microorganisms as well in plasmolysis of the cell constituents (Claus et al., 1960; Tabatabai et al., 1972). The results are very substantial in long term soil enzymatic assays having long incubation period, in case of short incubation period the addition of toluene can be overlooked (Verchot et al., 2005). The effect of toluene was noted in all the enzyme assays, it was evident in a few cases whereas inconspicuous in others. It has been identified that toluene is utilized by most

of the fungi and bacteria as Carbon source (Skujins, 1967 and Kaplan et al., 1979), toluene may not essentially fumigate soils but completely eliminate soil dehydrogenase and respiratory activities and hence there is a possibility of energy generation and enzyme synthesis (Ladd 1985). The methodologies used for soil enzyme estimation depends on the pH, temperature and soil moisture content. Enzymes activities in soil is critically function of microorganisms as well as other extracellular enzymes explain the role of soil organic matter as substrates.

Albiach (2000) discussed the activities of dehydrogenase, alkaline phosphomonoesterase, phosphodiesterase, arylsulphatase and urease under long field experiment in horticultural soil under organic amendments. Correlation between the enzyme activities and soil organic matter indicated the positive influence of organic amendments on soil enzyme activities. To simplify the confusion of source of enzyme in soil Skujins (1970) demonstrated the excretion of cellulases and proteinases by a number of microorganisms, these were responsible for degradation of substrates located at distant places from the cells. Udawatta and others (2010) indicated dehydrogenase activity as the backbone of microbial resilience against herbicide applications in prairie ecosystems in central Missouri, USA. Microbial enzyme activity in Upper Mississippi River basin was monitored as an indicator of nutrient limitation where nutrient composition in rivers sediments was linked to the enzyme activities under anthropogenic stress (Hill et al., 2010). An excellent plant and soil interaction was explained as substrate casein broken down into amino acid products by bacteria in soil and simultaneous uptake of the products my mycorrhizal components or roots of plants as Cyperaceae (Raab et al., 1999). Crop management activities and organic amendment

increases celluase and dehydrogenase activities in from biofarming field, Pulicherla, Andhra Pradesh (Prasanna et al., 2012). Evaluation of soil enzyme activities will provide a glimpse of soil health i.e. soil fertility and productivity as function of soil microbial population in presence of accessible organic matter in soil.

1.3.7 Pollution indices

Natural geophysical processes like atmospheric deposition and rapid urbanization and landuse activities have introduced a wide variety of point source pollution. Among the popular sources, urbanization and industrial activities, construction industries, metal mining, refining, and refinishing by products generate a huge amount of metal species into the environment. Soils act as a sink for heavy metal accumulation and finally discharged into the environmental systems (Banat et al., 2005). Therefore, sediments can be regarded as sensitive indicators for monitoring contaminants in aquatic environments (Pekey et al., 2004). There has been increasing concern for the aggravating environmental pollution basically related to soil and water seeking immediate attention most of the developing as well as developed countries worldwide (Zhang et al., 2007). In view of the rising apprehension about water and soil pollution it is essential to find out the pollution status through some defined pollution indexing methods.

There are numerous approaches to determine the water and soil quality indices formulated and successfully utilized by most of the researchers. According to Cheng and others (2007), development of ecological geochemistry survey and exploration, experimental data on heavy metals in water and sediments are used to assess the quality of ecological geochemistry environment. The calculation methods often employed to

assess the environmental quality are pollution index, principle component analysis, etc. (Qingjie et al., 2008). Pollution indexing is nowadays considered as a powerful as well as necessary tool for processing, analyzing, and conveying raw environmental information to decision makers, managers, technicians, and the public (Caeiro et al., 2005). Pollution indexing involves collection of simpler expression of more or less complex parameters that serve as water and soil quality measurements (Fernández et al. 2004).

Pollution indices are generally segregated into two types depending on the involvement of number of parameters for calculation. The first kind of indexing is known as, a) Single pollution indices and the second group of indices is somewhat more complex, b) Integrated pollution indices. Single Pollution Indices include Relative Abundance (Sany, 2012), Contamination factor (Martin et al., 1979), Enrichment Factor (Chakravarty et al., 2009; Cabrera et al., 1999; Duce et al., 1975; Zoller et al., 1974), Geoaccumulation Index (Ghrefat et al., 2011; Muller, 1979). Integrated pollution indices involve Contamination Degree (Abrahim et al., 2008), Pollution Load Index (Bhattacharya et al., 2006), Nemerow's Pollution index (NPI) (Cheng et al., 2007; Qingjie et al., 2008), Ecological Risk (ER) (Amuno, 2013; Hakanson, 1980) Potential Ecological Risk Index (PERI) (Zhu et al., 2012; Hakanson, 1980). Evaluation of pollution indices is motivated towards assessing the ecological risk by the presence of heavy metals in concentrations higher than the world average background concentration. Indexing of metals will develop to a baseline or determine the background metal concentration in an area.

1.3.8 Geostatistical analyses

The concern for aquatic and soil system pollution is primarily discussed in evaluation of pollution indices. Scientists have also adopted some radical methods of statistical analysis based spatial distribution of study sites and interpretation of highly correlated and uncorrelated parameters known as multivariate statistical analysis. Principal component analysis (PCA) and cluster analysis (CA) are the statistical tools used in the elaboration of pollution (Hani et al., 2011, Huang et al., 1994). Semivariogram analysis is an important component of geostatistical analysis associated focussed on spatial autocorrelation grounds.

Geostatistics analysis works on the concept of regionalized variable that uses the technique of semivariogram to measure the spatial variability of a regionalized variable and provides the input parameters for the spatial interpolation of kriging (Yao et al., 2013; Goovaerts et al., 2011). Issaks and others (1989) found that geostatistics can be used as a measure for risk assessment for variables exceeding critical values (regulatory thresholds and soil quality criterion) at unsampled locations and finally to simulate the spatial distribution of attribute values (Yang et al., 2014). Previous studies report that geostatistics provides the basis for the interpolation and interpretation of the spatial variability of soil properties (Cambardella et al., 1994). Geostatistics derives information on spatial variability of soil properties that may help in management decisions aimed at correcting problems and at least maintaining soil productivity and sustainability and thus increasing the precision of farming practices. A better understanding of spatial variability of soil properties based on geostatistical analyses would assist in refining agricultural management practices by identifying sites that

require remediation and management. Sustainable soil and land use are being promoted in spatial correlation studies and a baseline against which subsequent future measurements can be proposed on the basis of geostatistaical analytics (Haruna et al., 2013).

1.4 IMPORTANCE OF BIORESOURCE UTILZATION, NOVELS TRENDS IN BIORESOURCE UTILZATION

Bioresource in general refers to the biological resources derived from nature. The National Bioresource Development Board (NBDB), India was set up under the aegis of DBT in 1999 with a mission to evolve a broad policy framework for research and development of bioresorces. According to NBDB, bioresource utilization may be procured as "sustainable utilization of bioresources and an effective plan of action for economic prosperity of the nation through accelerated research and development using modern tools of biosciences." In this context interdisciplinary programs as bioresource engineering or bioengineering have come up in the recent phase. Among the classical trends, bioresource utilization is focused on energy bioresource from plants responsible for bioethanol and biodiesel production (Demirbas, 2007). Animal bioresources have also been recognized all over the world. Several institutions in India, Japan, China and Iran have been researching on biodiversity of silkworms and associated insects, pests and plant species (Sarmah et al., 2010; Bindroo et al., 2014; Banno et al., 2010; Jingade et al., 2011; Dalirsefat et al., 2007). Seribiodiversity is one among the traditional trends in bioresource utilization, associated with silk worm breeding and procurement of silk from different varieties of indigenous silk worm. Silk is nowadays recognized in widespread industrial and biomedical applications apart from textile firms and domestic

undertakings. Miscellaneous events of bioresource utilization techniques include engineering and application of plant and animal products for medicines (Zhang et al., 2009), enzymes (Madhavi et al., 2009; Boland et al., 1991), food (Gurib – Fakim et al., 2014; Ma et al., 2004) cosmetics (Alvarez et al., 2000), dyes, medical implants (Gurib – Fakim et al., 2014; Cooper et al., 2012; Anderson, 2001), household commodities (Misra et al., 2012; Ma et al., 2004), stockfeed (Thyagarajan et al., 2013) and numerous industrial yields (Arumugam et al., 2010; Wu et al., 2012).

1.4.1 Bioresource utilization for green synthesis of nanoparticles

Bioresources have a wide scope of application in biochemical sciences. In the fields of nanobiotechnology, plant bioresources are rationalized towards green chemistry of reduction of metallic salts to nanoparticles and promote sustainability of the environment friendly process known as green synthesis. The concept of "environmentally benign" biological sources is being reformed as a major alternative to traditional chemicals used for nanoparticle synthesis (Dubey et al., 2009). Biologically mediated nanoparticle synthesis facilitates capping or adsorption of stabilizing agents on the surface of nanoparticles that prevents the particles from agglomerating. Sustainable surface adsorption chemistry, stability and non-toxicity of nanoparticles are the desirable traits in biomedical applications.

Green synthesis has evolved as a cost-effective and eco-friendly method of nanoparticle synthesis from plant extracts since the time people realized the toxicity of chemically synthesized nanoparticles. Plant resources from Brahmaputra floodplain can be explored for application and synthesis of non-toxic and eco-friendly NPs. Brahmaputra River basin as aforementioned is rich in plant resources. Entire North East

India has a huge consortium of plant genetic resources (National Bureau of Plant Genetic Resources, Shillong) and contributes to a significant part of the Eastern Himalayan and Indo Burma Hotspot regions (covering Sikkim, Assam, and Arunachal Pradesh) (Sandeep et al., 2014). Larger speciation and high genetic diversity corresponds to the ecological humidity providing excellent habitat to a diversity of plant and animal species, thus increasing their endemicity to this region (Sandeep et al., 2014; Chatterjee, 1939). Plant species of this region belong to around 200 plant families, out of which 315 recorded are from North East India. 7000 (52%) of 13500 vascular plant species lying in the Indo-Burma hotspot region are endemic (Pawar et al. 2007; Tandon et al. 2009). *Nepanthaceae*, *Illiciaceae* and *Clethraceae* are some of the genera unique in the world and highly endemic to North Eastern Region (Chatterjee et al., 2006). Brahmaputra valley contributes to a significant portion of the entire floral diversity, especially the southern part of Brahmaputra River in the Indo-Burma hotspot region (Sandeep et al. 2014). WWF has considered Brahmaputra Valley as one of the ***"ecoregions"*** of North Eastern India (Chatterjee et al., 2006). Brahmaputra River floodplain is rich in bioresource. Plant species are considered as the key indicators of soil fertility and ecosystem health. Plant species have high ethnobotanical importance, especially plants are valued for their commercial and medicinal values. Since Brahmaputra floodplain is a huge repository of naturally occurring indigenous plants having high ethnobotanical significance, a new possible frontier of bioresource utilization would be green synthesis of nanoparticles from plant extract obtained from indigenous plants: Synthesis and characterization of gold and silver nanoparticles with economically valued plants has been emphasized in research trends since the last century. Especially green synthesized silver nanoparticles have high application in

water filtration devices due to its efficient antimicrobial and metal chelating properties (Ahmad et al., 2010). Moreover capping of nanoparticles by phytochemicals during synthesis masks the toxicity of otherwise toxic nanoparticles and make them desirable for use in even biomedical applications.

1.4.2 Some important plant species in Brahmaputra floodplain: Majuli and Kamrup

Plants resources in Majuli River Island and Kamrup are enclosed in the ecoregion of Brahmaputra valley. Majority of the vascular plants found in Brahmaputra floodplain are dicots and a few monocots.

In Majuli River island common plant species found are *Albizza procera* (Safed Siris), *Bischofla javanica* (Hollock), *Bombax ceiba* (Simul), *Lagerstroemia flosreginae* (Jarul/ Myrtte), *Eugeina jamboliana* (Kalojan or Black Plum), *Dillenia indica*, *Terminalia arjuna* (Arjuna), *Ficus glomerata* (Fig/ Damur), *Mesua ferea*, *Ficus reliogiosa*, *Acacia catechu*, *Baringtonia acutangla* (Indian Almond tree), *Anthocephalus cadamba* (Kadamba), *Azadirachta indica* (Neem) and *Terminalia chebula*. Grasses includes *Hemarthria pratesse* (Arali), *Chrysopogon aciculatus*, *Arundo donax*, *Erianthus ravennnae*, *Imperata cylindrica*, *Cynodon dactylon*, *Phragmites karka*, *Themeda arunidinacea* and *Vertivera zizaniodes*. Marshy vegetation includes *Eichornia crassipes*, *Pistia stratioles*, *Azolla pinnate*, *Nymphea nouchali*, *Nelumbo nucifera*, *Trapa bispinnosa*, *Euryale ferox*, *Hydrilla verticilliata*, *Cyperus* sp., *Ceratophyllum* sp., *Vallisneria spirillus*, *Alisma plantago*, *Polygonum hydropiper*, *Marsillea minuta*, *Alpinia allughas* and *Ipomea reptans* (Bhaskar et al., 2007). Bora (2011, 2012) reported 17 medicinal plant species, belonging to 14 families of

indigenous plants used to treat jaundice in Majuli. *Abutilon indicum* (L) Sw, *Cajanus cajan* Linn., *Bryophyllum calycinum* Salisb., *Drymeria cordata* Willd., *Mirabilis jalapa* Linn., *Stephania elegans*, H.K., *Phylenthus neuri* Linn., *Bombax ceiba* Linn., *Eugenia jambulena* Lam., *Dracaena angustifolia* Roxb., *Anonas comosus* (L) Merr., *Morus indica* Linn., *Mucona bracteata*, *Piper nigrum*, *Musa paradisiaca*, *Oryza sativa*, *Cicer arientum* (L) Bora (2012) also thoroughly studied the medicinal properties of plants used in dental, he listed them as *Acacia farnesiana* (L) Willd., *Achyranthes aspera* L., *Azadirachta indica* A. Juss., *Bambosa tulda* L., *Bambosa balcooa* L., *Borreria articularies* Will., *Calotropis gigantea* R. Br., *Curcuma angustifolia* Roxb., *Curcuma aromatic* Salisb., *Capsicum annum* Linn., *Cinnamomum tamala* Nees & Eberm, *Citrus limon* (L) Burm. f., *Glycosmis pentaphylla* Corr., *Grewa sapida* Roxb., *Jatropha curcas* Linn., *Mimosa pudica* L., *Nicotiana tabacum* L., *Psidium guajava* Linn., *Ricinus communis* L., *Smilax perfoliata* Bl., *Solanum khasianum* Clarke, *Spilanthes clava* DC., *Zantohxylum nitidium* DC., *Saccharum spontaneum*, *Cynodon dactylon*, *Vetiera zizanoides* and *Ipomea cerenae* were evaluated by researchers for their soil binding properties as a potential measure to prevent bank erosion (Biswas et al., 2000).

Plant diversity in Kamrup is similar to Majuli, especially grass species that are found scattered all over the alluvial floodplains of Brahmaputra River. Previous reports on medicinal properties of plants confirmed 22 plant species under 20 families having curing properties for reproductive health related ailments and contraception like leucorrhea, excess uterine bleeding, infertility in female, night fall or wet dream, vomiting at the time of pregnancy, gonorrhea, easy delivery of baby, increase of breast milk, irregular menstruation and female contraception (Choudhury et al., 2011). Plants

of ethnobotanical importance in Kamrup district were thoroughly studied by Sharma and others (2010), they reported a list of plants of indigenous origin and found all over Assam, these are *Achyranthes aspera* L., *Aegele marmelos* L., *Albizzia julibrissin* Durazz., *Alocasia indica* Schott., *Alstonia scholaris* R.Br., *Amaranthus spinosus* L., *Ananas comosus* L., *Boerhavia diffusa* L., *Bryophyllum calycinum* Salisb., *Caesalpinia digyna* Ratler., *Calotropis procera* R. Br., *Calotrpois gigantea* R. Br., *Clitoria ternatea* L., *Commelina benghalensis* L., *Curcuma longa* L., *Cuscuta reflexa* Roxb., *Cynodon dactylon* Pers., *Desmodium triquetrum* D.C., *Ecbolium linneanum* Kurz., *Eugenia jambolana* Lamk., *Garcinia cowa* Roxb., *Heliotropium indicum* L., *Hibiscus rosa chinensis* L., *Lawsonia alba* Lamb., *Leucas aspera* Spreng., *Momordica charantia* L., *Moringa oleifera* Lamk., *Musa balbisiana* Colla., *Nyctanthes arbor-tristis* L., *Physalis minima* L., *Premna latifolia* Roxb., *Punica granatum* L., *Rubus hexagynous* Roxb., *Spondius mangifera* Willd., *Tribulus terrestris* L., *Trigonella foenum-graceum* L., *Vitex negundu* L., *Wattakka volubilis* Staff., *Wedelia calendulaceae* Lees., *Xanthium strumarium* L., *Ziziphus jujuba* Lamk. Kotoky et al (2008) reported 24 plant species used as herbal remedies for the treatment of liver ailments. Deka and others (1983) provided a list of similar plants used as ayurvedic medicines, few of the plants are *Acacia catechu* Willd., *Acorus calamus* Linn., *Andrographis paniculata* Nees., *Asparagus racemosus* Willd., *Boerhavia repans* Linn., *Cleome viscosa* Linn., *Datura fastuosa* Linn., *Embelica officinalis* Gaert., *Gmelina arborea* Linn., *Holarrhoena antidysenterica* Wall., *Hydrocotyle asiatica* Linn., *Mesua ferea* Linn., *Mangifera indica* Linn., *Ocimum sanctum* Linn., *Oroxylon indicum* Linn., *Paederia faetida* Linn., *Piper longum* Linn., *Plumbago zeylanica* Linn., *Ricinus communis* Linn., *Saraca indica* Linn., *Sida rhomtfolia* Lonn., *Tamarindus indica* Linn., *Terminalia balerica* Roxb.,

Terminalia chebula Retz., *Tinopspora cordifolia* Miers. Deka and others (2012) studied the forest ecosystem in Chaygaon, Palasbari and Boko circle of Kamrup district, their extensive experimental findings revealed dominance of *Shorea robusta* followed by *Zizyphus rugosus*, other species recorded were *Erythrina suberosa*, *Delonix regia* and *Pterospermum acerifolium*. A comparable list of familiar herbaceous plant species of medicinal importance has also been provided by Das and others (2006).

1.5 Recent trends in nanobiotechnology

Nanotechnology has emerged out as an essential science concerned with design, characterization and application of nanomaterials that have at least one dimension on the nanometer scale (nm), ranging from a few to about 100 nm. The inherent property of metallic nanoparticles is Surface Plasmon Resonance (SPR) acquired due to oscillations of conduction electrons within the nanoparticles. Light waves direct the free-electrons in metal nanoparticles to oscillate. As light passes counteracts with the electrons, electron density in the particle is polarized to one surface and oscillates in resonance with the light's frequency producing a standing oscillation. The resonance condition is visible from absorption spectroscopy and depends on the shape, size, and dielectric constants of both metal and dispersing medium. Surface plasmons oscillate to absorb light imparting optical properties to the NPs ideal for application in fields of optoelectronics. Being the most inert materials, gold and silver nanoparticles are given high priorities in nanotechnology. Although chemically synthesized silver nanoparticles have toxicity concerns, green synthesized silver nanoparticles are proven non-toxic and suitable for biological applications as well (Mohanpuria et al., 2008). Besides gold and silver NPs, synthesis and applicability of Pt (Martínez-Rodríguez et al., 2014; Ahmadi

et al., 1996), Zn (Kumar et al., 2013), Cu (Peng et al., 2006), Ti (Sundrarajan et al., 2011), Pd (Nadagouda et al., 2008), Mn (Warad et al., 2005) and Fe (Smuleac et al., 2011) nanoparticles have also been widely reported. Non-metallic nanoparticles include polymeric (Raveendran et al., 2003) and ceramic (Vollath et al., 2001) nanoparticles developed worldwide.

The intersection of nanotechnology and biotechnology is evolving rapidly with time opening up new frontiers in synthesis and application of nanoscale structures for advanced biotechnology. Nanoparticles are synthesized from metallic salts or polymers having different compositions, sizes, shapes, and controlled dispersities (Akhtar et al., 2013). Biologically synthesized nanoparticles are capped with biomolecules that reduce the metal salts into nanoparticle. The biogenic nanoparticles, their capped nature and applicability have been gaining importance in the past few decades. Chemical and physical methods are expensive and generally involve toxic chemicals which are being adsorbed on surface of the synthesized nanoparticles. Chemically synthesized nanoparticles may be detrimental in biomedical applications (Gan et al., 2012). To overcome the toxic effects of nanoparticles, researchers have been motivated towards green synthesis of nanoparticles as an important trait of nanobiotechnology. Nanobiotechnology has varied application in clinical diagnosis, pharmaceuticals and healthcare (Jain, 2007). Recent trends in nanobiotechnology have attracted huge investment in research and development based on biomedical perspectives. Researchers have used the term, ***"nanodiagnostics"*** for application of non-toxic nanoparticles in molecular diagnostics (Kawadkar et al., 2011). Green synthesized gold nanoparticles are promising nanocarriers in target based drug delivery therapeutics (Jain, 2005).

Jain (2009) has highlighted the role of nanobiotechnology in personalized medicine as ***"the best way to integrate new biotechnologies into medicine for improving the understanding of pathomechanism of diseases, molecular diagnosis and integration with therapeutics."*** Nanotechnology can be well utilized in designing devices that can screen disease biomarkers for particular diseases and at very fast rates (Jain 2007).

Nanobiotechnology finds its importance in cytogentics as a part of molecular diagnostics, where the chromosome structure and its abnormalities related to disease can be identified. As in case of stem cell therapies, Jain (2008) indicated the need for tracking of stem cells introduced into the body where a superparamagnetic iron oxide nanoparticle can act as an ideal probe for noninvasive cell tracking. Nanoparticles of size 200 nm can be employed to label with endothelial progenitor cells, taken from human umbilical cord blood further be detected by magnetic resonance imaging (MRI) in vivo following administration (Partlow et al., 2007).

Nanobiotechnology incorporates a huge area of research interest in medical science. Besides the aforementioned topics, other areas of significant nanobiotechnological applications are clinical vaccination (as nanoencapsulating agents) (Akin et al., 2007); tools for nanosurgery (scope of microsurgery transition to nanosurgery for miniaturizing trauma during surgical processes, nanorobotic implants, etc.) (Jain 2008); nanorobotics (use of nanorobots that find and locate disease in the human body controlled by an external monitor) (Jain, 2008), nanoscale laser surgery (combined application of microscopy and nanosurgery on fluorescently labelled structures within living cells) (Sacconi et al., 2005); nanooncology (nanoparticles

acting molecular targeting agents, delivering chemotherapy drugs directly to tumor cells and giving off a signal after the cells are destroyed) (El-Sayed et al., 2006); nanoneurology (biocompatible and biodegradable nanoelectronics devices may be employed to establish cell-to-cell communication, create a bridge between severed nerves and muscles upto a meter away and hence opening up possibilities of repairing severed spinal cords and rehabilitation of stroke victims) (Silva et al., 2004); nanocardiology (cytokines, growth factors, and angiogenic factors can be encapsulated in biodegradable nanoparticles and embedded in tissue scaffolds and substrates to enhance tissue regeneration) (Lanza et al., 2006; Jain, 2008), nanoorthopedics (implantation of scaffolds or nanobones in the human human body for repair of bone defects after fractures or tumor removal and that can behave like an inert matrix on which cells can proliferate and deposit new living material, which becomes functional, normal bone) (Zanello et al., 2006) and nanoophthalmology (controlled release of ocular formulations by nanocarriers providing therapeutic concentrations for a long period of time at the site of action, thereby reducing the dose administered as well as the instillation frequency) (Vandervoort et al., 2007; Jain, 2008).

Nanobiotechnology has wide application in construction of bioelectronics devices, the binding property of nanoparticles with biomolecular moieties like DNA, proteins, etc. has been efficiently employed in designing biosensors (Khalid et al., 2010). Gold nanoparticles exhibit red light which is exploited in the design of experimental systems that kill cancerous cells with normal visible light, leaving normal cells unharmed (Khalid et al., 2010; O'Neal et al., 2004; Zharov et al., 2005). Furthermore, gold metal act as effective catalyst as the transition to nanoscale is

introduced. In case of silver nanoparticles, Wilsdon (2004) explained that silver nanoparticles exhibit bioactive properties that are not found in larger particles. These properties of gold and silver nanoparticles may be implemented for novel applications as nanobiosensors in the field of nanobiotechnology. Nanobiosensors have been fairly employed in detecting blood glucose concentrations as well as glucose in saliva, tears and urine (Wang, 2008). Combination of nanobiosensor with the ELISA immunoassay (enzyme-linked immunosorbent assay) has improvised the detection sensitivity of the nanobiosensor due to enzymatic amplification (Rai et al., 2012).

Some other significant application of nanobiotechnology includes the target based applicability of green synthesized nanoparticles in cytotoxicity assays and antimicrobial activity. This property of NPs has been implemented in industrial applications (Hajipour et al., 2012). Toxicity studies have proved the affectivity of biomolecules adsorbed on the surface of the nanoparticles knowing as capping or biofunctionalization, these capping agents (of biological origin) lead to cell membrane lysis, protein leakage, damage to nucleic acids and cell death (Kim et al. 2007; Kim et al. 2011). There are several reports on activity of green synthesized nanoparticles on cancer lines (Safaepour et al., 2009; Devaraj et al., 2013) and pathogenic microorganisms (Akhtar et al., 2013; Kim et al., 2011).

1.5.1 Gold nanoparticles

The yellow metal gold has an atomic number-79, atomic weight-196.97 amu, considered one of the most precious elements on earth. Gold in the form of nanoparticles (NPs) in colloidal solutions impart vibrant colors, this optical property have been utilized by artists since 1400-1300 Century BC. Properties of GNPs are

recalled from 4th century AD when the famous Glass Lycurgus Cup from the Romans times displayed dual color under different conditions of light. When viewed in reflected light or in daylight, it appeared green and when a light is shone into the cup, transmitted through the glass, it appeared red. The Glass Lycurgus Cup was composed of silver and gold nanoparticles in approximate ratio 7:3 of size diameter about 70 nm that resulted in special color display for the glass (Lee et al., 2005; Wiederrecht et al., 2004; Kurniawan, 2009). Scientist started studying the scientific attributes of gold nanoparticles from 1850 onwards. Gold being a soft and malleable metal, it is often alloyed with other metals to provide extra mechanical strength. Gold is a good conductor of heat and electricity, good reflector of infrared and is chemically inert material. The versatile surface chemistry of gold in nanoscale allows its coating with small molecules, polymers, and biological recognition molecules and thereby extending its range of application as nanoparticles. GNPs are synthesized from Chloroauric acid ($HAuCl_4$) in presence of a reducing agent. The synthesis process involves reduction of Au^{3+} ions to neutral gold atoms. In optimized conditions of reducing agent, temperature and mode of manufacturing (stirring, photosynthesis, UV-treatment, ultrasound application and microwave irradiation), the uniformity in size can be sustained. Colloidal GNPs of the smaller size range is reddish in color experiencing blue shift of plasmon resonance at absorption maximum peaked at 450 to 550 nm. At a particular wavelength and frequency of light the absorption maximum by GNPs depends on size, shape, surface and agglomeration. In absence of optimized conditions, more of these gold atoms are generated, the solution becomes supersaturated and begins to precipitate or agglomerate forming larger nanoparticles that undergo blue shift (Noginov et al., 2007). When the absorption maximum (lambda max) increases, the surface plasmon

resonance occurs both as transversal and longitudinal waves resulting in broadening of absorption peaks indicating formation of larger nanoparticles due to aggregation or agglomeration (lack of stability).

1.5.2 Application of gold nanoparticles

As already mentioned, GNPs are potential candidates in the fields of biomedical applications. In addition to it GNPs serve as multipurpose materials applicable in a wide range of traditional as well modern undertakings. GNPs are utilized in optoelectronics (Thomas et al., 2003; Shankar et al., 2004), electronic (Link et al., 1999), recording media (Sugiyama et al., 2001), sensing devices (Jena et al., 2006; Peng et al., 2010), catalysis (Thompson et al 2007; Corma et al. 2008) and commercial applications like nano-formulation in cosmetics (Patel et al. 2011). The most challenging application other than biomedical application would be the role of GNPs in climate change mitigation. Electrocatalytic reduction of CO_2 to CO on surface of GNPs has been recently reported (Zhu et al. 2013). Researchers believe that these findings could be an important new avenue for recycling CO_2 on a commercial scale.

1.5.3 Silver nanoparticles

Silver is white metal having atomic number-47 and atomic weight-107.87 amu. It is an important precious metal next to gold that has been used effectively since ancient civilizations till the modern era. Phoenicians in their historical background indicated the use silver to avail their anti-microbial properties acting as a natural biocide to coat milk bottles. Silver metal have unique optical, electrical, and thermal properties when reduced to nanoparticles. Silver nanoparticles (AgNPs) exhibit high electrical

conductivity, stability, and low sintering temperatures. The realization of optical properties of AgNPs along with gold nanoparticles was realized in 4th century when the famous Glass Lycurgus exhibited dual color under different circumstances of light shone. Over 120 years ago, in 1889, M. C. Lea reported the synthesis of a citrate-stabilized silver colloid (Nowack et al., 2011). The chemistry of AgNPs is similar to GNPs. The modes of synthesis, optimization of parameters are identical. AgNPs are synthesized form KNO_3 under the activity of a suitable reducing agent. Ag^+ ions are reduced to metallic Ag in colloidal solution of brown color. The concept and implication SPR in case of GNPs is equally justifiable in AgNPs. Like GNPs, the conduction band and valence band lie very close to each other which permit the electron to move freely and form SPR absorption band by oscillations in resonance with lightwaves. The size range of nanoparticles depend on the SPR shifts and absorption maximum that give rise intensely sharp peak for smaller nanoparticles and broad peak for larger nanoparticles. The quality of the AgNPs is assessed on the stability of the NPs. In presence of optimized experimental conditions and a proper surfactant or dispersing medium, the NPs tend to remain intact and avoid agglomeration.

1.5.4 Application of silver nanoparticles

AgNPs have been the focus of increasing research interest in the past decade. In the recent times, AgNPs serve as an excellent candidate for most of the therapeutic purposes (Jain et al., 2009). Studies on AgNPs have confirmed their potential application in almost fields of science (Hettiarachchi et al., 2011). In biomedical applications, AgNPs have shown positive results in wound healing (Atiyeh et al., 2007;

Tian et al., 2007; Mishra et al., 2008; Rigo et al., 2013) and in retinal therapies (Kalishwaralal et al., 2010), other conventional uses are being electronics, optics, catalysis, Raman scattering, DNA sequencing, and pharmaceuticals (Kreibig, 1974; Hilger, 2000; Zhang et al., 2005; Jiang et al., 2005; Cong et al., 2010; Aroca et al., 2005; Tripathi, 2003; Aymonier et al., 2003). The fundamental uses of AgNPs have been highly recognized in water treatment process. Contemporary AgNP filters are effective and utilized against contamination in water treatment and filtration processes (Jain et al., 2005; Tiwari et al., 2008). The efficiency of such filters is strongly attributed to the antimicrobial properties acquired by AgNPs (Rai et al., 2009).

1.5.5 Green synthesis of nanoparticles from plant extracts

"Environmentally benign" biological sources are nowadays successfully employed to produce ecofriendly NPs (Sahayaraj et al., 2012). Green synthesis of nanoparticles has been gaining importance since the time people realized the possible toxicity of chemically synthesized NPs (Mohanpuria et al., 2008). Biologically mediated NP synthesis provides capping or stabilizing agents on the surface of NPs masking the toxicity of nanoparticles and prevents the particles from agglomerating. Many biomolecules are found in plant extracts such as enzymes, proteins, amino acids, polysaccharides, antioxidants and vitamins that are environmentally benign, yet chemically complex (Sharma et al., 2009), these phytochemicals enable reduction of metals in ionic form to metallic NP and can help in overcoming the deleterious consequences of chemically synthesized NPs. This property of NPs has been recognized by several researchers as an efficient means for targeted treatment studies (Elechiguerra et al., 2005; Jain et al., 2009; Awasthi et al., 2013).

1.5.6 Antibacterial activities of silver nanoparticles synthesized from plant extracts

The anti-microbial history of silver dates back to the Phoenicians who recognized silver and used as a natural biocidal agent. Silver is even known to prevent HIV binding to host cells (Elechiguerra et al., 2005). Silver itself has a toxic effect on microorganisms and chemically synthesized AgNPs are reported to damage nucleic acids (Awasthi et al., 2013). Nanoparticles lead to an increase in reactive oxygen species (ROS) associated with DNA damage, apoptosis, and necrosis (Foldbjerg et al., 2011). Ag NPs are known to reduce mitochondrial function, increase membrane leakage in mammalian germline stem cells and increase ROS generation, deplete antioxidant reduced glutathione (GSH) content, and reduce mitochondrial function in rat liver cells (Braydich-Stolle et al. 2005).

Brahmaputra River floodplain represents a huge consortium of plant genetic resources of endemic origin and high ethnobotanical values. Considering the outputs of prevalent conventional methods of bioresource utilization, researchers have prioritized green synthesis of nanoparticles, utilization of the medicinal values of plants against the survival of pathogenic bacteria in water and soil. Green synthesized nanoparticles are capped with phytochemicals that mask the toxic effect of AgNPs, the antimicrobial activity is triggered by the large surface area of the small sized capped AgNPs available for interaction and hence more effective for biocidal activities than the larger NPs (Kvitek et al., 2008). The mechanism of antimicrobial activity may possibly involve growth inhibition by formation of free radicals that act upon the lipid membranes of bacterial cells. AgNPs may act differentially on Gram-positive and Gram-negative

bacteria due to differences in their cell wall structure i.e. presence of peptidoglycan layer (Kim et al., 2007). Li et al (2010) speculated that antimicrobial activity of AgNPs is initiated as a leakage of membrane followed by leakage of reducing on respiratory chain dehydrogenases. Amro et al (2010) recommended that metal depletion may lead to formation of irregularly shaped pits in the outer membrane and change membrane permeability, followed by progressive release of lipopolysaccharide molecules and membrane proteins. This mechanism defies the actual concept of pit formation and disruption of cell wall, because there has been no clear evidence of either positively charged Ag^{+} ions or negatively charged AgNPs are responsible for deformity of cell wall and pit formation (Sondi et al., 2004). This hypothesis is further supported by Kim et al (2009) and Li et al (2010), as they suggest release of silver ions from the AgNPs that may contribute to their bactericidal properties.

Antimicrobial activities of green synthesized AgNPs from plant extracts have been broadly studied. Some of them are *Argemone mexicana* against *Escherichia coli*, *Pseudomonas syringae* and *Aspergillus flavus* (Singh et al., 2010); *Cinnamon zeylanicum* against *Escherichia coli* (Sathishkumar et al., 2009); *Acalypha indica* against *Escherichia coli* and *Vibrio cholera* (Krishnaraj et al., 2010); *Ficus benghalensis* against *Escherichia coli* (Saxena et al., 2012); *Euphorbia hirta* against *Escherichia coli*, *Staphylococcus aureus*, *Bacillus cereus*, *Klebsiella pneumonia*, *Pseudomonas aeruginosa* (Elumalai et al., 2010); *Garcinia mangostana* against *Escherichia coli* and *Staphylococcus aureus* (Veerasamy et al., 2011); *Ocimum sanctum* against *Escherichia coli* and *Staphylococcus aureus* (Singhal et al., 2011); *Mentha piperita* against *Escherichia coli* and *Staphylococcus aureus* (Ali et al., 2011);

Polyalthia longifolia against *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* (Kaviya et al., 2011); *Moringa oleifera* against *Staphylococcus aureus*, *Candida tropicalis*, *Candida krusei* and *Klebsiella pneumoniae* (Prasad et al., 2011); *Nicotiana tobaccum* against *Pseudomonas aeruginosa* and *Escherichia coli* (Prasad et al., 2011); *Eucalyptus chapmaniana* against *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Proteus vulgaris*, *Staphylococcus aureus* and *Candida albicans* (Sulaiman et al., 2013); *Citrus limon* against *Fusarium oxysporum* and *Alternaria brassicicola* (Vankar et al., 2012); *Mimusops elengi* against *Klebsiella pneumoniae*, *Micrococcus luteus* and *Staphylococcus aureus* (Prakash et al., 2013); *Artemisia nilagirica*, *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, and *Proteus subtilis* (Vijayakumar et al., 2013); *Alternanthera sessilis* against *Staphylococcus aureus* and *Escherichia coli* (Niraimathi et al., 2013); *Salicornia brachiate* against *Staphylococcus aureus*, *Staphylococcus aureus*, *Bacillus subtilis* and *Escherichia coli* (Seralathan et al., 2014); *Annona squamosa* against *Bacillus cereus*, *Bacillus subtilis*, *Staphylococcus aureus*, *Staphylococcus typhimurium*, *Pseudomonas aeruginosa* and *Proteus vulgaris* (Jagtap et al., 2013); *Carthamus tinctorius* against *Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis* and *Candida albicans* (Sreekanth et al. 2011); *Millingtonia hortensis* against *Bacillus subtilis* and *Klebsiella planticola* (Gnanajobitha et al., 2013); *Boswellia serrata* against *Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Klebsiella pneumonia* and *Pseudomonas putida* (Kudle et al., 2013); *Datura metel* against *Micrococcus luteus*, *Escherichia coli*, *Staphylococcus aureus* and *Klebsiella pneumonia* (Nethradevi et al., 2012); *Catharanthus roseus* against *Escherichia coli*, *Pseudomonas putida*, *Klebsiella pneumonia* and *Bacillus subtilus* (Manisha et al.,

2014); *Dioscorea batatas* against *Staphylococcus aureus*, *Escherichia coli*, *Saccharomyces cerivisae* and *Candida albicans* (Nagajyothi et al., 2011) and *Brassica oleracea* against *Staphylococcus aureus* and *Escherichia coli* (Sridhara et al., 2013). Antimicrobial activity using green synthesized nanoparticles can be adopted as a cost effective and easy strategy for designing water filters to remove contamination of water.

In concluding remarks, it is mandatory to mention that ecological study encompasses a wide range of research perspectives. Productivity of a floodplain ecosystem is a key indicator of its health and ability to support human requirements. Assessment of ecological parameters reflects a monitoring criterion for sustaining a healthy ecosystem. A healthy ecosystem will provide better ecosystem support to the biological components. Thus proper monitoring and evaluation of a baseline status of riverine floodplain would open up broader scope of bioresource utilization in the future.

PART – A

ECOSYSTEM FUNCTIONS

CHAPTER 2

Analysis of floodplain characteristics vis-à-vis ecosystem support mechanism and evaluation of soil productivity as a function of nutrient cycling

2.1 INTRODUCTION

Brahmaputra River is ranked one among the highest specific discharge system in the world. The gradient of the river is confirmed by the steepness recorded as 4.3-16.8 m km^{-1} in the gorge section upstream of Pasighat and around 0.1 m km^{-1} in Guwahati (Kamrup) (Goswami, 1998). The flow of nutrients is directed from upstream to downstream low-lying plains in the river. Gradient of Brahmaputra flowing from Pasighat through Majuli to downstream Kamrup, accompanies a huge sediment discharge of 1128 tonnes km^{-2} $year^{-1}$. The sediment driven fertile alluvia are rich sources of nutrients desirable for crop management and developmental activities. Keeping the geomorphological features in consideration, two study areas having unique topographies in the Brahmaputra floodplain were selected for the research project. Majuli River Island lies at the upper middle stretch of Brahmaputra River at altitude of 84.50 m above the mean sea level (Phukan, 2005; Dutta et al., 2012). Ecological assessment in Majuli was compared to a similar downstream floodplain ecosystem in Brahmaputra Basin, Kamrup (Amingaon and Umananda River Island). Kamrup is located in the lower stretch of Brahmaputra River at altitude of 31 – 55 m above the mean sea level depending on variation in the hilly terrain. Majuli and Kamrup were considered as two different soil typologies in Brahmaputra River floodplain. Majuli represents the plains in upper Assam whereas Kamrup represents the hilly terrains in lower Assam.

In Majuli, annual tourism rush, agricultural activities, fishery, inland transportation and natural geophysical processes affect the aquatic as well terrestrial

ecosystems (Block Development Office, Majuli 2011). In Kamrup, large scale industrial activities, occupational and trespassing events in Amingaon and high tourism rush in Umananda indicate an impending hazard to environmental quality. From the ecosystem health perspective, water and soil monitoring was performed in Majuli and Kamrup according standard methods of ASTM and APHA.

Soil serves as a medium for flow and regulation of water and determines the availability of nutrients. Most of the elements leach deeper into soil, ground water aquifer and water bodies. The processes that influence soil quality are more or less dependent on intrinsic and extrinsic factors (Svoray et al., 2004). Among the intrinsic factors, soil water holding capacity, nutrient status and soil porosity determine the occurrence of vegetation, while extrinsic factors are associated with the environmental determinants like topography of a particular area (Svoray et al., 2004). These factors are intertwined with the biotic components and they collectively contribute to soil fertility and productivity. This vital property of soil is influenced by process of humification and OM mineralization that occur progressively (Sinsabaugh et al., 1991). Among the active pool of nutrients present in the soil, most important ones are Carbon, Nitrogen, Phosphorus and Sulphur. Biogeochemical cycles make these nutrients available to the living organisms through producer plants. The labile form of elements present in soil are fixed and made available to the living organisms through biochemical processes by microorganisms existing in soil most importantly bacteria, fungi and actinomycetes (Waldrop et al., 2000). Nutrients in soil are thus mineralized by microorganisms where a minor but significant quantity is retained by

microorganisms as microbial biomass accounting to nearly 2-10% of the total nutrient content (Kujur and Patel, 2012). Soil microbial biomass content is directly or indirectly influenced by the enzymes present in soil (Bruce, 2005). The most important ones are classified as extracellular enzymes from diverse sources of plants or animal or microbial origin, and intracellular enzymes confined to cellular components of the living organisms in soil (Pancholy and Rice, 1973). However factors as vegetation, fertilizers, pesticides and agricultural practices influence enzyme activities in soil (Dinesh et al., 2004; Gundi et al., 2007; Hargreaves et al., 2003).

In an effort to understand this attribute, soil samples were analysed for geochemical parameters and microbial population from health as well as productivity viewpoint. Soil microbial population count, soil microbial biomass (MB) characterization and soil enzyme activities were checked in order to evaluate soil fertility and scope of productivity with respect to nutrient mineralization dynamics. Statistical analyses helped to correlate the experimental variables and derive a functional relationship between the biotic and abiotic parameters in soil samples (all parameters contributing to nutrient mineralization).

Type of vegetation was studied in wetlands in Majuli and occurrence of similar species was checked in Kamrup. Brahmaputra River floodplain is rich in species composition. The fertile alluvial soil is homeland to a wide spectrum of endangered species of plants and animals with enormous variation in both vertical and horizontal distributions (Goswami, 1997). Vegetation study was carried out in Majuli by Quadrat Sampling Method. Occurrence of plant species recorded in Majuli was checked for

existence in Kamrup. Vegetation profile gave an overview of landuse activities and soil quality. Majuli was dominated by grassland vegetation which has now been converted gradually to agricultural lands and residential areas (confirmed by social survey). Vegetation in Majuli included some common plants as *Daucas carota*, *Abelmoschus esculentus*, *Oxalis repens*, *Mimosa pudica*, *Chrysopogon aciculatus*, *Centella asiatica*, *Solanum nigrum*, *Andrographis paniculata*, *Imperata cylindrica*, *Spilanthes paniculata*, *Hemarthria* sp., *Commelina benghalensis*, *Hydrocotyle rotundifolia*, *Ageratum conyzoides*, *Ficus reliogiosa*, *Dichanthium annulatum*, *Polygonum hydropiper* and *Eichornia crassipes*, etc. Plant species found in Majuli were also observed in Kamrup.

2.2 MATERIALS AND METHODS

Physicochemical characteristics of water samples included analysis of pH, electrical conductivity (EC), turbidity, nitrate (NO_3^-), ammonia (NH_3), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), fluoride (F^-), chloride (Cl^-), dissolved oxygen (DO), chemical oxygen demand (COD), most probable number (MPN) for faecal colonies, sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), total iron (Fe), manganese (Mn), copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), chromium (Cr), and nickel (Ni). Water quality indices were calculated to find out the suitability of water for irrigation activities. These included Sodium Absorption Ration (SAR), Soluble Sodium Percentage (SSP) and Kelly's Ratio (KR). Geochemical parameters included pH, EC, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), SO_4^{2-}, NH_3, NO_3^-, NO_2^-, Cl^-, Na, K, Ca and Mg. Soil microbial population was checked for bacterial CFU (BCFU) and fungal CFU (FCFU). Soil microbial biomass (MB) characterization

included MBC, MBN and MBP. Soil enzyme activities involved phosphatase, cellulase, amylase, dehydrogenase, invertase, protease and urease. All experimental analyses were carried out in triplicates. Statistical analysis involved correlation studies and regression curve fitting model that helped in validating the experimental results.

2.2.1 Description of study area

2.2.1.1 Majuli River Island

Majuli River Island is located in the heart of Brahmaputra River in the upper middle stretch of Assam in North East India. It has been designated as one of the world's largest river island (Figure 2.1). Majuli is situated in the north of Jorhat between 93°30' E to 94°35' E longitude and 26°50' N to 27°10' N latitude, extending from north to south direction with an altitude of 84.50 m above the mean sea level (Phukan, 2005; Dutta et al., 2012). Majuli subdivision is separated from the mainland on northern side of Jorhat district by the Brahmaputra. The land area of Majuli was initially 1246 km^2 till 1950 which reduced to 925 km^2 in 1971 due to flooding and bank erosion (Space Application Centre and Brahmaputra Board 1996; Mani et al. 2003; Kotoky et al. 2003 and Dutta et al. 2010). Total land mass of 50 km^2 has been lost in the time period of 1969 to 1994 (NBSS and LUP, ICAR, 2006). Activities of Brahmaputra River and Subansiri River collectively led to bank erosion in large scales. The eroded area due to Subansiri River is 3.91 km^2 (0.42% of total area) and due to Brahmaputra River is 46.36 km^2 (Singh, 2011). Majuli represents a unique fluvial geomorphology and experiences a tropical wet monsoon climate. Mean annual rainfall is more than 90%,

received in the months of April, May, June, July, August, September and October. Winter rainfall is observed in December and January which is less than 20% of the mean annual rainfall. The mean temperature is 24.1°C where mean summer temperature is 26.8°C and mean winter temperature is 7.3°C (NBSS and LUP, ICAR, 2006). Majuli is an agriculture dominated region mostly practising paddy cultivation and has a cropping intensity of 102% (NBSS and LUP, ICAR, 2006). The land area in Majuli experiences regular flood inundation in the banks. Most of the smaller islands or sand bars known as chars get submerged during the monsoon floods. The lithogenic composition varies from sandy loam to clay loam (Singh, 2011). The unique land form in Majuli is differentiated into seven significant geomorphic units, 1) Active Floodplains, 2) Sand Bars with grass covers, 3) Sand Bars, 4) Swamps, 5) Old Floodplains, 6) Channel Fills and 7) Natural Leeves (NBSS and LUP, ICAR, 2006).

Majuli has a huge wetland resource. A total of 112 wetlands covering an area of 20.13 km^2 was reported in 1917 and 50 wetlands covering an area of 17.88 km^2 was reported in 1966 to 1972 (Sarma et al., 2004). 64 wetlands are under Majuli Development Block, 61 wetlands are under Ujani Majuli Development Block, 6 wetlands are under Assam Fisheries development Corporation (AFDC) and 9 wetlands are under Revenue Bils (wetlands) (Nath 2009). Water sampling was carried out in 14 wetlands, out of which 2 wetlands are not named [Table A 2.1 (A), (B), Appendix 2]. Water and soil sampling were performed in the wetlands areas in Majuli River Island [Table A 2.1 (A), (B), Appendix 2].

Among the wetlands studied, Kharjan (Kharjan Morisuti), Daria (Doria), Bhereki (Bherek), Sarala (Charala), Tuni (Tuninodi Balichat) and Gakhajuwa (Gakhojuwa) wetlands are under Majuli Development Block; Kakarikata (Kakarikota) and Bhereki (Vereki) are under AFDC; and Daria (Doria dubi), Kharkhari (Kharkhori), Barbil (Dakhipat Borbil), Tuni (Tuni fishery) and Magurmara are under Revenue Bils. Theses wetlands are open wetlands connected to Brahmaputra and Subansiri during the monsoon floods. The details of all the wetlands studied are described in Table A 2.1 (A), (B), Appendix 2.

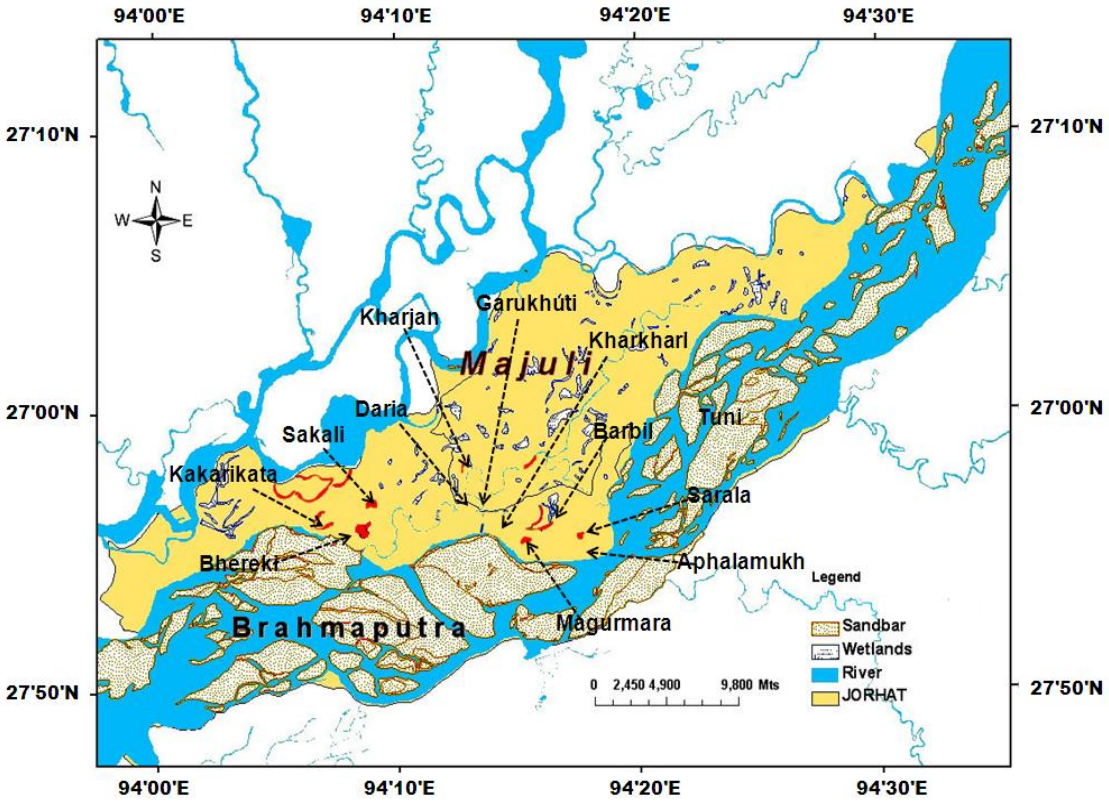


Figure 2.1 *Map of Majuli River Island showing sampling sites*

2.2.1.2 Kamrup: Amingaon and Umananda River Island

Kamrup is located between 25°46'0"N to 26°49'0"N latitude and 90°48'0"E to 91°50'0"E longitude in Assam, North Eastern India (Figure 2.2). The study sites in Kamrup are Amingaon situated on the mainland near the bank of Brahmaputra River in the north of Guwahati and Umananda River Island or Peacock Island lying on the north east of Guwahati (Figure 2.2). Kamrup is a large district in lower Assam occupying an area of around 4345 km^2. The topographic features consist of a combination of hilly landscape of undulant nature. The hills are scanty at places and dispersed with plain landmass. The hilly terrain extends upto Meghalaya on the southern part that gradually converge into a flat terrain towards Brahmaputra River. These areas are characterized by presence of small hills and residual hillocks. A major part of Kamrup district is occupied by the Brahmaputra River in the heart of Guwahati city. Adjoining smaller tributaries include Puthimari, Bornoi, Nona, Kulshi, Pagladia and Kalajal. Flooding events are observed in the months of May to August every year in low lying areas. Late floods occasionally occur in September and October. Flash floods are common in rainy season (State Level Nodal Agency, IWMP, Guwahati, 2014).

Kamrup has been experiencing an average annual rainfall of approximately 1738 mm since last ten years. According to metrological data, approximately 90% of rainfall occurs between April and September with maximum incidence in June, July and August. January is observed as driest month of the year with scanty rainfall of around 5.46 mm, during the last ten years. Highest temperature is recorded at 33°C in the month of July and August and minimum temperature is recorded at 10.82°C in the

month of January. Relative humidity is as high as 90% that creates a hot and humid climate in Kamrup. Maximum humidity is witnessed in the month of January. Kamrup is an earthquake sensitive zone and included in High Risk Zone-V of earthquake incidents, where a maximum intensity of IX can be expected (Guwahati City Disaster Management & Response Plan, 2014). Soil type varies between sandy loam, loam, sandy clay and clay loam depending on the lithogenic composition. River flow, steepness and gradient determine fertility of the alluvia in downstream areas of Kamrup (State Level Nodal Agency, IWMP, Guwahati, 2014).

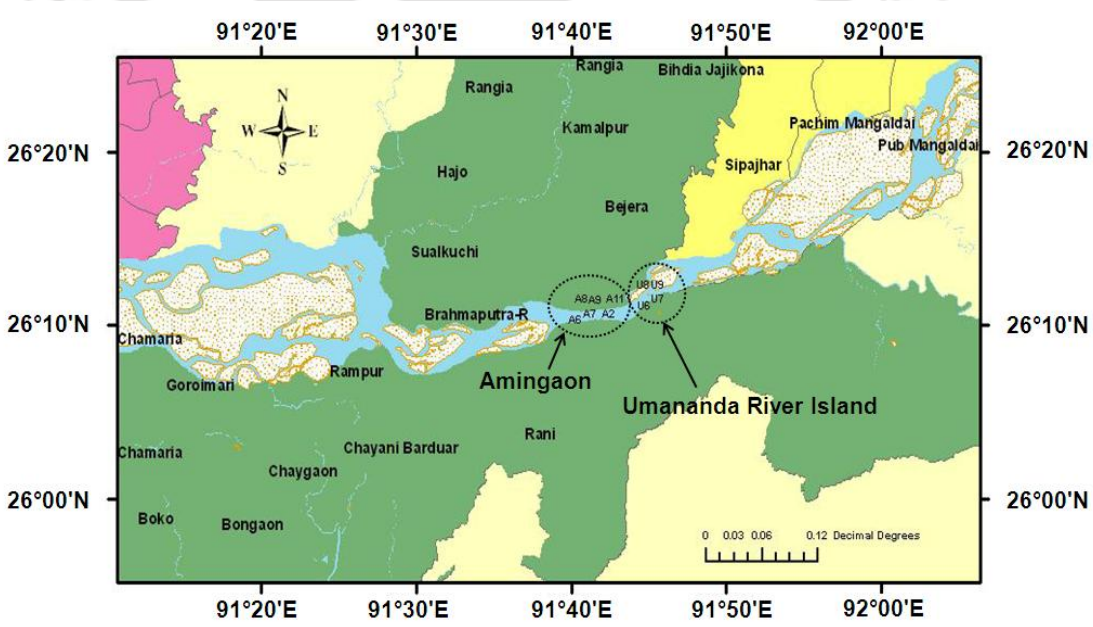


Figure 2.2 *Map of Kamrup showing sampling sites in Amingaon and Umananda River Island*

The research area is focussed on Amingaon and Umananda Island or Peacock Island, two economically important sites in Kamrup. Amingaon and Umananda experience a tropical wet monsoon climate in the district of Kamrup lying at an altitude of 31-55 m above mean sea level, depending on the terrain. Amingaon is known for its industrial activities in the core area. It is located between 26°11′0.5″N latitude and 91°40′1.2″E longitude in the north of Kamrup district. Umananda is a highly visited pilgrimage site, located between 26°11′47.76″N latitude and 91°44′43.44″E longitude. Umananda is also popularized due the occurrence of endemic species of Golden langur (*Trachypithecus geei*), exclusively in Kamrup.

Geomorphology of the study area represents an alluvial form of soil occurring in the family of Aquic Udifluvents (Vadivelu et al., 2004), desirable for agricultural activities. Soil in Amingaon and Umananda are of sandy clay loam nature and the pH ranges from slightly acidic to slightly alkaline in nature. The vegetation profile includes large trees, herbs and shrubs of great ethnobotanical importance. Flooding is witnessed by the inhabitants residing on the banks of Brahmaputra River. Increasing population density and industrial activities in Amingaon and concurrence of huge pilgrimage mass in Umananda appears to be a daunting challenge to the ecological entities in their natural habitat. Soil samples were collected from Amingaon and Umananda River Island in pre-monsoon and monsoon seasons.

2.2.2 Sampling

Sampling was carried out in two consecutive years i.e. 2011 and 2012. First sampling was performed in Majuli Island in two seasons – pre-monsoons (April, 2011) and monsoon (August, 2011), included water and soil samples [Table A 2.1 (A), (B), Appendix 2] [Figure 2.3 (A – H)]. Second sampling was carried out in Kamrup (Amingaon and Umananda Island) in two seasons-pre-monsoons (April, 2012) and monsoon (August, 2012), included soil samples only [Table A 2.1 (C), Appendix 2] [Figure 2.3 (I – J); Figure 2.4 (K – L)]. Majuli and Umananda represent two island ecosystems in two different stretches of Brahmaputra River whereas Amingaon represents a mainland at the bank of Brahmaputra River. Majuli is a huge river island representing a combination of both mainland as well as an isolated river island comparable to Amingaon and Umananda in Kamrup, this serves the main criteria for selection of Kamrup for comparison studies.

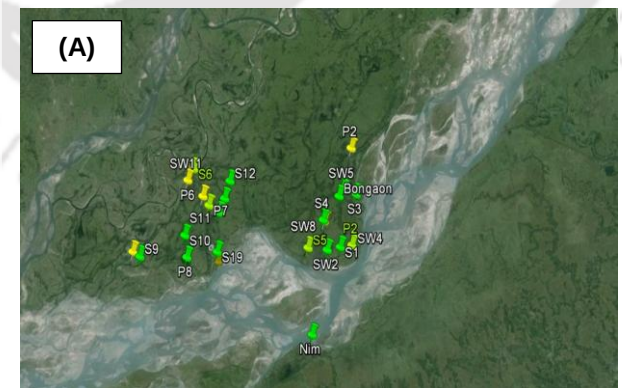


Figure 2.3 (A) *Map of Majuli River Island showing the sampling sites*

Figure 2.3 (B) *Nimatighat Bank (Nim Bank) showing a crowd boarding ferry to Majuli*

Figure 2.3 (C) *Residential area in Majuli River Island*

Figure 2.3 (D) *Polygonum hydropiper in Bhereki wetland (S12)*

Figure 2.3 (E) *Water body (S18) in Missing Gaon in Majuli River Island*

Figure 2.3 (F) *Water sample from Bhereki wetland (S12)*

Figure 2.3 (G) *Soil sampling with an auger at different depths in Majuli River Island*

Figure 2.3 (H) *Soil samples collected at different depths in Majuli River Island*

Figure 2.3 (I) *Map of Amingaon showing the sampling sites*

Figure 2.3 (J) *Soil sampling in Amigaon at a depth of 0 – 20 cm*

Figure 2.3 (K) *Map of Umananda River Island showing the sampling sites*

Figure 2.5 (L) *Main entrance (U1) in Umananda River Island*

2.2.3 Water samples

Water samples were collected from wetlands, ground water pumps and Brahmaputra River in Majuli. Sampling was carried out in pre-monsoon (April, 2011) and monsoon seasons (August, 2011) [Figure 2.1; Figure 2.3 (F); Table A 2.1 (A), Appendix 2]. Water samples were collected from 12 wetlands, 2 water bodies, 4 ground water samples and 2 river water samples (Brahmaputra River at two banks). Samples were

further grouped as a) residential area, b) grassland, c) agricultural field, d) ground water and e) river water based on land use activities and geomorphic origin. All samples were collected in triplicates. One set of samples was preserved with nitric acid (pH 2) for metals analysis. Second set of samples was collected in polypropylene bottles without any pre – treatment and the third set was stored at 4°C for microbiological analysis. pH, EC and turbidity at the time of sample collection whereas DO was analysed immediately after sampling.

2.2.3.1 Physicochemical characterization

All physicochemical parameters were analysed according to standard operating procedures (APHA, ASTM, EPA). Samples were stored at 4°C for further analyses.

2.2.3.1.1 pH

pH for water samples was recorded at the time of sampling with a pH electrode from Wagtech Potkait, water analyser portable kit.

2.2.3.1.2 Electrical conductivity

EC for water samples was recorded at the time of sampling with an EC electrode from Wagtech Potkait, water analyzer portable kit. EC was measured in μScm^{-1}.

2.2.3.1.3 Turbidity

Turbidity was checked at the time of sample collection with a turbidity meter (transparency tube) from Wagtech Potkait, water analyzer portable kit. Turbidity was measured in NTU (Nephelometric Turbidity Units).

2.2.3.1.4 Nitrate

Nitrate (NO_3^-) was estimated by Phenol Disulfonic Method (APHA). Nitrate reacts with phenol disulfonic acid to form a nitro-derivative which in alkaline medium develops a yellow colour. Absorbance for the yellow colour was recorded at 410 nm in Cary 100 UV − Visible spectrophotometer. Nitrate was calculated from a standard curve of absorbance versus concentration of KNO_3 solution ranging from 0 mg/L to 1 mg/L at an interval of 0.1 mg/L.

2.2.3.1.5 Ammonia

Ammonia was estimated by Micro Phenate Method (Clesceri, 1998; APHA) using sodium nitroprusside. Presence of ammonia was confirmed by development of an intensely blue compound known as indophenol, as a result of reaction between ammonia, hypochlorite, and phenol catalyzed by sodium nitroprusside. Absorbance for blue coloration was measured at 640 nm in Cary 100 UV − Visible spectrophotometer. Ammonia was calculated from a standard curve of absorbance versus concentration of NH_4Cl solution ranging from 0.1 mg/L to 1 mg/L at an interval of 0.2 mg/L.

2.2.3.1.6 Sulphate

Sulphate (SO_4^{2-}) was estimated by Turibidimetric Method (APHA). SO_4^{2-} is precipitated in the form of Ba_2SO_4 by adding $BaCl_2$ in acidic medium (HCl). Concentration of sulphate was determined from the absorbance of Ba_2SO_4 measured at 420 nm in Cary 100 UV − Visible spectrophotometer. SO_4^{2-} was calculated from a

standard curve of absorbance versus concentration of Na_2SO_4 solution ranging from 0 mg/L to 40 mg/L of SO_4^{2-} mg/L at an interval of 5 mg/L.

2.2.3.1.7 Phosphate

Phosphate (PO_4^{3-}) was estimated by Ammonium Molybdate Method (APHA). All forms of phosphorus in water were dissolved into inorganic form by digestion with concentrated $HClO_4$ – HNO_3. The phosphate released was colorimetrically measured in presence of $SnCl_2$ as an indicator, at 690 nm in Cary 100 UV − Visible spectrophotometer. The concentration of phosphorus was calculated from a standard curve of absorbance versus concentration of K_2HPO_4 solution ranging from 0.5 mg/L to 5 mg/L of PO_4^{3-} – P mg/L at an interval of 0.5 mg/L.

2.2.3.1.8 Fluoride

Fluoride (F^-) was estimated by SPADNS Method (APHA). SPADNS [2−(parasulfophenylazo)−1,8−dihydroxy−3,6−naphthalene disulfonate] and zirconyl chloride octahydrate ($ZrOCl_2$. $8H_2O$) together form an acid zirconyl−SPADNS reagent known as zirconium-dye lake. F^- reacts with the zirconium-dye lake, dissociating a portion of it into a colourless complex anion (ZrF_6^{2-}) and the dye. As the amount of F^- increases, the colour (initially reddish orange colour) produced becomes progressively lighter. Colorimetric absorbance was measured at 570 nm in Cary 100 UV − Visible spectrophotometer. F^- was calculated from a standard curve of absorbance versus concentration of NaF solution ranging from 0.1 mg/L at 1.0 F^- mg/L at an interval of 0.1 mg/L.

2.2.3.1.9 Chloride

Chloride (Cl^-) was estimated by Argentometric Method (Mohr's Method) (APHA). Cl^- reacts with $AgNO_3$ to form a slightly white precipitate of AgCl. In presence of chromate as an indicator, free Ag^+ react with chromate to form reddish brown complex detected by titration against $AgNO_3$. Cl^- concentration was obtained in mg/kg.

2.2.3.1.10 Dissolved oxygen

Dissolved oxygen (DO) was estimated after water sampling with a DO electrode (Make: Systronics). DO concentration was obtained in mg/L.

2.2.3.1.11 Chemical oxygen demand

Chemical oxygen demand (COD) was estimated by Titrimetric Method (EPA). Organic and oxidizable inorganic substances in water samples were oxidized by potassium dichromate in 50% sulfuric acid solution at a reflux temperature of 150°C. Ag_2SO_4 was used as a catalyst and Hg_2SO_4 was added to remove chloride interference. The excess $Cr_2O_7^{2-}$ was titrated with standard $(NH_4)_2\ Fe(SO_4)_2.\cdot 6H_2O$, using orthophenanthroline ferrous complex or ferroin as an indicator, color change visible as blue-green to a reddish hue at the end point.

2.2.3.1.12 Trace elements: Na, Ca, Mg and K

Trace elements (Na, K, Mg and Ca) for water samples were analysed in Flame Photometer (Make: Systronics), calibrated with standard reference material. The concentration of trace elements was obtained in mg/L.

2.2.3.1.13 Sodium Adsorption Ratio

Sodium adsorption ratio (SAR) is the proportion of sodium to Ca and Mg that can affect their availability to agricultural crops. SAR is often used to express the relative activity of Na ions in exchange reactions with soil. Greater the SAR value, the less suitable is the water for irrigation. SAR evaluates sodium hazard in relation to Ca and Mg concentrations. SAR was calculated as:

$$SAR = \frac{Na}{\frac{Ca+Mg}{2}}$$

The formula for SAR calculation was given by Richards (1954). He classified the water to be used for irrigation with SAR index less than 10 as excellent, between 10 − 18 as good, 18 − 26 as fair and greater than 26 as of poor quality (Table 2.1).

2.2.3.1.14 Soluble Sodium Percentage

Soluble Sodium Percentage (SSP) is referred to as Na percentage. Higher value of SSP indicates soft water whereas lower value of SSP indicates hard water. SSP was calculated as:

$$SSP = \frac{Na + K \times 100}{Ca+Mg+K+Na}$$

The formula for SSP calculation was given by Todd (1980). In general, values of SSP <50 indicate good quality of water and higher values (>50) indicate that the water is unsafe for irrigation purpose (Table 2.1).

2.2.3.1.15 Kelly's Ratio

Kelly's ratio (KR) is another important water quality indicator that check suitability of water for irrigation. Na is measured against Ca and Mg was considered by Kelly (1957) to calculate this parameter. Kelly's Ratio was calculated as:

$$KR = \frac{Na}{Ca+Mg}$$

The formula for KR calculation was given by Kelly (1963). The Kelly's ratio of unity or <1 is indicative of good quality of water for irrigation purpose, values >1 is suggestive of unsuitability of water for agricultural activities due to alkali hazards (Kumar et al., 2014) (Table 2.1).

Table 2.1 *The critical limits of water suitability for irrigation purpose (Source: Adapted from Kumar et al., 2014)*

Parameters	Range	Water Class
Sodium Absorption ratio	10	Excellent
	18	Good
	18-26	Doubtful
	26	Unsuitable
Soluble Sodium Percentage	<50	Good
	>50	Unsuitable
Kelly's Ratio	<1	Suitable
	1-2	Marginal suitable
	>2	Unsuitable

2.2.3.2 Most probable number for faecal colonies

Most probable number (MPN) was calculated according to MPN methods of determination faecal coliform (APHA). EC (*Escherichia coli*) medium was taken as a broth for inoculating water samples of various dilutions depending upon the source of sample collection. For each sample three inoculations were prepared in 3 separate sets of 5 test tubes, each bearing 10 mL, 1mL and 0.1 mL inoculum respectively. Each test tube was provided with a Durham tube to check bubble formation due to release of gas by microbial respiration. The test tube found with a bubble formation in Durham tube was considered as positive and similar positive responses were checked in set of 5 test tubes. For example: if 2 tubes (out of 5 tubes) were positive for 10 mL inoculation, MPN/100 mL was calculated from a chart specified in APHA methods (Table 2.2). According to the chart, 5.1 faecal coliform cells will be present per 100 mL of sample. A similar chart for combination of three sets is also provided by APHA method of MPN estimation.

Table 2.2 *MPN/100 mL values in five tubes, when 10 mL sample is inoculated (Source: APHA, 2002)*

No. of tubes giving positive results out of 5	MPN/100 mL
0	<2.2
1	2.2
2	5.1
3	9.2
4	16.0
5	>16.0

2.2.4 Soil samples

In Majuli Island, random un-submerged sampling sites separated by a distance of at least 1 km from each other were selected (Figure 2.1). Sampling was performed at 12 sampling sites and 2 river banks in Brahmaputra River, twice in a year, pre-monsoon period (April, 2011) and monsoon period (August, 2011). Soil boring was accomplished with a V-shaped auger at 5 different depths, from surface to 100 cm respectively at an interval of 20 cm. Soil samples were further categorized into 4 groups on the basis of land use activities, a) residential, b) grassland, c) agriculture and d) bank sediments [Table A 2.1 (A), (B), Appendix 2]. Vegetation at each sampling site was studied by quadrat sampling method prior to soil sampling in pre-monsoon season only as there was no visible difference in the vegetation profile in monsoon season.

In Kamrup (Amingaon and Umananda River Island), based on litter decomposition, land use activities and natural geomorphology, sampling sites were subdivided into a) disturbed low litter decomposition and b) undisturbed low litter decomposition and c) bank sediments. Sampling was performed in 12 random sites including river banks [Figure 2.2, Table A 2.1 (C), Appendix 2]. Soil samples were bored with an auger at a depth of 0-20cm in two sampling periods, pre-monsoon (April, 2012) and monsoon (August, 2012).

At the time of sampling, soil texture was observed in each study area. Soil samples were collected in 3 replicas in individual polypropylene bags. One set of replicate samples was stored at 4°C for microbiological analysis, second set was

preserved at −20°C for determination of soil enzymatic activities and the third set was allowed to air dry at room temperature for analysis of other soil parameters.

2.2.4.1 Analysis of geochemical parameters

Soil parameters were analysed according to standard operating procedures (ASTM, APHA, EPA). Samples for analysis of geochemical parameters were air dried and sieved (≤ 2 mm).

2.2.4.1.1 Soil pH

Soil pH was checked with a soil and deionized water suspension of 1:2 ratio with a pH electrode (Make: Thermoscientific), calibrated at pH 4, 7 and 10.

2.2.4.1.2 Soil electrical conductivity

Electrical conductivity (EC) was checked with a soil and deionized water suspension of 1:2 ratio with a EC electrode (Make: Systronics), calibrated with KCl solution of strength 1000 μScm^{-1}.

2.2.4.1.3 Grain size analysis

Grain size of soil samples were analysed by Hydrometer Method (ASTM). Particle size for fine sand, silt and clay was analysed for soil samples.

2.2.4.1.4 Total Organic Carbon

Total Organic Carbon (TOC) was measured by Potassium Dichromate Digestion Method described by Jenkinson and Powlson (1976). Organic Carbon (OC) is oxidized

in presence of excess of $Cr_2O_7^{2-}$, the amount of reduced $Cr_2O_7^{2-}$ is linked to OC content, based on quantifying the amount of oxidizable carbon. This method was slightly modified, adapted from TOC analysis of MBC fumigated sample (oven dry basis). The digested sample was titrated against [$(NH_4)_2$ Fe $(SO4)_2$. $6H_2O$] using ferroin indicator to obtain the Carbon content and also analysed for Carbon in CHNS elemental analyser (Make: Eurovector EA3000). The concentration of Carbon was obtained in mg/kg.

2.2.4.1.5 Total Nitrogen

Total nitrogen (TN) was estimated by Total Kjeldahl Method (APHA). Soil digestion and distillation was carried out in Kjeldahl Nitrogen Analyzer (Make: Velp Scientifica). Soil samples were digested with concentrated H_2SO_4 in presence of catalyst ($CuSO_4$ + K_2SO_4) at a temperature of 420°C, followed by distillation in alkaline condition (presence of NaOH) and titration against H_2SO_4. The concentration of Nitrogen was obtained in mg/kg. Kjeldahl Nitrogen includes only organic and ammonium nitrogen, it excludes nitrates.

2.2.4.1.6 Total Phosphorus

Total Phosphorus (TP) was estimated by Ammonium Molybdate Method (APHA). As already mentioned in section 2.2.3.1.7, Organic Phosphorus in soil was converted into inorganic Phosphorus through acid digestion (concentrated $HClO_4$ − HNO_3). Phosphorus in digested sample was then measured colorimetrically for in presence of $SnCl_2$ as an indicator, at 690 nm in Cary 100 UV − Visible spectrophotometer. Concentration of phosphorus was calculated from standard curve of absorbance versus

concentration of K_2HPO_4 solution ranging from 0.5 mg/L to 5 mg/L of PO_4^{3-} – P mgL^{-1} at an interval of 0.5 mg/L. The concentration of PO_4^{3-} was obtained in mg/kg.

2.2.4.1.7 Soil nitrate

Soil nitrate (NO_3^-) was estimated by Phenol Disulfonic Method (APHA). The concept and method of determination of NO_3^- is similar to nitrate in water samples. Soil solution for NO_3^- estimation was prepared as 1:5 soil and nitrate extraction solution ($CuSO_4$. $5H_2O$ + Ag_2SO_4) suspension. The filtrate was treated with $Ca(OH)_2$ and $MgCO_3$ to precipitate Cu and Ag prior to nitrate estimation. The concentration of NO_3^- was obtained in mg/kg. (Refer section 2.2.3.1.4).

2.2.4.1.8 Soil ammonia

Soil ammonia was estimated by Micro Phenate Method (Clesceri, 1998; APHA) using sodium nitroprusside. The concept and method of determination of ammonia is similar to ammonia in water samples. Soil solution for ammonia estimation was prepared as 1:5 soil water suspension. The concentration of ammonia was obtained in mg/kg. The filtrate was used for ammonia estimation. (Refer section 2.2.3.1.5).

2.2.4.1.9 Soil nitrite

Nitrite (NO_2^-) in water samples was estimated by Diazotization Method (APHA). Soil solution for nitrite estimation was prepared as 1:5 soil water suspension. The suspension was filtered and analysed for presence of nitrites. Nitrite forms a diazonium salt with sulphanilic acid in an acid medium (pH 2.0 – 2.5), this complex combines

with α – naphthylamine hydrochloride to form a pink coloured dye. The aborbance for pink coloration was measured colorimetrically at 520 nm in Cary 100 UV − Visible spectrophotometer. Concentration of soil nitrite was calculated from a standard curve of absorbance versus concentration of $NaNO_2$ solution ranging from 0 mg/L to 1 mg/L of NO_2^- – N mg/L at an interval of 0.1 mg/L. The concentration of NO_2^- was obtained in mg/kg.

2.2.4.1.10 Soil sulphate

Soil sulphate (SO_4^{2-}) was estimated by Turbidimetric Method (APHA). The concept and method of determination of sulphate is similar to sulphate in water sample. Soil solution for sulphate estimation was prepared as 1:5 soil water suspension. The suspension was filtered free of any kind of turbidity. The concentration of SO_4^{2-} was obtained in mg/kg. (Refer section 2.2.3.1.6).

2.2.4.1.11 Soil trace elements: Na, Ca, Mg and K

Digestion of soil samples for analysis of trace elements was performed with aqua regia (ASTM D3974, 2003). Trace elements (Na, K, Mg and Ca) were analysed in Flame Photometer (Make: Systronics) calibrated with standard reference material. Concentration of trace elements was obtained in mg/kg on a dry weight basis.

2.2.4.1.12 Soil Cation Exchange Capacity

Soil cation exchange capacity (CEC) measures the cation exchanges on mineral components (especially clay) in soil and organic matter surfaces. CEC quantifies the

amount of negatively charged sites on soil surfaces that can retain positively charged cations such Ca^{2+}, Mg^{2+} and K^{+} by electrostatics forces and this preserves the easily exchangeable cations in soil in terms of fertility. CEC ($cmol_c kg^{-1}$) was calculated as (meq÷100 g or $cmol_c kg^{-1}$) = (ppm Ca÷200) + (ppm Mg÷120) + (ppm K÷390).

2.2.4.2 Soil microbial colony forming unit by plate count method

Fresh soil samples were immediately extracted in 0.8 M NaCl solution. BCFU and FCFU were calculated by plate count method for 0.1 mL inoculum per square centimetres of the total area of culture plate i.e. 54.07 cm^2. Bacterial colonies were cultured on Nutrient Agar media and fungal colonies were cultured on Potato Dextrose Agar media using standard antibiotic in each case.

2.2.4.3 Soil microbial biomass characterization

Soil microbial biomass carbon (MBC), soil microbial biomass nitrogen (MBN) and soil microbial biomass phosphorus (MBP) were estimated according to standard methods of chloroform fumigation and incubation (CFI) (Brookes et al., 1985). CFI and extraction methods were described by Jenkinson and Powlson (1976). MBC, MBN and MBP were estimated after CFI. For each sample (5 g), 25 mL of ethanol free chloroform was added, stored in Nalgene bottles at 25°C in dark and fumigated gas was evacuated at regular intervals using a vacuum desiccator and a pump for a period of 24 hours. After CFI, each soil sample was extracted with three different extractants and incubated for 10 days under shaking condition, at room temperature. The fumigated samples were analyzed for MBC, MBN and MBP respectively. MBC was extracted with 0.5 M

NaOH and estimated by Jekinson and Powlson method, MBN was extracted in 0.5 M KCl and quantified by persulfate digestion method and analyzed for TN, and MBP was extracted in 0.5 M $NaHCO_3$ and estimated by ammonium molybdate method (Brookes et al., 1982). A similar set of non – fumigated samples were treated with extractant for Carbon, Nitrogen and Phosphorus. The difference between the fumigated and non – fumigated samples with correction factors (2.64 for Carbon, 0.4 for Nitrogen and Phosphorus) gave the MB content.

2.2.2.4 Soil enzyme assays

Soil enzymatic assay for the samples at each depth (0 – 100 cm), was carried out in sterile conditions. The samples were transferred to sterile test tubes and two sets of experiment were carried out in triplicates containing a blank and a control i.e. soil sample without any substrate. In the first set, soil samples were treated with 0.2 mL of toluene, in the second set samples were analyzed for enzyme activity without toluene. For each enzyme assay, different sterile buffers were used to maintain an optimum pH.

2.2.2.4.1 Cellulase assay

1 g of fresh soil was placed in a clean and sterile test tube, 5 mL of sterile 0.2 M sodium acetate buffer (pH 6) and 2 mL of 1% CMC was added (Kanazawa et al., 2012). The test tubes were incubated at 30ºC for 24 hours. After incubation, the reaction mixture was filtered and the glucose content was estimated by Nelson Somyogi (NS) method (Nelson, 1944; Pancholy et al., 1973).

2.2.4.4.2 Amylase assay

Amylase assay was adapted from a method developed by Cole (1977). To 1 g of fresh soil, 5mL of acetate buffer (pH 5) for samples with toluene, 5 mL of phosphate buffer (pH 7) for samples without toluene, and 50 mg of starch was added. The mixture was incubated for 24 hours at 25ºC (Gundi et al., 2007). The supernatant obtained after centrifugation was estimated for glucose content by Nelson Somyogi method (NS) (Nelson, 1944; Pancholy et al., 1973).

2.2.4.4.4 Invertase assay

To 1 g of fresh soil, 5 mL of universal buffer (pH 5 for samples with toluene and pH 7 for samples without toluene) and 2 mL of 10% sucrose solution added. The mixture was incubated at 37ºC for 24 hours. After incubation, the supernatant was analysed for reducing sugars by Dintrosalicylic (DNS) method (Frankenberger et al., 1983).

2.2.4.4.5 Protease assay

To 1g of fresh soil, 5 mL of 0.05 M Tris HCL buffer (pH 8.52 for samples with and without toluene respectively) and 2 mL of 1% casein was added. The mixture was incubated at 50ºC for 2 hours followed by addition of 2 mL of 5% Trichloro acetic acid (TCA) to stop further activity of protease enzyme. The supernatant obtained after centrifugation was analysed for protein content by Lowry's Method (Geisseler et al., 2008).

2.2.4.4.5 Urease assay

Urease assay was performed according to a method proposed by Pancholy et al (1973). To 1g of fresh soil, 2 mL of phosphate buffer (pH 10 for samples with and without toluene) (Kandeler and Gerber, 1988), 2 mL of 10% urea was added and incubated at 30°C for 24 hours. 1 N KCl was added to the reaction mixture for extraction of Nitrogen and the mixture was centrifuged at 9000 rpm for 10 min, the supernatant was analysed for Nitrogen mineralization by Phenol Sodium Nitroprusside Method (Reddy et al., 2011; Kandeler et al., 1988).

2.2.4.4.6 Phosphatase assay

Phosphatase assay was carried out for acid phosphatase and alkaline phosphatase following the method proposed by Verchot and Borelli (2005). For acid phosphatase activity, universal modified buffer of pH 5 was used and for alkaline phosphatase activity acetate buffer of pH 9 was used. For each enzyme assay, 6.7 mL of buffer and 2mL of 2 mmol p-nitrophenyl phosphate was added to 1 g of fresh soil and incubated at 25°C for 2 hours at 200 rpm. The supernatant was further treated with 1 N NaOH to stop the enzyme activity and change of color. Color absorbance was recorded at 410 nm and the amount substrate degraded was estimated against a standard curve plotted for p-nitrophenol as a product (Tabatabai et al., 1969).

2.2.4.4.7 Dehydrogenase assay

Dehydrogenase assay was adapted from methods suggested by Pancholy and Rice (1973), Casida et al (1964). To 0.3 g of soil, 0.3 mL of 1 % 2, 3, 5-triphenyltetrazolium

chloride (TTC) and 30 mg of $CaCO_3$ were added. The mixture was incubated in dark at 37°C for 24 hours. After incubation 3 mL of methanol was added, the mixture was vortexed thoroughly, allowed to settle at 4°C and finally centrifuged at 4500 rpm for 10 min at 4°C. Absorbance of the supernatant was recorded at 495 nm and the amount of 2, 3, 5-triphenyltetrazolium formazan (TPF) formed was calculated from the calibration curve obtained by plotting different concentrations of TPF.

2.2.4.5 Vegetation study by quadrat method

Ecological community by Quadrat Method involves a fixed sampling unit area of definite size within which the population, density and abundance of a species in a particular ecosystem can be studied. Quadrats of size 1 m^2 × 1 m^2 were studied in 12 sampling sites and plant species lying inside the quadrats were recorded. At each sampling site three quadrats were studied. Vegetation study through Quadrat Method was carried out in Majuli Island in pre-monsoon season only because there was no significant difference in the vegetation monsoon season.

2.2.5 Statistical Analysis

Each analysis included three sets of experimental results. Statistical analyses were performed for a depth of 0 – 20 cm, considering sub – surface soil as the active zone of nutrient availability and microbial activity (Fierer et al., 2003). Simple linear regression and Karl Pearson correlation analyses were performed among the basic physicochemical and biological properties. Statistical analyses were carried out separately for pre-monsoon and monsoon seasons in IBM SPSS Statistics 20 software.

2.2.5.1 Correlation studies

Karl Pearson correlation is an explanatory statistics used to examine significant relations between parameters or variables analysed i.e. whether an increase in one variable may be accompanied by increase or decrease in the other. Correlation studies were performed to check the relation between the parameters analysed. Variables were related and the type of linear relationship was determined was by correlation statistics.

2.2.5.2 Regression analysis

Linear regression was analysed between the set of variables obtained from experimental analysis (experimental units). A linear curve fitting regression model helped in determining whether the variables were functionally related. Linear regression describes a functional relationship between the variables or experimental units. In regression analysis, value of one variable (dependant variable-Y) has relationship to the other variable (independent variable-X), it is reasonable to hypothesize that the value of Y might be affected by an increase or decrease in X, but the reverse may not be true (McKillup et al., 2010).

2.3 RESULTS AND DISCUSSIONS

2.3.1 Ecological status of water and soil in Majuli and Kamrup

Water and soil quality monitoring is an essential component in assessment of ecological status. Exchange of nutrients between water and sediments occur naturally,

therefore to assess the physicochemical status of water in a river or lake it is essential to determine soil chemistry in the area (Ali et al., 1988).

2.3.1.1 Physiochemical characterization of water samples

Results of physicochemical parameters analyses in Majuli Island are presented in Table A 2.2, Appendix 2. pH in water samples was neutral to alkaline in either seasons. All parameters analysed were within the permissible limits given by BIS (Table 2.3), WHO and EPA except pH (in a few samples) and DO (Table A 2.2, Appendix 2). Concentrations of the parameters were comparatively higher in pre-monsoon season.

Table 2.3 *Permissible limits of water quality for drinking (Source: Kumar et al., 2012)*

Parameters	USEPA	WHO	ISI	ICMR	CPCB
pH	6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.2	6.5-8.5
Turbidity	-	-	10	25	-
Conductivity	-	-	-	-	2000
Alkalinity (mg/L)	-	-	-	-	600
Chloride (mg/L)	250	200	250	1000	1000
Sodium (mg/L)	-	-	-	-	-
Nitrate (mg/L)	-	-	45	100	100
Sulphate (mg/L)	-	-	150	400	400
Calcium (mg/L)	-	75	75	200	200
Magnesium (mg/L)	-	50	30	-	100
Fluoride (mg/L)	4.0	1.5	0.6 – 1.2	1.5	1.5
Escherichia coli (MPN)	-	-	-	-	No relaxation

Overall analysis showed that in pre-monsoon and monsoon season pH, EC, turbidity, NO_3^-, DO and ammonia showed relatively higher values in Group A (residential area) (Table A 2.2, Appendix 2). SO_4^{2-} showed higher values in Group C (agricultural field) and PO_4^{3-}, Cl^- and F^- showed high concentrations in Group D (ground water). DO was more or less similar in all sampling sites whereas COD was lower in residential areas. Higher values of physicochemical parameters in Group A may be attributed to household activities like waste disposal, washing and cleaning activities that increase pH and EC levels in water. SO_4^{2-} was high in agricultural samples, this indicated a probability of ongoing organic matter (OM) degradation processes. Leaching activities may contribute to high concentration of PO_4^{3-}, Cl^- and F^- in group D (ground water). Group E (river water) showed minimum concentrations of all parameters except DO, furthermore COD and Cl^- were notably higher in monsoon season. In general, it was observed among all physicochemical parameters analysed DO, COD and ammonia were comparatively higher in monsoon season [Table A 2.2, Appendix 2].

2.3.1.2 Trace elements and water chemistry in Majuli

Among the trace elements, occurrence of Na, Ca, Mg and K are discussed (Table A 2.3, Appendix 2). Trace elements naturally occur in water depending on the lithogenic composition of a particular region. The parent bed rock material could be a primary source of these inorganic elements in sediment and water. Inorganic elements

commonly Na, Ca, Mg and K were derived from minerals in the alluvial soil of Majuli. These minerals were possibly illite, kaolinite and chlorite (Singh, 2011).

Majuli is an agriculture based region and rich in water resources. In this context, suitability of water for agricultural activities was determined by computation of water quality indices like SAR, SSP and KR on the basis of concentration of Na, Ca, Mg and K in water. Critical limits of these indices are given in Table 2.1. SAR values were in the range of 0.81 – 3.05 in pre-monsoon season and 0.45 – 6.93 in monsoon season. It was observed that SAR values in water samples from Majuli were below 10 and hence categorized as excellent (Todd, 1980; Kumar, 2014; Raihan, 2008). Values <10 indicated that wetland water quality was good and suitable for irrigation purposes. SSP was in a range of 15.68 – 53.45 and 17.48 – 83.41 in monsoon season. SSP was highest in S8 (Barbil ground water) in pre-monsoon season while in monsoon, SSP was highest in S7 (Barbil wetland water), considered as unsuitable for irrigation (Wilcox 1950, Kumar 2014; Raihan 2008). KR ranged from 0.11 – 0.50 in pre-monsoon and 0.04–2.87. KR values less than 1 were considered as a good balance of Na, Ca and Mg. However, KR was permissible in pre-monsoon but in S10 (Kharjan wetland water), its value was greater 1 concluding that the wetland water was unfit for agricultural activities and labelled as poor (Kumar, 2014; Kelly, 1953; Raihan, 2008). In most cases, it was found that the indices for water quality monitoring were generally higher in monsoon water samples. Details of trace elements and their indexing for suitability in drinking, household and agricultural purposes is given in Table 2.3 and Table 2.1 respectively.

2.3.1.3. Enumeration of faecal coliform cells in water samples

MPN estimation showed presence of faecal coliform cells in two wetland water samples (Figure 2.4). This experiment was conducted for 10 mL sample in 5 set of test tubes in EC (*Escherichia coli*) medium. In S9 (Magurmara Bil), presence of coliform cells was evident in each season. In pre-monsoon, number cells/100 mL sample was estimated as 5 cells/100 mL sample. In monsoon number cells/100 mL was 2.2 cells/100 mL sample. In S18 (Missing Gaon water body), coliform cells were enumerated as 2.2 cells/100 mL in pre-monsoon only. The derivation of cells/100 mL is mentioned on a chart given by APHA (Table 2.3). S9 is a wetland water sample and S18 is a sample collected from a water body located at the vicinity of residential areas, thus chance of contamination of water is very high, human intervention is frequent in both sites. Lack of sanitation facilities and source of untreated drinking water indicate the reasons for presence of coliform species in water samples.

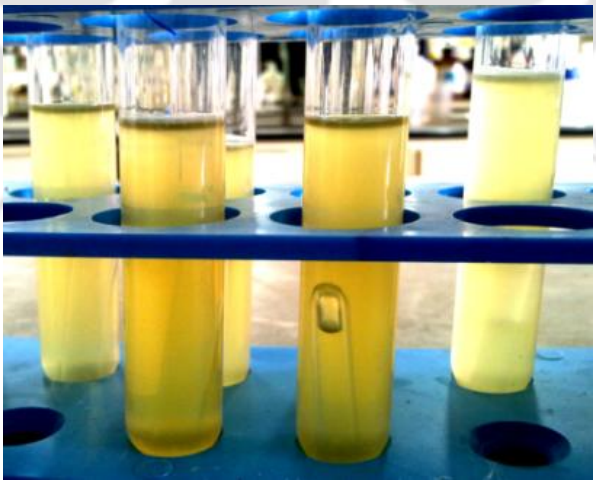


Figure 2.4 *MPN estimation for detection of faecal colony in S18 (Missing Gaon water body) in Majuli River Island*

2.3.1.3 Geochemical characterization

In Majuli, soil physicochemical parameters for the four test groups – residential area (Group A), grassland (Group B), agricultural fields (Group C) and bank sediments (Group D), for two sampling season are presented in [Table A 2.4 (A), Appendix 2]. All experimental analyses were performed at five depths i.e. 0 – 100 cm, at an interval of 20 cm except bank sediments. For each parameter, values for 0 – 20 cm are shown in one column and for the remaining four depths (> 20 cm), a range of values are shown in another column. In case of rivers banks, samples were collected from water and sediment interface, i.e. sediment just below the water column. Unlike water samples geochemical parameters showed relatively higher values of soil variables in Group C (agricultural fields). Soils of Group A were neutral to alkaline and that of Group B and Group C were acidic to slightly alkaline except S2 site of Group B. Agricultural operation in Group C seems to reduce pH through absorption of basic cations, acidity generation and reduction of organic matter (OM). This property of soil can be linked to high level of FCFU because low pH is known to favor fungal growth [Table A 2.5 (A), Appendix 2]. It was observed that the trend of pH was inclined towards alkalinity as the sampling period varied from pre – monsoon season to monsoon season. This change was evident in each sampling site. Likewise, levels of electrical conductivity (EC) were higher in pre – monsoon and lower in monsoon, more or less similar in Group A and Group B and slightly elevated in Group C (Group C> Group A ~ Group B). According to Corwin and Lesh (2005), EC is influenced by soil physicochemical properties. Infact EC has a positive connection with availability of nutrients in the form of cations or

anions in soil. Whether EC levels correlated with nutrient flow in the sampling sites, this was noticeable in the cation exchange capacity (CEC) trend. In general, higher levels of EC should promote rapid exchange of cations on the surface of clay minerals, accordingly the trend of CEC was Group A> Group B> Group C in the test groups, witnessed as a response towards soil EC levels. This trend was identical in monsoon season [Table A 2.4 (A), Appendix 2]. In addition to it, relatively low level of Cation Exchange Capacity (CEC) in Group C may be a result of reduced level of humus and recalcitrant OM present in soil or most of the cations were not present in their labile forms in soil. Moisture content (MC) was consistent in the sampling sites and higher in monsoon season. MC was in liaison with pH trend, however no significant relation was observed between MC and EC values. The results were similar to the soil EC – MC correlations described by Molin and Faulin (2013). Depthwise variation was prominent in pH, EC, CEC and MC. This gave an impression that as the soil depth increases, soil properties tend to change. This tendency may be interrelated to availability of basic nutrients in soil and their form of existence (Jobbágy and Jackson, 2001). Ammonia and nitrite concentrations were remarkable in Group A and Group B, nitrate concentrations were highest in Group C [Table A 2.3 (A), Appendix 2]. The observation trend in pre – monsoon and monsoon seasons were almost similar and depthwise variation was evident in most of the samples with a few exceptions [Table A 2.4 (A), Appendix 2]. Seasonal variance though significant, the margin of variation was minimal.

In Kamrup, pH of soil samples from Amingaon were in a range of slightly acidic to neutral in Group A (6.98 – 7.22) and Group C (6.87 – 7.13), and slightly alkaline in Group B (7.06 – 7.35). Umananda soil samples showed neutral to alkaline range of soil pH for each group (6.95 – 7.98). EC was higher in pre – monsoon and undisturbed samples and MC was conspicuous in monsoon and undisturbed samples in Amingaon as well as Umananda [Table A 2.4 (B), Appendix 2]. Sampling sites were not under any agricultural operation, high trespassing was the only common feature in the sampling sites. Household chores, markets and industrial activities in Amingaon and huge tourism rush in Umananda promoted sewage infiltration into the soil. The outcomes may be recounted as increase in buffering capacity of soil that may have promoted accumulation of several chemical species to proliferate within the domain (Bohn et al., 2001). Similar trend was observed for CNP budget where maximum SOM accumulation was observed in Group B and minimum SOM in Group C in each season. Amingaon and Umananda lie in the lower stretch of Brahmaputra River and experience sediment discharge in a downstream region. Geographical terrain and the mean sea level altitude (31 – 55m) indicated relatively greater increments of water transported fertile silt and numerous biogeochemical components. Seasonal variance in Amingaon and Umananda was minimal [Table A 2.4 (B), Appendix 2].

2.3.1.4 Trace elements and soil chemistry

Trace element analysis included Na, Ca, Mg, K and a few metals (broadly discussed in Chapter 3). CEC was expected to provide an overview of availability of trace elements, correlated to soil type in the study areas. In Majuli, CEC showed variations among the

sampling sites. The general trend of CEC was Group D> Group A> Group B> Group C in Majuli [Table A 2.4 (A), Appendix 2]. Surprisingly bank sediments showed higher CEC values, attributed to mineral composition. Size, mineral content and shape of sediment components are some important parameters of river sediment that vary at different locations of the same river system, depending on distance traversed by particles, gradient and geological formation of the river (Neopane et al., 2013). Moreover over deposition of OM may possibly add to the CEC levels in the sediments. In case of agricultural fields values of CEC were expected to be high, however low CEC in these areas may be linked to low level of humus in soil or recalcitrant nature of OM. Group A and Group B showed uniform CEC levels indicating uniformity in trace elements abundance. In Amingaon and Umananda, high CEC levels were significant in undisturbed soil samples (Group B) and bank sediments (Group C) (as observed in Majuli).

Particle size distribution confirmed sandy clay loam nature of the soil samples (excluding bank sediments) in Majuli as well as Amingaon and Umananda, at a depth of 0 – 20 cm. Since there was minimal difference between the soil type in pre-monsoon and monsoon season (confirmed by basic soil analysis method), particle size distribution was analysed for pre-monsoon season only. Particle surface area of soil provides a platform for adsorption of trace elements, the adsorption capacity by particles owing to surface area is inversely proportional to the particle size (Thomas et al., 1996). Occurrence of trace elements in Majuli, Amingaon and Umananda, cannot be attributed to the sandy clay loam nature of soil, CEC was negatively correlated to

silt and clay whereas positively correlated to fine sand in Majuli only, at a depth of 0 – 20 cm [Table A 2.7 (A), (B), (C)]. In this case, significant levels of trace elements in Majuli and Kamrup can be linked to secondary causes apart from bedrock composition in soil. Results were similar to the data reported by NBSS and LUP, ICAR (2006).

2.3.1.4 Soil microbial population

Plate culture method showed high growth intensity of fungal colonies compared to bacterial colonies, conspicuous in monsoon season in Majuli, at depth of 0 – 20 cm [Table A 2.5 (A), Appendix 2]. In Amingaon and Umananda, BCFU were more prominent than FCFU and higher in monsoon season, at depth of 0-20 cm [Table A 2.5 (B), Appendix 2]. Overall analysis showed that BCFU and FCFU were higher in Kamrup. In Kamrup, geochemical characterization revealed that the concentration of basic cations and CEC were comparatively higher than soil samples in Majuli. CEC is associated with OM transformation in soil. OM eroded from soil or degraded by microbial activity allows microorganisms to derive growth factors or nutrients from the soil. In Majuli low soil pH may possibly favour fungal growth. However in Kamrup, pH was neutral to alkaline in the soil samples, there are several factors in soil chemistry that influence growth of microorganisms including extrinsic factors like moisture content and temperature. Though MC of soil samples in Majuli and Kamrup were approximately similar, temperature of soil samples at the time of collection differed by 1 – 2°C i.e. 26 – 28°C in Majuli and 29 – 31°C in Kamrup. Moreover, the soil properties in Kamrup in the lower stretch of Brahmaputra River is linked to geomorphic factors as nature of deposited sediment and geographical terrain.

2.3.1.6 Vegetation profile

According to Eni et al (2012), soil and vegetation exhibit an integral relationship, soil provides moisture, nutrient, and anchorage to vegetation for their effective growth and in turn vegetation protects soil cover, suppresses soil erosion, and helps in maintaining soil nutrient through litter accumulation and subsequent decay (nutrient cycling). Vegetation profile was checked in 12 wetlands and a residential area in Majuli River Island [Figure 2.5 (S1) – (S12)].

Figure 2.5 (S1) *Quadrat (S1) showing Colocasia sp. with a dominant vegetation of Cynodon dactylon*

Figure 2.5 (S2) *Quadrat (S2) showing Ipomea aquatica with a dominant vegetation of Hemarthria sp.*

Figure 2.5 (S3) *Quadrat (S3) showing Colocasia sp. with a dominant vegetation of Hemarthria sp.*

Figure 2.5 (S4) *Quadrat (S4) showing Ageratum conyzoides with a dominant vegetation of Imperata cylindrica*

Figure 2.5 (S5) *Quadrat (S5) showing Mentha sp. with a dominant vegetation of Hemarthria sp.*

Figure 2.5 (S6) *Quadrat (S6) showing Mikania sp. with a dominant vegetation of Dicanthium annulatum*

Figure 2.5 (S7) *Quadrat (S7) showing Paspalum flavidum with a dominant vegetation of Imperata cylindrica*

Figure 2.5 (S8) *Quadrat (S8) showing Mikania sp. with a dominant vegetation of Chrysopogon aciculatus*

Figure 2.5 (S9) *Quadrat (S9) showing Dicanthium annulatum with a dominant vegetation of Hemarthria sp.*

Figure 2.5 (S10) *Quadrat (S10) showing Amaranthus spinosus with a dominant vegetation of Chrysopogon aciculatus*

Figure 2.5 (S11) *Quadrat (S11) showing Centella asiatica with a dominant vegetation of Dicanthium annulatum*

Figure 2.5 (S12) *Quadrat (S12) showing Dicanthium annulatum with a dominant vegetation of Hemarthria sp.*

Results showed that the most common species in Majuli Island was *Hemarthria* sp. (grass) whose highest frequency, density and abundance were recorded in five sites in Group A and Group B. This was by followed by highest frequency, density and abundance of *Cynodon dactylon* (grass) in three sampling sites in Group A and Group B (Table 2.4). However other species as *Colocasia* sp. *Diplazium esculentum, Cyperus rotundus, Gossypium* sp., *Cassia* sp., *Scoparia dulcis, Erianthus* sp., *Centella asiatica, Mimosa pudica, Mentha* sp., *Mikania* sp., *Solanum nigrum, Polygonum hydropiper, Commelina benghalensis, Hydrocotyle rotundifolia, Oxalis repens, Setaria flavidium, Andrographis paniculata, Spilanthes paniculata, Daucas carota, Cyperus esculentus, Ipomea aquatica, Eichornia crassipes, Xanthium strumarium, Alternathera* sp., *Spilanthes paniculata, Cassia occidentalis, Carica papaya, Ficus reliogiosa, Andropogon* sp., *Amaranthus spinosus,* etc. were also observed in the quadrats. Plant species recorded in Majuli were also available in Amingaon and Umananda.

Table 2.4 *Details of vegetation study in Majuli River Island, Hemarthria sp. is the most abundant species*

Quadrat	Sampling Sites	Geographical Location	Maximum occurrence	% Frequency	Density	Abundance	Occurrence in Kamrup sampling sites
Group A (Residential area)							
S1	Aphalamukh	N26°55'0.50" E94°16'44.40"	*Cynodon dactylon*	0.6	10.8	18	√
S5	Magurmara Bil	N26°55'11.97" E94°14'57.95"	*Hemarthria* sp.	0.6	12	20	√
S6	Kharjan Bil	N26°57'58.99" E94° 9'30.29"	*Dichanthium annulatum*	1	10.8	10.8	√
S11	Kharkhari Bil	N26°57'12.61" E94°10'18.27"	*Dichanthium annulatum*	0.4	5.8	14.5	√
Group B (Grassland)							
S2	Sarala Bil	N26°58'55.06" E94°17'57.43"	*Hemarthria* sp.	6.0	8.0	13.33	√
S3	Tuni Bil	N26°57'1.01" E94°17'56.89"	*Hemarthria* sp.	1.0	7.0	2.5	√
S4	Barbil	N26°56'13.06" E94°15'58.60"	*Imperata cylindrica*	0.8	7.2	9.0	√
Group C (Agricultural field)							
S7	Daria Bil	N26°57'34.47" E94° 9'46.60"	*Imperata cylindrica*	0.4	6.0	15	√
S8	Bhereki Bil	N26°55'37.65" E94° 8'14.81"	*Chryosopogon aciculatus*	0.8	8.6	10.75	√
S9	Kakarikata Bil	N26°55'58.37" E94° 5'39.82"	*Hemarthria* sp.	0.4	7	17.5	√
S10	Sakali Bil	N26°56'31.66" E94° 8'16.17"	*Chryosopogon aciculatus*	0.8	8	10	√
S12	Garukhuti Bil	N26°58'24.78" E94°11'5.25"	*Hemarthria* sp.	0.4	5.4	13.50	√

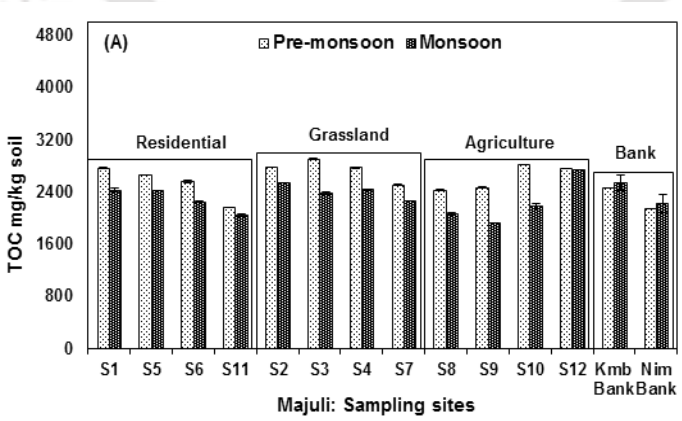
2.3.2 Nutrient mineralization in soil samples

Soil is a major part of the earth's crust providing essential as well as non-essential elements through biogeochemical cycles. Soil in a riverine ecosystem represents a complex system of nutrients, chelates, microorganisms, air and moisture upholding the most important components of a terrestrial ecosystem (Parton et al., 1987). In Brahmaputra floodplain, the top soil is continuously deposited by river transported sediments and the older alluvium is covered by newer alluvium, basically in flood prone areas. Sediment deposition is crucial for natural environment as it acts as a source or sink for many essential nutrients. These nutrients fuel biological productivity of any ecosystem.

In Majuli, TOC was highest in Group C (agricultural fields) followed by Group B (grasslands), Group A (residential area) and Group D (bank sediments) [Figure 2.6 (A)]. Depthwise variation of nutrient was conspicuous in the samples [Figure 2.9 (S1 – S12)]. Outcomes were similar for TN and TP analyses [Figure 2.7 (A); Figure 2.8 (A); Figure 2.10 (S1 – S12); Figure 2.11 (S1 – S12)]. In Kamrup (Amingaon and Umananda), values for TOC, TN and TP were highest in Group B (undisturbed samples) followed by Group A (disturbed samples) and Group C (bank sediments) [Figure 2.6 (B), (C); Figure 2.7 (B), (C); Figure 2.8 (B), (C)].

In Majuli, samples in Group C were under agricultural influence, though tillage was not evident in the area, addition of household manure like cowdung may possibly increase the SOM in addition to dead decaying residual plant matter. Group B showed

delayed SOM matter degradation activities whereas Group A revealed significant increments of a few soil variables due to residential intervention. Unlike Majuli, Kamrup sampling sites had no specific landuse demarcation, Amingaon was a commercial area with rapid industrial activities whereas Umananda was a pilgrimage site with a few temples located on a hilly terrain. The bank samples were however clearly differentiated. In non-agricultural regions of Amingaon and Umananda, soil functioned as a building material for earth filling, roads and pavements, the physical stability of soil was reflected in the chemical status. In case of disturbed soil, SOM accumulation was irregular, soil mixing released most of the nutrients from soil that leached into ground waters. In undisturbed soils, SOM was functionalized by microorganisms, nutrients were fixed and released gradually in course of time. Under such conditions, the microbial population was anticipated to be higher in Amingaon and Umananda. Results indicated that SOM accumulation was in an ascending order of Group B > Group A > Group C in Amingaon and Umananda.



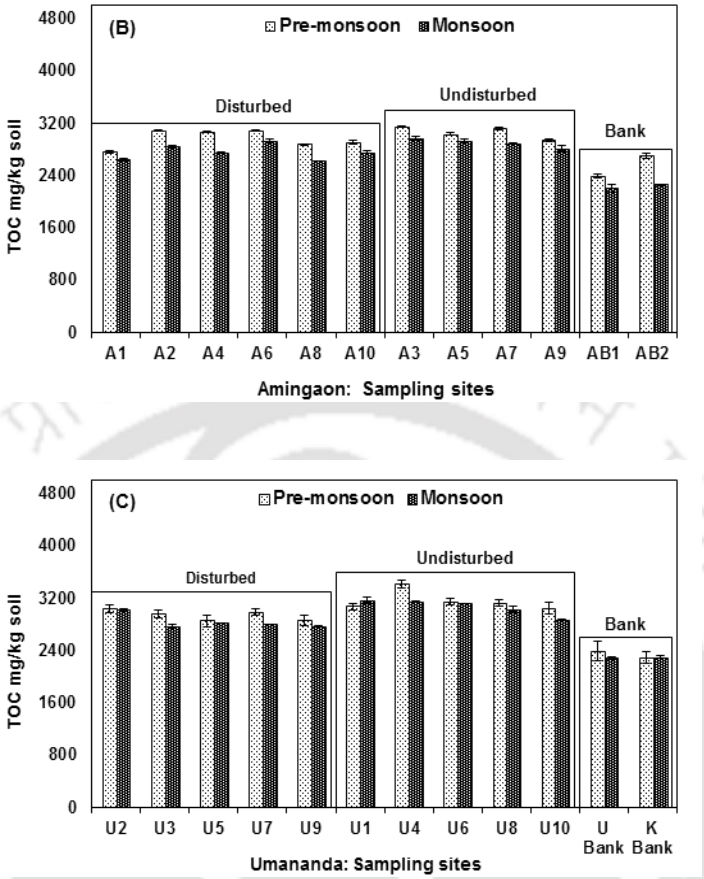
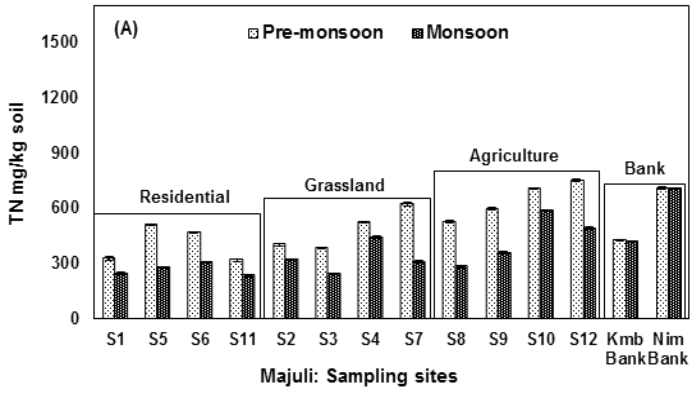
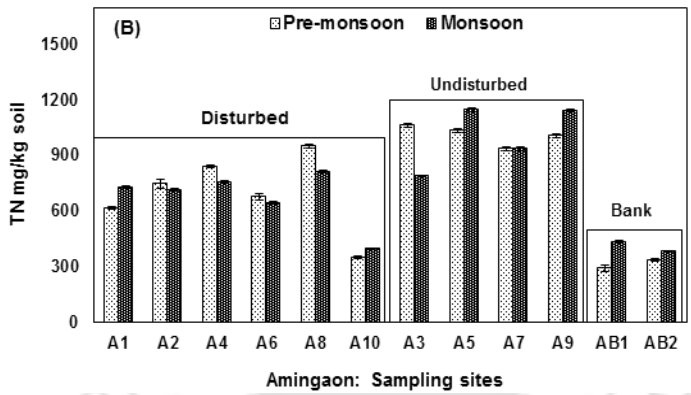


Figure 2.6 *TOC of soil samples in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*





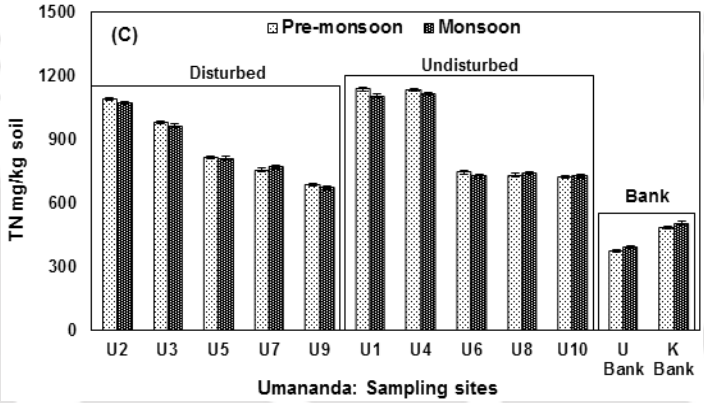
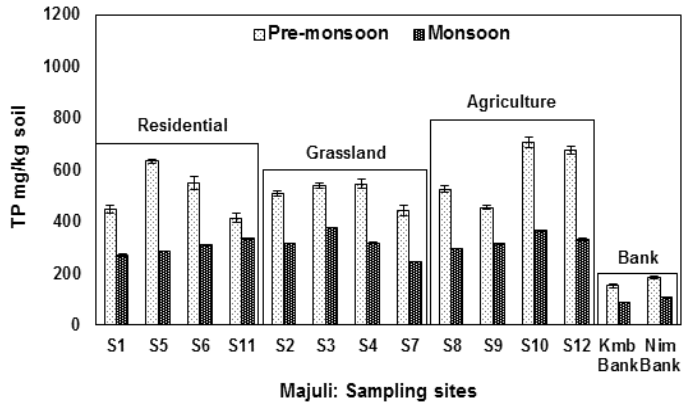


Figure 2.7 *TN of soil samples in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*



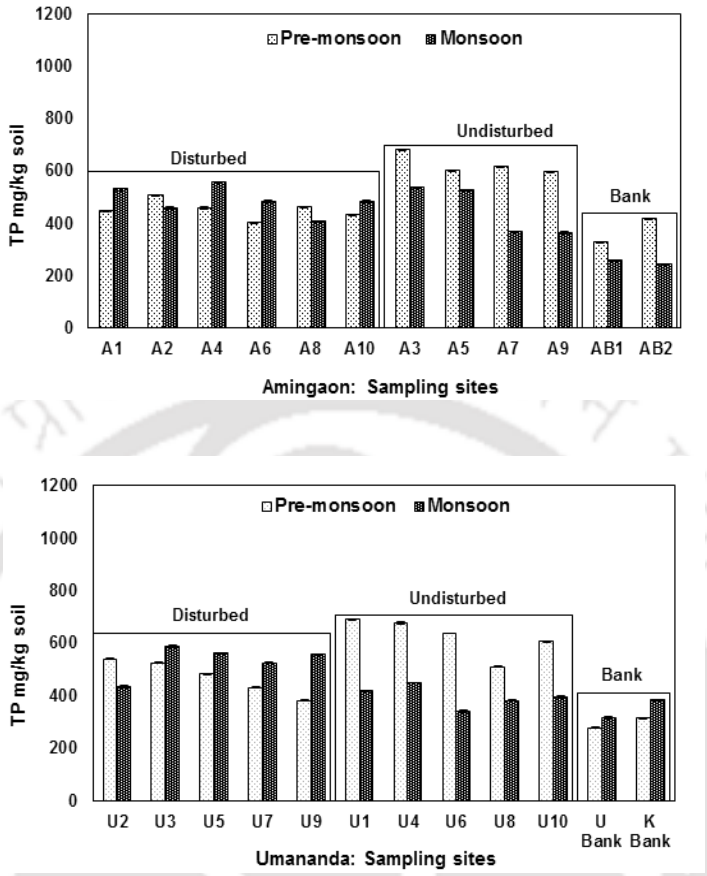
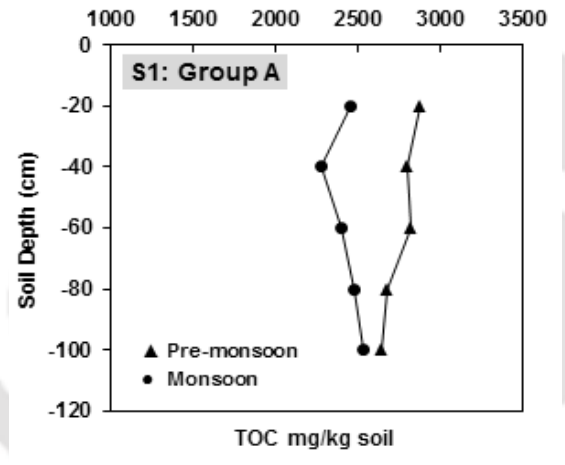
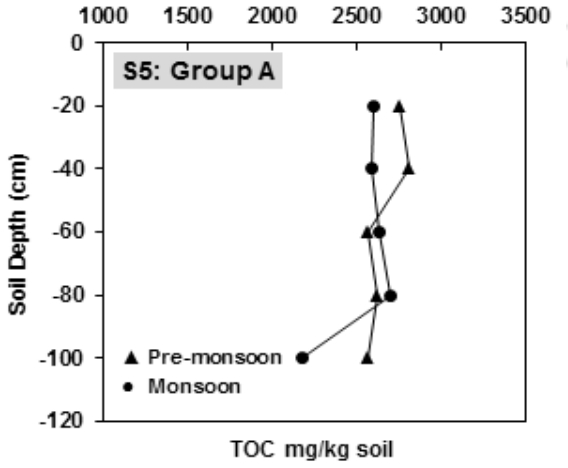


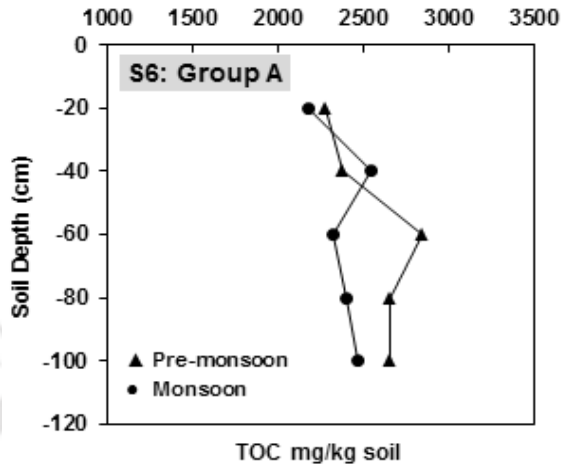
Figure 2.8 *TP of soil samples in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*

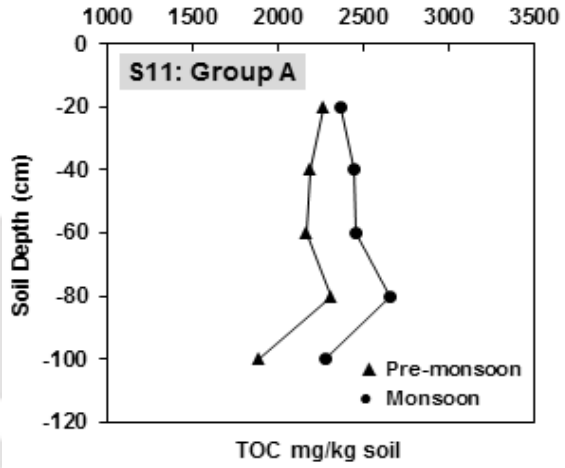
Nutrient mineralization in each season showed marginal difference, values of soil variables analysed in pre-monsoon season were slightly higher than values derived in monsoon season. In this context, it was assumed that MC and temperature may have possibly influenced the availability of nutrients in soil by mediating certain mechanisms of ion-soil interactions i.e. release of ions retained by the colloids or facilitating leaching activities. Additionally, Soil MC favoured leaching of elements (basically N and P). A strong of discrepancy of nutrient availability with increasing

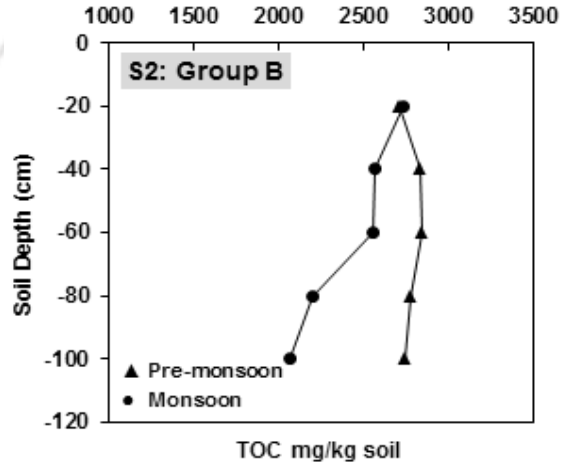
depth in case of Majuli samples was attributed to leaching activities (Figure 2.9; Figure 2.10; Figure 2.11). Soil CNP status in Majuli was positively and negatively correlated to pH, EC, CEC, BCFU, FCFU and grain size distribution respectively [Table A 2.7 (A), Appendix 2]. The correlation studies indicated an inter dependency of the soil variables. However in Amingaon and Umananda, CNP status in Majuli was positively correlated to pH, EC, CEC, BCFU, FCFU and grain size distribution [Table A 2.7 (A), (B), Appendix 2]. The variation in two seasons was significant in Majuli as well as in Amingaon and Umananda.

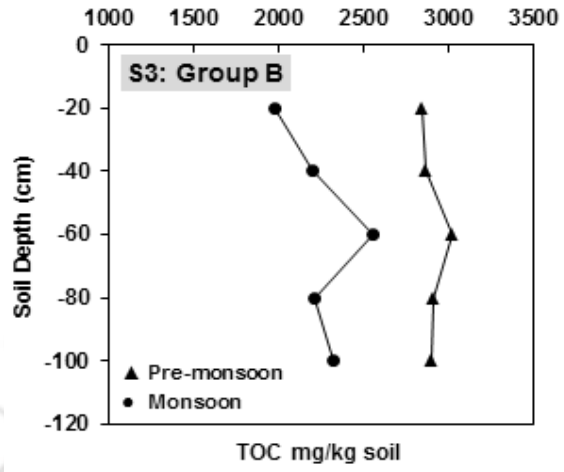


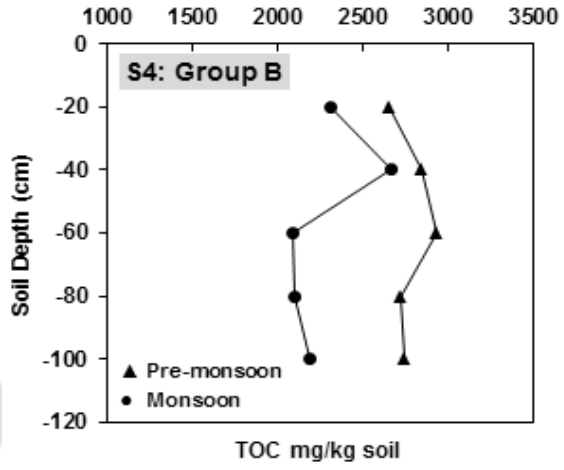


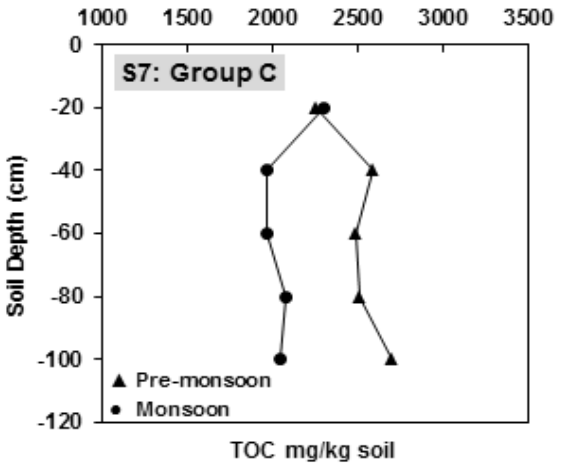


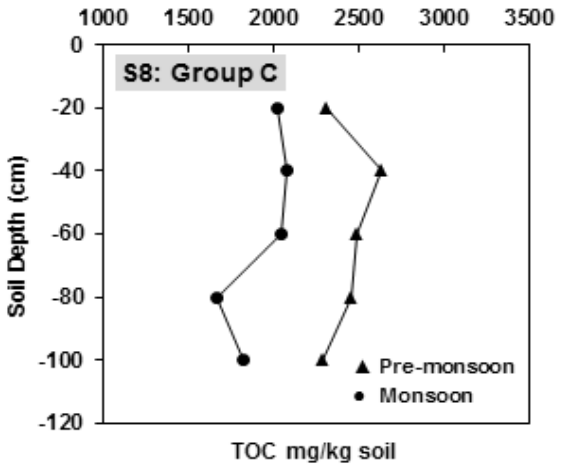


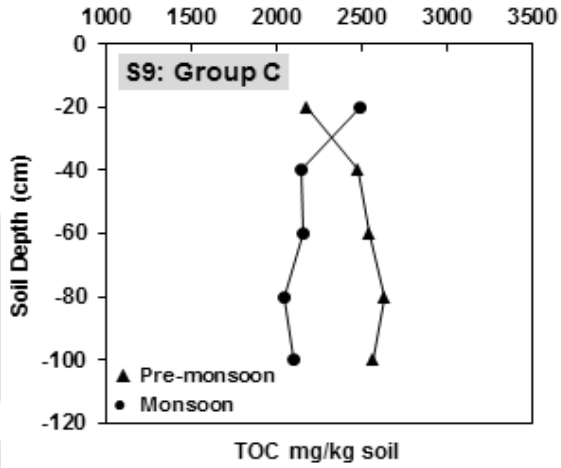


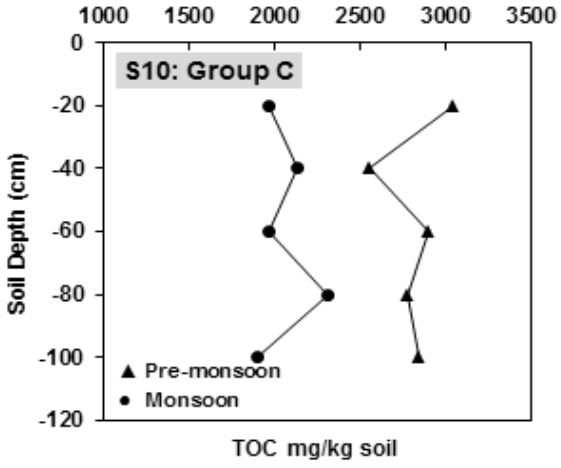












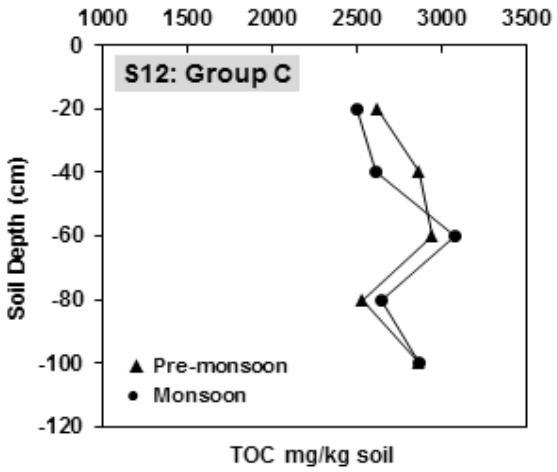
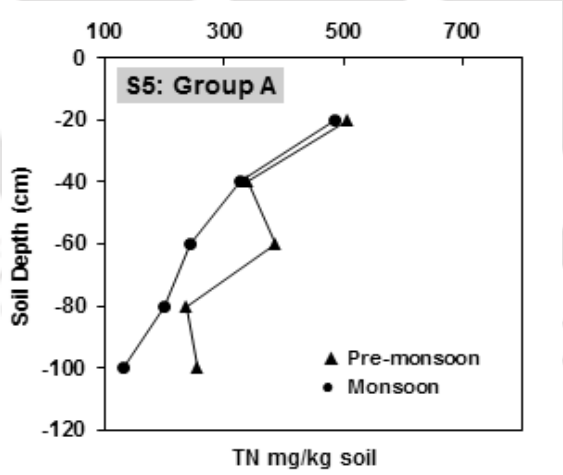
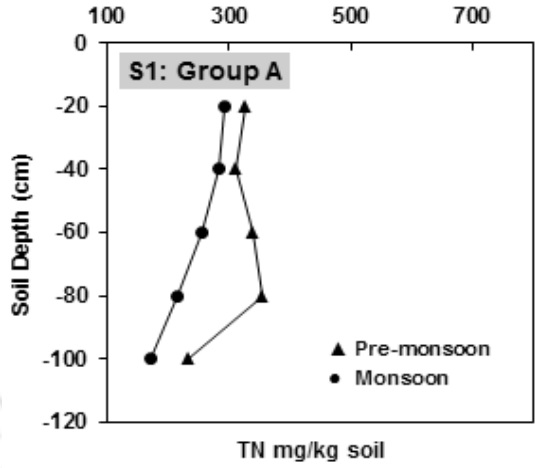
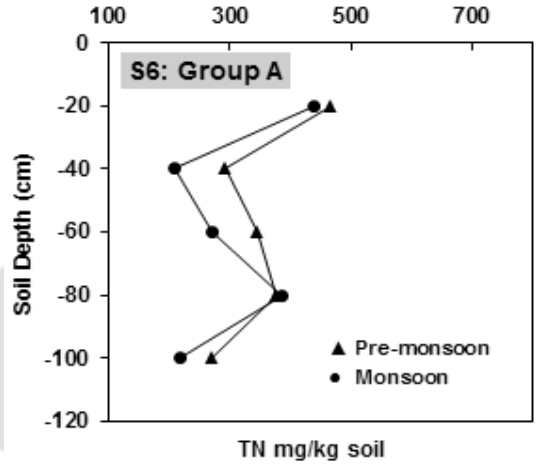
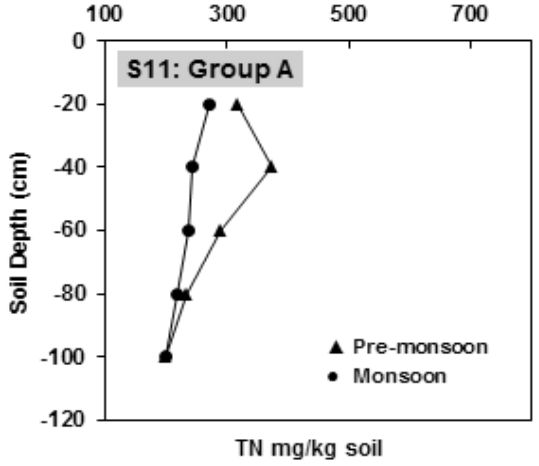


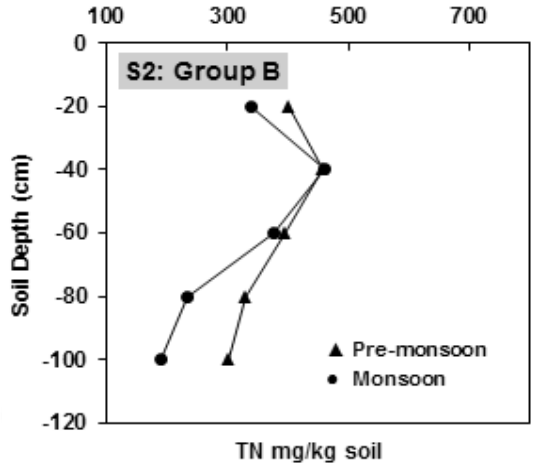
Figure 2.9 *Depthwise discrepancy soil TOC in Majuli, S1 – S12 divided in three Groups (**A**, **B** and **C**) in pre-monsoon and monsoon season, at depths 0 – 100 cm*

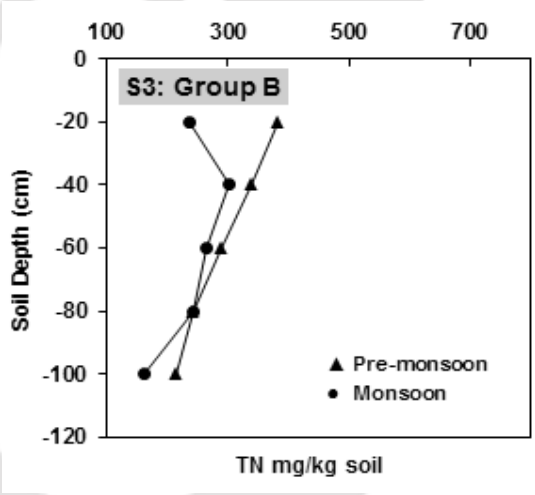


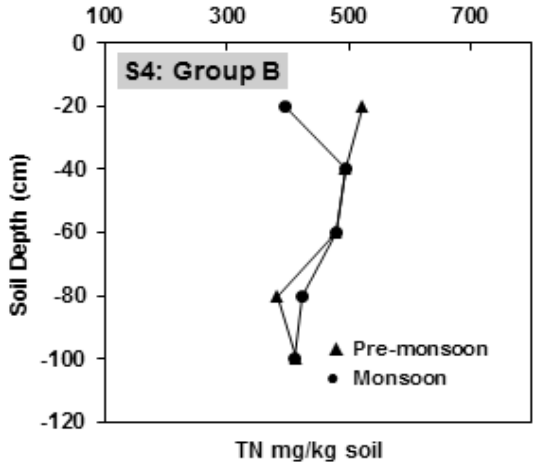


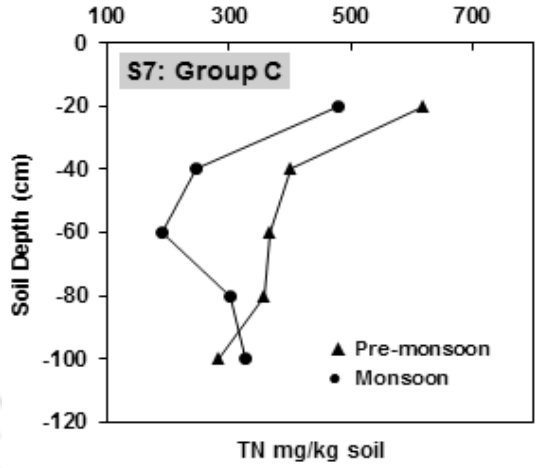


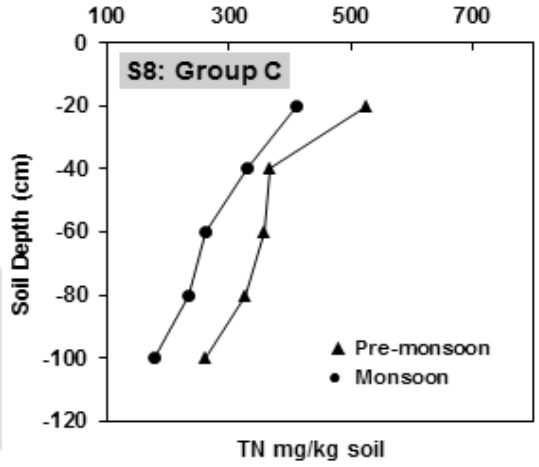


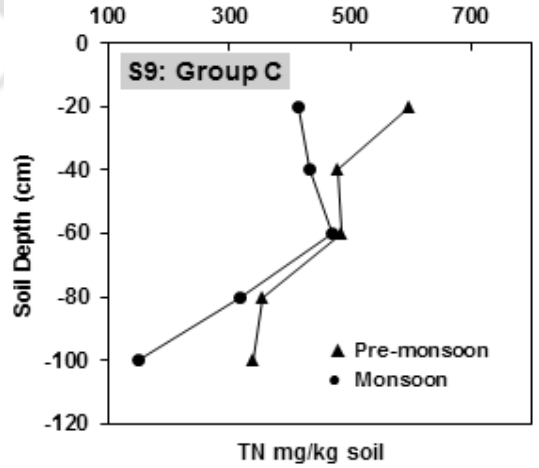












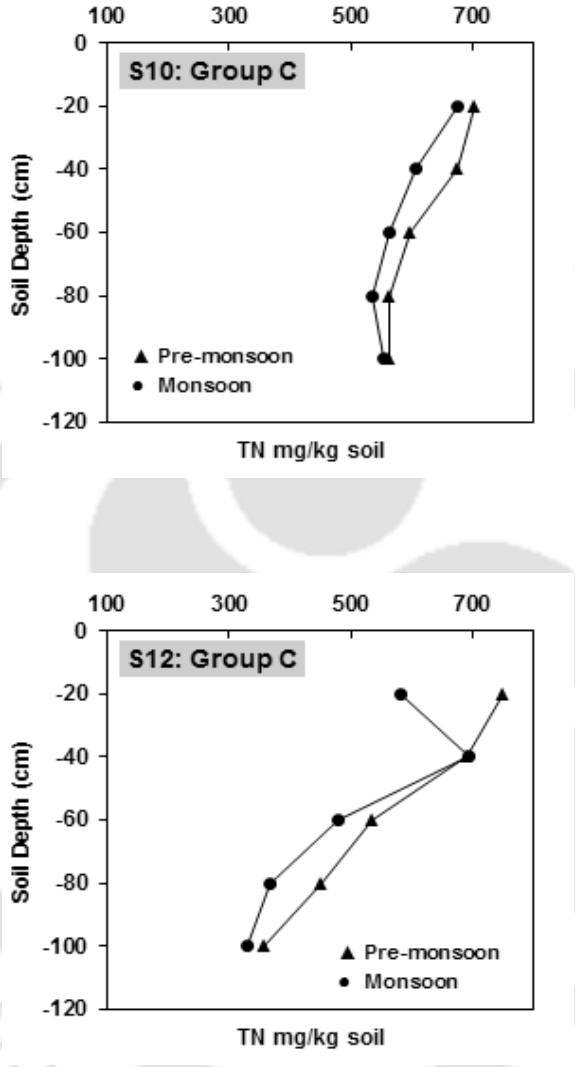
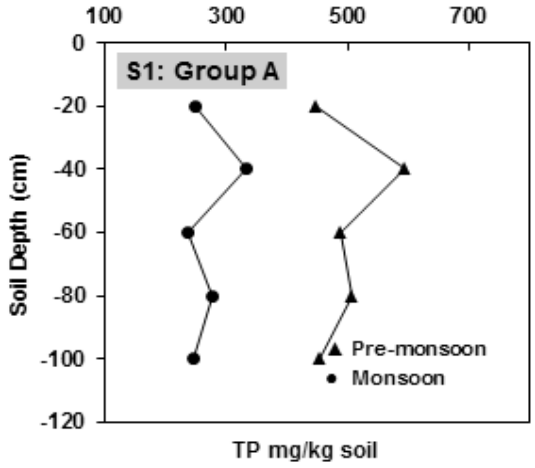
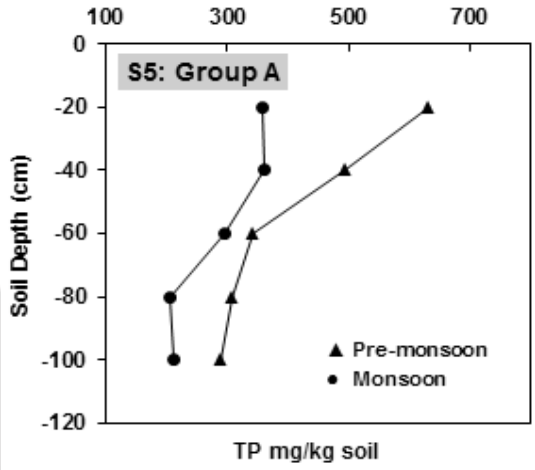
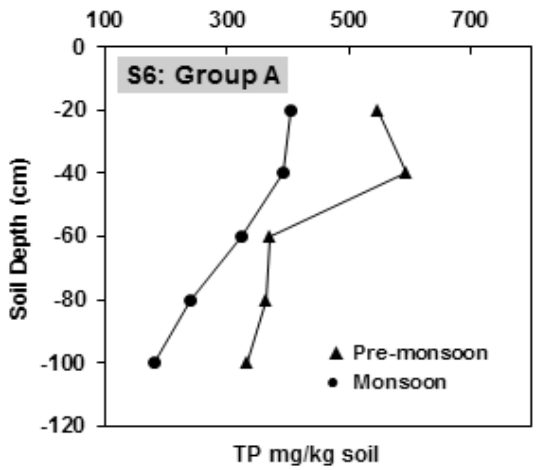
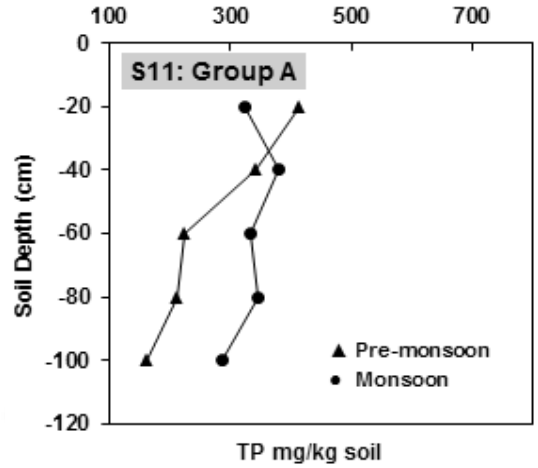


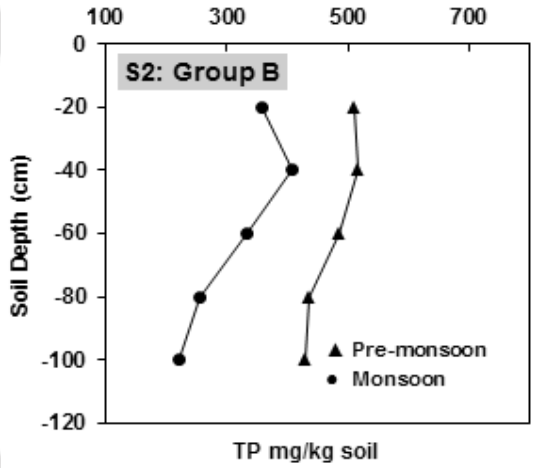
Figure 2.10 *Depthwise discrepancy of soil TN in Majuli, S1 – S12 divided in three Groups (**A**, **B** and **C**) in pre-monsoon and monsoon season, at depths 0 – 100 cm*

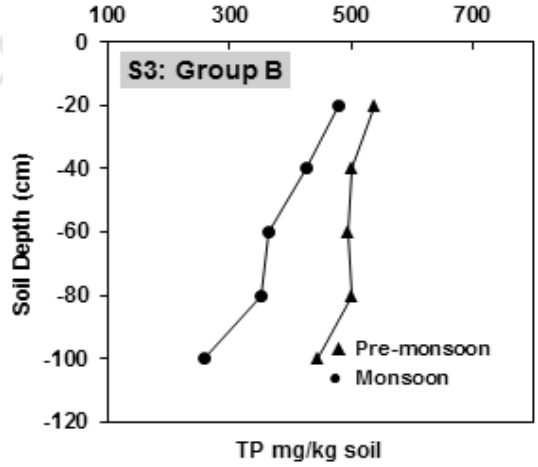


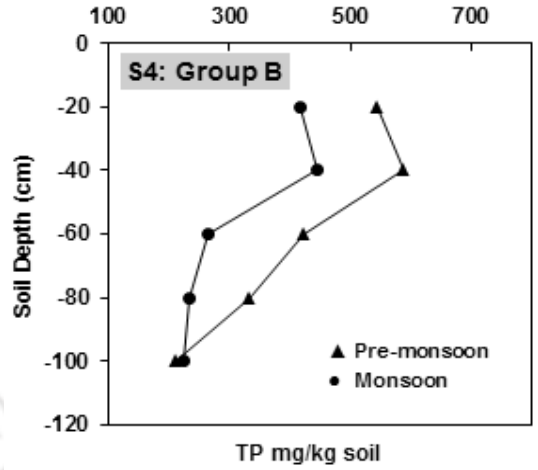


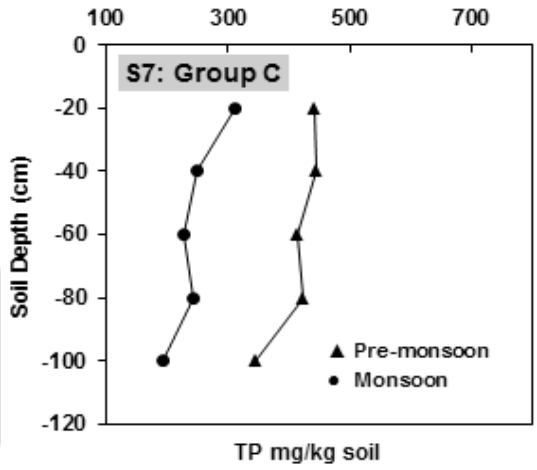


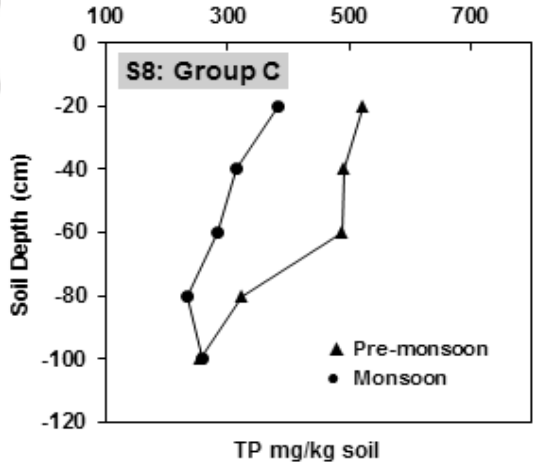












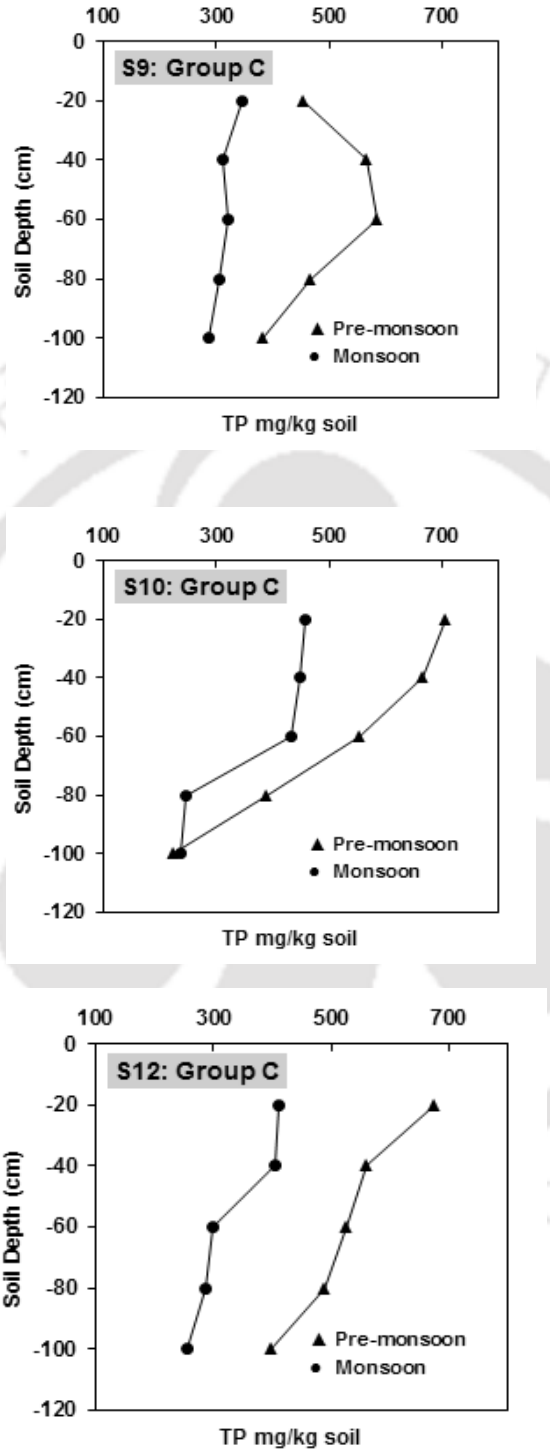


Figure 2.11 *Depthwise discrepancy of soil TP in Majuli, S1 – S12 divided in three Groups (**A**, **B** and **C**) in pre-monsoon and monsoon season, at depths 0 – 100 cm*

In case of bank sediments there was a probability of continuous exchange of nutrients at the water soil interface [Figure 2.6; Figure 2.7; Figure 2.8]. The sediment-water interface is a transition zone between water and underlying soil that affect most of the biochemical processes in flooded soils. OM in river sediments is linked to the type of sediment and its porosity. Moreover, bank sediments comprised of fine sand (visible texture). As aforementioned, adsorption capacity by particles owing to surface area is inversely proportional to the particle size. In bank sediments, higher percentage of fine sand indicated low capabilities of binding OM. In this context, Avnimelech et al (2001) mentioned a structural dependence of sediments on the coating and spacing of inorganic particles by hydrated OM. Thus nutrient mineralization in bank sediments was comparatively lower than the terrestrial sediments. Deposition of river driven OM at the water sediment interface may be linked to slightly higher OC than the terrestrial sediments. However there were a few exceptions in Majuli. There was no clear difference between the TP concentration in terrestrial soils and bank sediments in Majuli and Amingaon, but Umananda bank sediments showed lower TP concentrations than terrestrial soils). The TN concentrations were low in bank sediments in Majuli, Amingaon and Umananda. Availability of TP and TN followed the same concept of OM matter accumulation in flooded sediments.

2.3.2.1 CNP Stoichiometry

Carbon, Nitrogen and Phosphorus tend to follow a stoichiometric ratio in different types of ecosystems known as the Redfield like ratio as in planktonic biomass

(Cleveland, 2007). A Redfield like ratio in soil and soil MB has been reported to occur in the ratio of 186:13:1 and 60:7:1, respectively based on a worldwide survey. The ratio of CNP mineralization is dependent on substrate utilization rates as well as OM degradation process.

In Majuli, the CNP ratio was in a range of 16:1:1 – 33:6:1 in pre-monsoon season and 12:1:1 – 33:3:1 in monsoon season. CNP ratio was higher in S10 and lower in S12 (both occurring in Group C) in pre-monsoon season whereas in monsoon CNP ratio was higher in S6 (Group A) and lower in S3 (Group B) [Table A 2.6 (A), Appendix 2]. The CNP ratios indicated that substrate utilization (Nitrogen and Phosphorus) was high in Group C or OM degradation was low (evident from CEC), in pre-monsoon season. In monsoon, substrate utilization process by microorganisms was high, possibly due to microbial activity. This outcome is further supported by the fact microbial population was higher in monsoon season than pre-monsoon investigations.

In Amingaon CNP ratio was in a range of 12:3:1 – 20:4:1 in pre-monsoon and 13:3:1 – 24:4:1 in monsoon season respectively. CNP ratio was higher in A6 (Group A) and lower in A3 (Group B) in pre-monsoon season and higher in AB2 (Group C) and lower in A1 and A4 (Group A) in monsoon season [Table A 2.6 (B), Appendix 2]. In Umananda CNP ratio was in a range of 11:4:1 – 22:3:1 in pre-monsoon season and 12:4:1 – 24:5:1 in monsoon season respectively [Table A 2.6 (B), Appendix 2]. CNP ratios in Amingaon and Umananda indicated higher substrate utilization than Majuli samples. The seasonal variance in Amingaon and Umananda was minimal.

Finally, the experimental data were observed at a global scale by comparing it with SOM in terrestrial soils and alluvial deposits worldwide (Cleveland et al., 2007; Yang et al., 2013). It was apparent that CNP budget in the test groups in Majuli and Kamrup were rather inclined towards a moderate productive zone. However, Kamrup seemed to be more productive than Majuli (Table 2.5).

Table 2.5 *Details of a comparative study of the SOM fractions in Majuli and Kamrup and terrestrial soils worldwide*

Elements (g/kg)	Concentration in a wide variety of terrestrial soils (worldwide) (g/kg)	Concentration in Majuli (g/kg)	Concentration in Kamrup (g/kg)	References
Carbon	13.31 – 469.39*	2.18 – 3.04**	1.93 – 5.53**	ISI Web of Science online database (Cleveland et al., 2007)
Nitrogen	0.29 – 18.20*	0.32 – 0.75**	0.29 – 1.14**	
Phosphorus	upto 0.53* (alluvial deposits)	0.41 – 0.70**	0.25 – 0.72**	USDA website, Soil and Terrain database for Latin America and the Caribbean (SOTERLAC) (Yang et al., 2013)

*The unit of actual values have converted to g/kg

**Experimental data

Total Carbon content was reasonable, though less, whereas lower limit of Nitrogen and Phosphorus in the study areas were rational, emphasizing the acute role of terrestrial soils as a nutrient sink. Total phosphorus levels were fairly higher than the amount reported in alluvial deposits worldwide (Yang et al., 2013).

2.3.3 Role of microbial biomass and soil enzymes activities in soil fertility and productivity

Microbial biomass has a strong connection with soil properties and nutrient mineralization, sustained by soil enzymes activities. Microbial populations in soil together with SOM facilitate nutrient availability. SOM and grain size components have a good association that enhances CEC. More specifically clay minerals promote microbial growth by maintaining pH and hence buffering the nutrient supply. Similarly minerals have a strong affinity towards soil enzymes. Ros et al (2006) suggested that application of different composts to soil significantly enhanced enzyme activities. Fernández et al (2009) reported that application of composted or non-composted sewage sludge caused decreases in microbial biomass Carbon and enzyme activities. Thus it was observed that any kind of organic amendment or fluctuation in the organic matter levels in soil affect microbial biomass content and soil enzyme activities. Organic amendments were not prevalent in Majuli and Kamrup (Amingaon and Umananda).

2.3.3.1 Microbial biomass and nutrient mineralization

A Redfield like ratio was also evaluated in soil microbial biomass. In Majuli, the CNP ratio of microbial biomass in all samples of residential area and agricultural fields was higher in pre-monsoon compared to those in monsoon except of Kharkhari site (S11) [Table A 2.6 (A), Appendix 2]. On the other hand grass land samples showed higher microbial CNP ratio in the monsoon than in pre-monsoon samples except Sarala

wetland sample (S2). The soil CNP ratio in comparison to microbial biomass CNP ratio was quite lower and this may indicate a depletion of carbon pool and active utilization of carbon source for growth and metabolism in flood and precipitation dominated monsoon season. In Kamrup (Amingaon and Umananda), depending on the availability of substrates in river fed floodplain soil, the microbial CNP ratio was higher than soil CNP ratios in soil samples in each season (microbial CNP ratio of 16:3:1 – 28:3:1 in Amingaon and 16:2:1 – 23:3:1 in Umananda in pre-monsoon season; 18:2:1-28:1:1 in Amingaon and 16:1:1 – 32:4:1 in Umananda in monsoon season). Unlike SOM, higher CNP ratios were equally concentrated in disturbed soil site and river bank sediments as well as undisturbed samples. Nutrient mineralization by microorganism was based on MB characterization (including both culturable and unculturable microorganisms). Correlation studies showed positive and significant association of MB with most of the soil parameters in Majuli as well as Kamrup (Amingaon and Umananda) [Table A 2.7 (A), (B), (C), Appendix 2]. The depthwise discrepancy of microbial biomass was similar to SOM distribution.

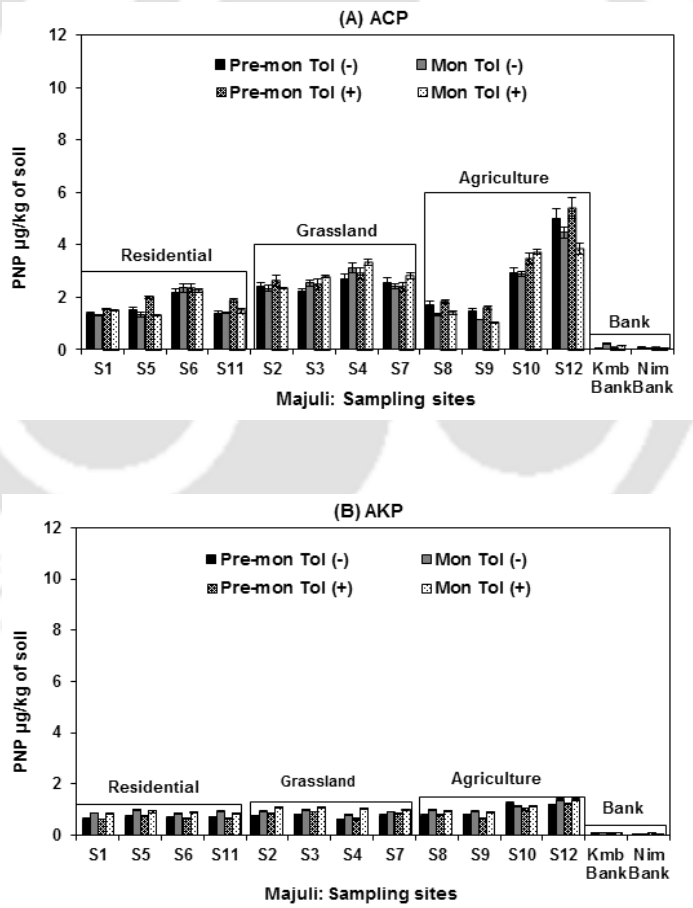
2.3.3.2 Soil enzyme activities as a function of soil fertility and productivity

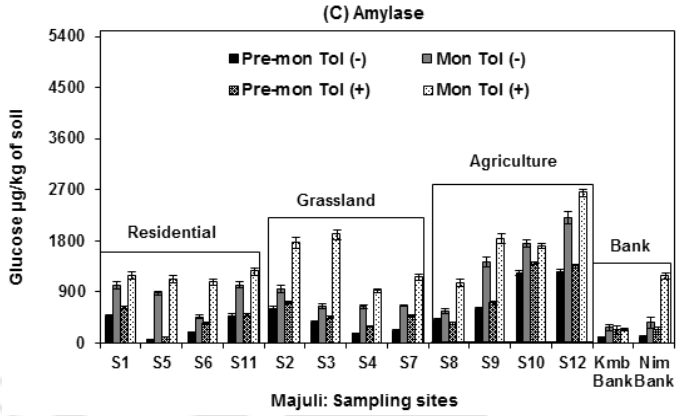
In Majuli soils, there was a continual change in enzyme activities with increasing depth, the decreasing trend of enzymatic activities was uniform and evident in each season [Figure 2.12 (A – H)]. The depth of incidence of high SOM and enzyme activities in most of the sampling sites peaked at 0 – 60 cm and reduced at 80 – 100 cm. To screen the critical role of microorganisms in soil enzymatic activities, toluene treatment was incorporated in the enzyme assays. Effect of toluene was marked in a

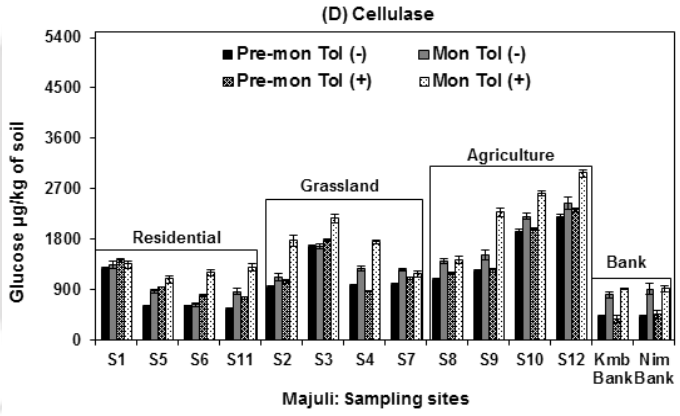
few enzymes and results complied with the data available in published archives (Pancholy and Rice, 1973; Cole, 1977; Tabatabai and Bremner, 1972; Ladd and Buttler, 1972). Observations indicated a clear demarcation of microbial enzyme activity and extracellular enzyme activity in few enzymes as cellulase, amylase, protease and urease. While in phosphatases, invertase and dehydrogenase, concerned sources of enzyme activities remained similar. The increasing depth conforms to decreasing nutrient content followed by lower enzyme activities. Seasonal variance was minimal in all sampling sites excluding urease [Figure 2.11 (A – H)]. Population of microorganism was higher in monsoon season (from plate count method), hence there is a possibility of more enzymatic activities projected for substrate utilization for maximum growth and metabolism by the microorganisms. This outcome was similar to the reports published by many researchers (Mahalaxmi et al., 2013; Cregger et al., 2012). There was no record of synthetic fertilizer application in Majuli (confirmed by social survey). However application of cow dung in agricultural soils was reported by local inhabitants. Cowdung in the form organic matter may possibly contribute to a small fraction of SOM and enhance soil enzymatic activities. Overall trend of soil enzyme activity was cellulase > amylase > invertase > urease > protease > dehydrogenase > phosphatases. This trend was equally conspicuous in Kamrup (Amingaon and Umananda) [Figure 2.13 (A – H); 2.14 (A – H)].

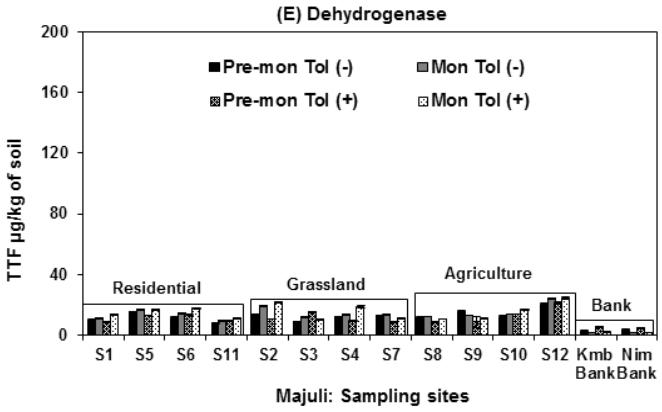
In Amingaon and Umananda, soil enzymatic assays depicted fertility and scope of productivity in the soils. Sampling sites in Kamrup were devoid of any kind of agricultural activity or organic amendments other than frequent human intervention.

Industrial and commercial activities were prominent in Amingaon whereas tourism activities were consistent in Umananda. Soil enzyme activities in Amingaon and Umananda showed that undisturbed soil held a better fertility and productivity potential followed by disturbed sites and bank sediments. In Amingaon and Umananda, there was no record of application of fertilizer or artificial manure from the sampling sites. The study areas showed organic and inorganic waste deposition activities only.









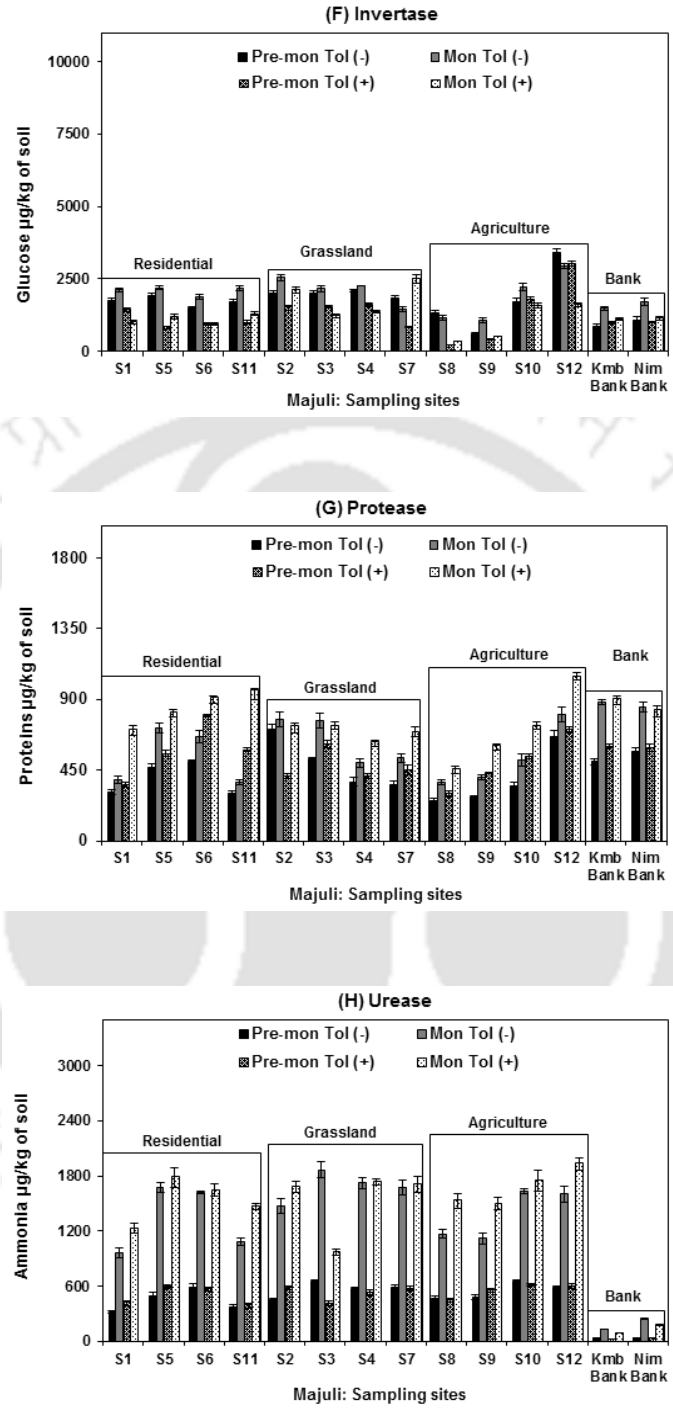
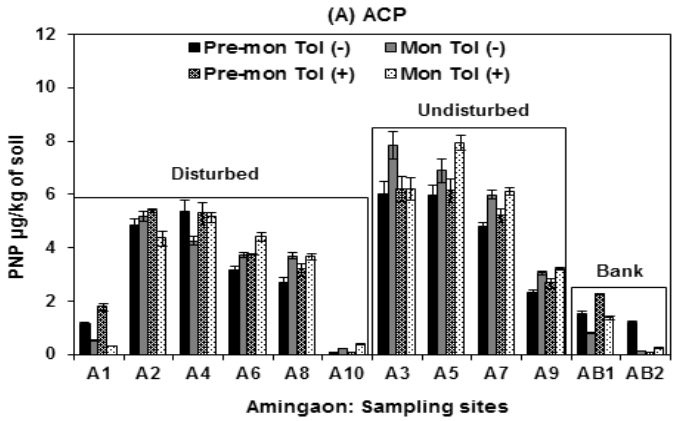
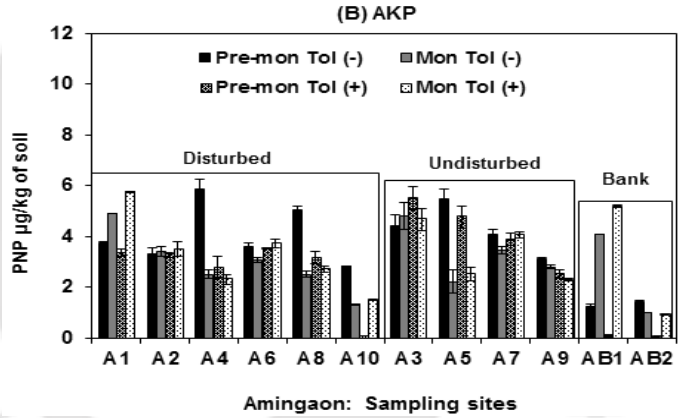
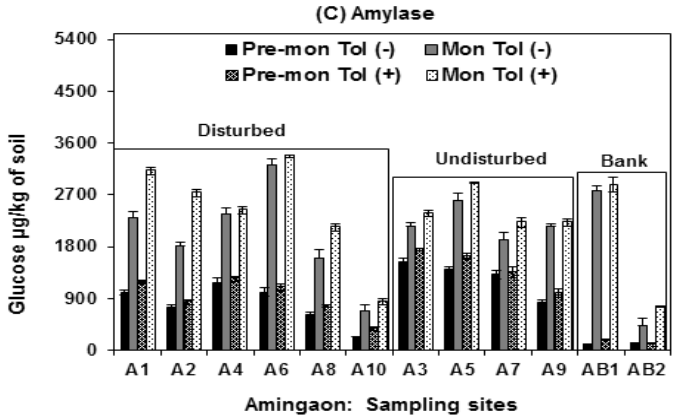
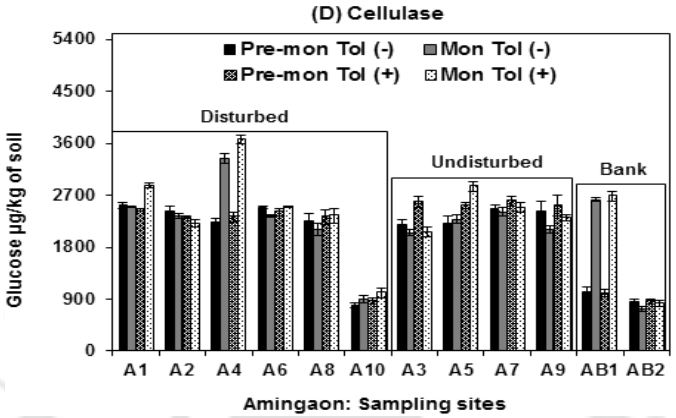


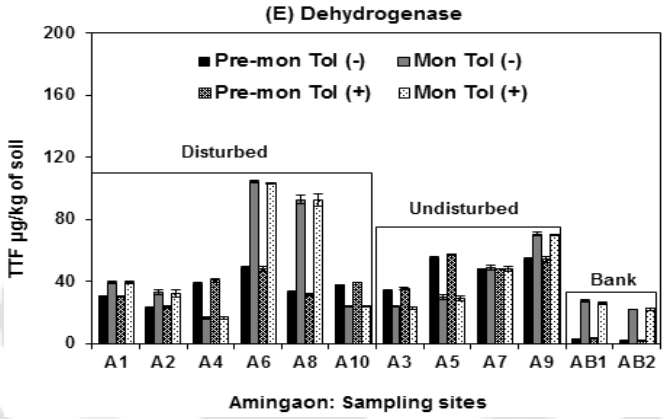
Figure 2.12 (A – H) *Soil enzyme profile of Majuli River Island in pre-monsoon and monsoon season, at a depth of 0 – 20 cm. Enzyme activities were checked in soil samples with varied landuse activities and geomorphic origin*

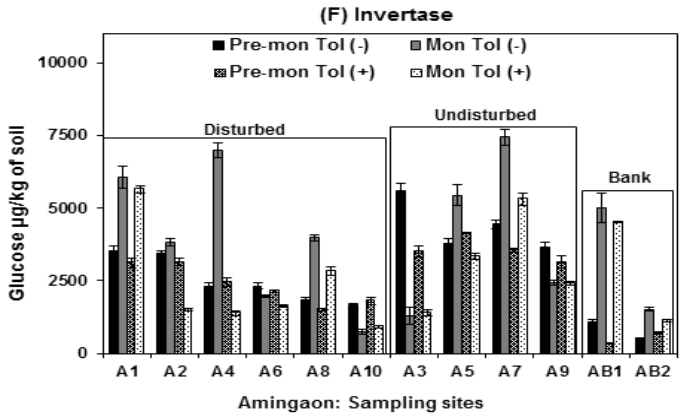












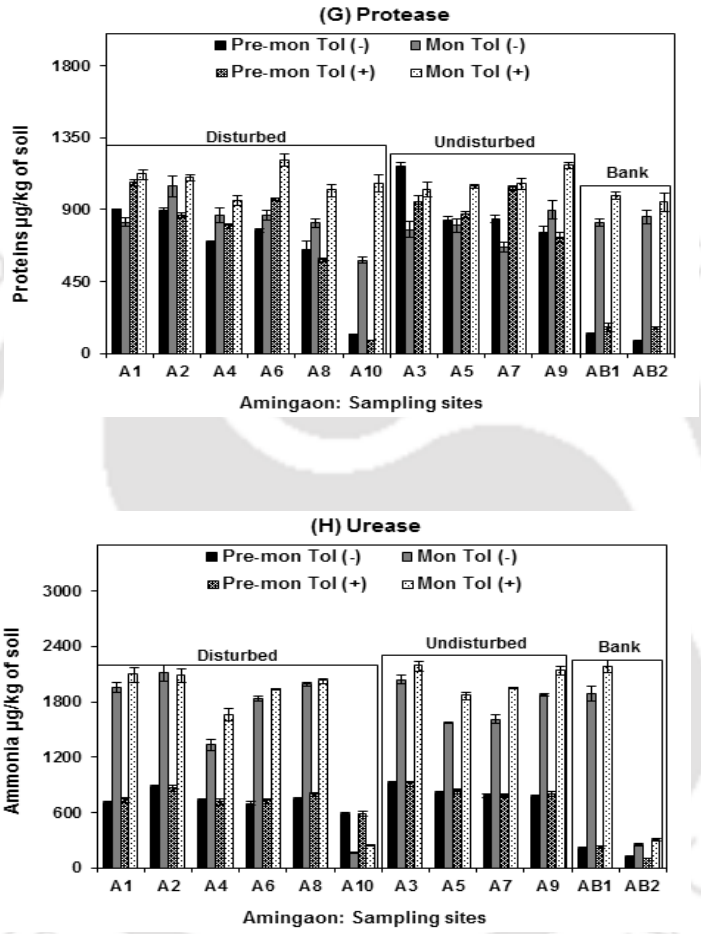
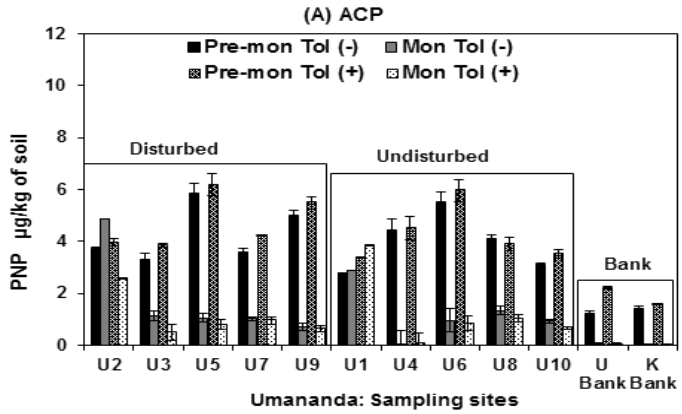
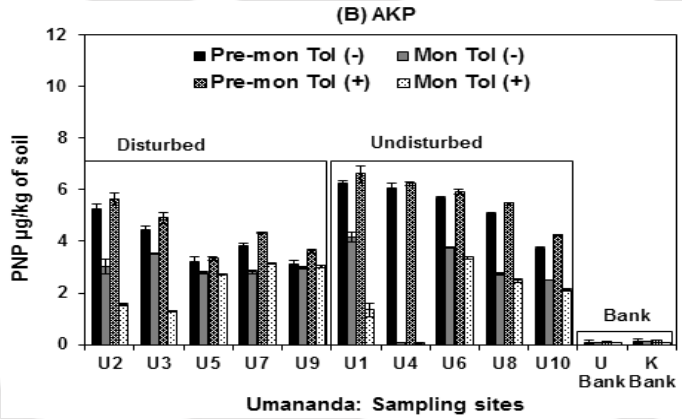
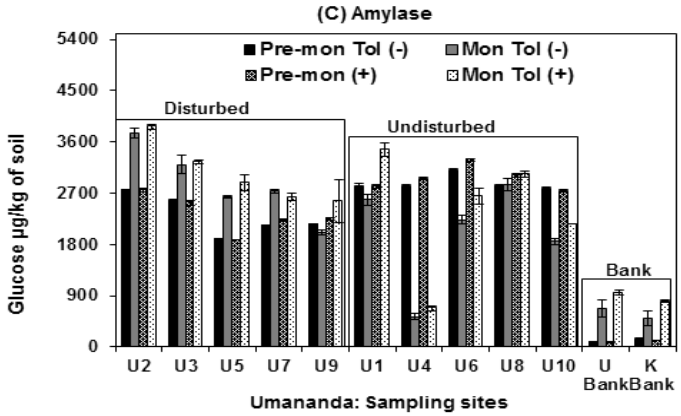
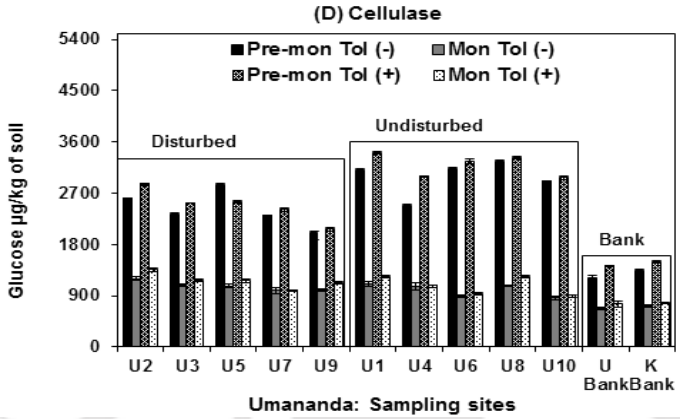


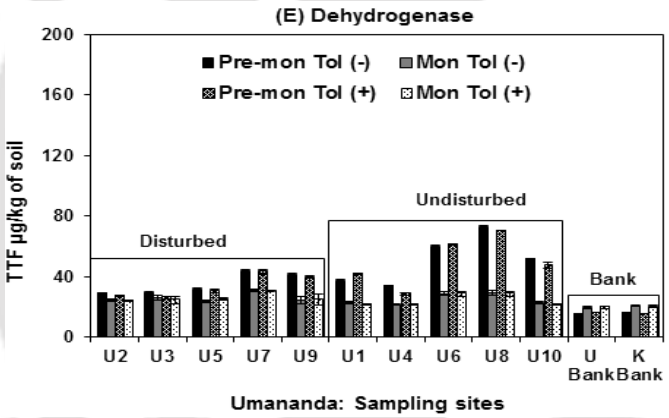
Figure 2.13 (A – H) *Soil enzyme profile of Amingaon in pre-monsoon and monsoon season, at a depth of 0 – 20 cm. Enzyme activities were checked in soil samples from disturbed areas, undisturbed areas and bank sediments*

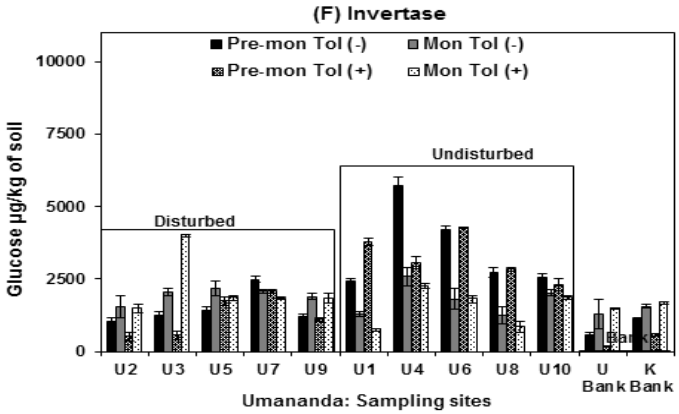












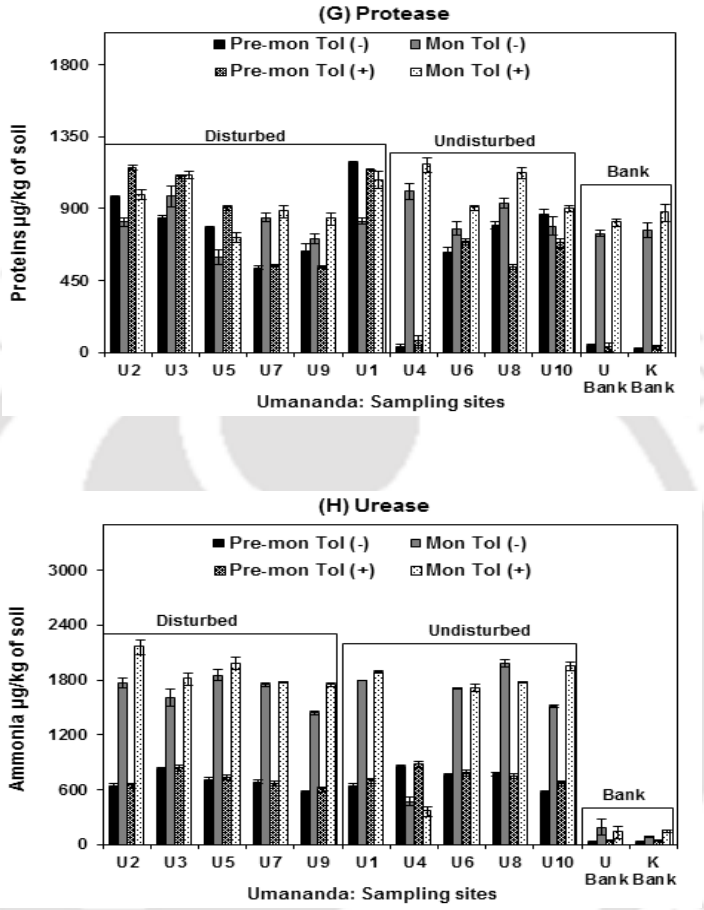


Figure 2.14 (A – H) *Soil enzyme profile of Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm. Enzyme activities were checked in soil samples from disturbed areas, undisturbed areas and bank sediments*

Enzymatic activities inferred soil richness in microbial population as a major factor of macronutrients availability (basically CNP), under influence of secondary factors like pH and trace elements. SOM and soil enzymatic activities are often

associated with the soil mineralogical nature. Sandy clay loam nature of the soil samples was intended to retain fair amount of SOM and promote enzymatic activities functionalized by soil microorganisms or secondary extracellular sources in Majuli and Kamrup (Amingaon and Umananda). CEC of sandy clay loam soil seem to rely on accessibility of basic cations from SOM that was relatively higher in Kamrup (Amingaon and Umananda). However, in Majuli, Amingaon and Umananda, soil CEC showed no virtual correlations with geochemical parameters proposing the recalcitrant nature of humic substances in Majuli soils and undisturbed soils in Amingaon and Umananda. Additionally, this outcome gave an overview of low humus content in disturbed soils in Amingaon and Umananda soil and bank sediments (Majuli, Amingaon and Umananda).

Enzyme activities and nutrient mineralization in Majuli were positively correlated in both pre-monsoon and monsoon seasons [Table A 2.8 (A), (B), Appendix 2]. The effect of toluene was evident in a few enzymes in the study areas. Results complied with the data published by many researchers (Pancholy et al., 1973; Nelson, 1944; Tabatabai et al., 1972). The by products obtained as a result of enzyme activities added to active nutrient budget or serve as an immediate source of SOM comprising C,N,P and MBC, MBN and MBP. A possible linkage of microorganisms with nutrient mineralization is also supported by the fact that in presence of some important soil enzymes, nutrient mineralization was prominent in both pre-monsoon and monsoon seasons. Factors as pH, sand, silt, clay, CEC and metals in soil were positively linked to a few enzymes (with and without toluene) illustrating that under existing environmental

conditions, enzymes activities may be accelerated or slowed down [Table A 2.8 (A), (B), Appendix 2]. In Kamrup (Amingaon and Umananda), results were similar, enzyme activities (with and without toluene) showed positive significant correlation with nutrient mineralization, except a few cases like invertase and TOC, dehydrogenase and MBN, etc. [Table A 2.9 (A), (B), Appendix 2] [Table A 2.10 (A), (B), Appendix 2]. CEC showed positive correlations with most of the enzyme activities in Majuli as well Kamrup (Amingaon and Umananda). Overall results indicated that soil enzyme activities in Kamrup (Amingaon and Umananda) were higher than Majuli. Theories apart, one possible reason would be occurrence of relatively greater microbial populations (both bacteria and fungus in Amingaon and Umananda). Significant soil enzyme activities could not be restricted to microbial populations and SOM alone, inherent soil properties characteristics of particular region, have an influence on geochemical parameters known as spatial variability (discussed in Chapter 4).

2.3.4 Influence of geochemical parameters on the biotic factors in soil

To understand the role of microbial activity in nutrient mineralization we used linear regression curve fitting model for SOM and biological parameters (0 – 20 cm depth) using SPSS software. From regression analyses, it was perceived that available OM in soil supported nutrient mineralization by the activities of microbial communities. A perfect relationship or dependency of nutrient mineralization on microorganisms cannot be established from the regression analyses or correlation studies because most of the microorganisms that have also contributed to microbial biomass content have been ruled out as unculturable microorganisms.

In Majuli, results were indicative of the fact that SOM was directly associated microbial activities. Outputs of some of the significant regression analyses are given in Table 2.6 and 2.7 SOM in pre – monsoon as well as monsoon seasons showed positive correlation with MBC. Microbial population more specifically a probable microbial community structure and its physiological mechanisms were primarily dependent on the CNP fractions of SOM. This observation indicated that functionality of MBC in Majuli wetlands is reliant on the availability of SOM.

Similarly, in Amingaon and Umananda, regression analysis showed that availability of OM promoted nutrient mineralization by the microbial communities. Soil CNP and microbial biomass CNP showed significant dependency on each other (Table 2.6, 2.7). Overall geochemical parameters were found to be uniformly linked to SOM predicting a scope of productivity in the test soils. Apart from association between SOM and microbial biomass pH and CEC showed association with SOM in Kamrup. CEC in a pH range of slightly acidic to slightly alkaline in the test groups was acceptable, referring to the availability of basic soil nutrients (Saidi, 2012). Pearson correlation matrix disclosed that SOM was positively related to most of the soil variables and soil enzymatic activities in Majuli as well as Kamrup [Table A 2.7 (A), (B), (C); Table A 2.8 (A), (B); Table A 2.9 (A), (B); Table A 2.10 (A), (B)]. Thus it was partially evident that available SOM supported OM mineralization aided by the activities of microbial communities.

Table 2.6 *Results of linear regression between SOM and soil microbial biomass in Majuli in pre – monsoon and monsoon season, at a depth of 0 – 20 cm*

Parameters	Regression Equation	R^2	P-Value
Pre-monsoon			
MBC	-10.01+0.095 OC	0.69	p<0.05
	66.59+ 0.37 TP	0.59	
MBN	-3.19+0.07 TN	0.92	
	1.07+0.05 TP	0.84	
Monsoon			
MBC	-114.83 +0.13 OC	0.88	p<0.05
MBN	-0.12 + 0.06 TN	0.92	

Table 2.7 *Details of regression analyses carried out among the geochemical parameters in Amingaon and Umananda in pre – monsoon and monsoon season, at a depth of 0 – 20 cm*

Parameters	Regression Equation	R^2	P-Value
Amingaon Pre – monsoon			
TOC	-46.22+0.10 MBC	0.72	p<0.05
	-1996.72+0.93 TN	0.52	
	5.51+0.001 pH	0.61	
	-11.75+0.17 MBP	0.50	

TN	2.36+0.05 MBN	0.72	p<0.05
	199.60+0.07 MBC	0.59	
	19.13+0.02 MBP	0.60	
	268.65+0.31 TP	0.70	
MBN	6.83+0.0004 pH	0.62	
	19.83+0.29 MBP	0.66	
TP	2.53+0.06 MBP	0.93	
	6.51+0.001 pH	0.74	
Amingaon Monsoon			
TOC	2.92+0.09 MBC	0.75	p<0.05
	-9.57+0.01 MBP	0.61	
	-432.49+0.32 TP	0.55	
TN	-14.94+0.07 MBN	0.95	
	12.09+0.04 MBP	0.91	
Umananda Pre – monsoon			
TOC	43.26+0.07 MBC	0.76	p<0.05
	-88.82+0.05 MBN	0.59	
	-25.38+0.02 MBP	0.74	
	-967.48+0.60 TN	0.60	
	-595.12+0.38 TP	0.75	
	130.38-0.03 CEC	0.55	

TN	190.56+0.09 MBC	0.65	p<0.05
	-10.35+0.08 MBN	0.93	
	14.45+0.03 MBP	0.71	
MBN	147.49+0.45 TP	0.65	
	202.92+1.14 MBC	0.69	
	19.70+0.31 MBP	0.62	
TP	172.46+0.18 MBC	0.80	
	-4.47+0.11 MBN	0.59	
	8.30+0.05 MBP	0.92	
	Umananda Monsoon		
TOC	1641.27+4.85 MBC	0.74	p<0.05
	-106.86+0.05 MBN	0.66	
	-956.08+0.62 TN	0.64	
MBC	-30.60+0.30 MBN	0.68	
	92.38-0.02 CEC	0.50	
TN	98.61+0.19 MBC	0.66	
	-21.16+0.08 MBN	0.94	
TP	-0.10+0.06 MBP	0.92	

2.4 CONCLUSIONS

Physicochemical characterization of water samples showed that in pre-monsoon and monsoon seasons, pH, EC, turbidity, nitrate, dissolved oxygen, ammonia showed relatively higher values in Group A (residential area). Sulphate showed elevated concentrations in Group C (agricultural field) and phosphate, chloride and fluoride

concentration were significant in Group D (ground water). DO was available in fair proportions whereas COD was lower in residential areas. Higher values of physicochemical parameters in Group A may be attributed to household activities that may elevate the levels of pH and EC in water. MPN estimation revealed faecal contamination in two wetland water samples only, S9 (Magurmara Bil) in pre – monsoon season as well as monsoon season and S18 (Missing Gaon water body) in pre – monsoon. Lack of sanitation facilities and untreated drinking may promote proliferation of coliform species in water. Evaluation SAR, SSP and KR on the basis of concentration of Na, Ca, Mg and K in water showed that a few sample especially S7 (Barbil wetland water) and S8 (ground water) had elevated SSP. S10 (Kharjan wetland water) challenged the critical limits of Kelly's ratio rendering the waters unfit for irrigation activities.

Geochemical analyses in Majuli revealed that the soil type i.e. sandy clay loam was a result of flooding activities. Soils contained higher percentage of fine sand followed by silt and clay. Soil typology was positively linked to most of the CNP parameters at all sampling sites. Grassland vegetation was profound though other large trees and shrubs equally existed in the wetlands. *Hemarthria* sp. was observed as the most abundant grass with highest number of occurrence in almost all sampling sites. Highest values for all the parameters were found in agricultural fields at the vicinity of wetlands. Values of majority of the parameters were highest in Garukhuti wetland (S12) and Sakali wetland (S10) and lowest in Aphalamukh residential area (S1), Tuni wetland (S3), Kharjan wetland (S6) and Kharkari wetland (S11), all located in the

western Majuli. Bank sediments (Group D) showed minimum concentration of SOM. Geochemical parameters were positively correlated to soil enzymatic activities. In most of the enzymatic assays, role of extracellular enzymes (released by addition of toluene) was more prominent than intracellular enzymes. Enzyme activities were more conspicuous in monsoon season than in pre-monsoon season. Experimental analyses, linear regressions and correlation studies gave an overview of the vital relationships between geochemical and biological parameters. It was observed that at a global scale, productivity in Majuli tend to represent a moderate productivity zone (Cleveland 2011) (Table 2.5). The global range of concentrations of TOC is 13307.08 – 469386.83 mg/kg and TN is 294.21 – 18213.00 mg/kg in terrestrial soils and concentration of TP in alluvial deposits is upto 528.00 mg/kg (Cleveland, 2011; Yang et al., 2013). Seasonal variation had a marginal effect on the soil variables. However location wise variation was significant and maximum scope of productivity was witnessed in the agriculture dominated areas (Group C). Soil fertility was confirmed by microbial and soil enzyme activities respectively. Majuli Island is principally agriculture and fishery centred region, the overall scenario of productivity of ecosystem unlocks need and scope for nutrient management in wetlands. However, an increase in intensity of crop management activities may indicate a call for organic amendments. In the long run, such modifications may be harmful to the pristine ecosystem in Majuli Island. Better utilization of wetland resources and sustainable crop management activities will help to retain the fertility of soil intact.

On the other hand, Amingaon and Umananda River Island in lower Brahmaputra floodplain represented a superior productivity zone when compared to Majuli River Island. Soil buffering capacity was in a neutral to alkaline range and soil CEC was higher than CEC in Majuli soils. Soil characterization further exhibited similarity in grain size distribution in Kamrup and Majuli, attributed to river transported or naturally formed riverine floodplain sediment of fluvial geomorphology. Vegetation profile in Kamrup was similar to Majuli. SOM and soil microbial biomass were enriched in Amingaon and Umananda. Kamrup also showed higher microbial populations and soil enzyme activities. The overall CNP stoichiometry was more pronounced in Kamrup (Amingaon and Umananda). Geochemical parameters were strongly correlated to biological parameters except CEC indicating a strong influence of abiotic parameters in maintaining biological processes in soil. High concentrations of SOM were concentrated in the undisturbed sampling sites (Group A). Like in Majuli, bank sediments (Group C) in Kamrup showed low scope of productivity.

In concluding remarks, based on the experimental analyses and productivity studies it will be obligatory to mention that Kamrup (Amingaon and Umananda) has a broader scope of productive ecosystem in comparison to the wetland ecosystems in Majuli River Island. Majuli was anticipated to have a productive ecosystem from agricultural perspective. Nevertheless, outcomes of this comparative assessment, difference in topography, environmental and manmade implications seems to project Kamrup as a better choice for agricultural operations.

CHAPTER 3

Assessment of metal status and pollution indices in water and soil in Brahmaputra River floodplain

3.1 INTRODUCTION

Metal enrichment in the environment is a long term process caused by geological sources and can be traced back to the genesis of soil occurring in a chronological order (Brannvall et al., 2001). The process is further sustained by industrial development, urbanization, agricultural and land use activities in course of time. Most of these elements have high affinity towards soil mineralogical composition and organic matter in a particular area (Fijalkowski et al., 2000; Dube et al., 2001). Soil naturally contains a wide spectrum of elements essential for growth of plants and soil organisms. The difference between the essential and toxic elements is a confusing topic as most of the elements are associated with vital physiological processes in living beings (Silva et al. 2005). The oxidation states and exceeding concentration govern the toxicity of metals. Hydrological regime (Jardine et al., 2002), precipitation (Teutsch et al., 1999), temperature (Pandey et al., 2014; Iskandar et al., 2001) and geochemical parameters (Grzebisz et al., 2002; Selim et al., 2004) determine the availability of metals and retardation as a function of leaching of metals into deeper soil, ground water aquifer and water bodies (Zhang et al., 2008).

North eastern (NE) India is a highly visited tourism centre with high vulnerability of non-point source pollution, metal accumulation may be one of the major outcomes of such human interventions (Das, 2013; Bhattacharya, 2008). Consequences of metal enrichment are rapidly increasing in most of the NE states in India in recent times (Deka et al., 2012; Chakravarty et al., 2009). The study area, Majuli River Island has a characteristic fluvial geomorphology pertaining to annual

flood and erosion processes. The chief occupation in this area is agriculture which may invite conspicuous metal deposition as a result of crop management practices (Bhaskar et al., 2013). Kaolinite and chlorite are the chief constituents of older alluvium (Singh et al., 2011) indicating a probability of metal enrichment. Secondary sources as sediment transport and anthropogenic activities strongly participate in increasing metal concentration in soil and water leaving a scope for metal pollution (Nath, 2012). Assessment of metal status, pollution indices and potential risk of toxicity was carried out in water and soil samples in Majuli present in both water and soil in Majuli and soil samples in Kamrup (Amingaon and Umananda River Island) in order to evaluate the pollution hazards due to presence of metals.

Trace element accumulation is evident in NE India, apparently maximum in the commercial and industrial areas (Chakravarty et al., 2009). In addition to anthropogenic causes, the parent bed rock material contributes as a primary source of these metals in water and soil, corresponding to the world Argillacean shale. High metal concentration in water used for drinking purpose or household activities like cooking affect the human body by direct exposure to metal hazards. Metal enrichment above permissible limits in soil is detrimental to physiological functions of the soil organisms as well other higher organisms that directly or indirectly derive nutrition from soil. Evaluation of metal pollution indices would enable us to know the status of ecological risk due to presence of metals in concentration exceeding the world average background concentration (Muller, 1969).

Urbanization and human intervention in Brahmaputra River floodplain is increasing at a fast pace, the chances of metal enrichment in soil and water is also

gaining concern. Water is commonly acts as a pollution indicator of trace elements. In association to water properties, sediment can also provide deeper insight into the pollution state of a water body. Sediment has been described as a sink or reservoir of contaminants including trace metals, where they concentrate according to the level of pollution (Becker et al., 2001; Onyari et al., 2003). Assessment of metal status in water and soil is a necessary step to validate water and soil monitoring in an ecologically sensitive zone like Brahmaputra floodplain. Considering the experimental findings, mitigation measures could be adopted to combat the ecological threats provided by the highly concentrated metals in the environment.

Assessment of metal status in water and soil needs concern because concentration of metals above threshold limits proves to be detrimental to plant and animal health. Presence of metals in soil have significant environmental implications that the affect the physiological mechanisms of living organisms. Most of the metals are core structural isomers of enzymes whereas a few metals do have an inhibitory effect on the soil enzymatic activities (Ebregt, 1977). In other words, the inhibitory effects may not be rigorous as the outcomes of enzyme activities are fairly high at a global scale. This fact may be justified by probable occurrence of naturally chelating agents in the soil system that form metal complexes and ligands and hence minimizing the availability of metals to participate in the inhibitory processes. Presence of organic acids, amides and phosphates act as precursors to metal transformations into non-toxic forms (Bohn, 1985). Occurrence of metals in water and soil has synergistic as well as antagonistic effects.

Assessment of metal status and their potential hazardous implications included evaluation of pollution indices according standard methods of analysis recommended by the previously published reports. Single pollution indices included Relative abundance (RA) (Sany et al., 2012), Contamination factor (C_f) (Liu, 2005) and Geoaccumulation index (I_{geo}) (Ghrefat et al., 2011). Integrated pollution indices involved Nemerow's pollution index (NPI) (Qingjie et al., 2008), Pollution load index (PLI) (Bhattacharya et al., 2006; Rabee et al. 2011; Aktaruzzaman et al., 2014), Contamination degree (C_d) (Abrahim et al., 2008), Ecological risk (Amuno, 2013) and Potential ecological risk index (PERI) (Zhu et al., 2012; Hakanson, 1980).

3.2 MATERIALS AND METHODS

3.2.1 Materials

Sample collection included soil and water samples, broadly discussed in Chapter 2, Section 2.2.2 [Table 2.1 (A), (B), (C)]. Metal assessment for ecological risk was carried out in this chapter. Water and soil physicochemical parameters, discussed in Chapter 2 were taken into consideration in this Chapter for correlation studies.

3.2.2 Study area

Majuli River Island is located in the north of Jorhat between 93°30' to 94°35'E longitude and 26°50' to 27°10'N latitude in Assam, North-east India (Figure 2.1, Chapter 2). Majuli lies in the heart of Brahmaputra River on the northern side of Jorhat district. The geographical area of Majuli is 92460 hectares, highly inundated by flood in monsoon season. Majuli is under regular threat of bank erosion in addition to

sediment deposition processes. A total land mass 50 km^2 has been lost in the time period 1969 to 1994 (NBSS and LUP, ICAR, 2006).

The second study area in Kamrup lies between 25°46'0"N to 26°49'0"N latitude and 90°48'0"E to 91°50'0"E longitude. Amingaon is located between 26°11′0.5″N latitude and 91°40′1.2″E longitude on the mainland near the bank of Brahmaputra River in the north of Guwahati. Umananda River Island or Peacock Island is located between 26°11′47.76″N latitude and 91°44′43.44″E longitude on a hilly terrain in the north east of Guwahati separated by the Brahmaputra River (Figure 2.2, Chapter 2). Amingaon is an industrial area whereas Umananda is a highly visited tourism site in Guwahati, Assam, India.

3.2.3 Sample collection

Sampling was carried out in pre-monsoon (April) and monsoon seasons (July) [Table 2.1 (A) (Chapter 2)]. Water samples were collected form 12 wetlands, 2 water bodies, 4 ground water samples and 2 surface water samples (Brahmaputra River at two banks). Samples were further grouped as, a) residential area, b) grassland, b) agricultural field, d) ground water and e) surface water based on land use activities and geomorphic origin. Water samples were collected in clean and sterilized polypropylene containers. Samples for metals analysis were preserved with nitric acid (pH 2).

12 soil samples were collected from the water sampling sites including 2 bank sediments [Table 2.1 (B) (Chapter 2)]. Soil samples were collected in clean and sterilized samples containers. Wetland soil samples were collected at 5 depths i.e. from

surface to 100 cm excluding the bank sediments. Soil samples were also grouped as a) residential areas, b) grasslands and c) agricultural fields and d) river banks based on landuse activities and geomorphic origin.

In case of Amingaon and Umananda, soil samples were collected from selective sites in Amingaon and Umananda River Island [Table 2.1 (C) (Chapter 2)]. Based on litter decomposition, land use activities and natural geomorphology, sampling sites were subdivided into a) disturbed (low litter decomposition) and b) undisturbed (high litter decomposition) and c) river bank sediments. Soil samples were air dried and sieved. Clean and sterilized samples containers were used to collect soil samples.

3.2.4 Sample preparation and analysis

The metals are analysed in this study are total Fe, Cu, Mn, Zn, Cd, Cr, Ni and Pb. Metal estimation was performed according to standard operating procedures (ASTM and APHA). Soil digestion for analysis of trace elements was performed with aqua regia (ASTM D3974, 2003). Trace elements were analyzed in flame photometer and metals were estimated in Atomic Absorption Spectrophotometer (AAS, Make: Varian) with standard reference material for each element.

3.2.5 Energy Dispersive X-ray (EDX) spectroscopy

Soil samples were vacuum dried, sputter coated with Au-Pd layer and mounted on stubs with conductive carbon tape. The samples were observed under Scanning Electron Microscope (SEM) (Make: LEO, Model: 1430 vp) and checked for elemental composition (trace elements) under EDX spectroscopy.

3.2.6 Calculation of pollution indices

Experimental analyses of water and soil samples provided the metal concentration for calculation of metal pollution indices. The calculations for pollution indices are described below:

3.2.6.1 Relative abundance

Relative abundance (RA) of metals in a place depends on biological and geological media such as igneous rocks, soils, fresh or marine water, land animals and land plants (Li et al., 2012). RA is intended to provide information about the background concentration of metals in a place. RA is estimated according to the method suggested by Sany et al., 2012. It is calculated as:

$$RA = \frac{Elements\ with\ high\ mean\ concentration}{Mean\ concentration\ of\ other\ elements}$$

This equation holds the largest value of relative abundance, omitted for every element in different media and the sum of these relative numbers has been estimated and divided into the lowest mean value of relative abundance.

3.2.6.2 Contamination Factor

Contamination factor (C_f) is the ratio obtained by dividing the mean concentration of each metal in soil by the baseline metal concentration or background metal concentration (Liu, 2005). It is calculated as:

$$C_f = \frac{C_n}{B_n}$$

Where, C_n is the concentration of metals in the sample and B_n is the world average background metal concentration (Martin et al., 1979).

Since there was no record of background metal concentration (B_n) in the study area, the B_n values given by Martin et al (1979) were adopted for the study. This data has been previously used in a similar analysis in Dikrong River sediment, Assam by Chakravarty et al (2009).

3.2.6.3 Pollution Load Index

The Pollution Load Index (PLI) is obtained collectively contamination factor (C_f) (Rabee et al. 2011). PLI is estimated by obtaining the n-root from the n – C_f of all metals analyzed. It is calculated as:

$$PLI = [C_{f1} \times C_{f2} \times C_{f3} \times \ldots\ldots C_{fn}]^{1/n}$$

Where C_f is the contamination factor

PLI provides comparative means for assessing a site quality, where a value of PLI < 1 denote perfection; PLI= 1 present that only baseline levels of pollutants are present and PLI >1 indicates deterioration of site quality (Aktaruzzaman et al., 2014) (Table A 3.1, Appendix 3).

3.2.6.4 Geoaccumulation Index

Geoaccumulation index (I_{geo}) is an important index in geochemistry for determining the extent of metal accumulation in sediments. It was introduced by introduced by Muller (1969) and divided into seven grades for deciding the extent of accumulation of metals in a particular area (Table A 3.1, Appendix). It is calculated as:

$$I_{geo} = log_2[\frac{C_n}{1.5 \times B_n}]$$

Where C_n is the concentration of metal in the samples and B_n is the background metal concentration like C_f, the B_n values were adopted from Martin et al (1979). According to Stoffers et al (1986), the factor 1.5 is introduce to minimise the effect of possible variations in the background values which may be attributed to lithologic variations in the sediments.

3.2.6.5 Contamination Degree

Contamination degree (C_d) provides an overall average value for a range of pollutants or metals in an area (Abrahim et al., 2008). Like I_{geo} and PLI, C_d has seven classified grades to measure the extent of contamination (Table A 3.1, Appendix 3). It is calculated as:

$$C_d = \frac{\sum C_f}{n}$$

Where C_d is the summation of C_f is single pollution index of an individual element.

3.2.6.6 Nemerow's Pollution Index

Nemerow's Pollution Index (NPI) is used to assess the quality of water and soil environment widely (Cheng et al., 2007). In case of soil, quality of soil environment is classified into fives grades from Nemerow pollution index (Table A 3.1 Appendix 3). NPI is calculated as:

$$NPI = \frac{\sqrt{1/m \sum (C_f)^2 + (C_{max})^2}}{2}$$

Where C_f is a single pollution index and C_{max} is the standard value of parameters in case of water and maximum value of single pollution indices of all the metals analyzed in soil.

3.2.6.7. Ecological risk and Potential Ecological Risk Index

Ecological risk (ER) is intended to provide an empirical basis for understanding the ecological risks associated with heavy metal concentration in soils (Amuno, 2013). ER is obtained the by multiplying C_f by their respective corresponding toxic response factors given by Hakanson (1980). ER has five grades of risk assessment (Table A 3.1 Appendix 3). Potential Ecological Risk Index (PERI) is the summation of ER obtained (Zhu et al., 2012). Like ER, PERI include four grades of ecological risk assessment developed by Hakanson (1980) (Table A 3.1 Appendix 3). ER and PERI are calculated as:

$$ER = T_r \, x \, C_f$$
$$PERI = \sum ER$$

Where T_r is the toxic response factor, the standard values of T_r has been recommended by Hakanson (1980) as Zn=1, Cu=5, Cr=5, Cd=30, Ni=5, Pb=5. C_f is the contamination factor.

3.2.7 Statistical analyses

Statistical analyses included correlation studies and Principal Component Analysis (PCA). Analytical results were linked to each other and most the physicochemical and geochemical parameters were correlated by Karl Pearson correlation matrix. Statistical analyses of a few significant metals are broadly demonstrated in Chapter 4. All analyses were performed in IBM SPSS 20 software.

3.3 RESULTS AND DISCUSSIONS

Physicochemical of water and soil samples have been discussed thoroughly in Chapter 2. For analytical review and correlation studies some of these parameters were taken into consideration.

3.3.1 Metal status in Majuli and Kamrup (Amingaon and Umananda)

From metal estimation results, it was evident that total Fe (in all sites), Cu (few sites) and Pb (few sites) concentration have highly enriched in water samples in Majuli (Table A 3.2, Appendix 3). Water samples in Majuli showed minimal values within the permissible limits except total Fe (Table A 3.1, Appendix 3). Since background concentration for metals in the study area is not available, world average rock background concentration was adopted to deride a comparative assessment of metals in soil (Chakravarty et al., 2009; Thomas et al., 1996). The world average background concentrations were detailed in Table 3.2.

Table 3.1 *Permissible limits of metals in drinking water quality assessment given by several organizations*

Parameters (mg/L)	USEPA	WHO	ISI	ICMR	CPCB
Iron	-	0.1	0.3	1.0	1.0
Copper	1.3	1.0	0.05	1.5	1.5
Manganese	-	0.4	0.1	-	-
Zinc	-	-	5	-	-
Lead	-	0.05	1.0	0.05	No relaxation

(Source: Kumar et al., 2012)

Table 3.2 *World average background concentrations for metals in soil*

Parameters	World surface rock average concentration (mg/L)
Iron	3.59
Zinc	129
Copper	32
Manganese	720
Cadmium	0.02
Chromium	97
Nickel	49
Lead	20

(Source: Chakravarty et al., 2009; Martin et al. 1979; Thomas et al.,1996)

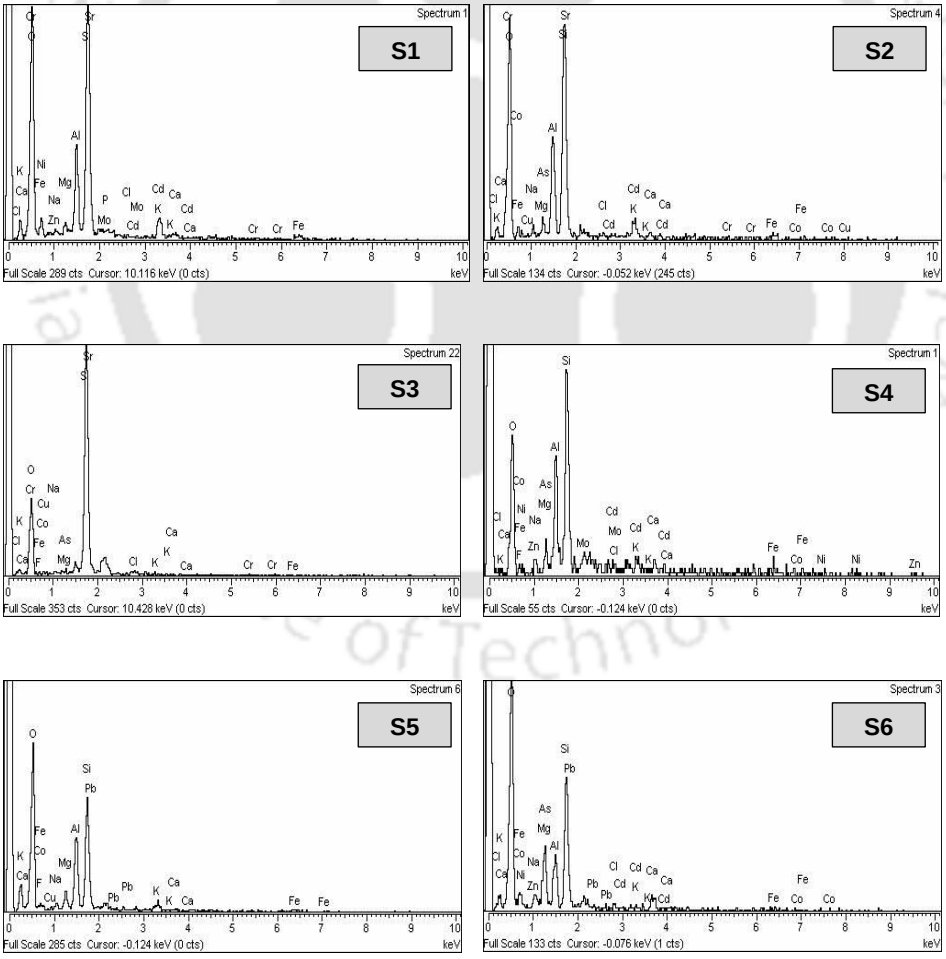
Metal concentration were exceedingly high for total Fe, Cu and Cd in soil samples in Majuli and Fe, Cu, Cd and Zn (in a few places) in soils of Kamrup (Figure 3.4 – 3.11). The presence of elements was further confirmed by EDX analysis (Figure 3.1 – 3.3). In Majuli total Fe was in the range of 3150.75 – 21148.02 mg/kg soil in pre-

monsoon and 4540.65 – 23912.31 mg/kg soil in monsoon season. Cu was in the range of 19.29 – 197.39 mg/kg soil in pre-monsoon season and 46.21 – 221.13 mg/kg soil in monsoon season. Cd was in the range of 0.03 – 0.20 mg/kg soil in pre-monsoon season and 0.02 – 0.18 mg/kg soil in monsoon season EDX analysis reported almost all the elements obtained by atomic absorption method except absence of Mn and Pb in a few samples [Figure 3.1 (S1 – Nim Bank); 3.2 (A1 – AB2); 3.3 (U1 – K Bank)].

In Kamrup, overall metal concentration estimated in Amingaon and Umananda was taken into consideration, total Fe was in the range of 1440.59 – 28157.78 mg/kg soil in pre-monsoon season and 1708.81 – 24261.75 mg/kg soil in monsoon season. Cu was in the range of 44.52 – 315.77 mg/kg soil in pre-monsoon season and 47.47 – 181.51 mg/kg soil in monsoon season. Cd was ranged from 0.30 – 0.61 mg/kg soil in pre-monsoon season and 0.27 – 0.67 mg/kg soil in monsoon season. Finally Zn ranged from 51.46 – 608.65 mg/kg soil in pre-monsoon season 49.57 – 577.20 67 mg/kg soil in monsoon season (Figure 3.4 – 3.11).

Pb was present in a few samples in Majuli but prominent in Amingaon and Umananda, however the Pb concentration in Majuli was higher than Amingaon and Umananda. Rest of the elements like Cu, Zn, Mn, Cd, Cr and Ni were higher in Amingaon and Umananda. Total Fe concentration was highest in Majuli followed by Amingaon and Umananda. In Majuli metals were concentrated in Group C followed by Group B, Group A and Group D. Ni was higher in Group D (bank sediments). In Umananda most the metals were concentrated in Group A (disturbed areas) as well as Group B (undisturbed areas) with least concentration in Group C (bank sediments).

Additionally, EDX spectra revealed presence of As in soil samples from Majuli and Kamrup (Amingaon and Umananda) and Hg in soil samples from Kamrup (Amingaon and Umananda) and bank sediments from Majuli. As was evident in Figure 3.1 (S2, S3, S4, S6, S8, S10, S11, S12, Kmb Bank and Nim Bank); Figure 3.2 (A2, A5, A6, A7, A9, A10, AB1 and AB2) and Figure 3.3 (U1, U6, U7, U9, U10 and U Bank). Hg was detected in Figure 3.1 (Kmb Bank and Nim Bank); Figure 3.2 (A4, A7, A8, A9, and AB2) and Figure 3.2 (U1, U3, U4, U5 and U6)



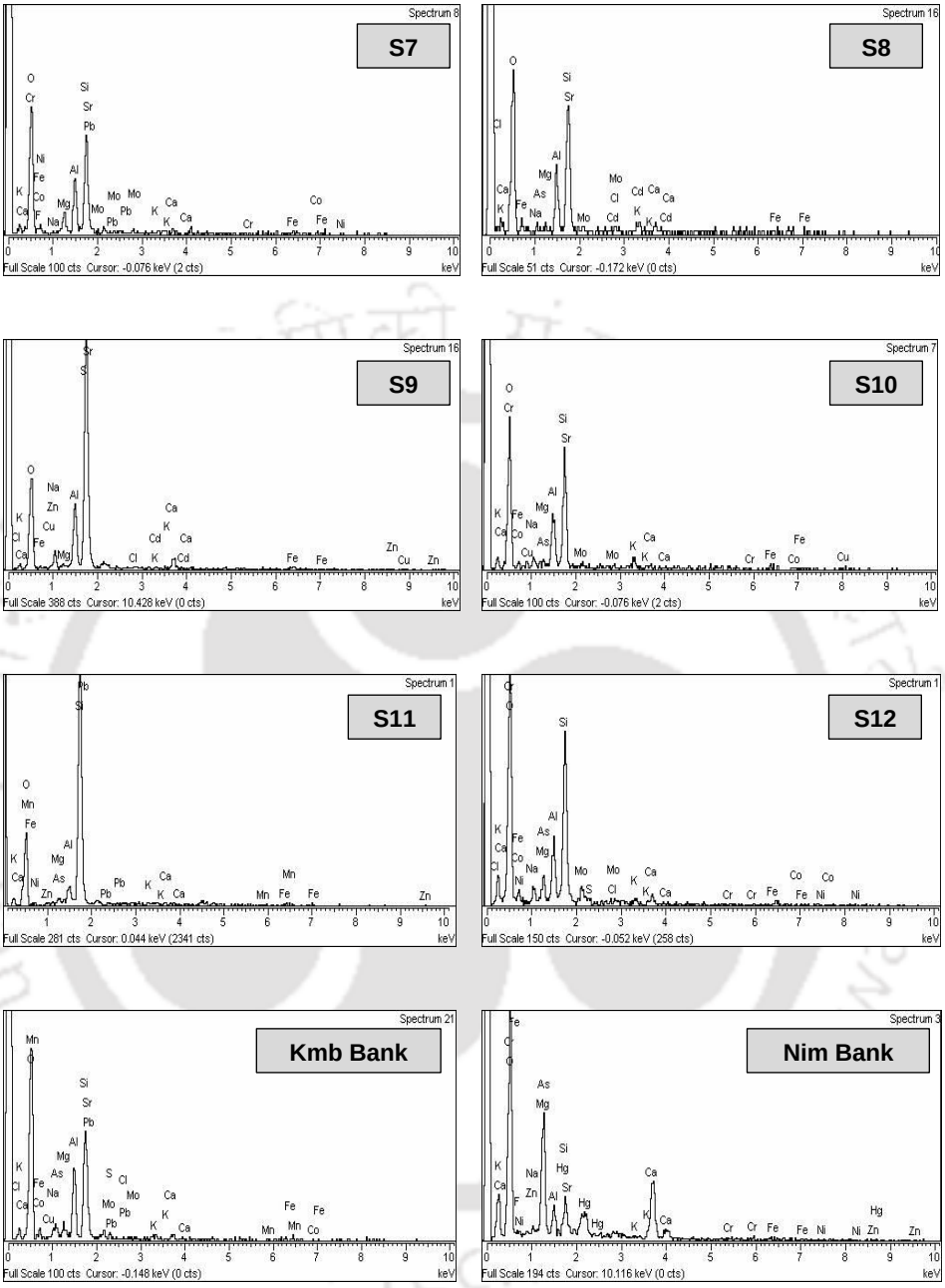
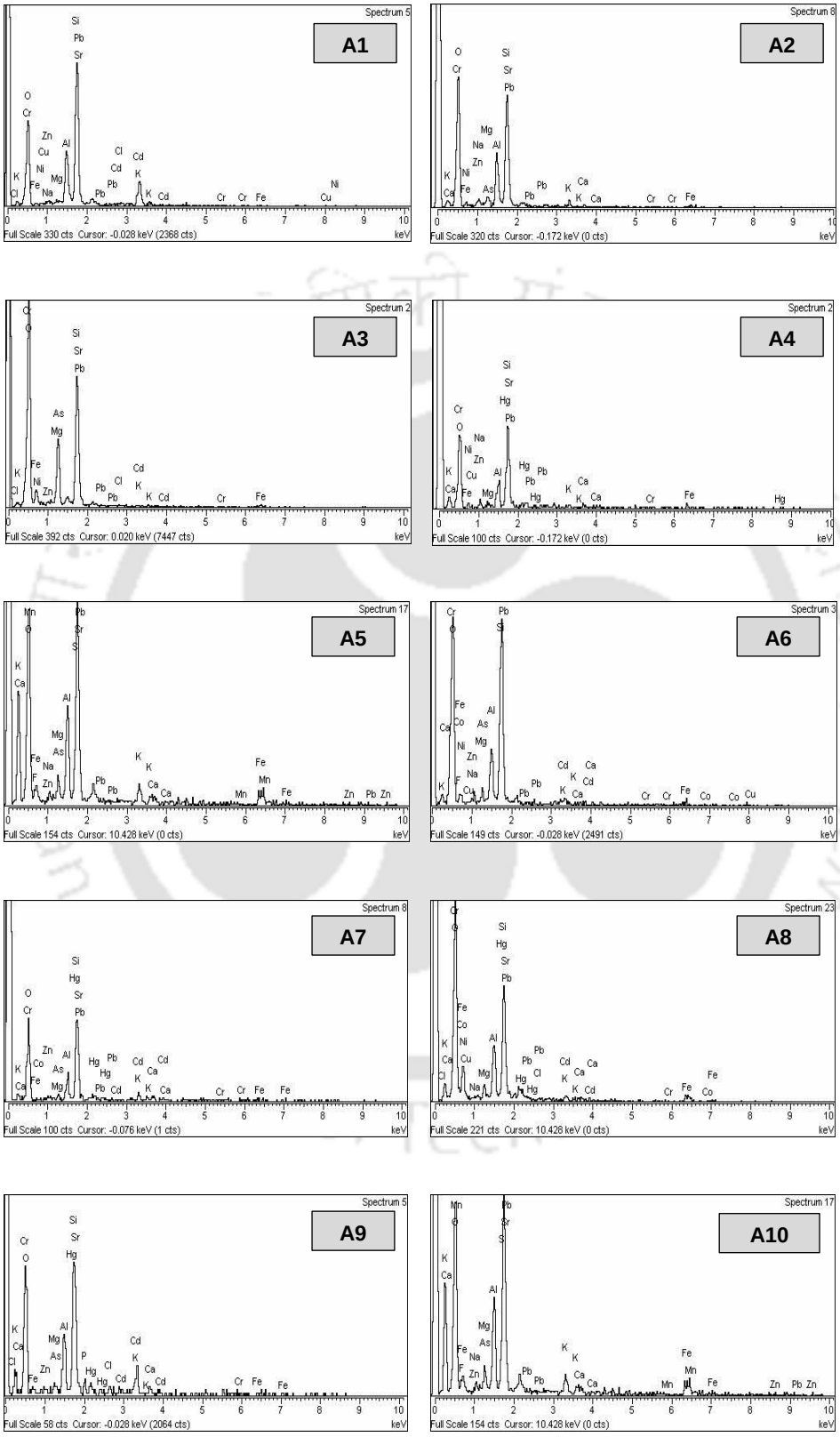


Figure 3.1 (S1 – S10) *EDAX profile of soil samples in Majuli, in pre-monsoon season at a depth of 0 – 20 cm*



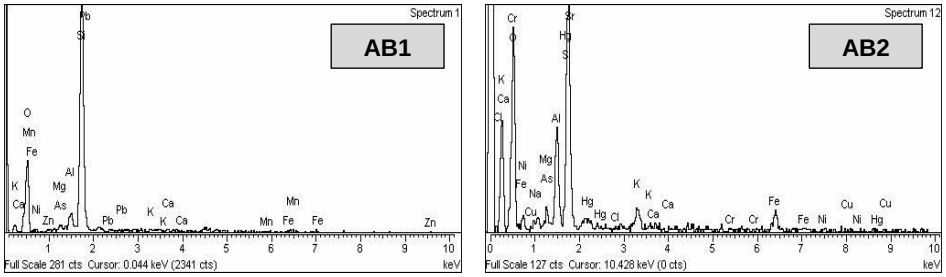
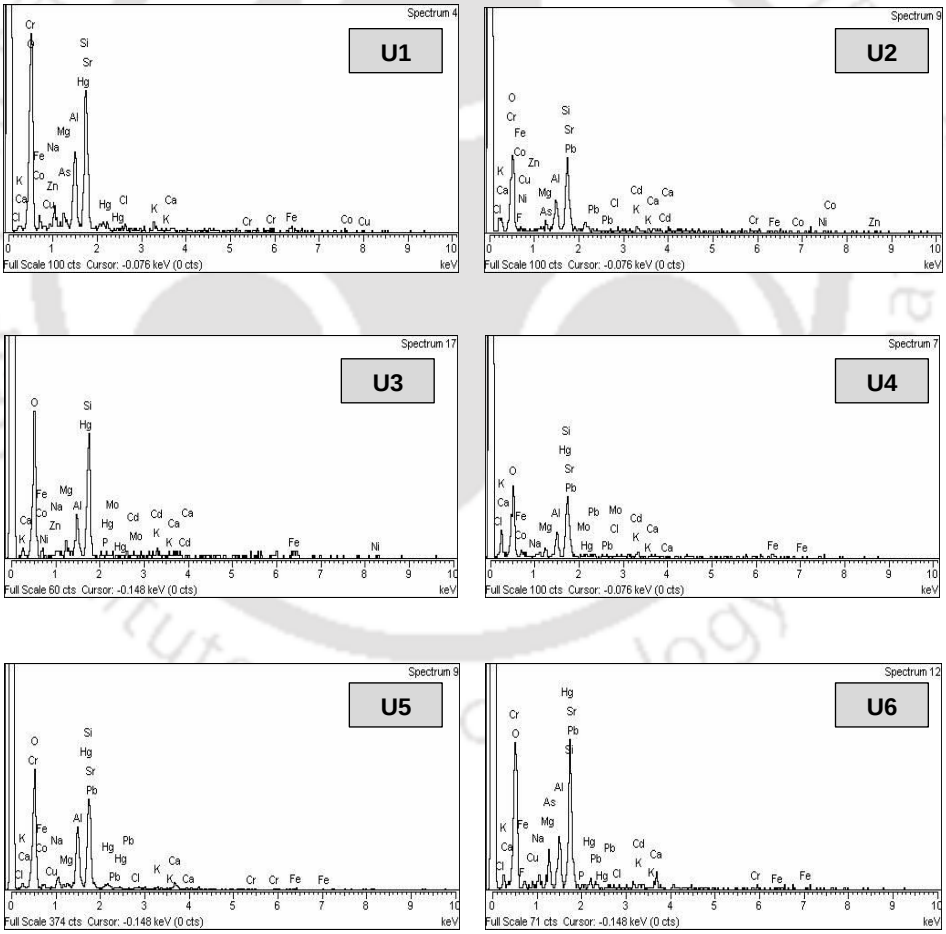


Figure 3.2 (A1 – AB2) *EDAX profile of soil samples in Amingaon, in pre-monsoon season, at a depth of 0 – 20 cm*



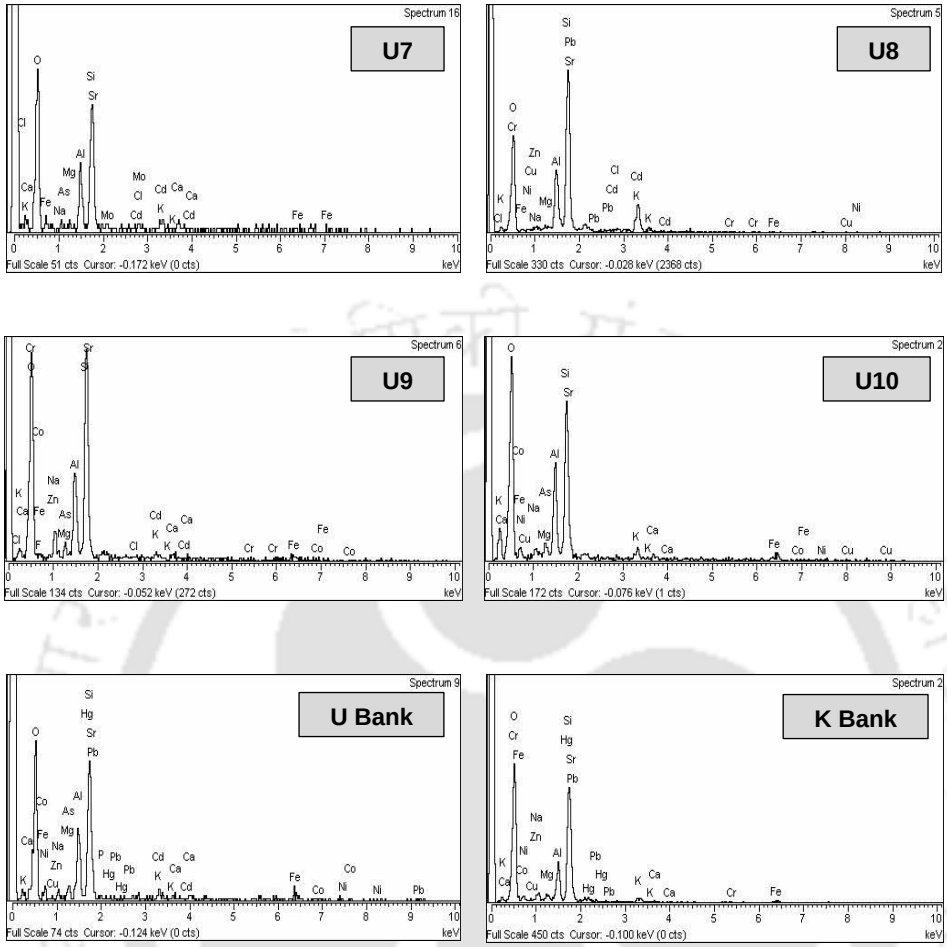
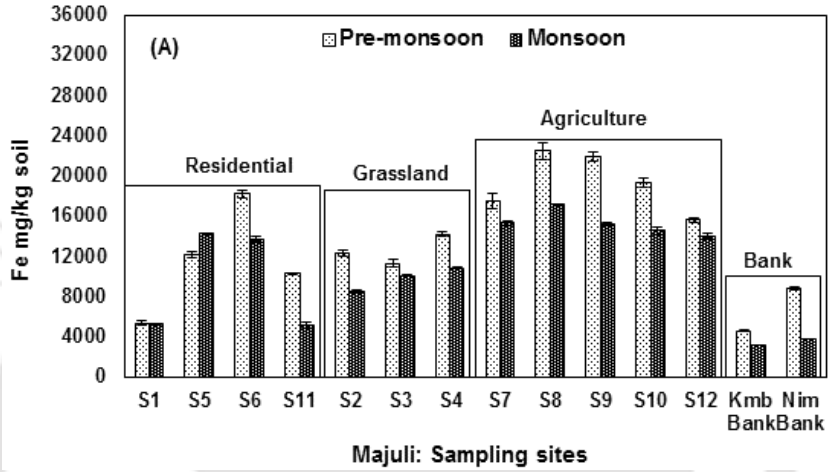
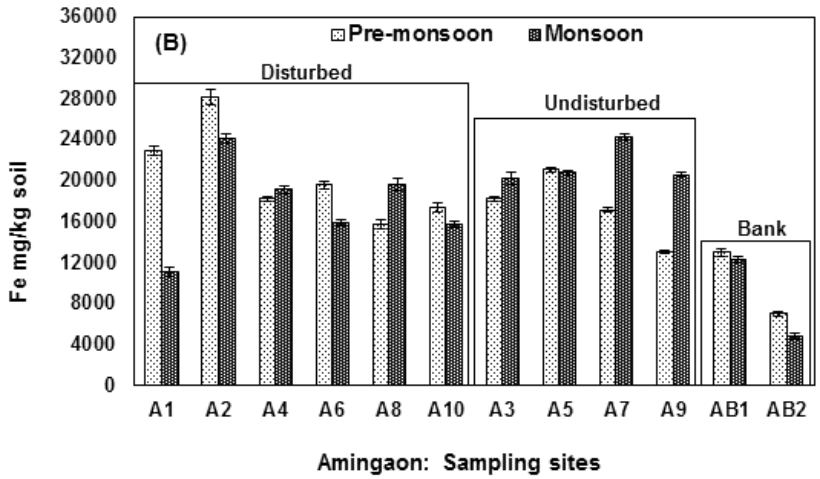


Figure 3.3 (U1 – K Bank) *EDAX profile of soil samples in Amingaon, in pre-monsoon season at a depth of 0 – 20 cm*

Most of the elements investigated in the study areas derive their origin from the type of shale, mineral composition and partially from the river transported sediments in the area. The Brahmaputra valley has a parent bedrock composition of Tertiary, Mesozoic and Archaean origin which has been gradually covered by newer alluvium in continuous deposition processes (DWRDM, IIT Roorkee, 2012). The occurrence of

trace elements in Majuli and Kamrup depends on the prevalent shale accompanying additional subordinate sources.





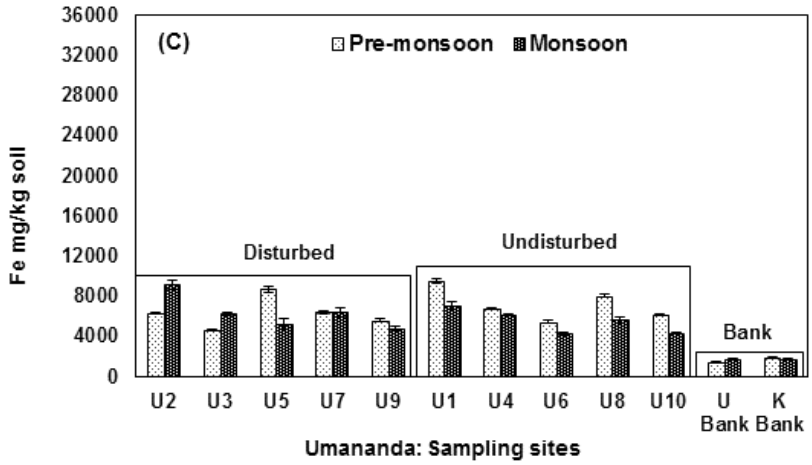
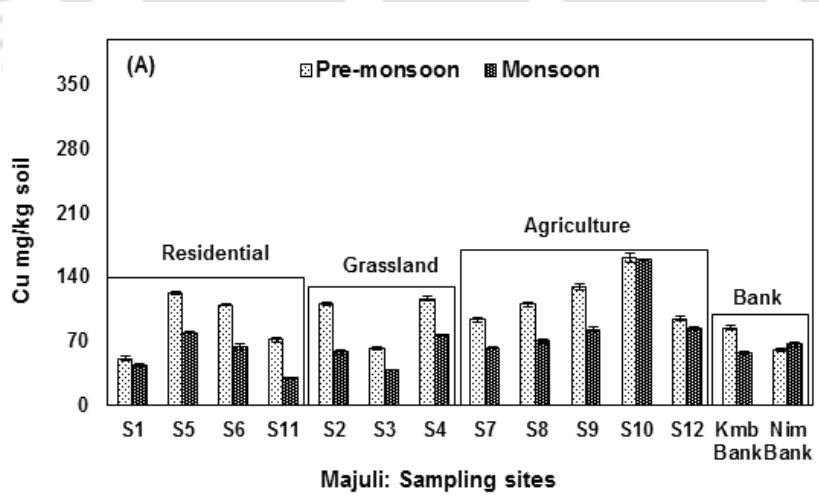


Figure 3.4 *Location wise concentration of total Fe in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*



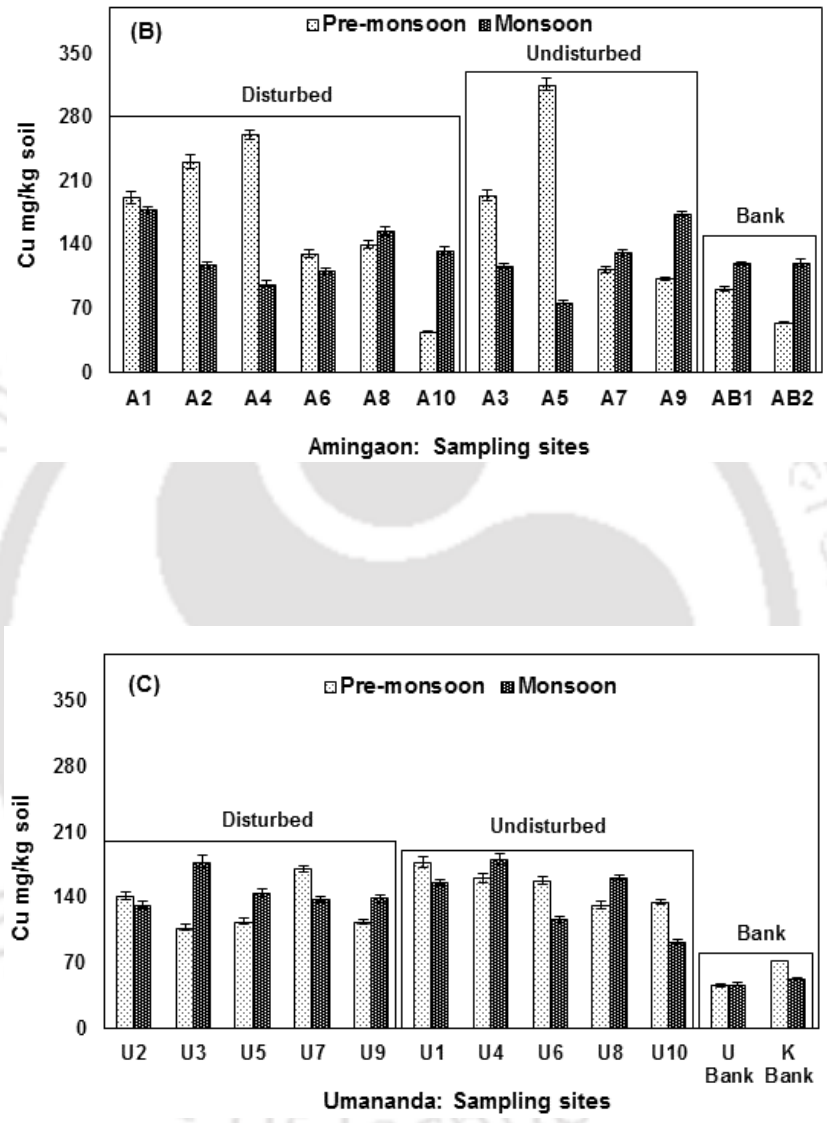
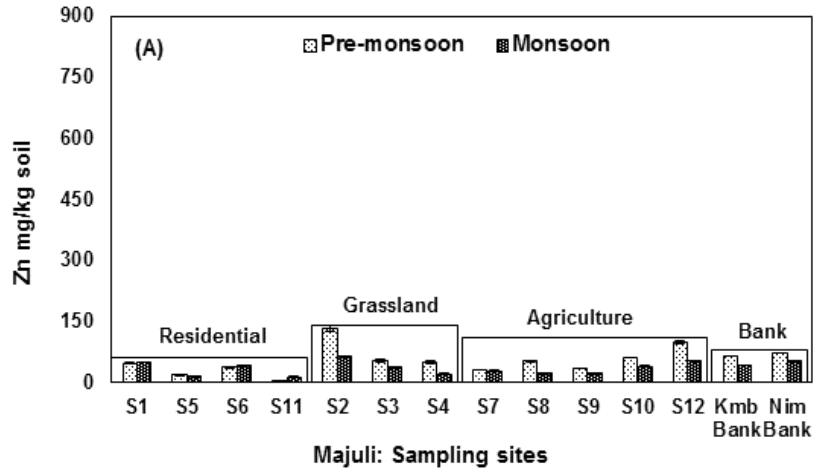
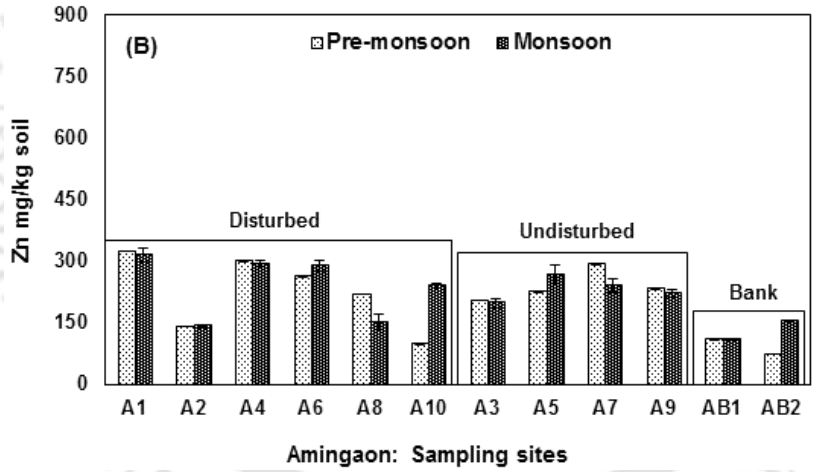


Figure 3.5 *Location wise concentration of Cu in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*





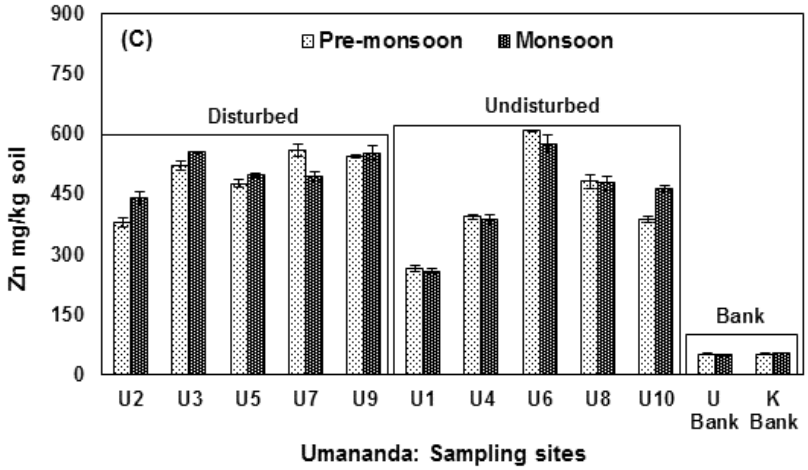
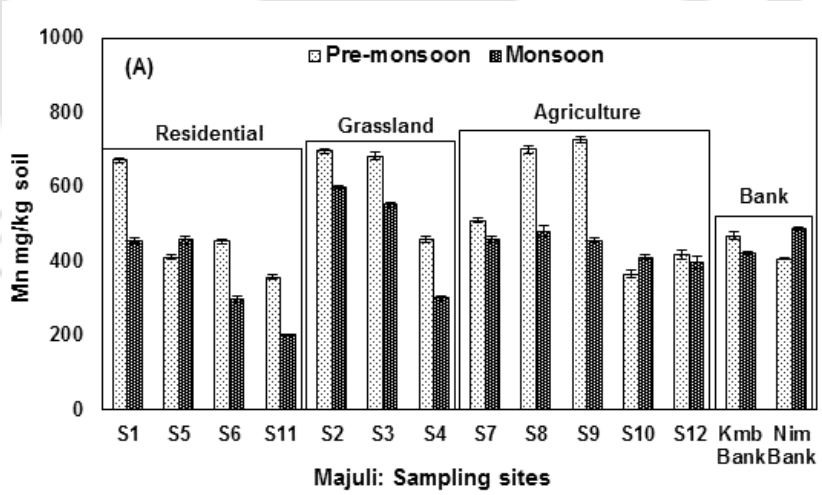


Figure 3.6 *Location wise concentration of Zn in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*



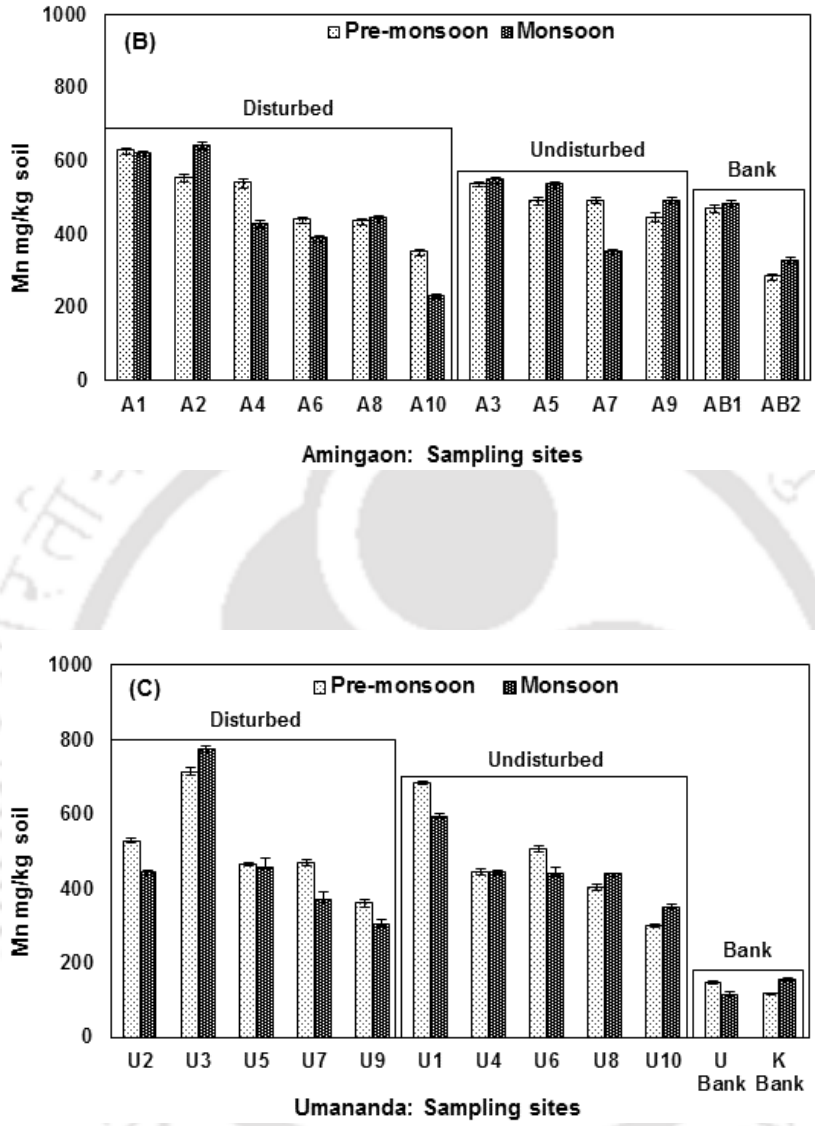
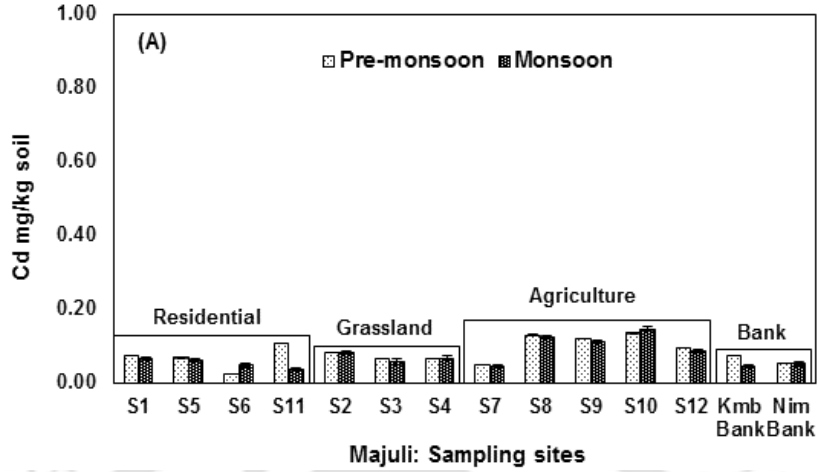
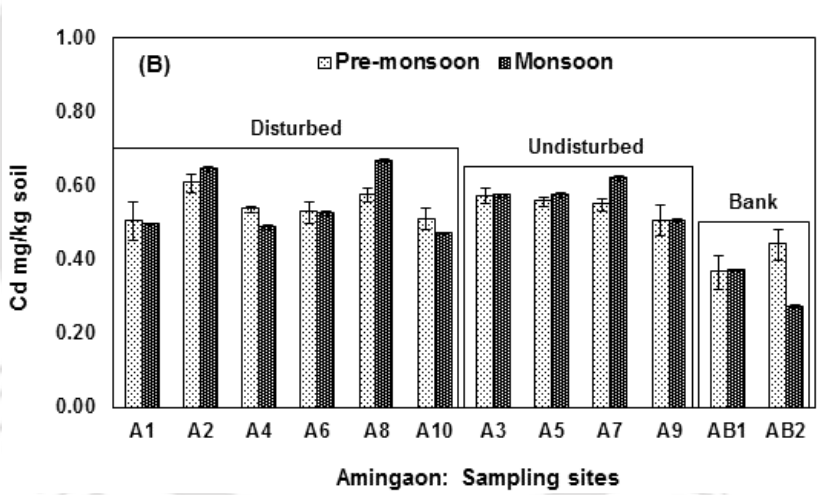


Figure 3.7 *Location wise concentration of Mn in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*





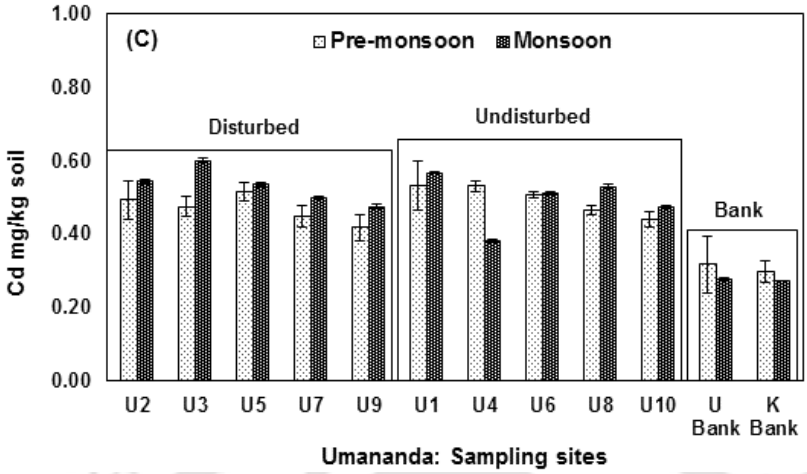
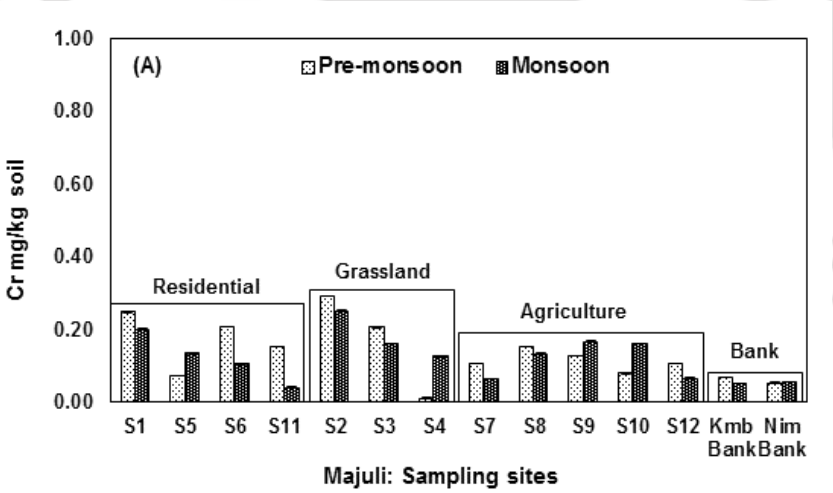


Figure 3.8 *Location wise concentration of Cd in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*



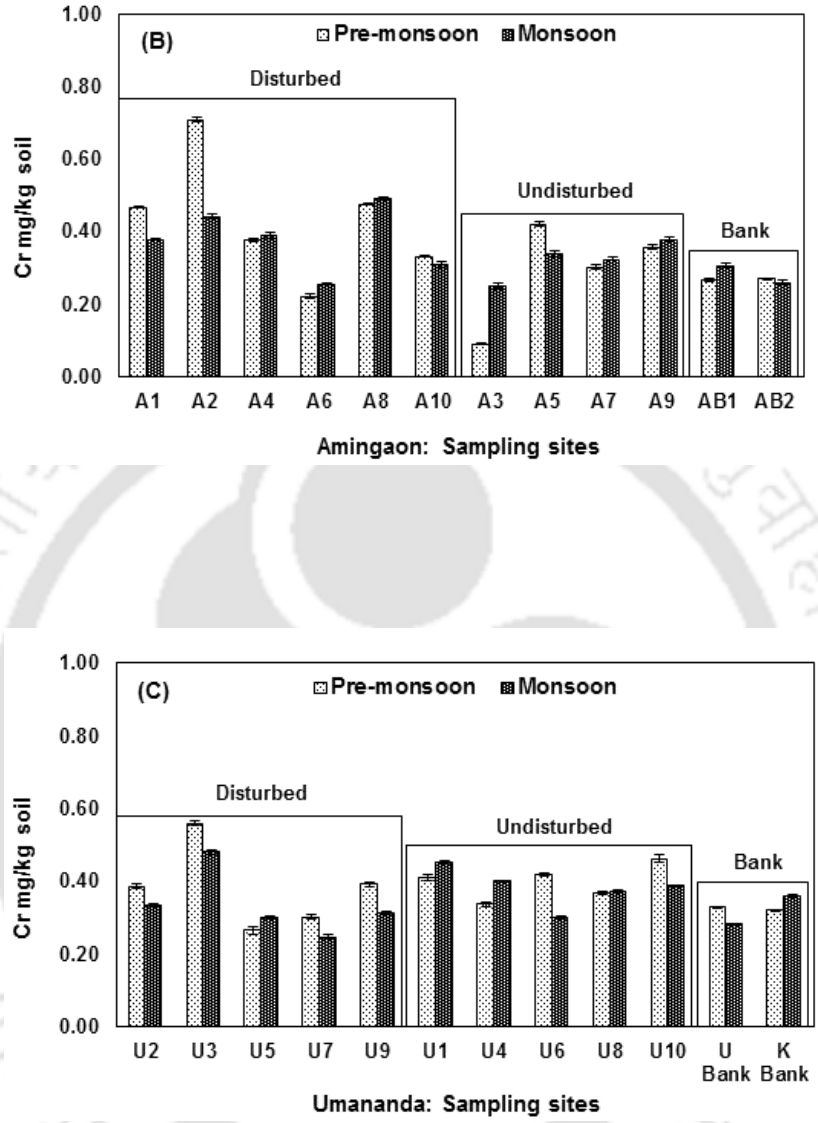
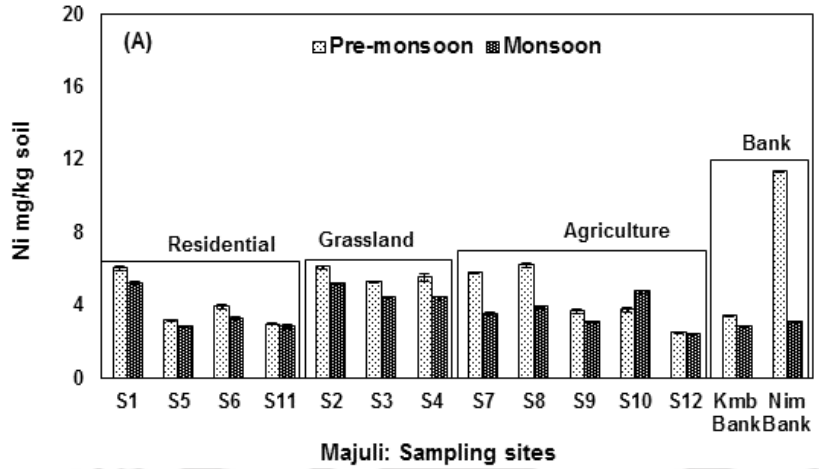
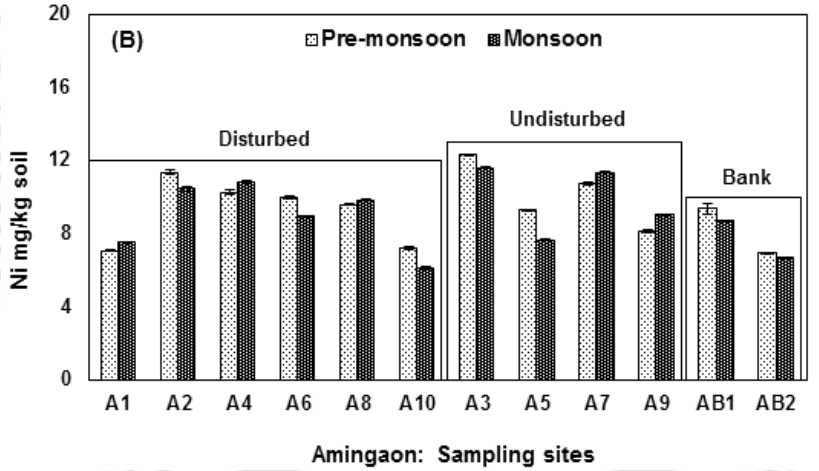


Figure 3.9 *Location wise concentration of Cr in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*





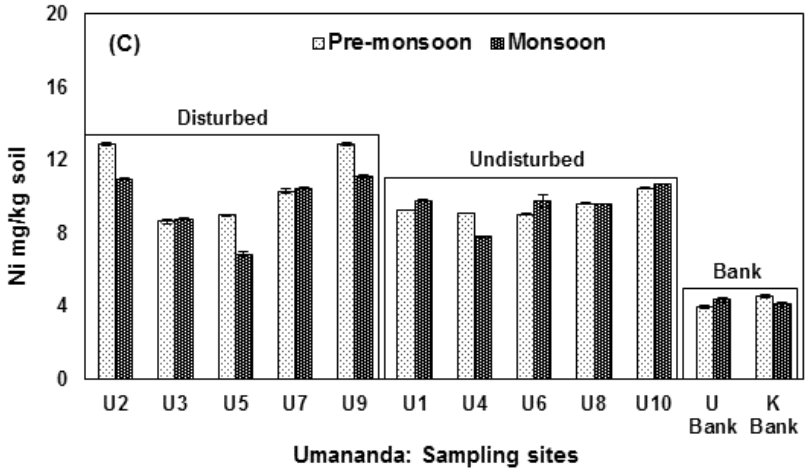
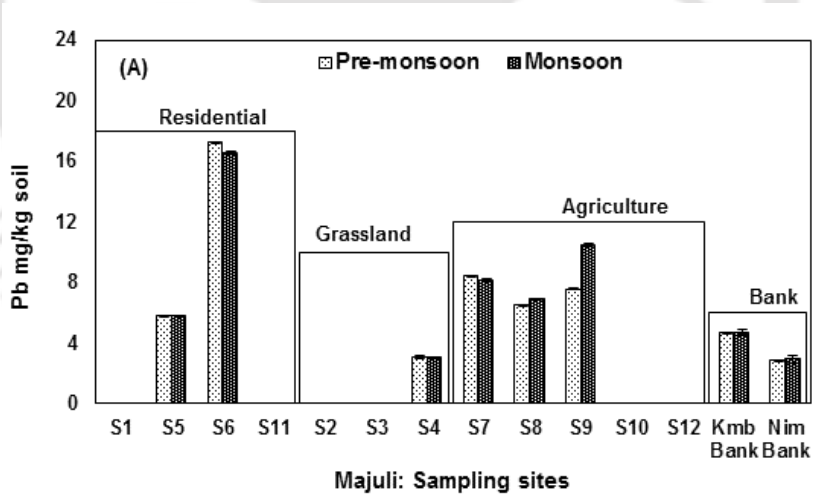


Figure 3.10 *Location wise concentration of Ni in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*



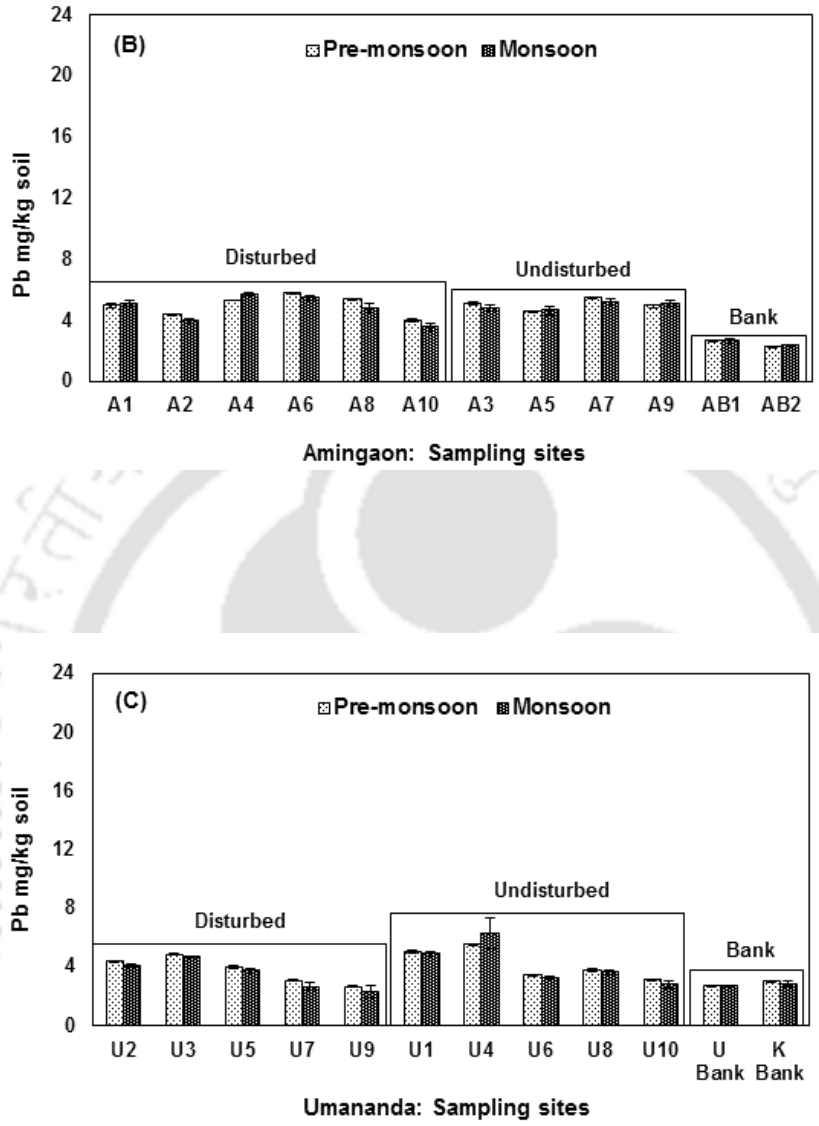


Figure 3.11 *Location wise concentration of Pb in* ***(A)*** *Majuli,* ***(B)*** *Amingaon and* ***(C)*** *Umananda in pre-monsoon and monsoon season, at a depth of 0 – 20 cm*

Weathering of rocks may release the inorganic elements or they may be introduced into the environment by human activities. Of the 45 inorganic elements analyzed, 41 were present in concentration greater than the analytical detection limit

(Breault et al., 1997). Most of these elements are essential for the growth and development of organisms. Among the naturally occurring metals that exist in high concentrations in Majuli are As, Fe and Mn (Bhaskar et al., 2013). The root causes or origin of these metals can be traced back to the geological past. The geomorphology of Majuli indicates a strong involvement of parent shale and sediment transport activities (NBSS and LUP, ICAR, 2006; Sarma, 1998; Kotoky et al., 2003; Mani et al., 2003; Singh, 2011). Higher concentration of trace elements may also be linked to secondary sources like land use activities, tourism activities and urbanization (Barman et al, 2013). Sediments in Majuli River Island are differentiated into fine sand, silt and clay with mineral composition like tourmaline, rutile, zircon, epidote, kyanite, silimanite, staurolite, micas (biotite and chlorite), hornblende, zoisite and opaque minerals and clay content containing mineral as illite, kaolinite and chlorite (Singh, 2011). Mineral composition indicates natural enrichment of elements like Al, Si, Fe, Zr, and Ti.

3.3.2 Pollution indices for metals in Majuli and Kamrup (Amingaon and Umananda)

The major concern for metal assessment was to evaluate ecological risk assessment due occurrence of metals in the study area. The synergistic effect of metals on soil biological properties and its linkage to soil properties provide a scope of understanding the underlying mechanisms. Pollution indices calculated were collectively similar in Amingaon and Umananda in both seasons with a remarkable deviation from Majuli samples. In case of water samples in Majuli, integrated pollution index, NPI was

evaluated whereas in soil samples both single pollution as well as integrated pollution indices were obtained respectively.

3.3.2.1 Single pollution indices

In Majuli, highest RA was observed for Fe followed by Mn, Cu and Zn in pre-monsoon as well as monsoon season in soil samples. The sequence of occurrence of metals is described in Table A 3.3, Appendix 3. It was observed that in each season, abundance of Pb was absent in a few samples in Group A, B and C but significant in Group E (bank sediments). Cr, Mn, Ni and Pb abundance was prominent in Group E. In Amingaon and Umananda, RA of metals was highest for total Fe/Fe followed by Cu, Zn, Mn, Pb, Ni, Cr and Cd in all the places. The sequence of abundance of metals in Kamrup was conspicuous for all groups, highest in Group A (disturbed) and lowest in Group C (bank sediments). The trend of RA in the Amingaon and Umananda was similar to the trend in Majuli except occurrence of Pb.

In Majuli, high C_f was observed for Fe in all samples followed by Cu, Mn, Zn in few of the samples (Table A.3.4, Appendix 3). Contamination factors of Cd, Cr, Ni and Pb were variable according to the concentrations present in soil samples in either season. In Amingaon and Umananda, C_f was highest for Cd, Zn, Mn, Pb, Ni and Cr as compared to the world average back ground metal concentration in soil and sediment (Table A 3.5, Appendix 3).

I_{geo} in Majuli was negative for all metals analyzed Fe and Cu. According to Muller's assessment and indexing of I_{geo}, Fe showed extremely contaminated levels

(Class 6) where Cu showed uncontaminated to moderately contaminated (Class 0–2) in soil samples in both the seasons (Table A 3.1, Appendix 3) (Müller 1969). In Amingaon and Umananda, I_{geo} showed similar trend with highest accumulation case for Fe followed by Cu, Cd and Zn, the trend of metal accumulation was identical for all the sampling sites.

3.3.2.2 Integrated pollution indices

PLI was in the range of 0.17 to 0.32 (both in Group C) in pre-monsoon and 0.24 (Group C) to 0.95 (Group A) in monsoon season. Overall highest PLI was observed in a range lower than 1 indicating no threat to pollution in Majuli River Island (Aktaruzzaman et al. 2014) (Table A 3.8, Appendix 3). Like Majuli, soils in Amingaon and Umananda witnessed PLI was less than 1 (Table A 3.9, Appendix 3).

C_d was lower than 1.5 in all the sampling sites in both pre-monsoon and monsoon season suggesting lower risk of pollution due to metal concentration in soil samples in Majuli (Abrahim et al., 2008) (Table A 3.8, Appendix 3). Individual concentration of Fe, Cd and Cu contributed to raised levels C_d in Majuli soils was S10 (Group C) in pre-monsoon and in S12 (Group C) monsoon (Table 3). In Amingaon and Umananda, C_d in general was observed in the range of low degree of contamination to moderate degree of contamination (Abrahim et al, 2008) in all the sampling sites, almost alike for both the seasons (Table A 3.9, Appendix 3). Thus the extent of metal contamination in Amingaon and Umananda was more prominent than Majuli.

In Majuli, NPI in water samples showed high risk of pollution due to elevated levels of turbidity in S9 (Group A) and S2 (Group B) (Table A 3.10, Appendix 3). Soil samples sampling sites were under slightly polluted domain in a few samples and seriously polluted domain in S10 (Group C) due to occurrence of relatively higher levels of Cd (Table A 3.8, Appendix 3). In Amingaon and Umananda, NPI identified the sampling sites as slightly polluted domain to seriously domain in both the seasons. The higher values of NPI are attributed to high concentration of Cu and Cd as compared to the world average background metal concentration (Table A 3.9, Appendix 3).

ER and PERI analyses revealed that Majuli soils are under low threat to pollution (Table 3.6, A 3.8, Appendix 3). However the values for ER and PERI were higher in monsoon season (Table A 3.8, Appendix 3). Observations were similar in Amingaon and Umananda, overall ER and PERI due to metals present was within low risk i.e. ER<40 and PERI<140 in each season (Table A 3.9, A 3.9, Appendix 3).

The abundance of elements corresponds to the parent rock material as there is no primary evidence of point source pollution increasing concentration of Fe, Cu and Mn in Majuli. Cd and Pb are related to agricultural and land use activities. Single pollution indices were remarkable in samples collected from agricultural fields followed by bank sediments, residential areas and grasslands. In case level of water samples in Majuli, maximum turbidity in a particular wetland (S9 and S2) contributed to the overall increment of NPI (Table A 3.10, Appendix 3). Results were similar in Kamrup, due to occurrence of three groupings in Kamrup, the trend was not as significant as in case of Majuli. The only noteworthy difference was that Group A and

Group B have higher level of pollution indices than Group C. Metals analysed i.e. Fe, Cu, Zn, Mn, Cd, Cr, Ni and Pb were conspicuous in Amingaon and Umananda (Figure 3.4 – 3.11). High concentration of Cu and Cd as compared to the world average background metal concentration triggered elevated ranks of PLI, Cd and NPI. The geographical terrain, parent lithogenic composition, industrialization, tourism and huge human intervention are assumed to be the root causes of metal enrichment in Amingaon and Umananda soils.

3.3.5 Correlation studies

Correlation studies were performed to check the existence of correlation between the metals and soil parameters. Correlation matrix in case of water samples in Majuli showed that in pre-monsoon as well as monsoon season, Fe was positively correlated to Cu only and Cu was positively correlated to Zn only (Table 3.3). The correlation may have insignificant rationalization except that their co-existence is evidenced in the natural or artificially introduced forms. In soil samples correlation strategies were similar in both the study areas. The correlation between metals was equally significant in Majuli and Kamrup (Amingaon and Umananda). An example of such significant correlation is presented in Table A 3.11, Appendix 3. In Majuli, excluding Fe and Zn; Fe and Cr; Ni and Fe; Mn and Cu; Cr and Cu; Pb and Cu; Mn and Zn; Pb and Zn; Cr and Pb; Mn and Cd; Cd and Ni; and Cd and Pb, rest of the metals of the combinations were positively associated. In Kamrup samples, i.e. Amingaon and Umananda, all metals were positively correlated except Fe and Zn.

The coexistence of metals and SOM and their influence on soil biological properties has been extensively reported. SOM helps in transformation of metal species from one form to another (Bohn, 2008). Metal have strong affinities towards minerals present in soil as well (Fijalkowski, 2012; Dube, 2001) (Table A 3.11, Appendix 3). The nature of soil (sandy clay loam) in the study area provides a suitable platform for metal enrichment and simultaneous involvement in soil physiological processes. Moderately high concentration of metals specified a strong collaboration of the metal species with soil biological parameters.

Table 3.3 *Correlation between metals in water samples in Majuli in pre-monsoon and monsoon season*

Parameters	Season	Fe	Cu	Zn	Mn	Pb
Fe	PM	+	+	-	-	-
	M	+	+	-	-	-
Cu	PM	+	+	-	-	+
	M	+	+	(+)*	-	-
Zn	PM	-	-	+	-	-
	M	-	(+)*	+	+	-
Mn	PM	-	-	-	+	-
	M	-	-	+	+	-
Pb	PM	-	+	-	-	+
	M	-	-	-	-	+

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

These biogenic metal interactions in soil is triggered by the organic acids and intermediate products obtained from soil enzymatic activities (both intracellular and

extracellular) (Appendix 2). As such microbial populations, MB and soil enzymes act as indicators of excessive metal concentration in the soil (Hargreaves, 2003). Naturally occurring bioremediation processes may be an inherent property of the predominant microorganisms in the study area that led to their stable existence along with relatively high metal concentration. Another prospect opens up probability of high metal resistance traits acquired by the microorganisms in course of time. Correlation studies showed positive association of the biological parameters with the metals estimated in the study area (Table A 3.11, Appendix 3).

Principal component analysis (PCA) showed that all the parameters analyzed in soil samples were positively linked to each other in pre-monsoon and monsoon (Figure 3.12 – 3.17). In case of geochemical parameters, Ni and Cd in pre-monsoon showed negative deviation from the remaining parameters [Figure 3.12 (A), (B)] in Majuli. Zn and Cr showed minimal deviation in Amingaon [Figure 3.13 (A), (B)] whereas Cr and Pb showed varied distribution in Umananda [Figure 3.14 (A), (B)]. Based on location and quantitative factors, PCA analyses were performed in soil sampling sites. In each situation, prominent clusters were scattered in positive components (Figure 3.15 – 3.16), specifying that studied sites are under exposure to similar kind of stress. Bank sediments in Majuli and Amingaon tend to have varied metal concentration and to some extent, this variability has secluded them from the rest of the sampling sites [Figure 3.15 (A), (B); Figure 3.16 (A), (B)]. In Umananda, sampling sites were evenly scattered in two principal component loadings [Figure 3.17 (A), (B)]. Furthermore, minor differences in characteristics of sampling sites studied delineate dominance of

metal species in soil as the root cause of variances observed. A broader aspect of influence of spatial variability is discussed in Chapter 4.

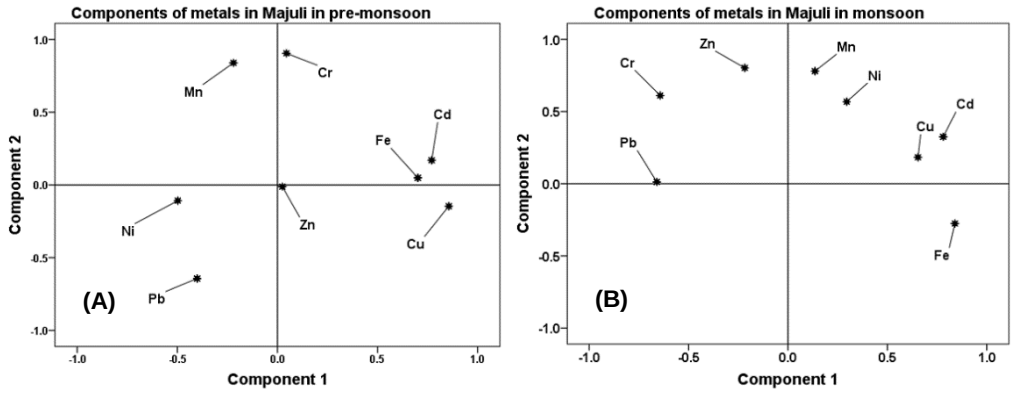


Figure 3.12 *Principal Component Analysis (PCA) of the metals showing their variances in soil samples in Majuli in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon seasons respectively*

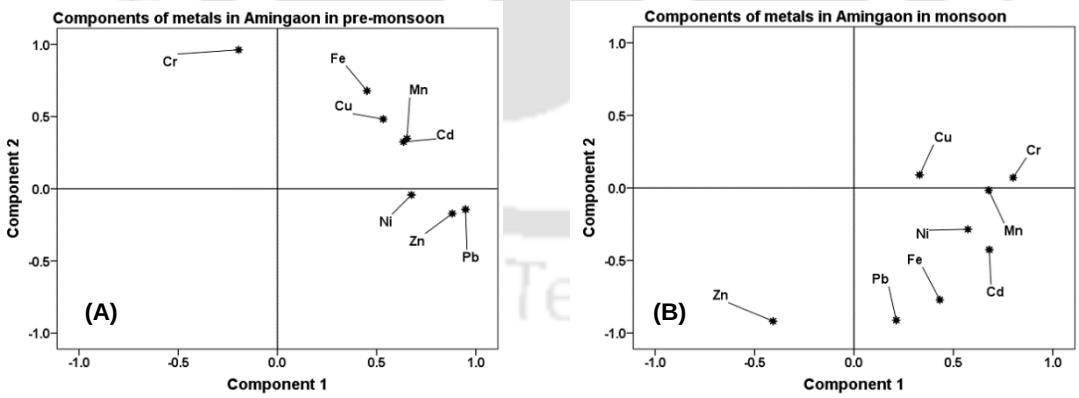


Figure 3.13 *Principal Component Analysis (PCA) of the metals showing their variances in soil samples in Amingaon in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon seasons respectively*

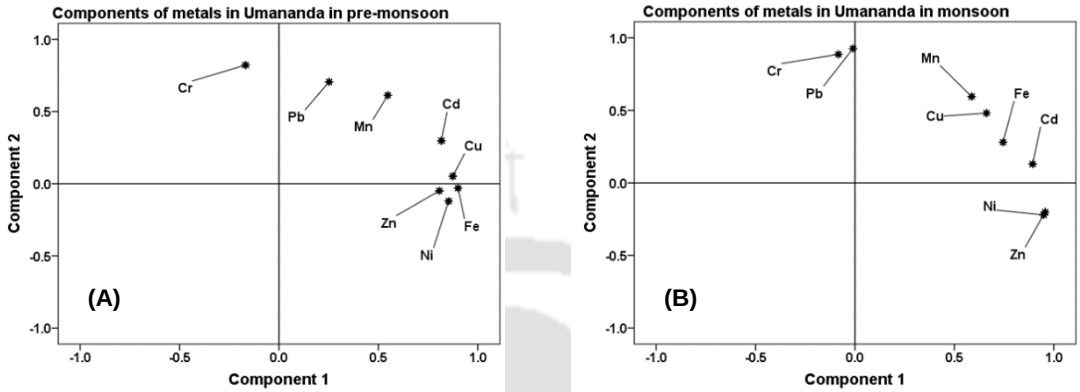


Figure 3.14 *Principal Component Analysis (PCA) of the metals showing their variances in soil samples in Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon seasons respectively*

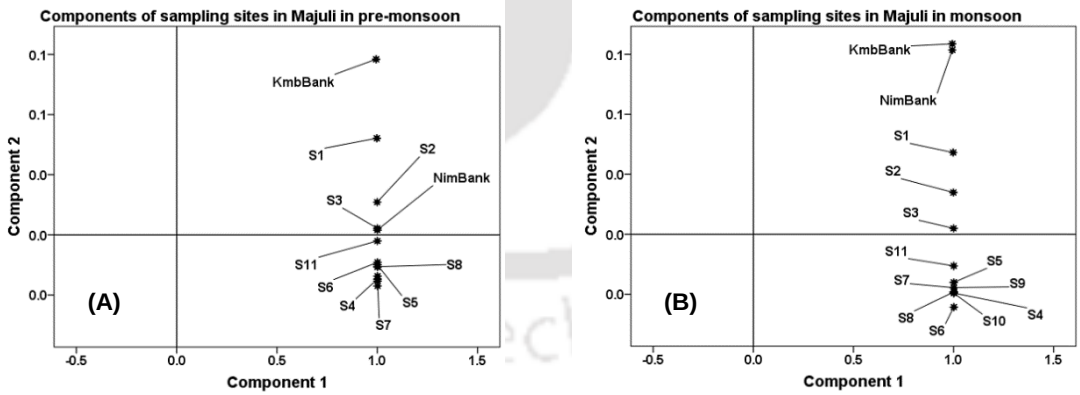


Figure 3.15 *Principal Component Analysis (PCA) of the sampling sites showing their variances in based on soil metal concentration in Majuli in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon seasons respectively*

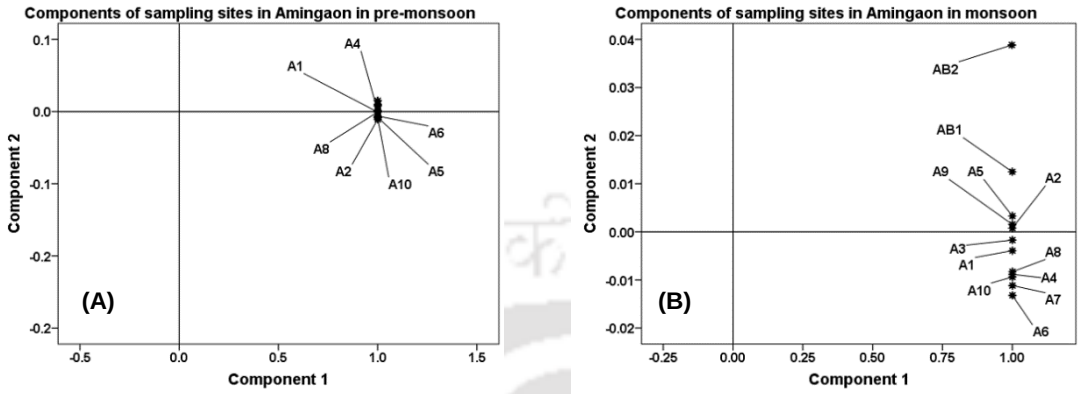


Figure 3.16 *Principal Component Analysis (PCA) of the sampling sites showing their variances in based on soil metal concentration in Amingaon in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon seasons respectively*

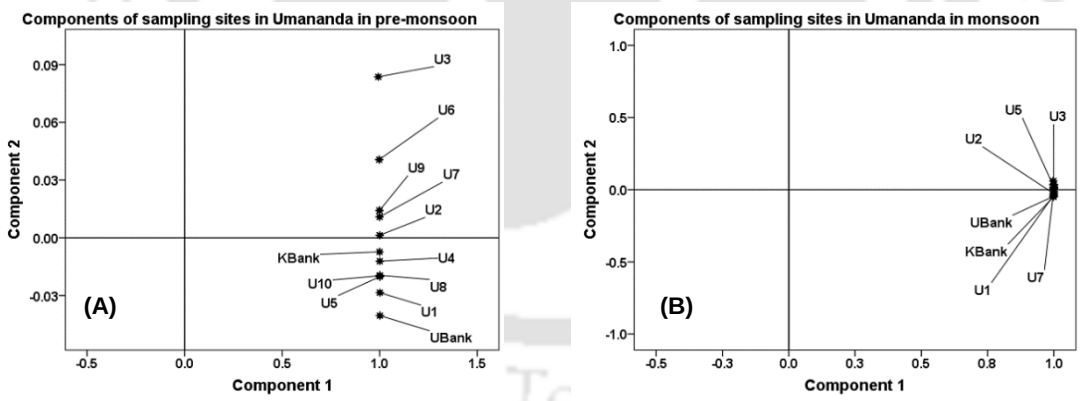


Figure 3.17 *Principal Component Analysis (PCA) of the sampling sites showing their variances in based on soil metal concentration in Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon seasons respectively*

3.4 CONCLUSIONS

Assessment of pollution indices revealed that Majuli Island has been temperately contaminated and not under severe threat to metal pollution. However presence of elevated levels of Fe Cu, Mn and Cd may possibly favor an impending ecological risk. Water samples showed presence of Fe, Cu, Mn and Pb with concentration much lower than the soils samples. Presence of plant species in water like *Eichornia crassipes*, may have some conspicuous effect on lower concentration of metals in water as compared to the soil samples. However NPI in water samples showed high risk of pollution due to elevated levels of turbidity in S9 (Group A) and S2 (Group B).

Relative abundance was higher for Fe followed by Cu and Zn. C_f was high for Fe followed Cu, Cu, Mn, Cd, Zn, Ni and Cr. However there were minor variances in the trend varying within the sampling sites. Depthwise variability was evident whereas seasonal influence remained passive except fluctuation in geochemical parameters and metal concentration. Cu and Cd were responsible for maximum rise in PLI, C_d, I_{geo} and PERI in soil. Impact of crop management and land use activities can be linked to Cd enrichment in Majuli. There was no natural source of Cd in the sampling sites (literature survey). The world average background concentration in soil showed remarkable deviation from the concentration of metals present in Majuli except Cd, Fe and Cu. PLI, C_d , ER and PERI indicated no threat to pollution in Majuli Island except individual contamination factors and a minor collective impact estimated as NPI. Majority of the pollution indices were significant in S10 (Sakali wetland under Group C). In recent decades, urbanization, high population density, huge tourism rush has

accumulated a huge quantity of domestic wastes as metal contaminants into water and soil in the study sites.

Pollution indices were collectively similar in Amingaon and Umananda in each season. Relative abundance of metals was highest for Fe followed by Cu, Zn, Mn, Pb, Ni, Cr and Cd in all the places. Metal concentration was conspicuous in undisturbed soils (Group A). Bank sediments showed low metal concentration and eventually low ecological risk exposure. C_f was highest for Cd, Zn, Mn, Pb, Ni and Cr. I_{geo} showed similar trend with highest accumulation for Fe followed by Cu, Cd and Zn. PLI was less than 1 whereas C_d was observed in a range of low degree of contamination to moderate degree of contamination (Abrahim et al., 2008) in all sampling sites, more ore less similar in either seasons. NPI values indicated that the sampling sites existed in a slightly polluted to seriously domain. Higher values of PLI, C_d and NPI were attributed to high concentration of Cu and Cd as compared to the world average background metal concentration. ER and PERI due to metals were within low risk.

Evaluation of pollution indices showed that pollution risk due to metals was low in Majuli and Kamrup (Amingaon and Umananda). PCA indicated variability in metal dominance in the sampling sites. Water samples showed low pollution as compared to soil samples. Single pollution indices in soil like C_f for Fe, Cu and Mn were evident in Majuli whereas Fe, Cu and Cd were marked in Kamrup. Cd and Cr concentration were prominent in Kamrup. Cd in most of the Majuli soil samples and almost all soil samples in Kamrup showed concentration greater than the world average background metal concentration. Correlation studies established the co-existence of metals in

natural medium that may or may not have a functional relation. Metal abundance in soil and its correlation with SOM and soil biological properties like enzyme activities and microbial populations provided an ephemeral understanding on the role of metals in physiological or bioremediating processes occurring in soil.

CHAPTER 4

Comparative assessment of geochemical parameters in two soil typologies i.e. Majuli in the middle stretch and Kamrup in the lower stretch of Brahmaputra River floodplain

4.1 INTRODUCTION

Majuli is located in the upper Brahmaputra floodplain with a mean altitude of 84.50 m above the mean sea level (Phukan, 2005; Dutta et al., 2012) whereas Kamrup is located in the lower Brahmaputra floodplain with a mean altitude of 31-35 m above sea level. As already discussed in Chapter 2, the gradient of the Brahmaputra River heading from Pasighat flowing through Dibrugarh, Majuli and Tezpur into low-lying areas of Kamrup is recorded as steep as 4.3-16.8 m km^{-1} in Pasighat, and near Guwahati it is found as flat as 0.1 m km^{-1} (Goswami, 1998). More specifically, Brahmaputra River has a gradient of 0.09 to 0.17 m km^{-1} near Dibrugarh, Assam at the head of the valley that gradually reduces to about 0.1 m km^{-1} near Guwahati. Through its flow in Assam, the long term average discharge increases from 8500 – 7000 m^3 s^{-1} (cumec) and the flows are augmented by some of the major adjoining tributaries (Phukan et al., 2012). The gradient of river amalgamated with topography directs its downstream flow. River flow dynamics indicate a differential sediment deposition event in the study areas i.e. Majuli and Kamrup (Amingaon and Umananda).

Brahmaputra is one of the most heavily sediment – charged large rivers in the world, second to the Yellow (Hwang Ho) River in China, in terms of amount of sediment transported per unit drainage area viz. 1128 tonnes km^{-2} $year^{-1}$ at Bahadurabad in Bangladesh. The river carries an average annual suspended load of 400 million metric tonnes at Pandu at an average daily rate of nearly two million metric tonnes in the rainy season (May to October) accounting for more than 95% of the annual suspended load (Goswami, 1985). During maximum annual discharges, the river is found to carry only 1.3 to 3.3% of the annual sediment yield on an average and as such

flow of nutrients is directed from upstream to the downstream low-lying plains in the river. During the river course through several places, overall sediment budget is appended by erosion activities at the banks. According to Thapa (2003), sediment particle size and mineral content are the characteristics factors of sediments that define its erosion potential. Size, shape and mineral content of sediment vary at different locations of the same river system, depending on distance traversed by particles, gradient of the river and the geological formation of the river course and catchments area. The collective sediment discharge during the passage of river accumulates at catchment areas. Most of these sediments deliver fertile alluvium rich in nutrients and mineral content, desirable for crop management and developmental activities. Considering the nutrient discrepancy in upstream floodplain in Majuli and downstream floodplain in Kamrup, the soil typologies in these two places are anticipated to differ in terms of soil properties, fertility, productivity and pollution load corresponding to the steepness of the river.

Considering these factors, comparative assessment was recognized as an essential tool to equate the soil properties, fertility, productivity and pollution load in these two soil typologies in the study areas. Comparative assessment was based on multivariate and geostatistical analyses with data imported from the outcomes of Chapter 2 and Chapter 3. Chapter 2 explored the physicochemical, geochemical and biological analyses in soil samples from Majuli and Amingaon and Umananda River Island in Kamrup and Chapter 3 discussed the metal status and pollution risk assessment of metals found in the geochemical environment. In general, linear comparison studies are intended to establish the fact that Kamrup being at a lower

altitude than upland Majuli River Island, the concentration of major soil parameters in Kamrup like SOM, MB, enzyme activities and metal concentration would be relatively higher. The main objectives of this chapter and criteria for implementation of methodologies in the comparative analysis were identified as:

1) Comparison of geochemical parameters in the upper and lower Brahmaputra floodplain
2) Geostatistical analysis for determining the role of spatial variability on geochemical parameters

4.2 MATERIALS AND METHODS

Details of study area and sampling sites were discussed in Chapter 2 (section 2.2.2). This chapter focuses on delimiting comparisons between the geochemical and biological parameters in Majuli and Kamrup.

4.2.1 Methodologies

Methods of analysis included estimation of frequency distribution statistics as mean, median and deviation, skeweness and kurtosis; covariances; factorial analysis or Principal Component Analysis (PCA) and variance between upland and lowland soil parameters by semivariograms based on Nugget to Sill ratios or DSD (%) obtained from a semivariogram model. Statistical analyses were performed in IBM SPSS 20 software, geostatistical analysis i.e. semivariogram model was run in Arc GIS 9.2 (GeoAnalyst tool pack), and documentation of variance by kriging method prepared in in Arc GIS 9.2 (GeoAnalyst tool pack).

4.2.2 Frequency distribution statistics

Frequency distribution statistics included calculation of mean, median, skewness and kurtosis for the experimental variables.

4.2.2.1. Mean and median

Mean is a descriptive statistics used to analyse normally distributed data. It is a measurement of central tendency in statistics, the average of samples and describes the location centre of normal distribution. Mathematically, it is the sum of all the values (X_1, X_2,….X_n) divided by the population size (N). Mean is designated as μ. The formula for mean is:

$$\mu = \frac{\sum_{i=1}^{N} X_1}{N}$$

Where X= samples or observations or variables and N= sample size or total number of observations

Like mean, median is a measure of central tendency. Median is the middle most value of a variable when the observations are arranged in ascending or descending order. Cumulative frequency is used in calculating the median in case of existence of frequency of variables. Median is designated as M. It is determined as:

$$M = \frac{N}{2}$$

$$N = \sum f_i$$

Where N = number of observations and f= frequency

Cumulative frequency, designated f_c is the frequency just greater than N/2. In case of determination median from a frequency distribution class, the following formula is used:

$$M = l + \frac{h}{f}\left(\frac{N}{2} - f_c\right)$$

Where l= lower limit of the median class, h= width of the median class, f_c= frequency before the median class and N= number of observations.

4.2.2.2 Skewness and kurtosis

Skewness is used as an indicator in distribution analysis, as a sign of asymmetry and deviation from a normal distribution whereas kurtosis measures flattening or "peakedness" of a distribution. Skewness and kurtosis are essential to determine the symmetry or uniformity of experimental data. Pearson (1905) introduced kurtosis as a measure of how flat the top of a symmetric distribution is when compared to a normal distribution of the same variance. In case of a normal distribution, skewness and kurtosis is close to zero.

4.2.3 Measurement of dispersion

Measurement of dispersion included calculation of standard deviation, quartile distribution and co-efficient of variation of the geochemical parameters.

4.2.3.1 Standard deviation

Standard deviation (S) computes absolute values that deviate from the mean. It is defined as the square root of the arithmetic mean of the squares of deviations from the

arithmetic mean or in other word the square root of variance. The formula for standard deviation is:

$$S = \sigma^2$$

$$\sigma = \sqrt{\frac{\sum(X_i - \mu)^2}{N}}$$

Where σ is the variance, X_i= observations or variables, μ = mean and N= sample size or total number of observations.

4.2.3.2 Quartile distribution

Quartiles are three points which divide the entire set of observations after being arranged in ascending order or descending order of magnitude, into four equal parts. Quartiles are designated as Q.

Q_1 is the first quartile, where 25% of the observations are less and 75% are greater than it. Q_2 is the second quartile, where 50% of the observations are less and 50% are greater than it. Therefore Q_2 is the median.

In the third quartile i.e. Q_3, 75% of the observations are less and 25% are greater than it.

Formula for Q_i is:

$$Q_1 = l_i + \frac{\frac{i}{4}N - f_c}{f} \times h$$

Similarly, Q_1, Q_2 and Q_3 are denoted by the following formulas respectively:

$$Q_1 = l_1 + \frac{\frac{N}{4} - f_c}{f} \times h$$

$$Q_2 = l_2 + \frac{\frac{N}{2} - f_c}{f} \times h$$

$$Q_3 = l_3 + \frac{\frac{3N}{4} - f_c}{f} \times h$$

Q= quartile, l= lower boundary of quartile group, f= frequency, f_c= cumulative frequency, h=width of the quartile group and N= number of observations.

Measurement of dispersion determined through quartiles is known as quartile distribution or quartile deviation. It is defined as half of the distance between the third and the first quartile. It is designated as QD. QD is determined as:

$$QD = \frac{Q_3 - Q_1}{2}$$

4.2.4 Co-efficient of variation

Co-efficient of variation is a statistical measure of the distribution of data points in a data series around the mean. It is associated with comparison of the degree of variation between various data sets, although the means are considerably different from each other. The coefficient of variation is determined as the ratio of standard deviation and mean. It is designated as CV. CV is calculated as:

$$CV\,(\%) = \frac{S}{\mu} \times 100$$

Where S= standard deviation and μ= mean.

4.2.5 Multivariate statistics

In this chapter, multivariate statistical analysis included Principal Component Analysis and geostatistical analysis involving semivariogram model and kriging.

4.2.5.1 Principal component Analysis

PCA is one of the oldest multivariate techniques known for dimension reduction of huge set of data bearing lots of redundancy i.e. two or more variables are highly correlated with each other. According to McKillup and others (2010), PCA identifies variables that are highly correlated and combine them to construct a new set of variables that still describes the differences among the samples. These new variables are known as principal components (PC).

In PCA, we expect to analyse a three dimensional dataset including a large number of variables. In this case, one or more covariance matrix is involved to deal with three dimensional data sets. Associated with the newly formed principal components or the three dimensional data sets processed by the covariance matrix, are the Eigen values and Eigen vectors. Eigen vectors are produced as result of multiplication of component matrices. They provide information about the pattern of data in a plot. In general, Eigen vectors are perpendicular to each other in a plane, they appear to pass through the middle of the points like line of best fit showing connection between the data sets along the line. Once the Eigen vectors are derived from the covariance matrices, they are arranged in terms of Eigen value which is the amount by which the vectors are scaled after multiplication by the square matrices, in a sequence highest to lowest. The results are obtained in the form of order of significance of the PCs obtained (Smith, 2002). Eigen value gives the percentage of variation explained by each PC. Most importantly, while reducing the number of variables to help visualize the relationships among the variables under study, PCA also gives the relative contribution of the original values to each Eigen value. The outputs of PCA contain a

list of the original variables and their correlations with each of the PCs (McKillup, 2010).

A scree plot generally shows the rate of change in the magnitude of the eigenvalues for the PCs obtained. Scree plot is obtained by plotting the eigenvalues against the corresponding PCs. The point, at which the curve bends, is considered to indicate the maximum number of PCs to extract. PC loadings are determined as correlation coefficients between the PC scores and the original variables. PC scores are the derived composite scores computed for each observation based on the eigenvectors for each PC. PC loadings measure the importance of each variable in accounting for the variability in the PC. It is possible to interpret the first few PCs in terms of 'overall' effect or a 'contrast' between groups of variables based on the structures of PC loadings (Fernandez, 2003).

In case of two PCs, high correlation between a first PC1 and a variable indicates that the variable is associated with the direction of the maximum amount of variation in the dataset. More than one variable might have a high correlation with PC1. A strong correlation between another variable and a second PC2 indicates that the variable is responsible for the next largest variation in the data perpendicular to PC1, and so on. If a variable does not correlate to any PC, or correlates only with the last PC, or one before the last PC, this usually suggests that the variable has little or no contribution to the variation in the dataset. Therefore, PCA may often indicate which variables in a dataset are important and which ones may be of little consequence (Fernandez, 2003).

In general, Bi-plot display is a visualization technique for investigating the inter-relationships between the observations and variables in multivariate data through PCA.

4.2.5.2 Geostatistical analysis

Geostatistical analyses involved a classical method of multivariate statistical analysis based on spatial distribution of experimental variables. Geostatistics works on the concept of regionalized variable involving the technique of semivariogram to measure the spatial variability of a regionalized variable and provides input for the parameters to be included in spatial interpolation of kriging.

4.2.5.3 Semivariogram spherical model

Semivariogram is developed on the basis of semivariance between the sampling sites. ***Semivariance*** is half the expected squares of differences between the sampling sites separated a distance (h). Semivariance is a statistics that quantifies the amount of regional dependence between two points (McKillup et al., 2010). It expressed as:

$$\gamma = \frac{X_i - X_j\ ^2}{2}$$

Where X= value of the variable points at X_i and X_j. For two identical values, the semivariance will be zero. As the difference between them increases, the semivariance will increase, which can only ever be zero or greater.

Semivariance is used as an accurate and precise statistics to quantify the dissimilarity of a variable between a specifically chosen central point (X_1) and each of several other points (X_1, X_2, etc.) increasingly distant from it. For each pair of points

[(X_1, X_2), (X_1, X_2), etc.], the value of semivariance is plotted on the Y axis of a scatter plot against the distance between them on the X-axis. This scatter plot is known as experimental or empirical semivariogram.

The relationship between the semivariance and distance from a central point will depend on the regional dependence. In absence of a regional dependence, the value of variables at central point will tend to remain unrelated. The semivariance will be larger as the distance from the central point increases, the amount of regional dependence reduces and become scattered. In presence of a regional dependence, the value of variables tends to remain closer to the central point and shows some relation. The semivariance will thus be smaller and amount of regional dependence is significant.

When the variables are plotted, semivariogram shows a smoothed line of best fit. There are some restrictions that the line fitting must start from a relatively low value at a central point, subsequently increase and eventually plateau out. Figure 4.1 shows the example of a semivariogram with a significance regional dependence, the points or the variable tends to remain close to a central point showing significant semivariance.

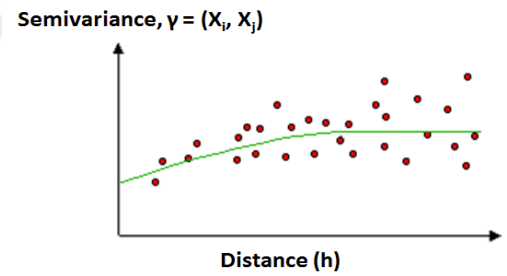


Figure 4.1 *Representation of a semivariogram model showing the extent of semivariance. The points tend to show a relationship based on regional dependence (Adapted from ESRI 2011)*

The semivariance function γ at a given lag (h) in a semivariogram model is is represented as γ (h). Semivariance is described by the following equation:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{n(h)} Z(X_i) - Z(X_i + h)^2$$

Where, γ (h) is a semivariance function, Z is regionalized variable, $Z(X_i)$ is a measured sample at point Xi, $Z(Xi + h)$ is a measured sample at point $(X_i + h)$, N(h) is the number of pairs separated by distance (h) or lag (h) (Piotrowska, 2011).

Semivariogram analysis is an important component of geostatistical analysis associated with data analysis based on spatial autocorrelation grounds which means measure of the degree to which a set of spatial features and their associated data values tend to be clustered together in space (positive spatial autocorrelation) or dispersed (negative spatial autocorrelation). A semivariogram model includes the following important components:

a) Range

The distance where the model first flattens is known as the range. Range represents the average maximum distance over which variables are related. Sample locations separated by distances closer than the range are spatially autocorrelated, whereas locations farther apart indicate that the range are not are spatially autocorrelated. Range is designated as R.

b) Nugget (C_o)

At an infinitely small separation distance, the semivariogram often exhibits an effect known as **Nugget**, which is a value greater than zero. Nugget is a minor variance

associated with the model either by fine scale variability (i.e. less than the sampling interval) or measurement error. Measurement error occurs because of the error inherent in measuring devices (Figure 4.2). It is designated as C_o.

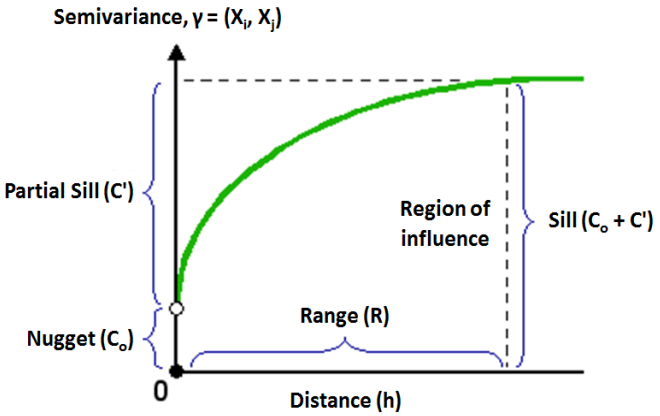


Figure 4.2 *Representation of a semivariogram model demonstrating Range, Nugget, Sill and Partial Sill (Adapted from ESRI 2011)*

c) Sill (C)

The value at which the semivariogram model attains the range (the value on the Y-axis) or the semivariance attains the maximum height, is known as the **Sill.** Sill is more specifically considered as overall variance. A **Partial Sill (C')** is also observed when the semivariance has reached its maximum limit, represented as the difference between the Sill and Nugget. Nugget and Partial Sill collectively provide the Sill and represent a region of influence in the semivariogram model. Sill is designated as C and Partial Sill is represented as C'. Sill (C) is calculated as:

$$Sill\ (C) = [Nugget\ (C_o) + Partial\ sill\ (C')]$$

Camberdella (1994) defined as a concept known as Degree of Spatial Dependence (DSD) which is the ratio of Nugget to Sill values. DSD considers the effect of regional dependence. DSD below 25% is assigned as strong, moderate when 25 %< DSD ≤ 75% and weak when DSD>75%. DSD is determined as:

$$DSD\ (\%) = [C_o / (C_o + C) \times 100]$$

In this study, a spherical semivariogram model is employed. A spherical model shows a progressive decrease of spatial autocorrelation (equivalently, an increase of semivariance) until some distance, beyond which autocorrelation is zero. The spherical model is one of the most commonly used models (ESRI, 2011).

4.2.5.4 Kriging

Kriging is an interpolation tool based on statistical models involving spatial autocorrelation. It is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points. The basic foundation of kriging is a semivariogram model. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. It is a multistep process, includes exploratory statistical analysis of the data, semivariogram modeling, creating the surface, and (optionally) exploring a variance surface.

Kriging is most appropriate when there is a spatially correlated distance or directional bias in the data. It is similar to Inverse Distance Weighting (IDW) that weights the surrounding measured values to derive a prediction for an unmeasured

location. The general formula for both interpolators is formed as a weighted sum of the data:

$$Z(S_o) = \sum_{i=1}^{N} \lambda_i Z(S_i)$$

Where Z (S_i) = the measured value at the i^{th} location, λ_i = an unknown weight for the measured value at the i^{th} location, S_o = the prediction location and N = the number of measured values.

4.3 RESULTS AND DISCUSSIONS

Combined measurement of distribution and dispersion of the experimental data gave an overview of the trend of data uniformity in Majuli and Kamrup. The pattern of soil properties and its correlation with the geopositional features of sampling sites was interpreted collectively in the two study areas.

4.3.1 Variation in geochemical parameters based on statistical analysis

The pertinent property of statistics to check inequality of data may or may not be fully justifiable with the real world data. Perfectly symmetrical condition is a rare feature of experimental analysis. Frequency distribution in soil properties envisages the symmetry in data obtained through experimental analysis and whether they are acceptable on a real world platform. Taking this into consideration skewness, kurtosis and co-efficient of variation with to respect to mean, median and standard deviation, were intended to show distribution of data based on spatial variability of soil geochemical characteristics.

Analysis of quartile deviation is anticipated to help in visualizing spatial variability in the parameters analysed in pre-monsoon and monsoon season as well as in providing a broader explanation of skewness and kurtosis distribution (visible in box plots). In this study, quartiles displayed deviation of data from mean and median values, confirmed by box plot method. Furthermore, quartiles exhibited the values that showed narrowed distribution or broad distribution with to respect to mean and median values.

PCA is another useful tool for explanation of the essential correlating features of spatial variability in soil samples in the study areas. PCA have been employed by researchers worldwide with an aim of exploring and characterizing the relationships between regionalized variables and related environmental factors, quantifying the spatial variability pattern of these variables (Kumar et al., 2012). PCA was used a mandatory statistical tool in this study, as of now spatial variability of predetermined geochemical characteristics in the study sites was studied on the basis of linear comparison methods (Chapter 2).

4.3.1.1 Measurement of distribution and dispersion in experimental data

In this study, positively skewed as well as negatively skewed data were equally identifiable in the study areas [Table (A 4.1 – A 4.3), Appendix 4]. Positively skewed data indicated that values were greater than the mean and median and hence they were skewed towards the right tail of frequency distribution. Similarly negatively skewed data were motivated towards the left tail due to occurrence of values lower than the mean and median values.

Statistical analyses of all the geochemical parameters were performed separately for Majuli and Kamrup. In Majuli, all parameters were positively skewed except pH, MBC, TP, MBP, TP, AKP, AKP (with toluene), invertase, protease (with toluene), urease, urease (with toluene), total Fe, Mn, fine sand (%), silt (%) and clay (%) in pre-monsoon season. In monsoon season, pH, TP, MBP, AKP, AKP (with toluene), invertase, invertase (with toluene), urease, urease (with toluene), BCFU, total Fe and Mn were negatively skewed [Table A 4.1, Appendix 4]. Kurtosis was negative for pH, CEC, TOC, invertase, invertase (with toluene), protease, FCFU, total Fe, Mn, Zn, Cd and Cr in pre-monsoon season whereas pH, CEC, TOC, MBN, MBP, ACP (with toluene), invertase, invertase (with toluene), protease, protease (with toluene), BCFU, FCFU, total Fe, Zn, Cr and Ni in monsoon showed negative kurtosis [Table A 4.1, Appendix 4].

In Amingaon, all parameters except pH, TOC, MBC, TN, MBN, ACP (with toluene), AKP, AKP (with toluene), amylase, amylase (with toluene), cellulase, cellulase (with toluene), dehydrogenase, dehydrogenase (with toluene), invertase (with toluene), protease, protease (with toluene), urease, urease (with toluene), total Fe, Mn, Zn, Cd, Pb, Ni, fine sand, silt and clay were positively skewed in pre-monsoon and TOC, MBC, MBN, TP, MBP, AKP (with toluene), amylase, amylase (with toluene), cellulase, cellulase (with toluene), protease (with toluene), urease, urease (with toluene), total Fe, Mn, Cd, Pb and Ni were negatively skewed in monsoon season. Kurtosis showed significant negative values for pH, TN, MBN, TP, MBP, ACP ACP (with toluene), AKP, AKP (with toluene), amylase, amylase (with toluene), cellulase, cellulase (with toluene), dehydrogenase, dehydrogenase (with toluene), invertase,

invertase (with toluene), protease, protease (with toluene), BCFU, FCFU, Cu, Zn and Pb in pre-monsoon season. In monsoon season, negative kurtosis was observed in pH, TN, MBN, TP, MBP, ACP ACP (with toluene), AKP, AKP (with toluene), invertase, invertase (with toluene), protease (with toluene), BCFU, FCFU, Cu, Mn, Zn, Cr, Pb and Ni [Table A 4.2, Appendix 4].

Likewise in Umananda, pH, conductivity, TOC, MBC, TN, MBN, TP, ACP, ACP (with toluene), AKP, AKP (with toluene), amylase, amylase (with toluene), cellulase, cellulase (with toluene), protease, protease (with toluene), urease, urease (with toluene), BCFU, total Fe, Cu, Mn, Zn, Cd, Pb, fine sand, silt and clay in pre-monsoon season showed negative skewness. In monsoon season, EC, TOC, MBC, TN, MBN, AKP, AKP (with toluene), amylase, amylase (with toluene), cellulase, cellulase (with toluene), urease, urease (with toluene), BCFU, total Fe, Cu, Zn, Cd and Pb were negatively skewed. In case of kurtosis, pH, CEC, TN, MBN, TP, MBP, ACP, ACP cellulase, cellulase (with toluene), dehydrogenase (with toluene), invertase (with toluene), protease, protease (with toluene), FCFU, Mn, Cr and Ni were negatively peaked in pre-monsoon season [Table A 4.3, Appendix 4] pH, CEC, TN, MBN, TP, MBP, AKP, amylase, amylase (with toluene), cellulase, cellulase (with toluene), dehydrogenase, dehydrogenase (with toluene), invertase, protease (with toluene), urease, urease (with toluene), Cu, Cr and Pb showed negative values for kurtosis in monsoon season.

The seasonal influence though minimum in each of the sampling sites (evident from the results obtained in Chapter 2), most of the parameters as aforementioned in Majuli, Amingaon and Umananda were positively or negatively skewed in a particular

season. Majority of the parameters were skewed towards the left tail of peaked distribution. Skewed data indicated asymmetrical distribution, it was further obvious from experimental results that showed distinct variation between the three sampling locations in upper and lower Brahmaputra floodplain respectively (Chapter 2). Spatial distribution of the sampling sites, to some extent, is intended to render negative skewness. Kurtosis demonstrated the lack of peaked distribution of the parameters as observed in skewed nature of the data. A generalized observation indicated that soil buffering capacity and SOM components as well as inorganic components showed asymmetry in experimental data and thus hampered sharply peaked distribution. Lack of uniformity in data obtained in experimental analysis can be linked to soil properties and spatial distribution.

The results of skewness and kurtosis were further sustained by analysis of co-efficient of variation (CV). CV (%) is another important statistical tool that helps in correlating the spatial variability of soil properties (Singh et al., 2008). CV (%) in general was highest for a few enzymes and lowest for pH and soil organic matter in Majuli, Amingaon and Umananda in pre-monsoon and monsoon season respectively. Though CV (%) deviated from the skewness and kurtosis values in a few cases, the magnitude of variability can linked to the asymmetry in distribution of data in a few parameters like pH and TOC. Details of CV (%) are mentioned in a separate column in [Table (A 4.1 – A 4.3, Appendix 4]. CV (%) is a measure of relative precision to assess inequality in data, it is invariant to scale changes but not invariant to location change. The slight increase in the mean does not change the monotonically increasing nature of CV. CV (%) is a more sensitive measure of the (right) tail of the distribution. For example in case of pH and TOC, in each of the sampling sites, the variability is

minimal, but the data are negatively skewed and lacked peaked distribution. In this context, CV (%) being lower in value, tend to support the positively skewed nature of pH data. Another observation pointed out the distribution Pb in Majuli sediments. Pb showed scattered distribution, absent in majority of the sampling sites in Majuli. Lack of uniformity in distribution resulted in a high CV (%) > 100 in Majuli. Similarly unevenness in ACP activities in Umananda gave high CV (%) output.

Soil properties and environmental parameters are intertwined, topography and microclimate of the three sampling sites may possibly have an influential effect on the soil properties (Egli, 2013). It has been previously discussed in Chapter 2, that Kamrup (Amingaon and Umananda) represented a relatively high productivity zone as compared to Majuli River Island in terms of SOM and biological properties. The trace elements proportion in soil was additionally conspicuous and as such outcomings like metal contamination clearly indicated natural and anthropogenic influence on the natural soil system, equitable at the three sampling locations in Majuli, Amingaon and Umananda respectively.

From the three set of observations, i.e. Majuli, Amingaon and Umananda, it could be concluded that the nature of uniformity in data obtained from geochemical and biochemical characterization of soil samples, were identical in both the study areas. The seasonal variance was inconspicuous, however minor variances were observed in the skewed nature of the data that resulted in reduction of peak distribution in the two seasons respectively. In case of linear comparison of variables under study, it was observed that the mean, median and standard deviation values for all the parameters were higher in Umananda followed by Amingaon and lower in Majuli.

The percentiles for quartile deviation are enlisted in separate columns in Table A 4.1 – A 4.3, Appendix 4. A detailed discussion of quartile deviation of a few important soil parameters is given in the following section.

4.3.1.2 Measurement of dispersion in some important geochemical parameters

While observing the experimental data (Chapter 2), variability was found to be highly significant in soil buffering capacity, SOM content, soil MB, CEC and a few metals as total Fe (relatively lower in Umananda), Cd, Cr and Pb. Soil microbial colony forming units and soil enzymatic were considered as more or less trivial against SOM and MB, because it was assumed that soil organic matter governs all other soil physiochemical properties. More specifically, soil OC has predominant soil biophysical, biochemical and biological implications. Schmidt (2011) has highlighted a new frontier of soil OC dynamics, persistence of soil OC is not attributed to the intrinsic properties of the OM itself, but because of physicochemical and biological influences from the surrounding environment that reduce the probability (and therefore rate) of decomposition, thereby allowing the organic matter to persist. Thus persistence of soil organic carbon primarily can be considered as an ecosystem property that influences rest of the ecological parameters. As frequency distribution pattern was studied in majority of the parameters, quartile distribution was concentrated on a few ecologically significant parameters in this study like pH, soil organic matter, soil MB, total Fe, Cd, Cr and Pb.

Quartile distribution was analyzed by box plot method (Figure 4.3 – 4.13). From the box plot spatial variability was distinct and at the same time, distribution of values of parameters around a central value or away from central became prominent. pH in Amingaon showed very narrowed distribution in both the seasons. Significant

asymmetry in data was observed in TOC in Amingaon and Umananda, bank sediments (AB1 in Amingaon, U Bank and K Bank in Umananda) tend to remain as outliners indicating maximum deviation from the median values (Figure 4.4). In case of TP in Majuli S11 (Group A, Residential area) was much lower than the median value (Figure 4.6). Other than TOC, bank sediments in Amingaon and Umananda were lower than the median values in a few more parameters like MBC and Cd. Additionally, Umananda bank sediments showed deviation in Pb. U4 (Group B, undisturbed sample) showed maximum concentration of MBC in monsoon season in Umananda, similarly U3 (Group A, disturbed sample) showed maximum Cr concentration and U2, U9 (Group A, disturbed sample) showed high concentration of Pb in monsoon season respectively. Maximum skewed nature of Pb values in Umananda resulted in overlapping of quartiles in pre-monsoon season. While in Majuli, Pb concentration in majority of the sites were zero, since the lower limit of data entered were zero, whiskers and quartiles in values lower than median overlapped each other showing abnormal distribution (Figure 4.13). Quartile distribution of Pb in Majuli supports the CV (%) discussed previously. Rest of the parameters in all three locations showed conspicuous deviation from the median values.

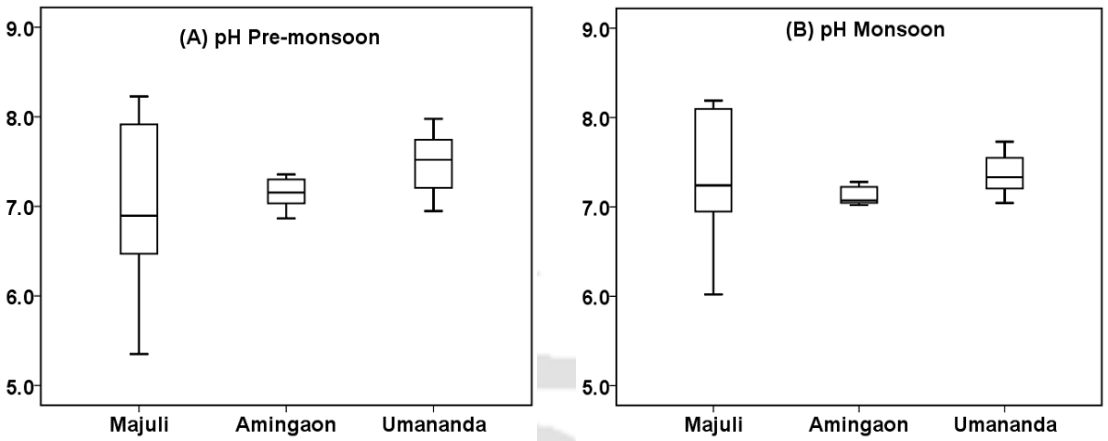


Figure 4.3 *Quartile distribution of soil buffering capacity in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

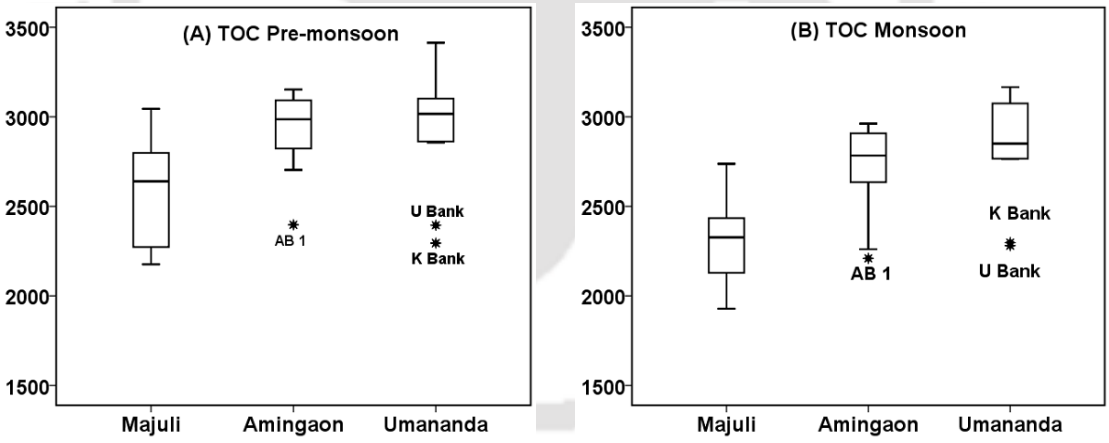


Figure 4.4 *Quartile distribution of TOC (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

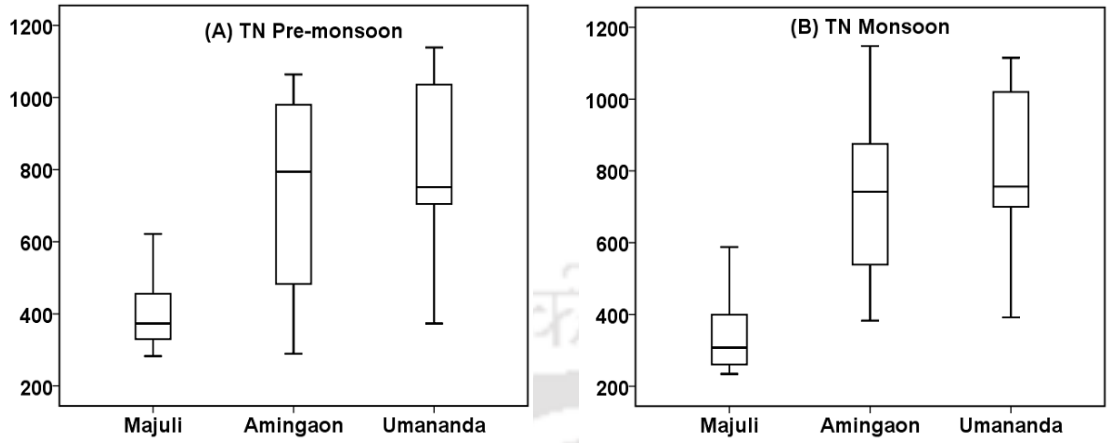


Figure 4.5 *Quartile distribution of TN (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

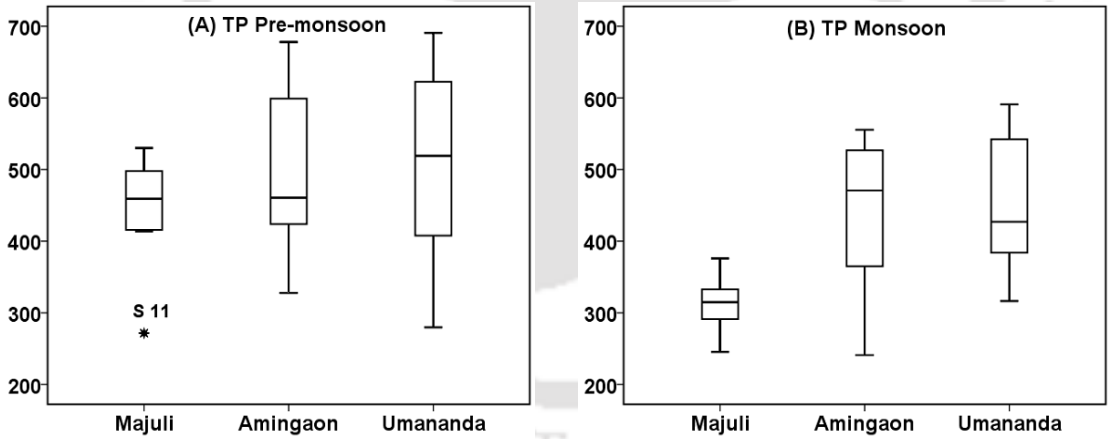


Figure 4.6 *Quartile distribution of TP (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

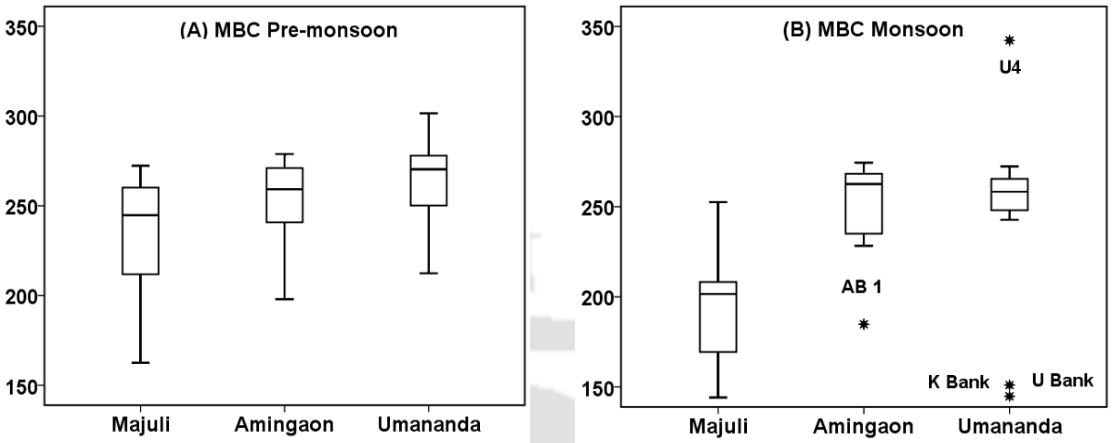


Figure 4.7 *Quartile distribution of MBC (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

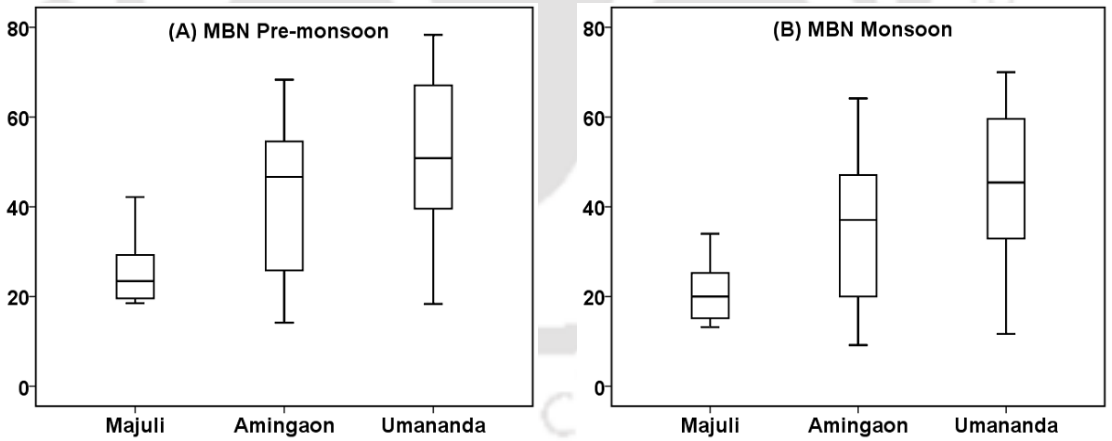


Figure 4.8 *Quartile distribution of MBN (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

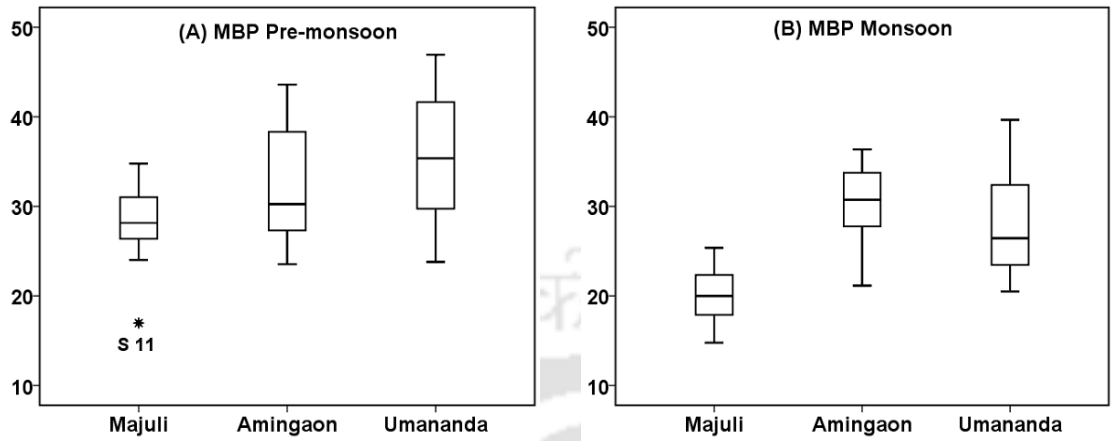


Figure 4.9 *Quartile distribution of MBP (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

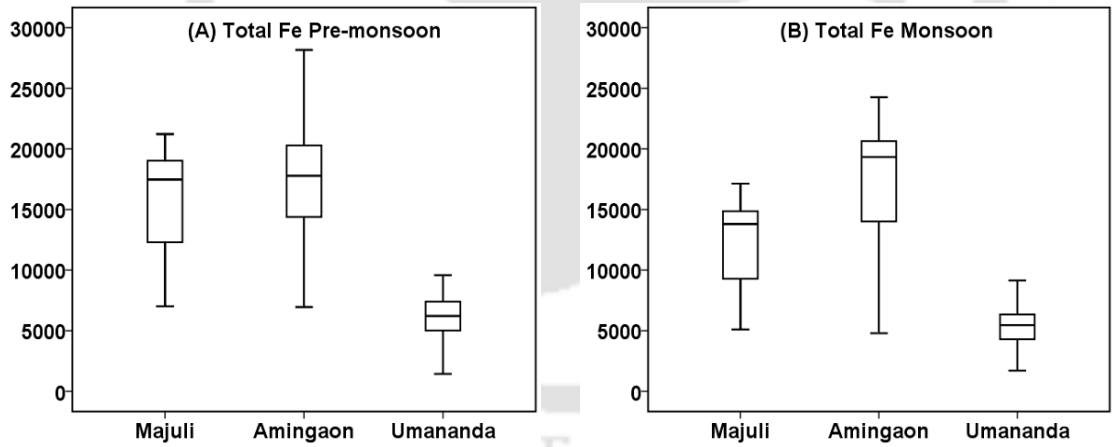


Figure 4.10 *Quartile distribution of total Fe (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

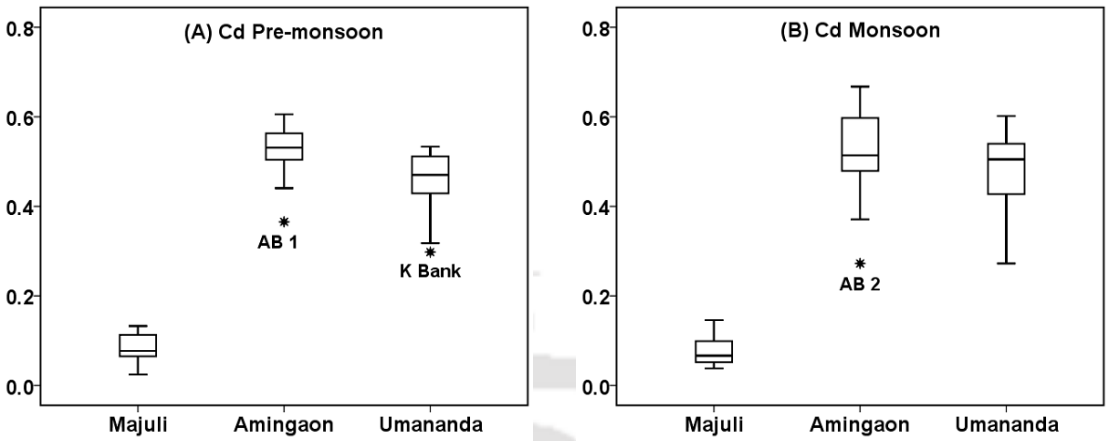


Figure 4.11 *Quartile distribution of Cd (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

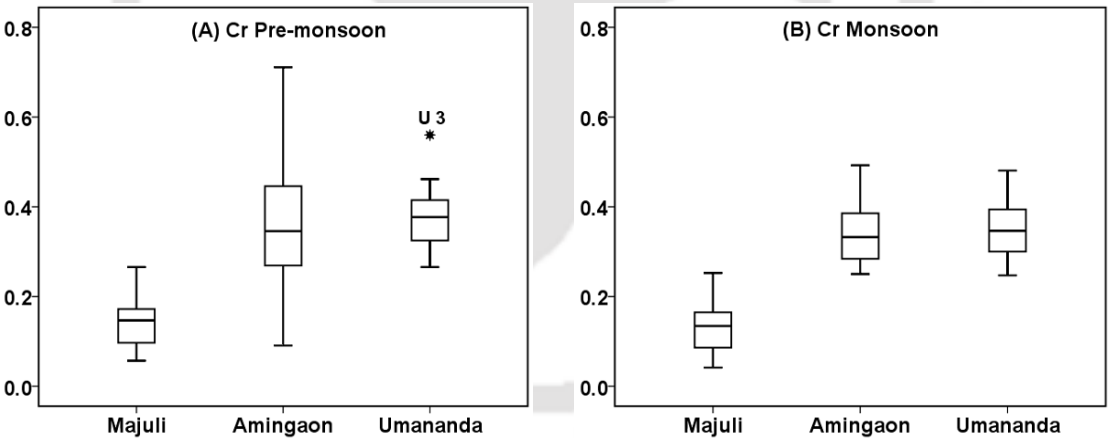


Figure 4.12 *Quartile distribution of Cr (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

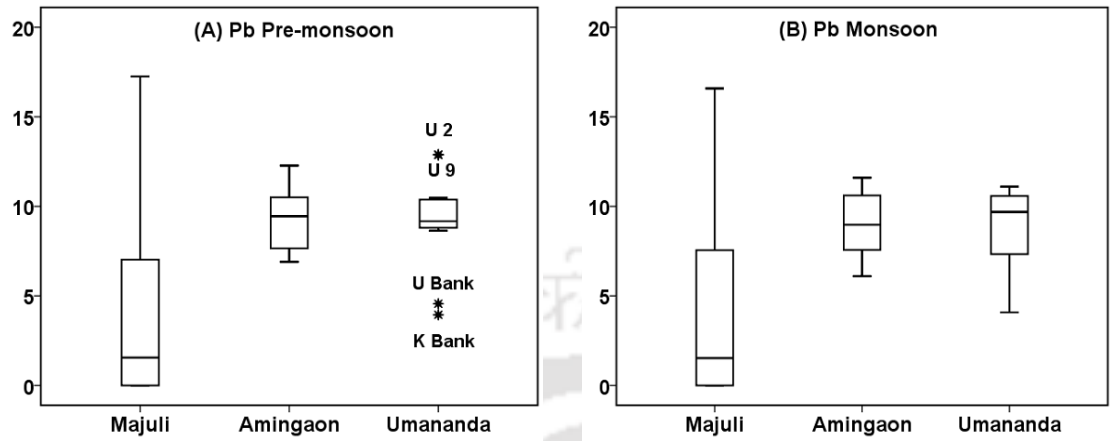


Figure 4.13 *Quartile distribution of Pb (mg/kg soil) in Majuli, Amingaon and Umananda in* ***(A)*** *pre-monsoon and* ***(B)*** *monsoon season respectively*

Quartile distribution through Boxplot observations showed asymmetrical distribution of data, already confirmed by skewness and kurtosis statistics. In addition to lack of uniform distribution, quartile deviation showed location wise and season variability of experimental data. Quartile distribution hinted the role of spatial variability in unusual distribution of data. Box plots depicted the range of SOM and other geochemical parameters. Soil parameters in three locations i.e. Majuli, Amingaon and Umananda, tend to fluctuate within a defined range indicating a biased impact of soil ecological properties on soil physicochemical features.

4.3.1.3 Principal components analysis of soil properties and its linkage to spatial variability

PCA was performed for location wise and season wise comparative assessment of geochemical parameters in Majuli, Amingaon and Umananda. Considering the status of metals as a source of ecological risk (discussed in Chapter 3), PCA was also performed

to assess the relativity and variability of metal status to check the metal dominance in Majuli, Amingaon and Umananda.

PCA showed two way interpretations. In first case, the geochemical parameters and biological parameters in each season and in each of the sampling sites appear to exist as positive influential components that directly or indirectly govern the concurrence of each other. Secondly, the sampling sites based on all parameters analysed tend to remain positively associated with each other lying in the positive components of 2D rotated PC plots [Figure 4.15 (A), (B); Figure 4.17 (A), (B), Figure 4.19 (A), (B) and Figure 4.20 (A), (B)]

The number of components extracted in each case was determinant to a scree plot bearing Eigen values and number of possible PCs that could be extracted. Based on the scree plots it was observed, geochemical parameters in Majuli and Amingaon were extracted into 7 components in pre-monsoon and 8 components in monsoon season respectively [Figure 4.14 (A), (B); Figure 4.16 (A), (B)]. In Umananda 6 components were extracted in pre-monsoon as well as monsoon season [Figure 4.18 (A), (B)]. Results showed uniformly distributed positive as well negative PCs for geochemical parameters in each study area in pre-monsoon and monsoon season respectively.

In Majuli, highest absolute PC loadings were observed for AKP (alkaline phosphatase enzyme activity) and lowest loadings for Pb, in pre-monsoon season indicating predominant activity of AKP and negatively significant nature Pb abundance in Majuli soils [Table 4.1 (A)]. In monsoon high absolute loadings was observed in AKP (with toluene treatment) and MBC. Like in pre-monsoon AKP enzyme activity acts a function of SOM sustaining events whereas MBC in monsoon tend to show

minimum correlation with the soil geochemical properties [Table 4.1 (B)] [Figure 4.14 (A), (B)]. High PC loadings for AKP showed that AKP is positively associated with most of the parameters analysed in Majuli River Island. In case of sampling sites, based on soil properties high PC loadings were observed in S4 (Group B) and low PC loadings in Kmb Bank (Group D) in pre-monsoon season [Figure 4.15 (A)]. In monsoon, PC loadings were high in S3 (Group B) and low in Kmb Bank (Group D) (Table 4.2) [Figure 4.15 (B)]. Bank sediments tend to deviate from the rest of the sampling sites in terms of concentration of geochemical parameters analysed.

In Amingaon, urease enzyme activity showed highest and CEC showed lowest absolute PC loadings in pre-monsoon season [Table 4.3 (A)]. Fe showed highest and MBC showed lowest PC loadings in monsoon season [Table 4.3 (B)]. Urease enzyme activity and presence of Fe were highly correlated to other soil parameters and thus predict a strong relation to environmental processes that vary with physiographic locations [Figure 4.16 (A), (B)]. Screening of sampling sites for possible connectivity within the domain showed that A4 (Group A) had highest and AB2 (Group C) had lowest PC loadings in pre-monsoon [Figure 4.17 (A)], whereas A8 (Group A) had highest and AB1 (Group C) had lowest PC loadings in monsoon season respectively [Figure 4.17 (B)]. Interpretations of bank sediment characteristics were similar to results in Majuli.

In Umananda, amylase enzyme activity showed highest and BCFU showed lowest PC loadings in pre-monsoon [Figure 4.18 (A)]. In monsoon, PC loadings were highest for Cd and lowest for AKP activity with toluene treatment [Table 4.5 (A), (B)] [Figure 4.18 (B)]. Like Majuli and Amingaon, sampling sites showed high PC loadings

in U7 (Group B) and U Bank (Group C) in pre-monsoon [Figure 4.19 (A)]. In monsoon, U9 showed high and K Bank showed low PC loadings (Table 4.6) [Figure 4.19 (B)]. In contrast to predominant enzyme activities in the previous study areas, Umananda showed higher dominance of Cd in monsoon season. It was assumed that Cd and dominance may have overcome the enzyme activities consistency by a marginal difference. Pollution indexing (discussed in Chapter 3) has clearly shown the contribution of Cd in raising the levels of pollution indices in soil. Majority of the negative loadings were attributed to weak correlation among the parameters.

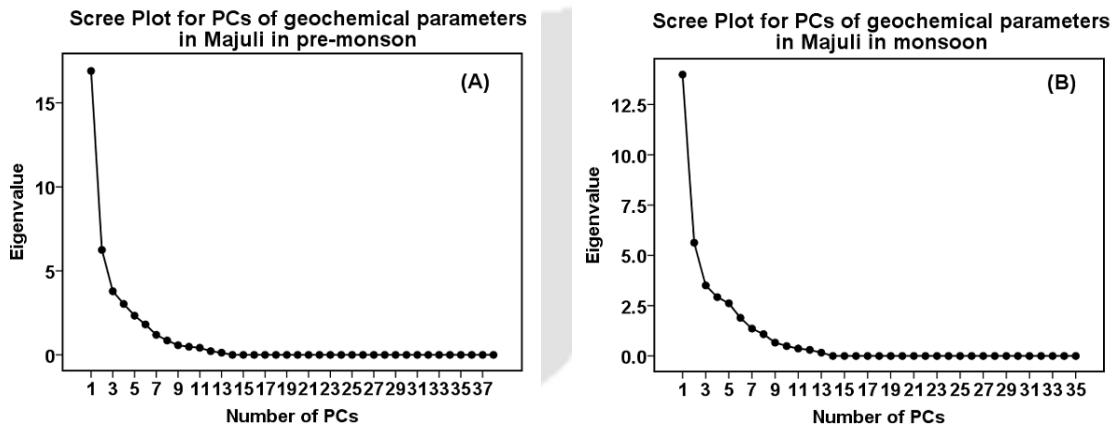


Figure 4.14 (A), (B) *Scree plots showing PCs of geochemical parameters in Majuli in pre-monsoon season and monsoon season respectively*

Table 4.1 (A) *Component matrix showing 8 PCs extracted for geochemical parameters in Majuli in pre-monsoon season, number of PCs and their absolute loadings correspond to scree plot [Figure 4.13 (A)]*

Component Matrix for geochemical parameters in Majuli in pre-monsoon							
(A)	Principal components						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigen Value	16.90*	6.25	3.79	3.03	2.34	1.81	1.19
% of Variance	44.48	16.44	9.97	7.98	6.15	4.77	3.13
Cumulative %	44.48	60.93	70.90	78.88	85.03	89.80	92.93
pH	-0.26	0.12	0.62	0.09	0.60	-0.30	0.08
Cond	-0.22	-0.19	0.32	0.27	0.70	0.05	-0.02
CEC	-0.54	0.62	0.17	0.17	0.09	-0.25	0.37
TOC	0.45	0.39	0.37	0.39	0.02	-0.18	-0.47
MBC	-0.28	0.72	-0.13	0.37	0.26	0.28	-0.21
TN	-0.07	0.77	-0.35	-0.27	0.32	0.21	0.04
MBN	0.83	0.29	-0.06	-0.41	0.15	-0.02	0.08
TP	0.91	-0.12	0.20	0.07	0.03	0.27	-0.07
MBP	0.66	0.30	-0.15	-0.01	0.18	0.61	0.02
ACP	0.90	0.06	-0.37	0.12	-0.03	0.02	0.05
ACP_T	0.91	0.09	-0.34	0.12	0.05	-0.10	0.01
AKP	0.96	-0.06	0.10	-0.05	-0.14	-0.04	0.02
AKP_T	0.95	0.02	0.09	-0.05	-0.09	0.00	-0.15
Amy	0.69	0.66	0.05	-0.05	-0.07	-0.13	0.13
Amy_T	0.62	0.71	0.07	-0.01	-0.03	-0.13	0.12
Cell	0.82	0.39	-0.10	-0.06	-0.21	0.23	0.07
Cell_T	0.88	0.32	-0.11	-0.06	-0.13	0.14	0.08
Deh	0.87	0.03	-0.17	0.14	0.09	-0.04	0.39
Deh_T	0.89	0.09	-0.07	0.23	0.27	-0.13	0.14
Inv	0.77	-0.27	-0.14	0.38	-0.09	-0.25	-0.09
Inv_T	0.50	0.39	-0.38	0.59	-0.09	0.08	-0.18
Pro	0.69	-0.16	0.25	0.60	0.10	0.08	0.18
Pro_T	0.73	-0.38	-0.13	0.29	0.19	-0.13	0.06

(A)	Principal components						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Urea	0.90	-0.32	-0.07	-0.11	0.07	0.06	-0.20
Urea_T	0.89	-0.35	0.08	0.08	0.19	-0.06	-0.04
BCFU	0.32	0.48	0.48	-0.47	0.16	-0.06	-0.34
FCFU	0.20	0.15	0.80	-0.04	-0.32	0.33	-0.03
Fe	0.65	-0.31	-0.19	-0.51	0.28	0.23	0.05
Cu	0.52	0.37	0.14	-0.42	0.48	-0.32	-0.20
Mn	0.07	-0.39	0.63	0.17	0.02	0.43	0.32
Zn	0.09	0.86	0.17	0.29	0.09	-0.05	0.15
Cd	0.34	0.34	0.33	-0.58	-0.35	-0.23	0.22
Cr	0.29	-0.10	0.88	0.14	-0.09	0.10	0.02
Pb	-0.16	-0.62	-0.16	-0.28	0.59	0.22	0.08
Ni	-0.49	0.45	0.06	0.02	-0.03	0.49	-0.17
Fine Sand	0.71	-0.57	0.14	0.10	-0.19	-0.14	-0.19
Silt	0.87	-0.30	0.24	-0.16	-0.05	0.03	0.07
Clay	0.94	-0.14	0.03	-0.27	0.05	0.01	-0.06

*Initial Eigen value from scree plot

Table 4.1 (B) *Component matrix showing 8 PCs extracted for geochemical parameters in Majuli in monsoon season, number of PCs and their absolute loadings correspond to scree plot [Figure 4.13 (B)]*

Component Matrix for geochemical parameters in Majuli in monsoon								
(B)	Principal components							
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
Eigen Value	13.99*	5.63	3.50	2.93	2.62	1.89	1.36	1.08
% of Variance	39.97	16.09	10.01	8.36	7.49	5.41	3.89	3.09
Cumulative %	39.97	56.06	66.07	74.43	81.92	87.33	91.22	94.31
pH	-0.28	0.04	0.07	0.43	0.66	-0.37	0.30	0.17
Cond	-0.03	0.20	-0.19	0.03	0.77	0.18	0.34	-0.36
CEC	-0.02	0.42	0.19	-0.04	-0.20	-0.70	0.43	0.13

(B)	Principal components							
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
TOC	0.11	0.78	0.26	-0.20	0.32	0.21	-0.12	0.05
MBC	-0.72	0.62	-0.05	0.22	0.09	0.08	-0.16	0.06
TN	-0.14	0.51	-0.36	0.60	-0.09	-0.18	-0.32	0.07
MBN	0.83	0.15	-0.34	0.30	0.01	-0.07	-0.08	0.22
TP	0.88	-0.23	0.05	-0.25	-0.03	-0.13	0.04	-0.19
MBP	0.81	0.04	-0.11	-0.08	-0.18	-0.11	-0.13	-0.37
ACP	0.89	0.29	-0.11	-0.10	-0.04	-0.01	-0.26	0.13
ACP_T	0.88	0.25	-0.08	-0.09	0.00	-0.08	-0.35	0.13
AKP	0.95	-0.17	-0.03	-0.13	0.04	0.01	0.14	-0.04
AKP_T	0.96	-0.17	0.04	-0.16	0.12	0.04	0.01	0.01
Amy	0.66	0.55	-0.19	0.07	-0.21	0.11	0.31	0.10
Amy_T	0.68	0.51	0.02	0.04	-0.20	0.26	0.31	-0.10
Cell	0.71	0.41	-0.13	0.23	-0.40	0.24	0.02	-0.10
Cell_T	0.81	0.36	-0.05	0.18	-0.35	0.15	0.05	-0.07
Deh	0.88	0.16	0.001	-0.13	0.12	0.18	0.21	0.28
Deh_T	0.82	0.37	-0.03	-0.19	0.23	0.06	0.24	0.18
Inv	0.33	0.71	0.32	-0.31	0.31	-0.11	-0.21	-0.15
Inv_T	0.68	0.18	0.16	-0.12	0.45	-0.31	-0.16	-0.08
Pro	-0.58	0.71	-0.01	0.02	0.18	0.28	-0.10	-0.06
Pro_T	-0.66	0.61	-0.22	-0.23	0.13	0.02	0.03	-0.05
Urea	0.89	-0.10	0.10	-0.27	0.20	0.04	-0.19	-0.11
Urea_T	0.81	-0.15	-0.17	-0.20	0.24	-0.19	-0.03	0.27
BCFU	0.47	-0.60	0.24	0.36	0.33	0.20	-0.14	0.06
FCFU	0.09	-0.21	0.76	-0.06	-0.32	0.20	0.09	0.33
Fe	0.69	-0.42	-0.36	0.19	0.15	0.31	-0.01	0.05
Cu	0.46	0.09	-0.37	0.71	0.16	-0.23	-0.12	-0.09
Mn	0.02	0.07	0.61	0.46	0.04	0.49	0.03	-0.17
Zn	-0.06	0.65	0.46	0.33	0.07	0.13	-0.05	0.30
Cd	0.57	-0.13	-0.08	0.70	-0.18	-0.14	0.19	-0.14
Cr	0.44	-0.20	0.70	0.31	0.23	-0.04	0.12	-0.15
Pb	-0.17	-0.56	-0.43	0.08	0.38	0.36	-0.04	0.29
Ni	0.32	-0.16	0.79	0.24	-0.02	-0.27	-0.28	0.002

*Initial Eigen value from scree plot

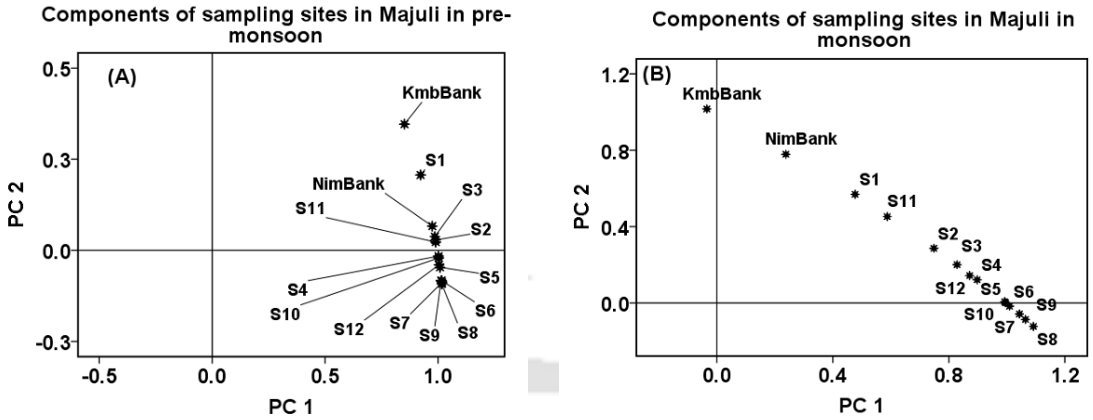


Figure 4.15 (A), (B) *PCs of samplings sites in Majuli in pre-monsoon season and monsoon season respectively*

Table 4.2 *Component matrix showing 2 PCs, each extracted for the sampling sites in Majuli, number of PCs and their absolute loadings correspond to the rotated plots in [Figure 4.14 (A), (B)], in pre-monsoon and monsoon season respectively*

Component Matrix for sampling sites in Majuli in pre-monsoon and monsoon season respectively				
	Components in pre-monsoon		Component in monsoon	
	PC 1	PC 2	PC 1	PC 2
Eigen Values	13.72*	0.19	13.20*	0.61
% of Variance	97.98	1.35	94.27	4.35
Cumulative %	97.98	99.33	94.27	98.62
S1	0.98	0.19	0.97	0.21
S5	1.00	-0.06	0.99	-0.14
S6	0.99	-0.10	0.98	-0.15
S11	1.00	0.01	0.98	0.14
S2	1.00	0.01	0.99	0.03
S3	1.00	0.02	1.00	-0.02
S4	1.00	-0.03	1.00	-0.07
S7	0.99	-0.10	0.98	-0.17
S8	0.99	-0.10	0.97	-0.21

	Components in pre-monsoon		Component in monsoon	
	PC 1	PC 2	PC 1	PC 2
S9	0.99	-0.10	0.98	-0.19
S10	1.00	-0.04	0.99	-0.13
S12	0.99	-0.05	0.99	-0.05
Kmb Bank	0.94	0.32	0.85	0.50
Nim Bank	0.99	0.05	0.92	0.34
*Initial Eigen value from scree plot (not shown)				

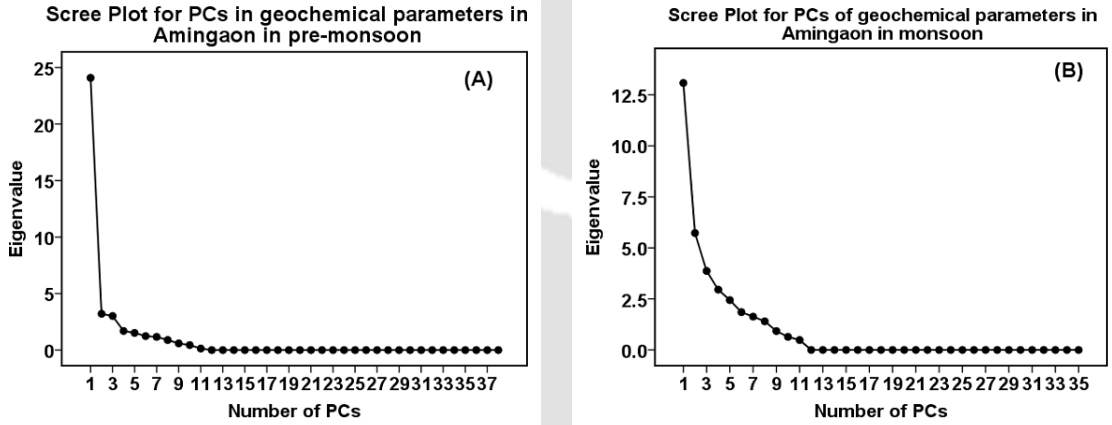


Figure 4.16 (A), (B) *Scree plots showing PCs of geochemical parameters in Amingaon in pre-monsoon season and monsoon season respectively*

Table 4.3 (A) *Component matrix showing 7 PCs extracted for geochemical parameters in Amingaon in pre-monsoon season, number of PCs and their absolute loadings correspond to scree plot in Figure 4.15 (A)*

Component Matrix for geochemical parameters in Amingaon in pre-monsoon							
(A)	Principal components						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigen Values	24.09*	3.21	3.01	1.69	1.52	1.24	1.17
% of Variance	63.38	8.46	7.93	4.46	4.00	3.26	3.07
Cumulative %	63.38	71.84	79.77	84.23	88.24	91.49	94.56
pH	0.75	-0.49	-0.02	0.04	-0.15	0.28	0.21

(A)	Principal components						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Cond	0.58	-0.50	-0.33	0.06	0.28	0.04	0.14
CEC	-0.72	-0.03	0.33	-0.06	0.12	0.52	0.08
TOC	0.83	-0.02	-0.20	0.21	-0.36	0.11	0.12
MBC	0.92	-0.05	-0.15	-0.02	-0.07	-0.13	-0.18
TN	0.91	-0.23	-0.02	0.08	0.00	0.16	-0.04
MBN	0.82	-0.20	-0.07	-0.003	0.44	0.12	0.17
TP	0.79	-0.52	-0.003	0.12	0.10	0.01	0.21
MBP	0.74	-0.56	-0.05	0.004	0.24	-0.11	0.09
ACP	0.76	-0.19	0.45	0.22	-0.30	0.17	-0.12
ACP_T	0.81	-0.09	0.45	0.18	-0.24	0.07	-0.14
AKP	0.95	-0.06	0.13	-0.24	0.01	0.01	0.12
AKP_T	0.94	-0.004	0.21	-0.13	-0.09	0.03	0.11
Amy	0.93	-0.12	0.17	-0.20	-0.11	0.05	-0.10
Amy_T	0.94	-0.11	0.15	-0.18	-0.05	-0.01	-0.10
Cell	0.88	0.24	0.04	-0.18	0.09	0.22	0.01
Cell_T	0.94	0.09	0.06	-0.16	0.06	0.17	-0.02
Deh	0.78	-0.08	-0.49	-0.03	0.04	0.02	-0.26
Deh_T	0.78	-0.10	-0.47	0.00	0.03	0.01	-0.29
Inv	0.89	-0.23	0.16	-0.08	0.15	-0.20	0.19
Inv_T	0.92	-0.09	0.02	0.06	0.24	0.04	0.06
Pro	0.95	0.07	0.19	-0.13	0.03	0.00	0.15
Pro_T	0.89	0.19	0.16	-0.30	0.03	0.17	0.06
Urea	0.95	0.16	-0.11	0.19	0.01	-0.13	0.04
Urea_T	0.95	0.17	-0.14	0.15	0.04	-0.13	0.03
BCFU	0.28	0.49	0.13	-0.44	-0.10	-0.25	0.56
FCFU	0.26	-0.35	0.60	0.19	0.34	-0.46	-0.23
Fe	0.61	0.62	0.22	0.24	0.12	-0.18	0.08
Cu	0.66	0.22	0.50	0.20	0.09	0.18	-0.28
Mn	0.64	0.39	0.48	-0.16	0.29	-0.16	-0.15
Zn	0.72	0.24	-0.08	-0.50	0.06	0.20	-0.32
Cd	0.82	0.23	-0.14	0.36	-0.19	0.11	0.25
Cr	0.12	0.62	0.05	0.53	0.44	0.33	0.08
Pb	0.60	-0.07	0.46	0.21	-0.50	-0.15	0.04

(A)	Principal components						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Ni	0.86	0.25	-0.31	-0.18	-0.19	-0.01	-0.14
Fine Sand	0.84	0.28	-0.39	0.08	0.04	-0.13	-0.08
Silt	0.76	0.39	-0.42	0.23	-0.04	-0.09	0.04
Clay	0.87	0.02	-0.23	0.10	-0.09	-0.09	-0.04

*Initial Eigen value in scree plot

Table 4.3 (B) *Component matrix showing 8 PCs extracted for geochemical parameters in Amingaon in monsoon season, number of PCs and their absolute loadings correspond to scree plot in Figure 4.15 (B)*

(B)	Component Matrix for geochemical parameters in Amingaon in monsoon							
	Principal components							
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
Eigen Values	13.08*	5.73	3.87	2.95	2.44	1.85	1.63	1.40
% of Variance	37.37	16.36	11.05	8.44	6.97	5.29	4.66	4.00
Cumulative %	37.37	53.73	64.78	73.22	80.19	85.47	90.14	94.14
pH	0.54	-0.40	-0.10	0.53	-0.22	0.04	0.17	-0.14
Cond	0.39	-0.58	-0.07	0.51	0.01	0.37	0.14	0.24
CEC	-0.37	0.66	-0.35	-0.22	0.16	-0.13	0.15	0.10
TOC	0.73	-0.63	-0.13	-0.07	-0.11	-0.02	0.06	-0.01
MBC	0.41	-0.85	-0.11	-0.09	-0.07	-0.12	-0.06	-0.07
TN	0.74	-0.21	-0.12	0.15	0.35	0.29	0.16	0.33
MBN	0.78	-0.24	-0.27	0.08	0.29	0.28	0.04	0.29
TP	0.61	-0.35	-0.23	-0.47	-0.28	0.00	-0.35	-0.02
MBP	0.65	-0.36	-0.32	-0.38	-0.29	0.12	-0.23	0.08
ACP	0.72	-0.27	-0.46	0.28	0.10	-0.15	0.12	-0.18
ACP_T	0.70	-0.23	-0.48	0.11	0.24	-0.21	0.22	-0.08
AKP	0.65	0.49	0.09	0.18	-0.49	0.15	0.02	-0.19
AKP_T	0.54	0.61	0.17	0.05	-0.48	0.10	0.11	-0.23
Amy	0.73	0.41	0.00	-0.15	-0.09	-0.34	0.27	0.24
Amy_T	0.80	0.46	0.11	-0.11	-0.11	-0.26	0.04	0.16
Cell	0.75	0.49	-0.18	-0.22	0.20	-0.10	-0.01	-0.02

(B)	Principal components							
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
Cell_T	0.74	0.45	-0.19	-0.35	0.24	-0.04	0.00	0.10
Deh	0.35	-0.19	0.77	0.03	0.28	-0.30	0.24	0.03
Deh_T	0.34	-0.20	0.78	0.03	0.28	-0.29	0.23	0.04
Inv	0.43	0.52	-0.22	-0.36	0.40	0.30	0.08	-0.16
Inv_T	0.30	0.61	0.22	-0.12	0.03	0.52	0.35	-0.08
Pro	0.28	0.27	0.09	0.35	0.19	-0.41	-0.53	0.34
Pro_T	0.49	-0.29	0.60	0.003	-0.24	-0.06	0.14	0.36
Urea	0.84	0.38	0.20	0.31	0.01	-0.08	-0.05	-0.02
Urea_T	0.85	0.42	0.10	0.26	0.05	-0.03	0.06	0.02
BCFU	0.64	-0.01	0.34	-0.07	-0.48	-0.09	-0.20	-0.15
FCFU	0.18	0.35	-0.60	0.43	-0.35	0.09	0.09	0.31
Fe	0.87	-0.05	0.27	-0.30	-0.07	-0.07	-0.15	-0.21
Cu	0.02	0.02	0.72	0.15	-0.06	0.59	-0.10	0.04
Mn	0.63	0.42	-0.04	0.31	-0.17	0.08	-0.46	0.23
Zn	0.42	-0.29	-0.01	-0.76	-0.19	0.15	0.12	0.22
Cd	0.77	-0.29	0.09	0.12	0.23	0.08	-0.13	-0.34
Cr	0.31	0.10	0.23	0.01	0.62	0.28	-0.57	-0.07
Pb	0.67	0.04	-0.24	0.33	0.17	-0.12	0.05	-0.47
Ni	0.84	-0.28	0.08	-0.35	0.12	0.05	0.07	-0.01

*Initial Eigen value in scree plot

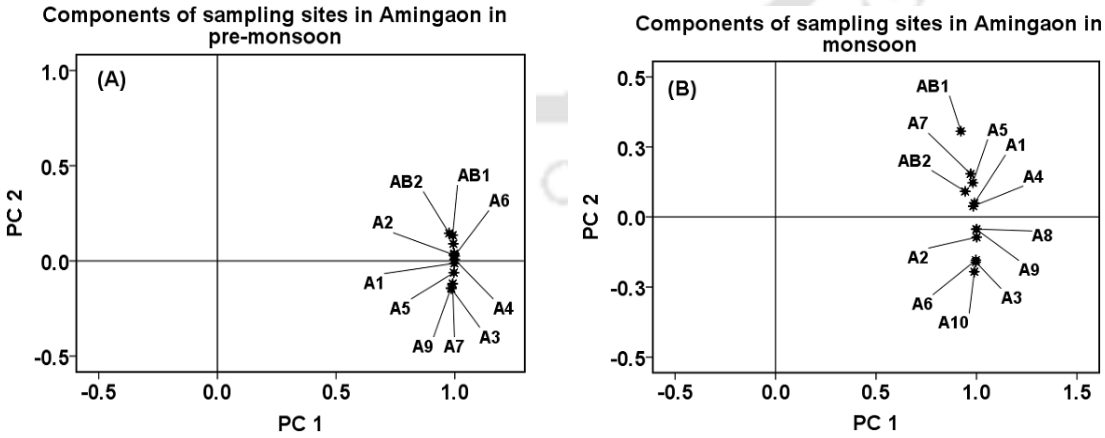


Figure 4.17 (A), (B) *PCs of samplings sites in Amingaon in pre-monsoon season and monsoon season respectively*

Table 4.4 *Component matrix showing 2 PCs, each extracted for the sampling sites in Amingaon, number of PCs and their absolute loadings correspond to the rotated plots in [Figure 4.16 (A), (B)], in pre-monsoon and monsoon season respectively*

Component Matrix for sampling sites in Amingaon in pre-monsoon and monsoon season respectively				
	Components in pre-monsoon		Components in monsoon	
	PC 1	PC 2	PC 1	PC 2
Eigen Values	11.82*	0.11	11.57*	0.24
% of Variance	98.46	0.92	96.42	1.99
Cumulative %	98.46	99.38	96.42	98.41
A1	1.00	-0.01	0.99	0.04
A2	1.00	0.03	1.00	-0.08
A4	1.00	0.01	0.99	0.03
A6	1.00	0.03	0.98	-0.16
A8	1.00	0.04	1.00	-0.05
A10	0.99	0.09	0.97	-0.20
A3	0.99	-0.15	0.98	-0.17
A5	1.00	-0.06	0.99	0.12
A7	0.99	-0.12	0.98	0.15
A9	0.99	-0.14	1.00	-0.05
AB1	0.99	0.14	0.95	0.30
AB2	0.97	0.15	0.95	0.09

*Initial Eigen value from scree plot (not shown)

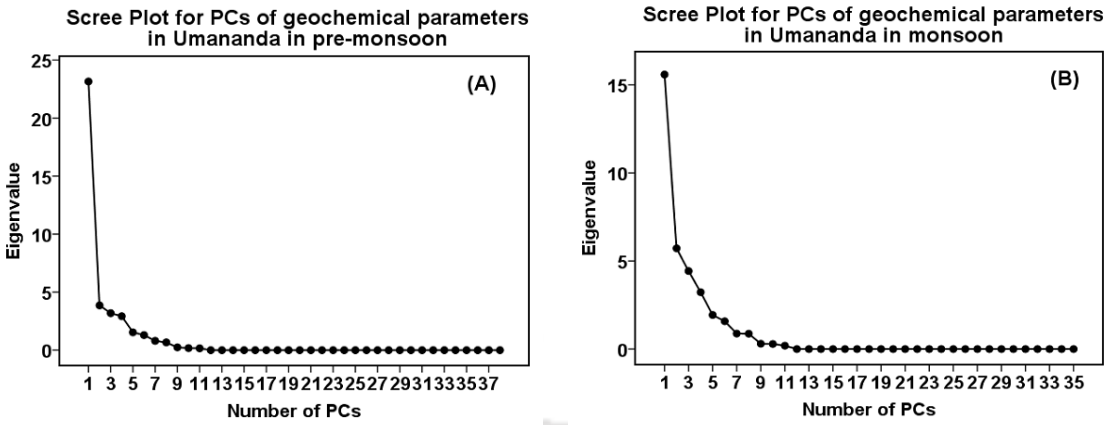


Figure 4.18 (A), (B) *Scree plots showing PCs of geochemical parameters in Umananda in pre-monsoon season and monsoon season respectively*

Table 4.5 (A) *Component matrix showing 6 PCs extracted for geochemical parameters in Umananda in pre-monsoon season, number of PCs and their absolute loadings correspond to scree plot in Figure 4.17 (A)*

Component Matrix for geochemical parameters in Umananda in pre-monsoon						
(A)	Principal components					
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Eigen Values	23.16*	3.86	3.19	2.92	1.54	1.30
% of Variance	60.94	10.15	8.39	7.68	4.04	3.42
Cumulative %	60.94	71.09	79.49	87.17	91.21	94.63
pH	0.35	0.70	-0.19	0.28	0.28	0.33
Cond	0.37	0.54	-0.17	0.45	-0.31	-0.21
CEC	-0.73	0.23	-0.13	0.32	-0.27	0.24
TOC	0.94	0.17	0.06	-0.18	0.01	-0.20
MBC	0.93	0.21	-0.16	0.05	-0.19	0.07
TN	0.80	-0.09	-0.45	-0.33	-0.16	-0.05
MBN	0.81	-0.15	-0.43	-0.22	-0.24	-0.03
TP	0.88	0.30	-0.29	-0.05	0.14	-0.02
MBP	0.85	0.30	-0.31	-0.22	0.12	0.03
ACP	0.69	-0.13	0.57	-0.19	-0.08	0.22
ACP_T	0.66	-0.20	0.57	-0.19	-0.05	0.24
AKP	0.97	0.10	-0.13	-0.10	0.04	-0.06

(A)	Principal components					
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
AKP_T	0.97	0.06	-0.11	-0.06	0.03	-0.10
Amy	0.98	-0.01	0.03	0.06	0.08	-0.16
Amy_T	0.97	0.02	0.08	0.04	0.09	-0.17
Cell	0.91	0.15	0.03	0.28	0.03	0.20
Cell_T	0.93	0.25	-0.11	0.16	0.07	0.05
Deh	0.64	0.25	0.48	0.43	0.16	-0.08
Deh_T	0.63	0.26	0.44	0.49	0.16	0.00
Inv	0.57	0.67	0.17	-0.35	0.17	-0.12
Inv_T	0.69	0.60	0.13	0.14	0.14	0.20
Pro	0.69	-0.40	-0.24	0.52	-0.09	0.14
Pro_T	0.65	-0.56	-0.33	0.29	-0.02	0.23
Urea	0.94	-0.14	0.15	-0.20	0.06	-0.01
Urea_T	0.95	-0.12	0.12	-0.16	0.07	-0.03
BCFU	-0.22	0.18	0.42	-0.82	0.05	0.17
FCFU	0.29	-0.63	-0.03	0.18	0.38	0.44
Fe	0.84	0.06	-0.03	0.12	-0.39	0.26
Cu	0.88	0.19	-0.01	0.03	-0.18	-0.05
Mn	0.81	-0.38	-0.29	-0.14	0.14	0.17
Zn	0.75	-0.33	0.55	-0.04	0.12	-0.03
Cd	0.95	-0.01	-0.09	-0.20	-0.07	0.19
Cr	0.34	-0.36	-0.33	0.20	0.65	-0.40
Pb	0.73	-0.35	0.21	0.13	-0.36	-0.35
Ni	0.60	0.07	-0.56	-0.51	0.03	0.11
Fine Sand	0.96	-0.15	0.11	-0.04	-0.06	-0.06
Silt	0.87	-0.34	0.20	0.03	-0.07	-0.18
Clay	0.86	-0.18	0.23	0.14	-0.23	0.004

*Initial Eigen value from scree plot

Table 4.5 (B) *Component matrix showing 6 PCs extracted for geochemical parameters in Umananda in monsoon season, number of PCs and their absolute loadings correspond to scree plot in Figure 4.17 (B)*

Component Matrix for geochemical parameters in Umananda in monsoon						
(B)	Principal components					
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Eigen Values	15.59*	5.72	4.43	3.23	1.93	1.58
% of Variance	44.54	16.33	12.65	9.22	5.53	4.51
Cumulative %	44.54	60.87	73.52	82.74	88.27	92.78
pH	0.17	0.31	-0.62	0.53	0.35	-0.05
Cond	0.13	-0.14	-0.57	0.60	0.02	-0.43
CEC	-0.55	-0.37	-0.09	-0.44	-0.18	0.31
TOC	0.82	0.23	-0.27	0.37	-0.11	-0.05
MBC	0.76	0.39	0.10	0.42	-0.21	-0.13
TN	0.80	0.52	-0.08	-0.10	-0.18	-0.07
MBN	0.84	0.42	-0.15	-0.08	-0.21	-0.14
TP	0.50	-0.04	0.77	-0.21	-0.15	-0.19
MBP	0.40	0.03	0.79	-0.27	0.01	-0.25
ACP	0.63	-0.11	-0.49	-0.46	-0.25	0.07
ACP_T	0.60	-0.06	-0.61	-0.38	-0.13	-0.09
AKP	0.83	-0.44	-0.08	-0.09	0.23	-0.08
AKP_T	0.53	-0.73	0.12	0.40	-0.02	-0.05
Amy	0.85	-0.38	-0.04	-0.26	0.01	0.17
Amy_T	0.85	-0.40	-0.14	-0.30	0.04	0.06
Cell	0.91	0.20	0.03	-0.12	-0.30	0.06
Cell_T	0.87	0.10	-0.07	-0.27	-0.29	0.07
Deh	0.58	-0.44	0.12	0.41	0.14	0.49
Deh_T	0.52	-0.51	0.21	0.46	-0.02	0.45
Inv	0.18	0.32	0.67	0.42	-0.16	-0.32
Inv_T	0.13	0.25	0.79	-0.12	0.38	0.02
Pro	0.30	0.69	-0.01	0.17	0.31	0.49
Pro_T	0.45	0.72	-0.20	0.05	0.25	0.35
Urea	0.88	-0.43	-0.08	0.08	0.05	-0.03
Urea_T	0.86	-0.46	-0.07	-0.02	0.06	-0.17
BCFU	-0.37	0.19	0.42	0.29	-0.56	0.33

(B)	Principal components					
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
FCFU	0.44	-0.41	0.34	-0.33	0.39	0.01
Fe	0.89	0.17	-0.11	-0.14	-0.30	0.10
Cu	0.84	0.35	0.27	0.12	-0.10	0.09
Mn	0.86	0.26	0.19	-0.16	0.29	0.04
Zn	0.78	-0.25	0.35	0.38	0.04	-0.03
Cd	0.96	-0.19	0.04	-0.08	0.14	-0.03
Cr	0.35	0.64	-0.08	-0.31	0.54	-0.16
Pb	0.81	-0.22	-0.15	0.25	0.03	-0.09
Ni	0.43	0.85	-0.01	-0.06	-0.10	0.04

*Initial Eigen value from scree plot

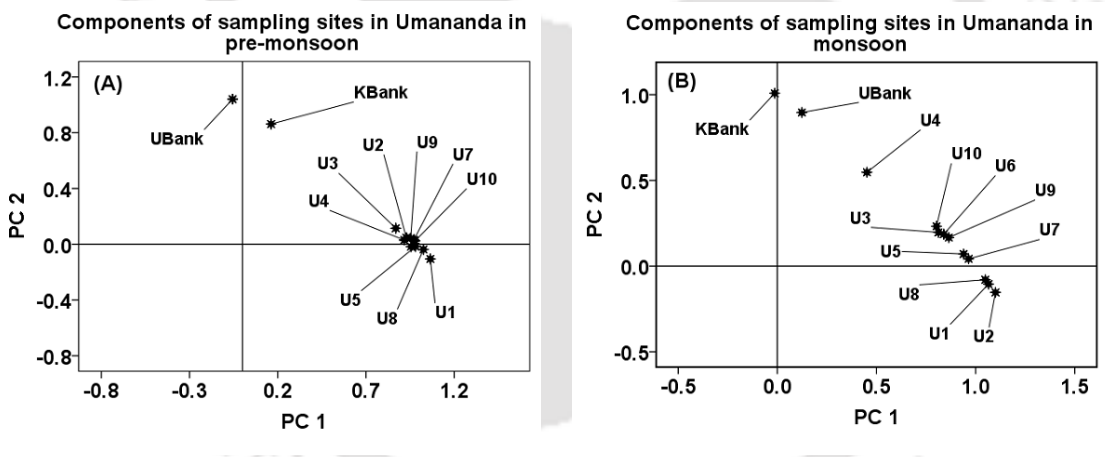


Figure 4.19 (A), (B) *PCs of samplings sites in Umananda in pre-monsoon season and monsoon season respectively*

Table 4.6 *Component matrix showing 2 PCs, each extracted for the sampling sites in Umananda, number of PCs and their absolute loadings correspond to the rotated plots in [Figure 4.18 (A), (B)], in pre-monsoon season and monsoon season respectively*

Component Matrix for sampling sites in Umananda in pre-monsoon and monsoon season respectively				
	Components in pre-monsoon		Components in monsoon	
	PC 1	PC 2	PC 1	PC 2
Eigen Values	10.82*	0.65	10.92*	0.74
% of Variance	90.15	5.43	91.03	6.15
Cumulative %	90.15	95.58	91.03	97.19
U2	0.96	-0.07	0.96	-0.26
U3	0.96	-0.02	0.97	-0.03
U5	0.96	-0.11	0.99	-0.12
U7	0.99	-0.08	0.99	-0.14
U9	0.99	-0.07	1.00	-0.05
U1	0.97	-0.17	0.96	-0.23
U4	0.94	-0.08	0.91	0.22
U6	0.94	-0.11	0.99	-0.04
U8	0.99	-0.12	0.97	-0.21
U10	0.99	-0.09	0.99	-0.01
U Bank	0.81	0.59	0.88	0.45
K Bank	0.88	0.46	0.84	0.53
*Initial Eigen value from scree plot (not shown)				

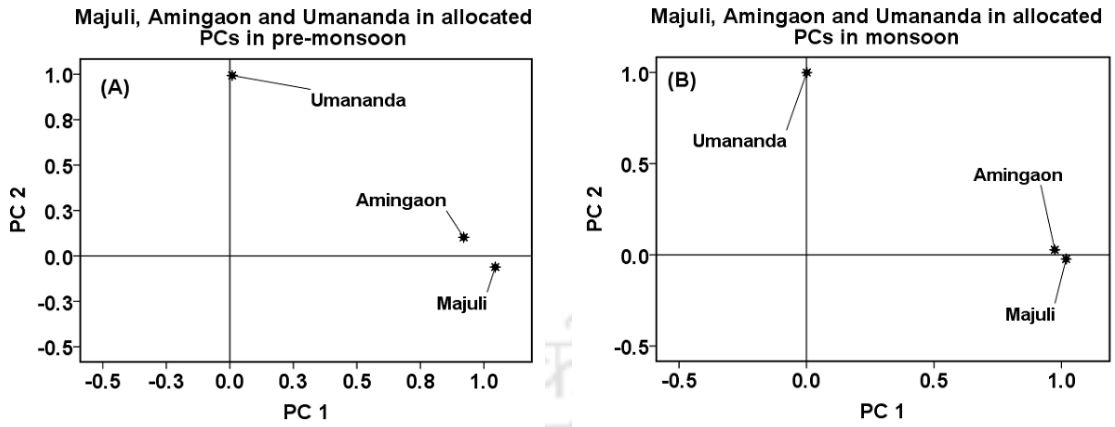


Figure 4.20 (A), (B) *PCs allocated in Majuli, Amingaon and Umananda based on geochemical properties in pre-monsoon season and monsoon season respectively*

Table 4.7 *Component matrix showing 2 PCs, each extracted for the sampling sites in Majuli, Amingaon and Umananda, number of PCs and their absolute loadings correspond to the rotated plots in [Figure 4.19 (A), (B)], in pre-monsoon season and monsoon season respectively*

Combined Component Matrix for sampling sites in Majuli, Amingaon and Umananda in pre-monsoon and monsoon season respectively

	Components in pre-monsoon		Components monsoon	
	PC 1	PC 2	PC 1	PC 2
Eigen Values	2.68*	0.32	2.83*	0.16
% of Variance	89.44	10.52	94.49	5.27
Cumulative %	89.44	99.96	94.49	99.75
Majuli	0.96	-0.27	0.98	-0.17
Amingaon	0.99	-0.16	0.99	-0.15
Umananda	0.88	0.47	0.94	0.33

*Initial Eigen value from scree plot (not shown)

Overall results indicated that bank sediments in Majuli, Amingaon and Umananda have soil properties unique and different from the terrestrial sediments. The occurrence of spatial variability was established by combined PC loadings of Majuli,

Amingaon and Umananda plotted in a 2D plane. PCA were higher in Amingaon due to high positive correlation incidences of geochemical parameters (Table 4.7). PC plot clearly delineated Umananda from Majuli and Amingaon based on geochemical properties and spatial variability [Figure 4.20 (A), (B)]. In Chapter 2 and Chapter 3, relatively high fertility and productivity in terms of SOM, microbial population and enzyme activity; significant metal concentration (except total Fe); CEC and increasing levels of pollution indices were observed in Umananda. Thus geochemical properties experienced substantial spatial variability and in addition to it, influence of regionalized soil properties demarcated Majuli, Amingaon and Umananda into distinct pockets. Majuli and Amingaon showed similarity in soil properties that allocated them in close proximity in PC loading plots.

4.3.2 Variation in geochemical parameters based on geostatistical analysis: semivariogram spherical model and kriging

To establish the effect of spatial variability on soil parameters, geostatistical analysis was performed using Arc GIS 9.3: GeoAnalyst tool. Semivariogram analysis is an important component of geostatistical analysis associated with data analysis based on spatial autocorrelation grounds. A semivariogram spherical model was employed to check the effect of spatial variability on geochemical properties under the influence of regionalized and pertinent soil properties in the three study areas. Geochemical parameters analysed in Majuli, Amingaon and Umananda were used as raw data for the semivariogram model. Semivariograms gave an overview of the differences between the three locations based on geochemical properties (Figure 4.21). Geographical location of the sampling sites is an important criterion for studying spatial variability.

According to Loescher et al (2014), choosing an appropriate distance between samples is important and the sampling sites should ideally be spaced sufficiently far apart to avoid correlation and pseudoreplication in measurements at a given scale. Distance between Majuli and Guwahati is approximately 264 km which is fairly acceptable for spatial variation studies.

Semivariogram spherical model outputs showed mixed results, based on the semivariogram plot and DSD (%) it was found that geochemical parameters like EC (in monsoon), CEC (in monsoon), TOC (in monsoon), TN (in monsoon), TP (in pre-monsoon), MBC (in pre-monsoon), MBP (in pre-monsoon), ACP activity, AKP activity (in pre-monsoon and monsoon), dehydrogenase activity (in pre-monsoon), invertase activity (in pre-monsoon), protease (in pre-monsoon and monsoon), urease, Fe (in pre-monsoon and monsoon), Cu (in pre-monsoon) and Cd (in pre-monsoon) showed minimal variation with respect to geo position. In this context, results seemed to vary from PCA and quartile deviation analysis, but it indicates a new frontier of existence of more or less a similar kind of stress in case of a few geochemical parameters in Majuli, Amingaon and Umananda.

Parameters, EC (in pre-monsoon), TN (in pre-monsoon), MBP (in monsoon), amylase activity (in monsoon), invertase (in monsoon), Zn in (in pre-monsoon and monsoon) and Pb (in pre-monsoon and monsoon) showed strong spatial variability as the DSD (%) was less than 25 %. Surprisingly parameters that presented weak DSD (%) in one season turned out to exhibit strong spatial variability in the other season, this indicate seasonal variability as another important function of geostatistical analyses. pH (in pre-monsoon and monsoon), CEC (in pre-monsoon), MBC (in monsoon), MBN (in

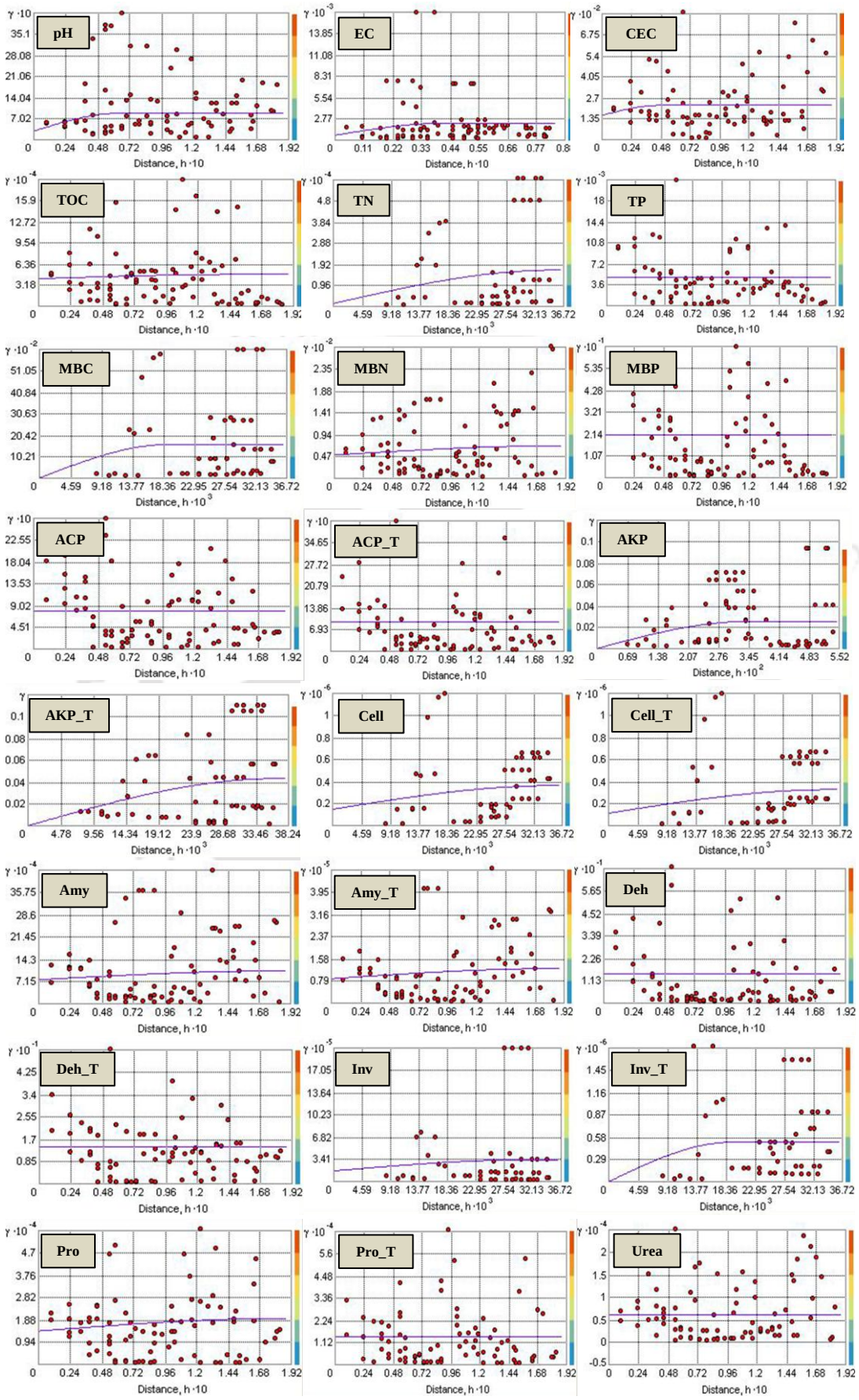
pre-monsoon), AKP (in pre-monsoon), cellulase (in pre-monsoon and monsoon), amylase, dehydrogenase (in monsoon), invertase (in pre-monsoon), protease (in pre-monsoon), Mn (in pre-monsoon), Cr (in pre-monsoon and monsoon) and Ni (in monsoon) showed moderate spatial variability. Rest of the parameters showed weak to negligible spatial variability under a seasonal influence. Details of geochemical parameters and their extent of spatial variability in pre-monsoon and monsoon season respectively are discussed in Table 4.8

Table 4.8 *Results of semivariogram model analysis, values of model parameters and DSD (%) in Majuli, Amingaon and Umananda in pre-monsoon and monsoon season respectively*

Parameters	Season	Nugget C_o	Partial Sill C'	Range (R)	Sill (C_o +C')	Nugg/Sill ratio	DSD (%)	Extent of degree of variability
pH	PM	0.29	0.59	0.016	0.88	0.32	32.44	Moderate
	M	0.27	0.32	0.010	0.59	0.45	45.12	Moderate
EC	PM	626.23	1568.3	0.007	2194.53	0.29	28.54	Strong
	M	2080.10	0	0.016	2080.10	1.00	100.00	Weak
CEC	PM	155.68	64.89	0.016	220.57	0.71	70.58	Moderate
	M	0	152.90	0.003	152.90	0	0	-
TOC	PM	41346	6476	0.016	47822.00	0.86	86.46	Weak
	M	0	49475	0.012	49475.00	0	0	-
TN	PM	1300	15220	0.003	16519.90	0.08	7.87	Strong
	M	12070	0	0.016	12070.00	1.00	100.00	Weak
TP	PM	4925.90	0.00	0.016	4925.90	1.00	100.00	Weak
	M	681.09	639.01	0.016	1320.10	0.52	51.59	Moderate
MBC	PM	0	1600.60	0.003	1600.60	0	0	
	M	30.85	12.75	0.016	43.60	0.71	70.76	Moderate
MBN	PM	50.13	19.73	0.016	69.87	0.72	71.76	Moderate
	M	46.16	6.76	0.016	52.92	0.87	87.23	Weak
MBP	PM	20.90	0	0.016	20.90	1.00	100.00	Weak
	M	3.43	22.21	0.016	25.64	0.13	13.37	Strong

Parameters	Season	Nugget C_o	Partial Sill C'	Range (R)	Sill (C_o +C')	Nugg/Sill ratio	DSD (%)	Extent of degree of variability
ACP	PM	0.79	0	0.016	0.79	1.00	100.00	Weak
	M	0.75	0	0.016	0.75	1.00	100.00	Weak
ACP_T	PM	0.92	0	0.016	0.92	1.00	100.00	Weak
	M	0.83	0	0.016	0.83	1.00	100.00	Weak
AKP	PM	0	0.03	0.005	0.03	0	0	-
	M	0.01	0	0.016	0.01	1.00	100.00	Weak
AKP_T	PM	0	0.04	0.004	0.04	0	0	-
	M	0.02	0	0.016	0.02	0.81	81.34	Moderate
Cell	PM	147310.00	214880.00	0.003	362190.00	0.41	40.67	Moderate
	M	79569.00	140060.00	0.016	219629.00	0.36	36.23	Moderate
Cell_T	PM	112580.00	214130.00	0.003	326710.00	0.34	34.46	Moderate
	M	145770.0	168630.0	0.016	314400.0	0.5	46.4	Moderate
Amy	PM	77308.00	28034.00	0.016	105342.00	0.73	73.39	Moderate
	M	59143.00	260750.00	0.016	319893.00	0.18	18.49	Strong
Amy_T	PM	86784.00	36333.00	0.016	123117.00	0.70	70.49	Moderate
	M	112580.00	287590.00	0.016	400170.00	0.28	28.13	Moderate
Deh	PM	14.80	0	0.016	14.80	1.00	100.00	Weak
	M	4.87	10.51	0.016	15.38	0.32	31.66	Moderate
Deh_T	PM	14.132	0	0.016	14.13	1.00	100.00	Weak
	M	10.049	21.768	0.016	31.82	0.32	31.58	Moderate
Inv	PM	161710.00	168520.00	0.003	330230.00	0.49	48.97	Moderate
	M	72275.00	229680.00	0.016	301955.00	0.24	23.94	Strong
Inv_T	PM	0	514560.00	0.003	514560.00	0.00	0	
	M	139400.00	3722.30	0.016	143122.30	0.97	97.40	Weak
Protease	PM	14023	5353	0.016	19376.00	0.72	72.37	Moderate
	M	0	33670	0.010	33670.00	0	0	-
Pro_T	PM	14047.00	0	0.016	14047.00	1.00	100.00	Weak
	M	0	29739.00	0.003	29739.00	0	0	-
Urea	PM	6009.9	0	0.016	6009.90	1.00	100.00	Weak
	M	50363.00	15667.00	0.016	66030.00	0.76	76.27	Weak
Urea_T	PM	12939.00	3253.90	0.016	16192.90	0.80	79.91	Weak
	M	0	1041800.0	0.016	1041800.0	0	0	-

Parameters	Season	Nugget C_o	Partial Sill C'	Range (R)	Sill (C_o +C')	Nugg/Sill ratio	DSD (%)	Extent of degree of variability
Fe	PM	0	2.02E-07	0.010	0.01	0	0	-
	M	1.4×10^{-8}	3.2×10^{5}	0.016	3.2×10^{5}	4.3×10^{-14}	4.3×10^{-12}	-
Cu	PM	855.20	0	0.016	855.20	1.00	100.00	Weak
	M	1095.00	0	0.016	1095.00	1.00	100.00	Weak
Mn	PM	6019	7297.50	0.003	13316.50	0.45	45.20	Moderate
	M	11830	760.80	0.016	12590.80	0.94	93.96	Weak
Zn	PM	181.61	967.93	0.003	1149.54	0.16	15.80	Strong
	M	221.02	721.22	0.016	942.24	0.23	23.46	Strong
Cd	PM	0	0.01	0.008	0.01	0	0	-
	M	0	0	0.003	0	0	0	-
Cr	PM	0.0020573	0.00	0.016	0.01	0.41	41.13	Moderate
	M	0.00188	0.002406	0.016	0.00	0.44	43.87	Moderate
Pb	PM	0	57.67	0.008	57.67	0	0	Strong
	M	0.54	54.75	0.007	55.28	0.01	0.97	Strong
Ni	PM	0.69	0.23	0.016	0.91	0.75	75.31	Weak
	M	0.61	0.41	0.016	1.02	0.60	59.89	Moderate



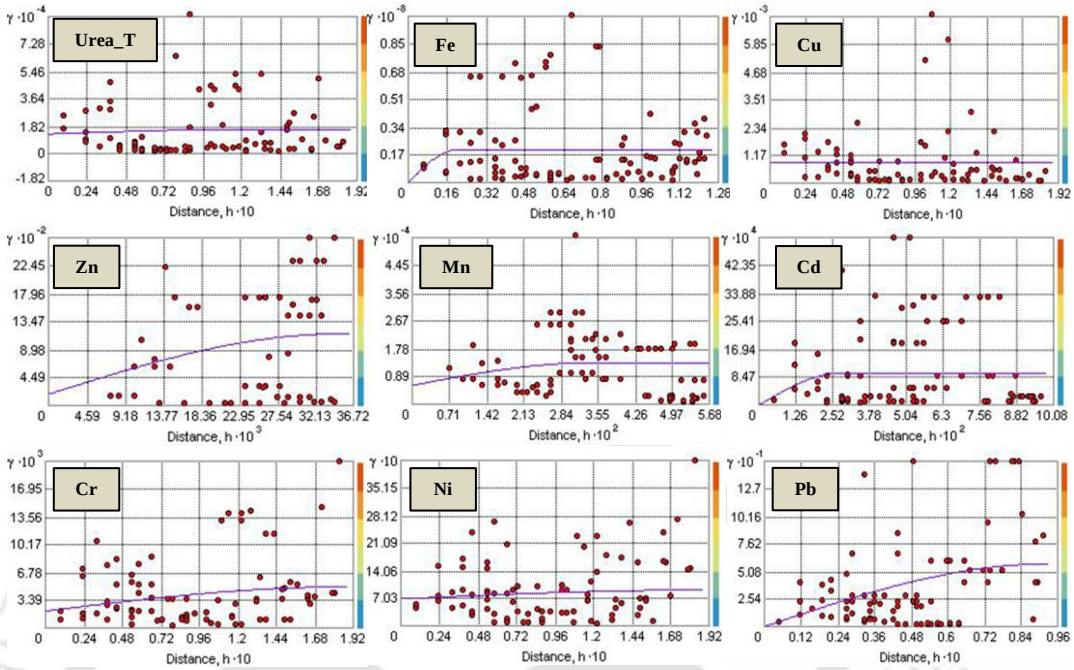


Figure 4.21 *Semivariograms of geochemical parameters showing semivariance plots and trend of Range, Nugget and Partial Sill, in pre-monsoon season*

Figure 4.21 explains the reason behind the high or low spatial variability of geochemical parameters. Piotrowska et al (2011), considered Nugget effect as the root cause of moderate to weak variability among soil parameters. A similar set of semivariograms was also obtained for monsoon season. As mentioned above, Nugget is responsible for random variances where variability due to semivariogram model is not taken into account, rather measurement error due to factors like fine scale variability are considered, this is known as the Nugget effect. In this case Nugget effect was assumed to render lower spatial variability among the geochemical parameters. In case of weak spatial variability cases like TOC and TP in pre-monsoon, the semivariogram plots [Figure 4.21: TOC and TP] showed a flat a curve fitting, with insignificant

demarcation of Range, Nugget and Partial Sill. This resulted in flattening of the semivariance plot along the distribution space. These outputs also indicate that at a particular geographical coordinate and space, TOC and TP may have experienced identical stress related to environmental implications, human intervention or pertaining soil properties that led to less variability in their weighted values.

In support of the semivariogram spherical model outputs, kriged maps were generated. These maps gave a visualization of spatial variability in defined geographical coordinate axes. Colour patches indicate the intensity of dominance of a parameter in a region. The advantage of kriging is that it estimates surface from a scattered set of points fits a mathematical function to the specified number of points, within a specified radius and determine the output value for each location. Kriged maps of a few visibly significant parameters are presented in [Figure 4.22 (A), (B); 4.23 (A), (B); 4.24 (A), (B)]. Figure 4.22 (A), (B) shows overall depiction of spatial variability in Majuli in the upper middle region of Brahmaputra floodplain and Kamrup (Amingaon and Umananda) in the lower Brahmaputra floodplain. Figure 4.23 (A), (B) shows individual spatial variability among geochemical parameters in Majuli whereas Figure 4.24 (A), (B) shows similar illustration in Amingaon and Umananda.

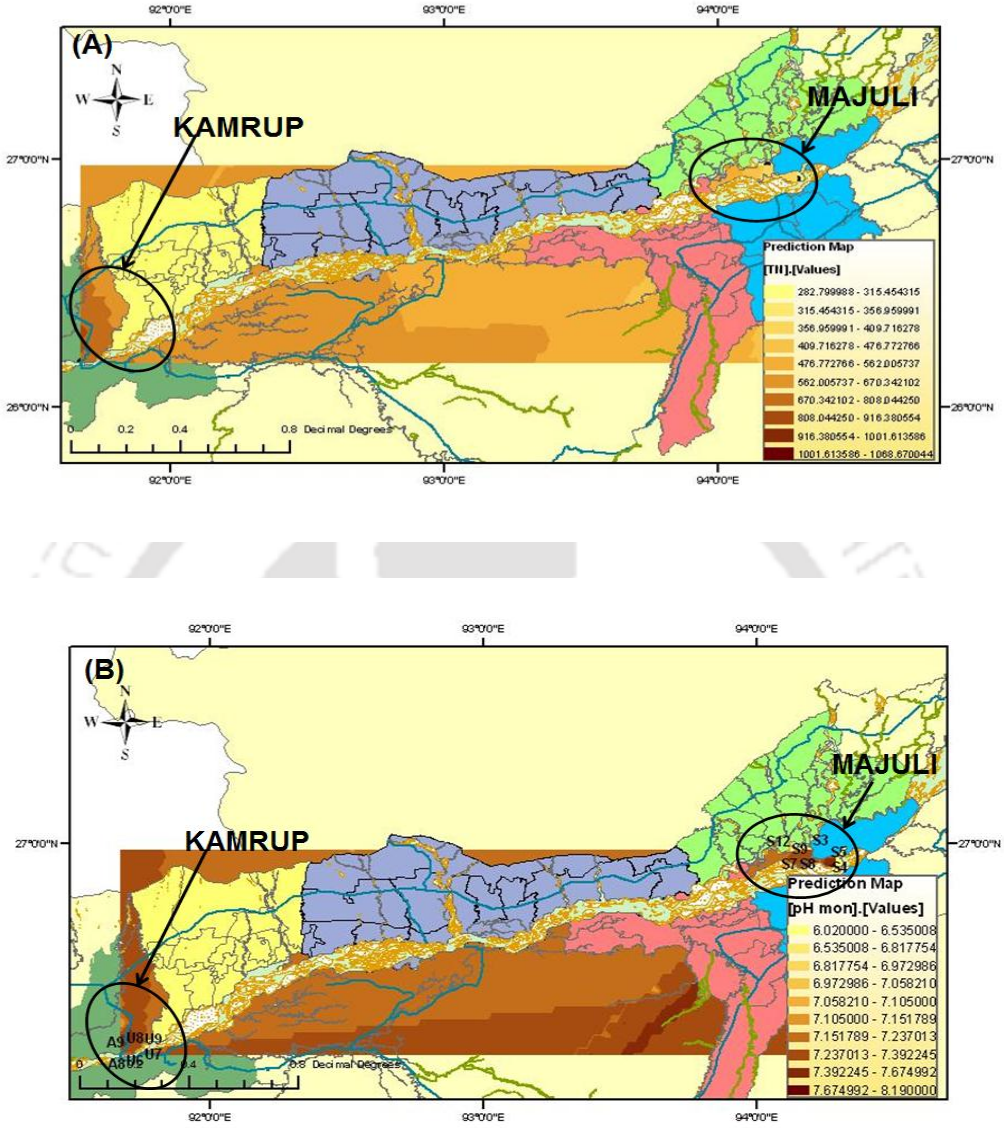


Figure 4.22 (A), (B) *Kriged maps showing the variation of TN in pre-monsoon and pH in monsoon based on geoposition in Majuli and Kamrup (Amingaon and Umananda) respectively*

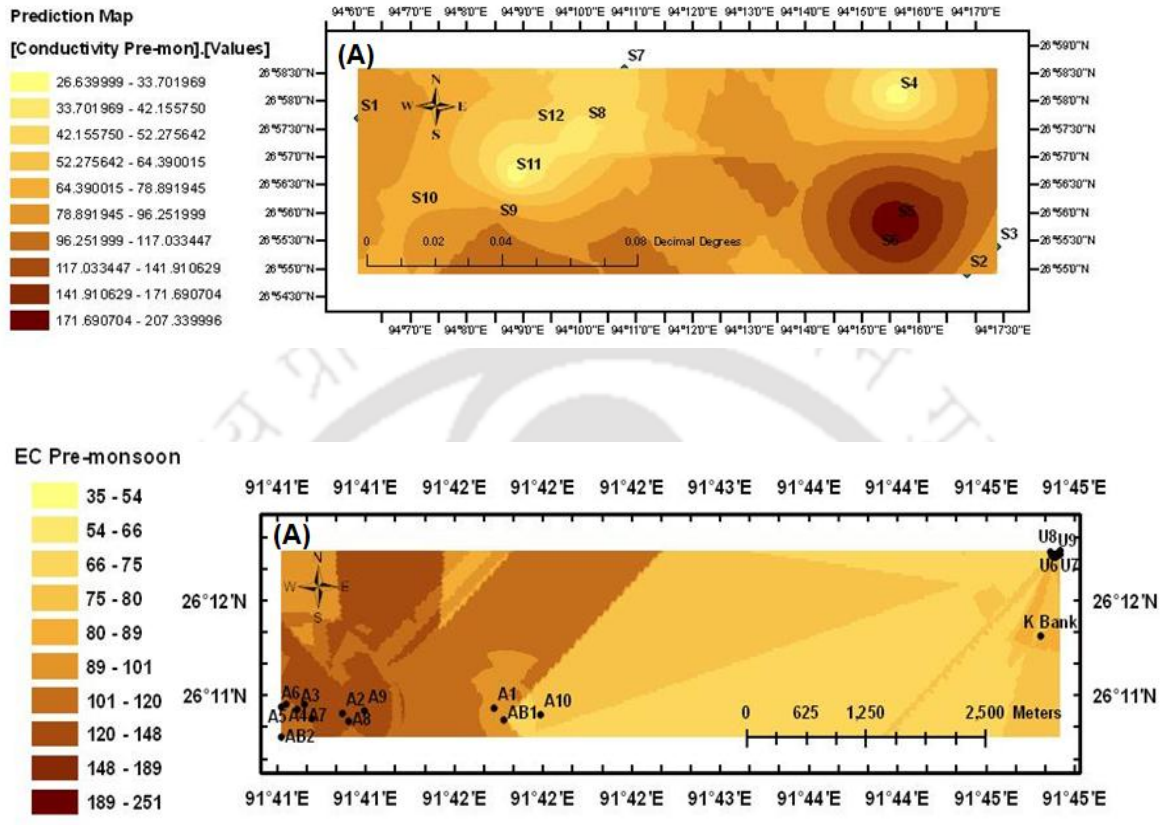
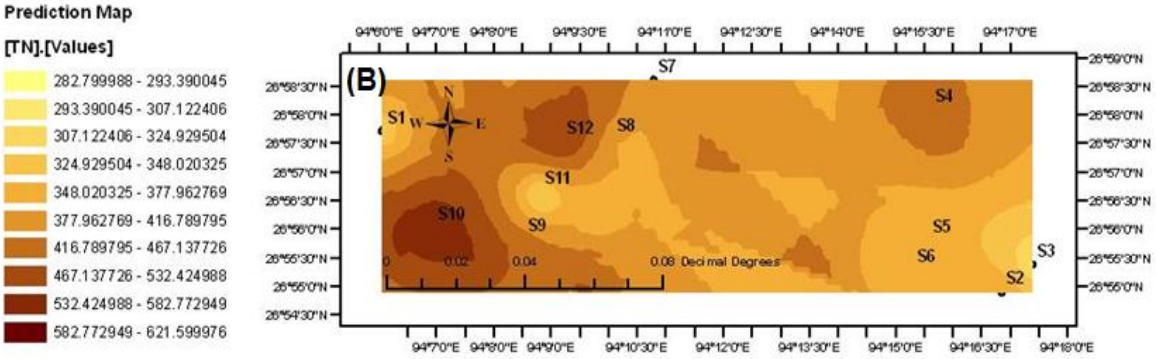


Figure 4.23 (A), (B) *Kriged maps showing the variation of EC based on geoposition in Majuli and Kamrup (Amingaon and Umananda) in pre-monsoon season*



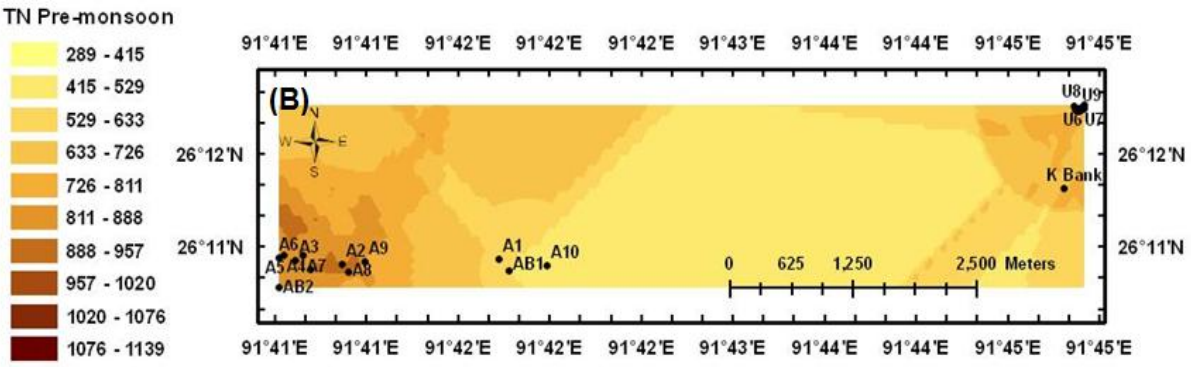


Figure 4.24 (A), (B) *Kriged maps showing the variation of TN based on geoposition in Majuli and Kamrup (Amingaon and Umananda) in monsoon season*

4.4 CONCLUSION

This chapter demonstrated a comparative assessment of two soil typologies in Brahmaputra floodplain based on geochemical parameters and their relative spatial variability. Linear comparison studies based on frequency distribution statistics, measurement of dispersion and co-efficient of variation showed that Kamrup being at a lower altitude (35 – 55 m above mean sea level) than upland Majuli River Island, the concentration of soil parameters like SOM, soil MB, enzyme activities and metal concentration were relatively higher. Nature of experimental data was asymmetrical in Majuli as well as in Amingaon and Umananda confirmed by skewness and kurtosis distribution. Mean values and corresponding standard deviation activities of geochemical parameters were higher in Umananda and Amingaon in Kamrup. CV (%) linked skewed nature data to some kind of spatial variability among Majuli, Amingaon and Umananda. Kurtosis explained that most of the positively or negatively skewed data were directed towards either right tail or left tail of frequency distribution

indicating that the values of geochemical parameters were higher or lower than mean values. A better picture of variability of gecochemical parameters among the three sampling locations was given by quartile distribution studies. Box plots highlighted deviation of the geochemical parameters from mean and median values and at the same time provided a clear picture of location wise and season wise variability of the geochemical parameters.

Multivariate statistics further widened the scope of understanding the probable impacts of spatial variability on geochemical parameters. Geochemical parameters in Majuli and Amingaon were extracted into 7 components in pre-monsoon and 8 components in monsoon season respectively. 6 components were extracted in Umananda in pre-monsoon as well as monsoon season. PCA showed positive and negative absolute PC loadings for geochemical parameters in each season. These PC loadings when plotted in a 2D plane, demarcated the sampling sites in each study based on weightage of geochemical parameters. PC loadings further revealed that bank sediments have properties different from the terrestrial sediments. Overall analysis provided an essence of spatial variability that delineated Umananda from Majuli and Amingaon based on geochemical properties, environmental factors, anthropogenic factors and regionalized soil properties.

Geostatistical analysis involving development of semivariograms revealed influence of spatial variability on geochemical parameters. In support of frequency distribution and dispersion statistics and PCA, semivariograms provided a strong notion that geochemical parameters may vary from place to place depending on geographical location and regionalized soil properties. It was observed that Majuli and Kamrup (Amingaon and Umananda) were moderately under the influence of geographical

separation. Semivariogram analysis showed the presence of a strong (<25%) to weak (>75%) spatial dependence of soil properties. EC, TN, MBP, amylase and invertase enzymatic activities, Zn and Pb showed strong DSD (%), other geochemical parameters showed moderate to weak spatial dependence. Occurrence of spatial variability and its influence on geochemical parameters was attributed to variability in soil properties and related environmental determinants in Majuli, Amingaon and Umananda.

PART – B

BIORESOURCE UTILIZATION

CHAPTER 5

Green synthesis of gold and silver nanoparticles using plant extracts from indigenous plants in Majuli and Kamrup and antimicrobial studies of silver nanoparticles obtained by green synthesis

5.1 INTRODUCTION

Brahmaputra Valley contributes to a significant portion of floral diversity in the southern part of Brahmaputra River in the Indo – Burma hotspot region (Sandeep et al., 2014). WWF has specified Brahmaputra Valley as one of the "ecoregions" of North Eastern India (Chatterjee et al., 2006). Majority of the plants occurring in this region have remarkable ethnobotanical importance. Researchers have been exploring the properties of indigenous plants to obtain productive outputs like energy production, medicinal evaluation, tissue culture, transgenic studies, animal feed, green synthesis of nanoparticles (NPs), biopesticides, manure, textile synthesis, carbon sequestration, bioremediation, green design, landscape design, ornaments, etc. The scientific domain of explorable plants is very large and requires proper knowledge of utilization techniques.

Ecological studies of riverine ecosystem have been reported at a global scale to meet the demands and adversities of nature. These studies help in adopting mitigation strategies to develop a better and sustainable way for living with the available resources. In this chapter, bioresource utilization was fulfilled as green synthesis of gold and silver NPs from plants of high economic importance occurring in Brahmaputra River floodplain. The floodplain represents a huge consortium of plant genetic resources of endemic origin and high ethnobotanical values. Considering the outputs of prevalent conventional methods of bioresource utilization, green synthesis of NPs has been prioritized based on literature review, medicinal values of plants and occurrence of pathogenic bacteria in the environment. Green synthesis of NPs focusses on efficiency of plants to synthesize non-toxic and stable NPs. Basically NPs

synthesized from silver are well utilized in designing filters that can destroy biological water contaminants like coliform and disease causing bacteria. This method of environmental friendly synthesis of NPs from plant extract has been extensively reported in the last two decades.

While reviewing the synthesis studies of nanoparticle synthesis from plant extract, it was found that the concept of "environmentally benign" biological sources is being reformed as a major alternative to traditional chemicals used for nanoparticle synthesis (Savithramma et al., 2009) Biologically mediated nanoparticle synthesis facilitates capping or adsorption of stabilizing agents on the surface of NPs that prevents the particles from agglomerating. Sustainable surface adsorption chemistry, stability and non-toxicity of NPs are some desirable traits in biomedical applications. In this context, phytochemicals present in plant extracts are rationalized towards green chemistry of reduction of metallic salts to NPs and sustainability of the environment friendly synthesis process (Babu et al., 2012; Elechiguerra et al., 2012; Jain et al., 2009). Phytochemicals like phenolic compounds, terpenoids, alkaloids etc. are suitable reducing agents with high efficiency (Song et al., 2009; Song et al., 2010).

Vegetation study was carried out in Majuli by Quadrat Sampling method. Occurrence of these plant species was checked in Kamrup (Chapter 2). Apart from the vegetation within the quadrats studied in Majuli and the vegetation recorded within the sampling sites in Kamrup (Amingaon and Umananda), other vegetation found in the locality are *Imperata cylindrica*, *Hemarthria* sp., *Mimosa pudica*, *Cynodon dactylon*, *Cyperus rotandus*, *Scoparia* sp., *Mikania* sp., *Diplazium esculentum*, *Erianthus* sp., *Paspalidium flavidum*, *Eclipta alba*, *Dichanthium annulatum*, *Sida cordifolia*,

Commelina benghalensis, *Oxalis repens*, *Centella asiatica*, *Calotropis giganteum*, *Xanthium strumarium*, *Colocasia esculenta*, *Ageratum conyzoides*, *Euphorbia hirta*, *Heydiotis pinnifolia*, *Hydrocotyle rotundifolia*, *Lantana camara*, *Leucas aspera*, *Spilanthes paniculata*, *Portulaca oleracea*, *Alternanthera sessilis*, *Setaria flavidium*, *Ficus religiosa*, *Amaranthus spinosus*, *Adhatoda vasica*, *Gossypium arboreum*, *Nyctanthes arbor – tristis*, *Paderia scandens*, *Azadiractha indica*, *Dilenia indica*, *Musa* sp., *Calotropis procera*, *Lagerstroemia* sp., *Lawsonia inermis*, *Anthocephalus cadamba*, *Solanum nigrum*, *Daucus carota*, *Chrysosogon aciculatus*, *Polygonum hydropiper*, *Andrographis paniculata*, *Eichornia crassipes*, *Nelumbo* sp. and *Ipomea aquatica.* A few of these plants have been already utilized in green synthesis of NPs.

Scope of utilization of indigenous plants for synthesizing gold and silver NPs or biologically mediated nanoparticle synthesis include two important requirements, a) ***reducing ability*** and b) ***capping efficiency***. Ecofriendly bio– organics in plant act as both reducing and capping agents. Capping of NPs i.e. biofunctionalization is an inbuilt trait of plant mediated synthesis of NPs. In a continuous effort of screening new plant material in the study areas, leaves and flower extract from indigenous plants have been selected for synthesis of gold nanoparticles (AuNPs) and silver nanoparticles (AgNPs). Flowers of *Nyctanthes arbor – tristis* L. and leaves of *Amaranthus spinosus* L. have been used to synthesis AuNPs. Similarly AgNPs were synthesized from *Nyctanthes arbor – tristis* L. flowers extract.

Nyctanthes arbor – tristis L. (Family: Oleaceae) commonly known as “Parijat” or “Harsingar” is an important plant in the traditional Indian medicinal system (Agrawal et al., 2013) Medicinal properties of the flowers enlist antimicrobial,

antimalarial, antispasmodic, antihelminthic and antidepressant activities. Naturally occurring phytochemicals in *Nyctanthes arbor – tristis* L. flowers were explored as anti-oxidants, phenolic compounds and flavonoids. (Nair et al., 2005; Khatune et al., 2001; Misra et al., 1991; Das et al., 2010; Sureka et al., 2009; Khatune et al., 2001; Champa et al., 2012; Rathee et al., 2007). Earlier studies concentrate on the reducing efficiency of alcoholic extract of *Nyctanthes arbor – tristis* L. flowers (Vankar et al., 2008).

Amaranthus spinosus L. (Family: Amaranthaceae) is known as "Khutura" or "Kanatabhajii" in traditional medicinal system of India (Kirtikar et al., 2001). The species is well known for its many remedial properties (Zeashan et al., 2009; Hema et al., 2006; Odhav et al., 2007; Cao et al., 1996; Gil et al., 1999; Vinson et al., 1998; Srinivasan et al., 2005; Ibewuike et al., 1997; Rastogi et al., 1999; Stintzing et al., 2004; Hilou et al., 2006). Previous reports on the strong antioxidant nature of ethanolic leaf extract (EFE) presents a scope for gold and silver nanoparticle synthesis (Cai et al., 2003).

5.2 MATERIALS AND METHODS

5.2.1 Materials

Flowers of *Nyctanthes arbor – tristis* L. were collected from IIT Guwahati residential campus and Majuli River Island. Healthy and fresh leaves of *Amaranthus spinosus* L. were collected from a local farm. Chlorauric acid ($HAuCl_4.4H_2O$) was purchased from Sigma (India) and silver nitrate ($AgNO_3$) was procured from Merck (India). Chemicals were of analytical grade.

5.2.2 Preparation of plant extract

5.2.2.1 Nyctanthes arbor – tristis L. ethanolic flower extract

Flowers were shade dried at room temperature for about 1 month in a dust free condition. Dried flowers were grinded and sieved to obtain fine powder. One gram of the powder was mixed with 10 mL of ethanol and incubated under mild shaking condition at room temperature (25ºC). After 72 hours, the ethanolic flower extract (EFE) was obtained by filtering the mixture. EFE may be directly used in the synthesis of NPs or stored at 4ºC for further experiments.

5.2.2.2 Amaranthus spinosus L. ethanolic leaf extract

Leaves were collected and washed with double distilled water and shadow dried before being grinded to fine powder. Fine powder was sieved to remove coarse particles. One gram leaf powder was mixed with 10 mL of ethanol and the mixture was left in a shaking incubator operating at 200 rpm, 25°C for 24 hours. The ethanolic leaf extract was filtered and the filtrate was used for AuNPs synthesis.

5.2.3 Synthesis of AuNPs using *Nyctanthes arbor – tristis* L. ethanolic flower extract and *Amaranthus spinosus* L. ethanolic leaf extract

In cases of *Nyctanthes arbor – tristis* L., the AuNPs synthesis protocol was optimized by stirring a mixture of EFE (1– 10% volume fractions) and 1 mM $HAuCl_4.4H_2O$ aqueous solution at 200 rpm (C– MAG-HS7, IKA®) at 80ºC for 30 min and observed for any color change. All reactions were carried out in closed glass vials and the final reaction volume made up to 2 mL with double distilled water. With optimized volume fraction of the EFE, an additional reaction was carried out at room temperature (25ºC)

to analyze the effect of reaction temperature on AuNPs synthesis. Resultant AuNPs were characterized for optical and physicochemical properties.

For *Amaranthus spinosus* L., optimization of concentration of ethanolic leaf extract was carried out. Various concentrations (1% – 5%, v/v) of the ethanolic leaf extract of *Amaranthus spinosus* L. were mixed with aqueous solution of $HAuCl_4.4H_2O$ (1 mM) and the reaction volume was made upto 2 mL with distilled water. The mixture solution was left on constant magnetic stirring at room temperature (25°C) and observed for change in colour.

5.2.4 Synthesis of AgNPs using *Nyctanthes arbor – tristis* L. *ethanolic flower extract*

For synthesis of AgNPs from *Nyctanthes arbor – tristis* L., EFE concentration of 5 % (v/v) was treated with 1 mM aqueous solution of $AgNO_3$, with a reaction volume of 500 µL and final volume made up to 2 mL with double distilled water. The reaction mixture was subjected to mild stirring (C– MAG-HS7, IKA®) of 200 rpm at 80 ^{0}C till color change. Reaction parameters were optimized by varying the volume of EFE (1– 10 %), (v/v) against 1 mM $AgNO_3$, molar concentration kept fixed at 80 ^{0}C. The reducing capability of the EFE was observed as a function of EFE and $AgNO_3$ concentration respectively.

5.2.5 Characterization studies of AuNPs and AgNPs

5.2.5.1 UV − visible spectroscopy

UV – visible spectroscopic studies were performed in a Cary 100 BIO UV − visible spectrophotometer (Varian, Palo Alto, CA, USA).

5.2.5.2 Transmission electron microscopy

For Transmission electron microscopy (TEM) analysis, colloidal solutions of NPs (5 mL) were double centrifuged at 20,000 rpm for 20 min and redispersion of NPs in 1 mL of distilled water. Well dispersed NPs were loaded a carbon-coated copper grid and dried in a hot air oven at 60 °C for 4 hours, prior to examination under TEM (JEOL model 2100, JEOL Ltd., Tokyo, Japan) operated at 190 V of 200 kV.

5.2.5.3 X– ray Diffractrogram analysis

X– ray Diffractrogram (XRD) analysis included drop-coating NPs on a glass slide and allowed to dry in a hot air oven at 50 °C until layer formation. Dried samples were analyzed in an XRD instrument (Bruker Advance D8 XRD machine, Bruker, Madison, WI, USA), with a Cu source at 1.5406 Å wavelengths in thin film mode.

5.2.5.4 Fourier Transform Infra– Red spectroscopy

For Fourier Transform Infra– Red (FTIR) spectroscopy, debris free NPs were lyophilized (Christ Gefriertrocknungsanlagen GmbH Model 1 − 4, Osterode, Germany) for 16 hours. The IR spectra of the lyophilized sample was recorded in a Fourier transform infrared (FTIR) spectroscope (Spectrum One, Perkin Elmer, Waltham, MA, USA) from 4,000/cm to 450/cm, with a resolution of 2 cm and five scans/sample by using 1 mg of finely powdered NPs prepared with 200 mg of KBr.

5.2.6 Antimicrobial studies of AgNPs synthesized from *Nyctanthes arbor – tristis* L. ethanolic flower extract

In vitro antibacterial activity was evaluated using agar well diffusion assay and zone of inhibition test, in Mueller Hinton Agar (MHA) as a growth media. The antibacterial

activity was evaluated against gram negative bacteria *Escherichia coli* MTCC 443 by treatment with varying concentrations of AgNPs synthesized from of *Nyctanthes arbor – tristis* L. EFE. Fresh inoculums of *Escherichia coli* MTCC 443 (100 µL) were seeded on MHA plates using sterile cotton swabs. Agar media was bored with a sterile gel borer to create wells of 5 mm in diameter. 100 µL of different concentration of AgNPs (50, 150, 250 and 500 µg/mL) were poured into separate wells and plates were incubated at 37 ^{0}C for 24 hours. The diameters of inhibition zones were measured to determine the antimicrobial activity. Growth curve of AgNP treated *Escherichia coli* MTCC 443 was obtained at an optical density of 600 nm after inoculating 10^{3} CFU/mL cells in Mueller Hinton broth. The results were further documented by morphology study under FESEM (Zeiss, Sigma).

5.2.7 Statistical analysis

Experiments with quantitative data, in case of antioxidant activity of *Nyctanthes arbor – tristis* L. EFE was performed in triplicates of three independent experiments and the results were expressed as Mean ± Standard Error (*n = 3*).

5.3. RESULTS AND DISCUSSIONS

5.3.1 UV– visible spectroscopy of AuNPs

5.3.1.1. UV– visible spectroscopic analysis of AuNPs synthesized from Nyctanthes arbor – tristis L. ethanolic flower extract

Unique surface plasmon resonance (SPR) property of AuNPs originating from collective oscillation of conduction band electrons on absorption of visible light provides an easy way for visual detection of AuNPs synthesis. Change in the original

yellow color of gold aqueous solution of *Nyctanthes arbor – tristis* L. flower extract containing gold cations, to different shades of red color indicated colloidal gold that can be best studied with UV – visible absorption scanning of the colloidal solution. In AuNPs synthesis experiment involving different volume fractions of EFE (1 – 10%) at 80ºC, change in original yellow color of the reaction mixture within 30 min confirmed reduction of $HAuCl_4.4H_2O$ to AuNPs. UV – visible scanning of the product showed SPR absorption bands and peaks [Figure 5.1 (A), (B)]. 1% of EFE was unable to reduce Au^{3+} ions to AuNPs, as no SPR band appeared in analysis of the product. Though reduction of Au^{3+} ions occurred at 2% and 3% of EFE, the SPR band intensities were lesser and broader which suggested partial reduction of Au^{3+} ions and formation of larger AuNPs respectively. At 4% of EFE, SPR intensity changed drastically with blue shifted SPR peak. Further increase in the EFE volume fractions (5 – 10%) caused change in both SPR intensities and peaks.

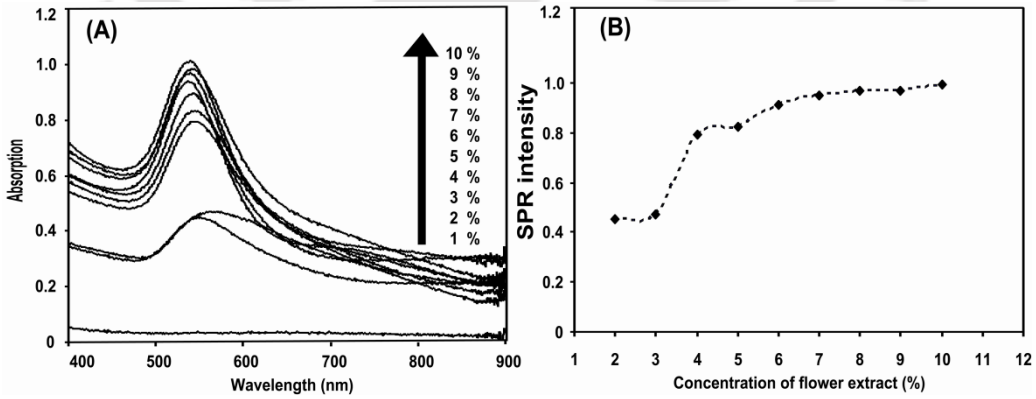


Figure 5.1 *UV – Visible spectra of AuNPs synthesized by reacting 1 mM $HAuCl_4.4H_2O$ aqueous solution with different volume fractions of EFE of Nyctanthes arbor – tristis L. (1 – 10%)* ***(A)*** *SPR peaks;* ***(B)*** *Relation between EFE volume fraction and SPR intensities*

Keeping in mind that a synthesis reaction should meet the criterion of optimization of a variable factor, values of SPR intensities were plotted against variable concentrations of EFE [Figure 5.1 (B)]. Analysis of SPR intensities obtained against EFE volume fractions showed negligible increase at and above 7% of EFE and became saturated indicating complete reduction of 1 mM gold ions. SPR peak positions above 7% also exhibited red shifts. Thus for maximum yield of reduced sized AuNPs, 7% of EFE was an optimum concentration under reaction condition of 80ºC and 30 min time.

5.3.1.2. UV – visible spectroscopic analysis of AuNPs synthesized from Amaranthus spinosus L. ethanolic leaf extract

In case of synthesis of AuNPs from *Amaranthus spinosus* L. ethanolic leaf extract, it was observed that the yellow colour of reaction mixture ($HAuCl_4.4H_2O$ + EFE) kept at room temperature (25°C) under constant stirring gradually turned into ruby-red after 4 hours. Scanning of the coloured solution in UV – visible spectroscopy (400 – 800 nm) range showed absorption bands with sharp peaks (535 – 565 nm) (Figure 5.2).

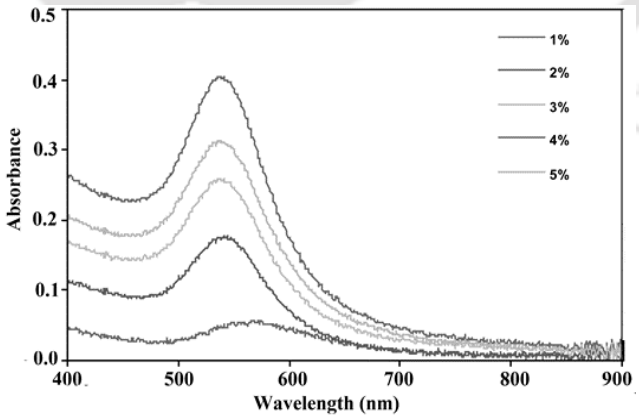


Figure 5.2 *UV – Visible absorption spectra of AuNPs synthesized by treating 1 mM $HAuCl_4.4H_2O$ solution with different concentrations (1% – 5%, v/v) of Amaranthus spinosus L. ethanolic leaf extract at 25°C under magnetic stirring*

Absorption bands originated from surface optical property of gold exhibited at nano dimension, known as surface plasmon resonance (SPR). Appearance of SPR bands confirmed formation of AuNPs. At 1% plant extract concentration, SPR peak was centered at around 565 nm. At higher concentration (2% – 5%), a blue shift in the peaks was observed and peak maxima were located at around 535 ± 3 nm. As position of SPR peaks is correlated with particles size, it was evident that for 1 mM of $HAuCl_4.4H_2O$ solution, more than 1% of plant extract was required to synthesize AuNPs of suitable size (<50 nm) for bio-medical applications. With higher plant extract concentration, the absorbance intensities of SPR band gradually increased indicating formation of more AuNPs.

5.3.2 Transmission Electron Microscopy studies of AuNPs and AgNPs

5.3.2.1 TEM studies of AuNPs synthesized from Nyctanthes arbor – tristis L. ethanolic flower extract

TEM analysis of AuNPs synthesized from 7% *Nyctanthes arbor – tristis* L. EFE volume fraction and 1 mM $HAuCl_4.4H_2O$ at 80 ºC, revealed abundance of spherical particles [Figure 5.3 (A)]. Selected-area electron diffraction pattern (SAED) confirmed the crystalline nature of AuNPs [Figure 5.3 (B)]. A total of four Debye – Scherrer's rings corresponding to (1 1 1), (2 0 0), (2 2 0) and (3 1 1) gold crystalline planes were visulized. Ultra High Resolution TEM (UHRTEM) image displayed clear lattice fringes on the particle surface [Figure 5.3 (C)]. A histogram representing the size distribution of AuNPs corresponding to TEM image exhibited variation in the particle sizes [Figure 5.3 (D)]. The average particle size was obtained as 19.8 ± 5.0 nm.

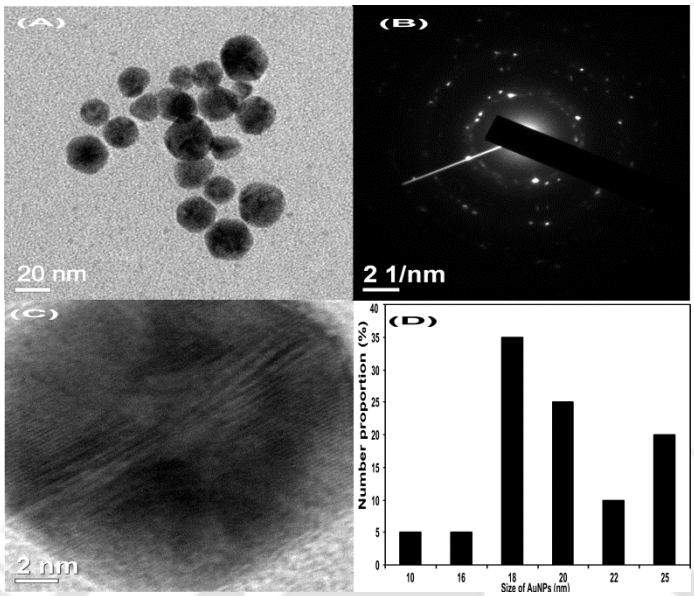


Figure 5.3 (A) *TEM,* ***(B)*** *SAED patterns,* ***(C)*** *HRTEM and* ***(D)*** *size distribution histograms of AuNPs synthesized with optimized Nyctanthes arbor – tristis L. EFE volume fractions*

5.3.2.2 TEM analysis of AuNPs synthesized from Amaranthus spinosus L. ethanolic leaf extract

AuNPs synthesized with 5% (v/v) *Amaranthus spinosus* L. ethanolic leaf extract against 1 mM aqueous solution of $HAuCl_4.4H_2O$, were spherical in shape with few triangular morphologies [Figure 5.4 (A)]. Selected area electron diffraction pattern (SAED) of a single spherical particle confirmed the crystalline nature of AuNPs. It was observed rings corresponding to (111), (200) and (220) planes of fcc crystalline lattices of gold [Figure 5.4 (B)]. Ultra high resolution TEM (UHRTEM) images displayed clear lattice fringes on the particle surfaces [Figure 5.4 (C)].

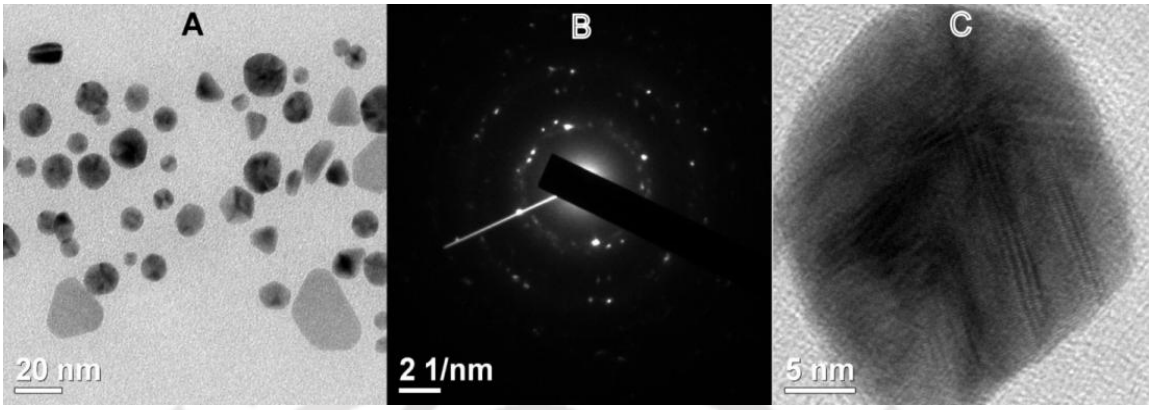


Figure 5.4 (A) *TEM image of AuNPs synthesized by reacting 5% (v/v) EFE of Amaranthus spinosus against 1 mM $HAuCl_4.4H_2O$ aqueous solution at 25°C under magnetic stirring;* ***(B)*** *SAED pattern of a AuNPs;* ***(C)*** *URHTEM image of a spherical GNP showing lattice fringes*

5.3.3 X – ray Diffractrogram analysis of AuNPs

5.3.3.1 XRD analysis of AuNPs synthesized from Nyctanthes arbor – tristis L. ethanolic flower extract

XRD pattern of AuNPs showed four prominent Bragg reflections which were indexed on the basis of fcc structure of gold (Figure 5.5). Intensities of the (1 1 1), (2 0 0), (2 2 0) and (3 1 1) diffraction peaks corresponded to 38.1º, 44.4º, 64.8º and 78º respectively and confirmed the crystalline nature of AuNPs (Figure 5.5).

5.3.3.2 XRD analysis of AuNPs synthesized from Amaranthus spinosus L. ethanolic leaf extract

XRD analysis of the AuNPs exhibited Bragg's reflections identical to the XRD patterns of AuNPs synthesized with optimized *Nyctanthes arbor – tristis* L. EFE. The diffraction peaks (111), (200) and (220) corresponding to 38.1°, 44.5° and 64.8° 2θ angles, respectively, confirmed that the AuNPs were of crystalline nature (Figure 5.6). The width of the (111) Bragg reflection, was determined for calculating the mean size of AuNPs by using Debye-Scherer's equation which was found to be around 10.74 nm [visible in TEM micrographs, Figure 5.4 (A)].

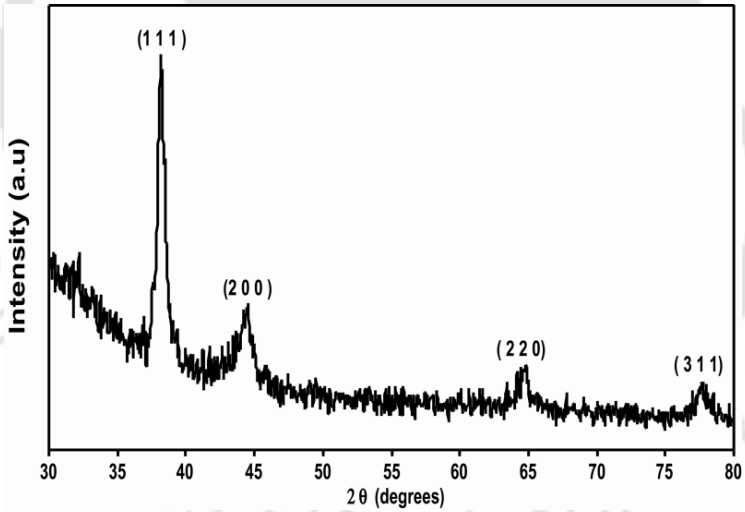


Figure 5.5 *XRD patterns of AuNPs synthesized with optimized Nyctanthes arbor – tristis L. EFE volume fractions*

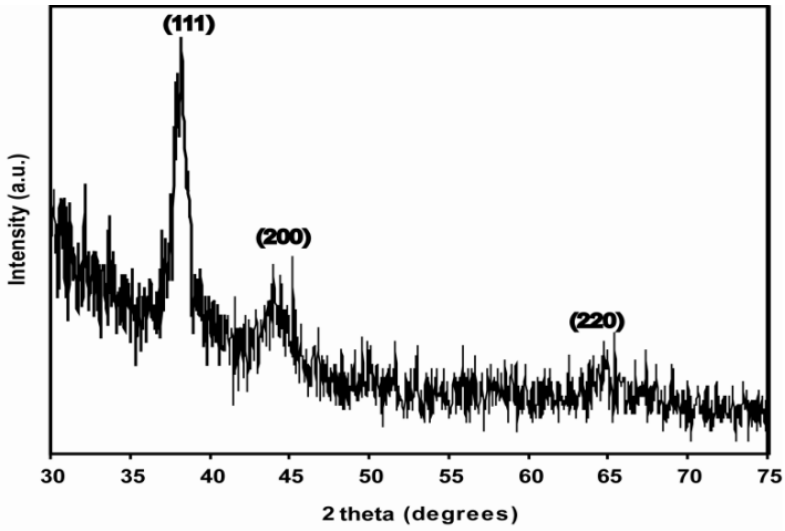


Figure 5.6 *XRD spectrum of AuNPs synthesized with Amaranthus spinosus L. ethanol leaf extract*

A strong diffraction peak located at around 38.15° was ascribed to the (111) facets of face – centered cubic metal gold structures, while diffraction peaks of other facets were much weaker (Figure 5.6). Broadening of Bragg's peaks provided additional indication of formation of the AuNPs.

5.3.4 Fourier Transform Infra – Red spectroscopy of AuNPs

5.3.4.1 FTIR analysis to determine the involvement of functional groups in AuNPs synthesized from Nyctanthes arbor – tristis L. ethanolic flower extract

FTIR spectra [curve 1, Figure 5.7 (A)] of lyophilized EFE showed strong IR bands characteristic of hydroxyl (3220 – 3250 cm^{-1}), alkanes (715, 2,895 and 2,960 cm^{-1}), C=C of benzene (1,627 cm^{-1}), aromatic amines (1,374 cm^{-1}) and aliphatic amines (1,040 and 1,053 cm^{-1}) functional groups. These signals originated from the phytochemicals present in EFE. Analysis of FTIR spectra obtained for purified and lyophilized AuNPs [curve 2, Figure 5.7 (A)] revealed strong interactions with the EFE

during their synthesis. Almost all IR bands of AuNPs were similar to IR bands that appeared for AuNPs. Bands at 3,403 cm^{-1} (OH), 2,890 cm^{-1} (alkane), 1,611 cm^{-1} (C=C of benzene), 1,378 cm^{-1} (aromatic amines) and 1,016 cm^{-1} (aliphatic amines) suggested that after interaction with AuNPs the original transmittance level of EFE changed considerably. The FTIR analysis strongly supported the capping behaviour of EFE which in turn imparted high stability to the AuNPs.

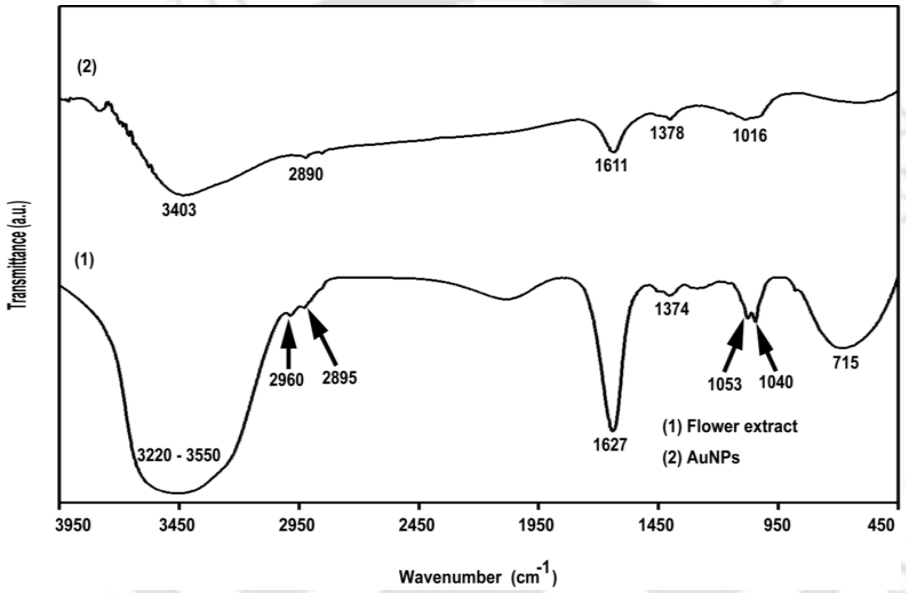


Figure 5.7 (A) *FTIR spectra of Nyctanthes arbor – tristis L. EFE (curve 1) and AuNPs (curve 2)*

In addition to FTIR data for the lyophilized AuNPs, antioxidant activity strongly supports the occurrence of phytochemicals in the EFE (Vankar, 2008). The DPPH radical scavenging assay for varying concentrations of EFE (5 – 500µg/mL) showed antioxidant activity in a range of 17.54 ± 0.40 to 83.16 ± 1.06 µg/mL of the EFE (Table 5.1).

Table 5.1 *Results of DPPH scavenging assay of Nyctanthes arbor – tristis L. EFE*

Concentration of EFE (µg/mL)	% Inhibition
5	17.54 ± 0.40
10	37.06 ± 0.99
20	50.01 ± 0.66
40	58.09 ± 0.86
50	65.66 ± 0.89
100	75.61 ± 1.51
150	77.61 ± 0.46
250	78.17 ± 0.53
500	83.16 ± 1.06

5.3.4.2 FTIR analysis to show involvement of functional groups in AuNPs synthesis from Amaranthus spinosus L. ethanolic leaf extract

FTIR spectra of *Amaranthus spinosus* L. ethanolic leaf extract showed characteristic bands for several functional groups. IR peaks for hydroxyl (–OH), aromatic amines (–$C_6H_5NH_2$), aliphatic amines (R–NH_2), carbonyl (>C=O), C-H and C=C (benzene) functional groups were observed at around 3378, 1118, 1380, 1040, 1694, 2848 and 1604 cm^{-1} respectively [Figure 5.8 (A)]. These findings were supported by some previous reports that evaluated the profile of compounds (like amaranthine type betacyanin, amaranthine, isoamaranthine, phenols, flavanoids, lysine, etc.) present in alcoholic leaf extract of many species under the genus *Amaranthus* (Cai, 2003). Chemical structures of these compounds justified the IR bands obtained. To determine whether during AuNPs synthesis some bio-molecules particularly those with free carboxylic (–COOH) or amino (–NH_2) groups present in the ethanolic leaf extract have bound to gold surface, purified and lyophilized AuNPs samples were subjected to FTIR studies. IR band of AuNPs showed peaks for hydroxyl (3388 cm^{-1}), aromatic and

aliphatic amines (1391 and 1018 cm^{-1} respectively), carbonyl (1685 cm^{-1}), C=C of benzene (1607 cm^{-1}) and C-H (2842 cm^{-1}) functional groups [Figure 5.8 (B)]. As reported earlier, ethanolic leaf extract of *Amaranthus spinosus* L. is very rich in anti-oxidant property due to the presence of many compounds with functional groups (hydroxyl or imino) carboxylic moieties, capable of binding to free gold surface. This suggested that during the reduction process of Au^{3+} ions to Au^{0}, such molecules have tightly bound to the gold surface as detected in the FTIR spectra of AuNPs.

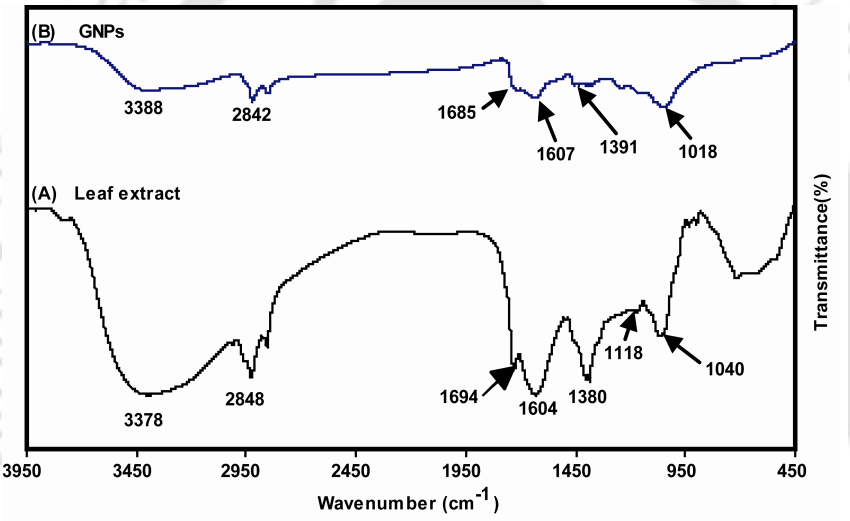


Figure 5.8 *FTIR spectra of* ***(A)*** *Amaranthus spinosus L. ethanolic leaf extract; and* ***(B)*** *AuNPs synthesized from Amaranthus spinosus L. ethanolic leaf extract*

5.3.5 UV – visible spectroscopy of AgNPs

UV – visible spectroscopic studies helped in determining the optical properties of AgNPs were synthesized from *Nyctanthes arbor – tristis* L. EFE. UV-visible spectra revealed excitation of surface plasmon oscillations of AgNPs at lower wavelength undergoing blue shift. SPR peaks at lower concentration 1 – 2% (v/v) of EFE were broad. On increasing the concentrations of EFE marginally, SPR peaks intensified and

narrowed. At very higher concentration of EFE (8 – 10%), the SPR bands broadened like in 1 – 2% (v/v) EFE concentrations showing that at very higher and lower concentration, formation of is anisotropic [Figure 5.9 (A)]. SPR peak intensities also explained the logarithmic trend in connection with formation of AgNPs from lower to higher concentration of EFE [Figure 5.9 (B)].

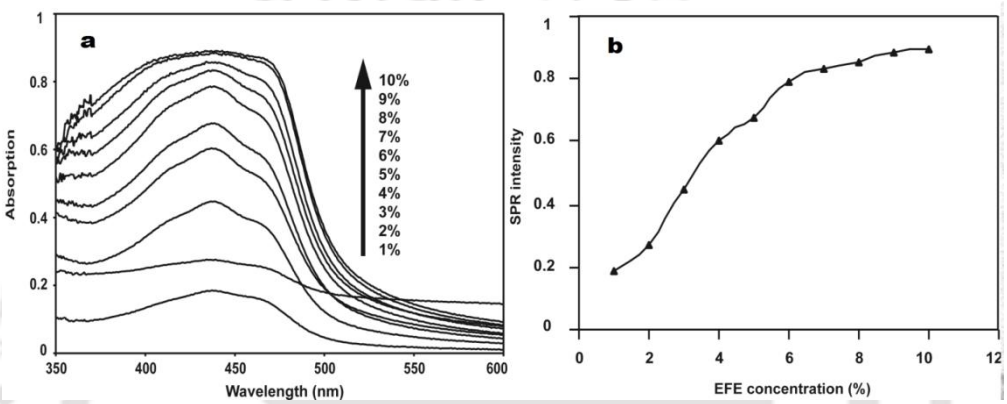


Figure 5.9 (A) *UV – Visible absorption spectra of AgNPs synthesized by different concentration of Nyctanthes arbor – tristis L. EFE (1 – 10%) against 1 mM $AgNO_3$ at 80^oC,* ***(B)*** *The SPR peak intensities of against different concentration of EFE (1 – 10%)*

5.3.6 Transmission Electron Microscopy studies of AgNPs

It was observed that at 5% (v/v) EFE, absorbance intensity of AgNPs stabilized around 450 – 500 nm. Beyond this range of absorption, the surface plasmons vibrated in both transverse and longitudinal planes resulting in broader peaks. Considering the stability kinetics, AgNPs synthesized with 5% (v/v) EFE were examined under TEM. TEM micrographs clearly exhibited morphology of AgNPs being spherical, hexagonal and oval in shape [Figure 5.10 (A)]. The size of synthesized AgNPs ranged from 5 – 20 nm [Figure 5.10 (B)]. UHRTEM showed the atomic level of AgNPs and helped in characterizing lattice fringes on the surface of AgNPs (Majeed et al., 2011) [Figure

5.10 (C)]. Uniform shapes acquired by the AgNPs explained that there was no secondary nucleation or agglomeration in the synthesis process.

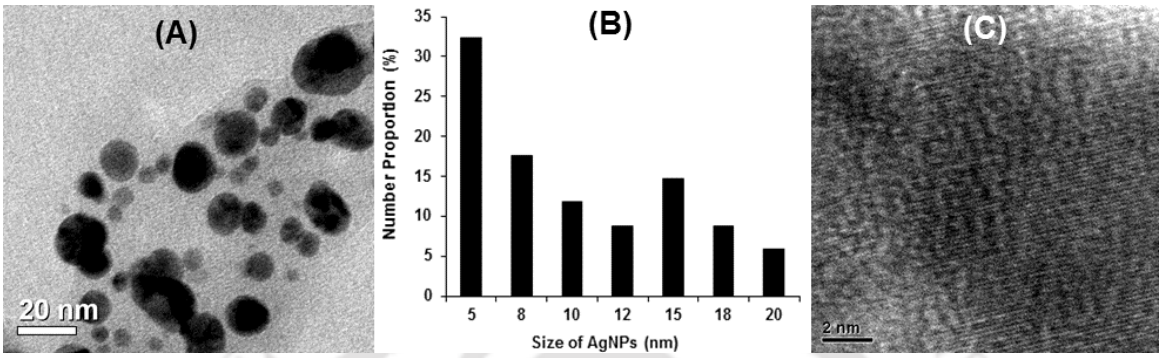


Figure 5.10 (A) *TEM,* ***(B)*** *UHRTEM of AgNPs synthesized from Nyctanthes arbor – tristis L. EFE, at optimum concentration (5% EFE) at 80ºC*

5.3.7 X – ray Diffractrogram analysis of AgNPs

XRD showed four Bragg reflections depicting fcc structure of the AgNPs (Figure 5.11). Diffraction peaks of the XRD pattern linked to their relative intensities as (111), (200),(220) and (311) for 38.1°, 44.4°, 64.8° and 77.11° respectively confirming the crystalline structure of the AgNPs (Zargar et al., 2011).

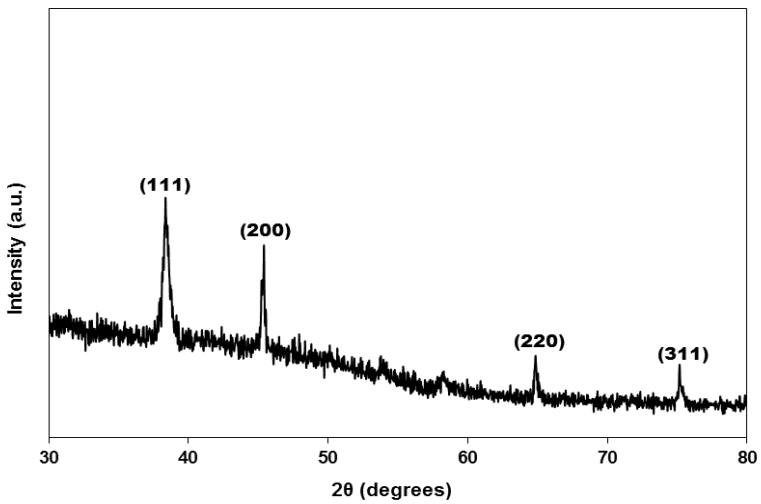


Figure 5.11 *XRD pattern of AgNPs synthesized using Nyctanthes arbor – tristis L. EFE*

5.3.8 Fourier Transform Infra – Red spectroscopy of AgNPs

FTIR analysis of lyophilized EFE displayed distinct spectra of IR bands characteristic of hydroxyl (3220-3250 cm^{-1}), alkanes (715, 2895 and 2960 cm^{-1}), C=C of benzene (1627 cm^{-1}), aromatic amines (1374 cm^{-1}) and aliphatic amines (1040 and 1053 cm^{-1}) functional groups (Figure 5.12, spectrum 1). *Nyctanthes arbor – tristis* L. EFE were previously reported to contain phytochemicals as phenolics, flavonoids, tannins, terpenoids, saponins and phlobatannins. Similar kind of IR bands for lyophilized AgNPs were obtained at 3430 cm^{-1} (OH), 2917 cm^{-1} and 2848 cm^{-1} (alkanes), 1696 cm^{-1} (carbonyl), 1435 cm^{-1} (germinal methyl) and 1044 cm^{-1} (aliphatic amines) (Figure 5.12, spectrum 2). Appearance of these bands confirmed the capping of AgNPs by phytochemicals present in the EFE. Minor shifts in the band spectra of Figure 5.12 (spectrum 2) from the spectra 1 was due to interaction of EFE with AgNPs which changed the original transmittance level of EFE.

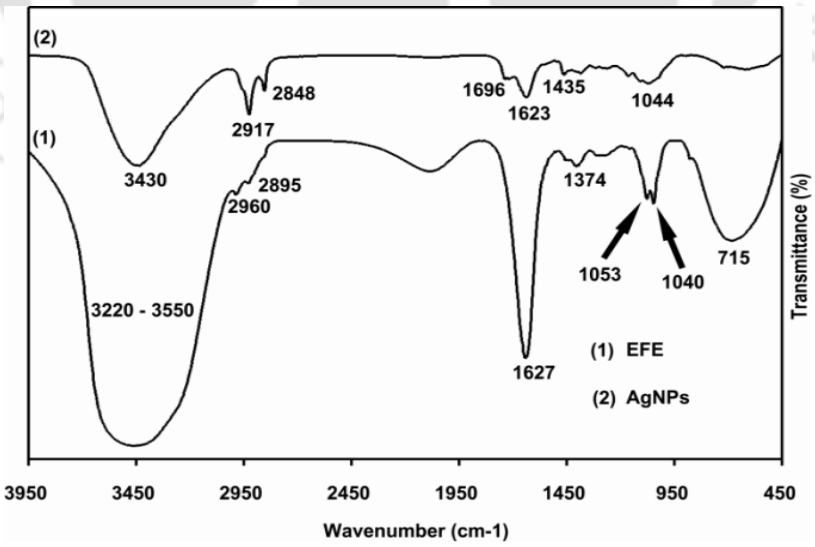


Figure 5.12 *FTIR spectra of lyophilized Nyctanthes arbor – tristis L. EFE (spectrum 1) and AgNPs (spectrum 2)*

5.3.9 Antimicrobial activity of AgNPs on *Escherichia coli* MTCC 443

Escherichia coli MTCC 443 has been studied as a model organism for antibacterial studies using green synthesized AgNPs, by most of the researchers for (Sondi et al., 2004). Agar well diffusion assay showed that 500 µg/mL of AgNP had a significant inhibition activity against *Escherichia coli* MTCC 443. The clear zones of inhibition are shown in Figure 5.13 (plate 2). Inhibition zone surrounding the bore having a radius of 1.47 ± 0.18 cm illustrated antimicrobial activity of the AgNPs. However, negative control did not show any clear zone. MHA involving streptomycin as a positive control showed clear zones of inhibition in a range of 50 – 500 µg/mL. Initially, AgNPs capped with polyphenolic compounds damage the cell membranes of bacteria, most effectively on Gram-negative bacteria by producing reactive oxygen species and free radicals that induce membrane damage (Kim et al., 2007). Once the membranes are damaged, the membrane potential is disturbed by loss of intracellular K^+ ions. Further consequences lead to cytoplasmic leakage and finally release of lipopolysaccharide molecules and membrane proteins. The lipid bilayer of outer membrane is asymmetric and composed of lipopolysaccharide whereas the inner wall is close-packed phospholipid chains exhibiting turbulence in membranous permeability. According to Kim et al (2007), AgNPs being smaller in size accumulate on the bacterial membranes to form irregular pits that initiate leakage of cell components. Apart from these physiological mechanisms, capping of AgNPs with EFE may supplement additional antimicrobial activity.

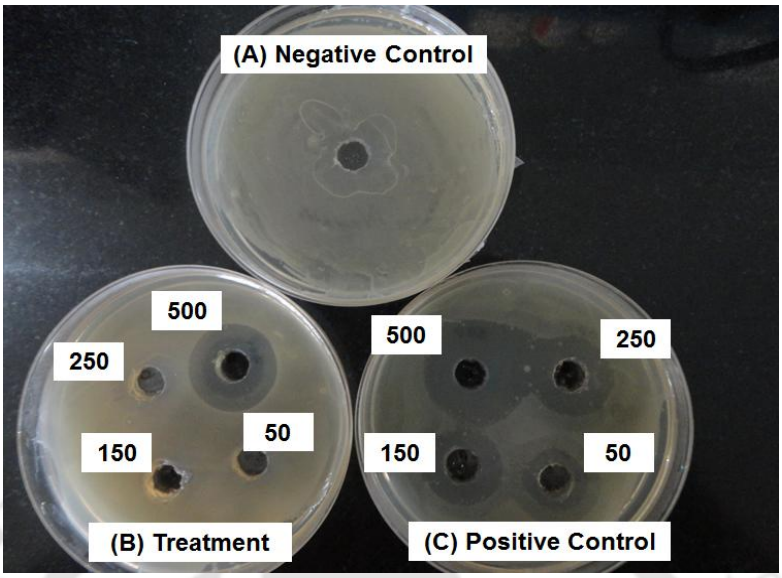


Figure 5.13 *Antibacterial assay: Inhibition zone for Escherichia coli;* ***(A)*** *Negative Control,* ***(B)*** *Positive control; Treatment with different concentrations (50, 150, 250 and 500 µg/mL) of streptomycin,* ***(C)*** *Treatment with different concentrations (50, 150, 250 and 500 µg/mL) of AgNPs*

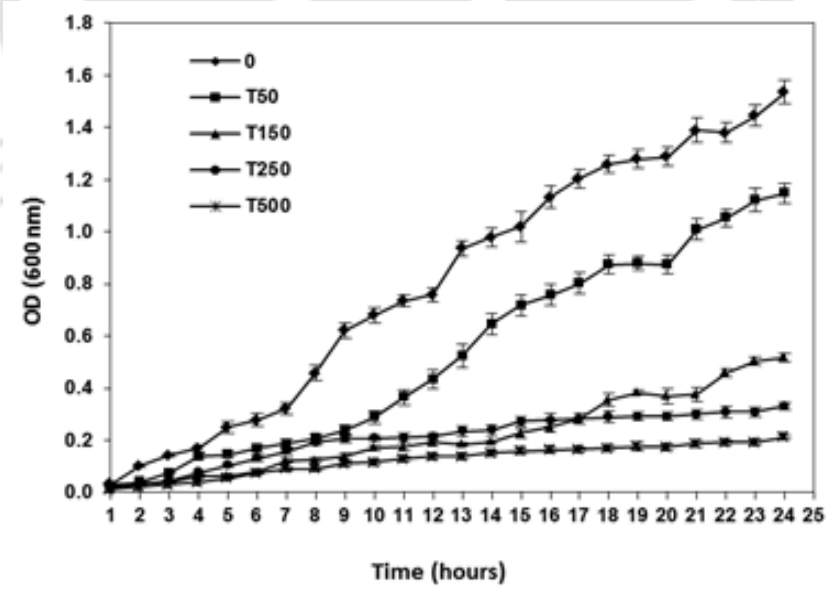


Figure 5.14 *Growth curve of AgNPs treated Escherichia coli cells (OD 600 nm)*

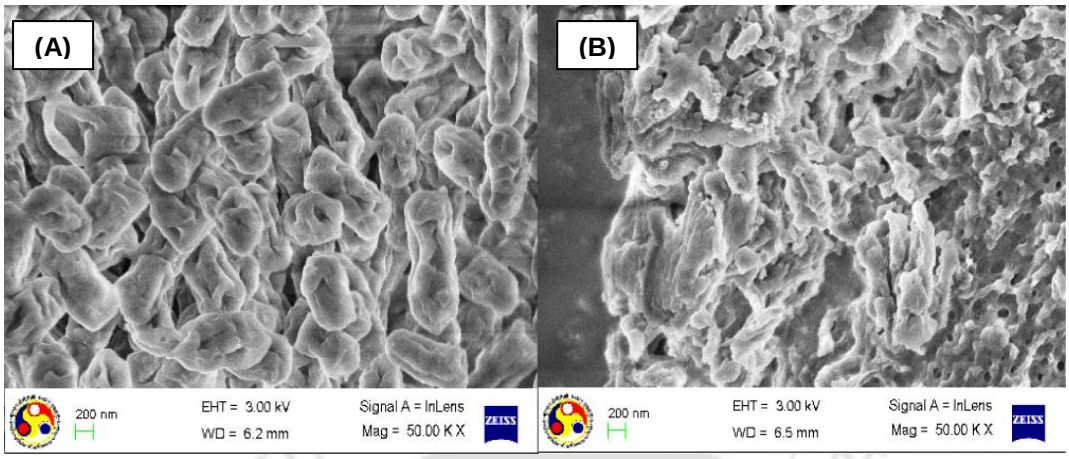


Figure 5.15 *FESEM micrograph showing morphological difference between AgNPs treated and untreated Escherichia coli cells,* ***(A)*** *untreated Escherichia coli cells,* ***(B)*** *treated Escherichia coli cells showing maximum damage and rupture of cell walls*

The antimicrobial activity was correspondingly confirmed by growth curve study of *Escherichia coli* MTCC 443 treated with several concentrations of the AgNPs. 500µg/mL of AgNP treated bacterial cells (10^3 CFU/mL) showed maximum growth inhibition in a time period of 24 hours incubated in MH broth at 37°C (Figure 5.14). Field Emission Scanning Electron Microscopy (FESEM) (Make: Zeiss, Model studies: Sigma) imaging also showed damage of bacterial cells after treatment with variable concentration of AgNPs [Figure. 5.15 (A), (B)].

5.4 CONCLUSIONS

In this chapter, an ecofriendly and cost effective method of bioresource utilization by synthesis of gold and silver NPs using plant extracts has been discussed. UV – visible spectroscopy and TEM confirmed successful reduction of metallic ions to NPs. XRD revealed crystalline nature of the NPs. Phytochemicals present in the EFE and ethanolic leaf extract were adsorbed on the surface of NPs (both AuNPs and AgNPs), evident as

distinct IR bands in the FTIR spectra. Finally, AgNPs synthesized form *Nyctanthes arbor – tristis* L. flower extract showed positive antibacterial activity against pathogenic strain of *Escherichia coli* MTCC 443.

A novel application of EFE of *Nyctanthes arbor – tristis* L.and ethanolic leaf extract of *Amaranthus spinosus* L. fortified screening of plant materials as a potential source of reducing agents for synthesis of AuNPs. UV – Vis spectroscopy analysis confirmed formation of AuNPs. Typical bright-field TEM image with optimum reaction conditions revealed circular shapes of the NPs. AuNPs showed that average particle size diameters calculated from *Nyctanthes arbor – tristis* L. (AuNPs) was 19.8 nm. Crystallinity of AuNPs was confirmed from typical selected area electron diffraction (SAED) pattern with bright circular rings corresponding to the (1 1 1), (2 0 0), and (2 2 0) planes. AuNPs were well capped and hence they can be used efficiently in bio-medical applications like contrasting agents in bio-imaging, etc. It was speculated that these capped AuNPs have the potential to cross the barrier of cytotoxicity which is a prior requirement for such applications.

Reducing capabilities of *Nyctanthes arbor – tristis* L. EFE were also checked for AgNPs synthesis. Like AuNPs, phytochemicals primarily antioxidants, flavonoids and phenolic compounds present in *Nyctanthes arbor – tristis* L. were actively involved in bioreduction of silver ions to AgNPs. UV – visible spectroscopy indicated formation of AgNPs. TEM images showed that AgNPs were predominantly spherical or oval in shape with a size distribution range of 5 – 20 nm, desirable for most of the therapeutic applications and water treatment processes. Diffraction peaks (1 1 1), (2 0 0), (2 2 0) of XRD patterns, confirmed the crystalline nature of AuNPs. FTIR studies revealed that

the bioactive molecules present in EFE facilitated reduction of the Ag^{+} ions to Ag^{0} and later capped the AgNPs during particle growth termination process Antibacterial activity of AgNPs was efficient against pathogenic gram negative bacteria (*Escherichia coli* MTCC 443) forming an inhibition zone of 1.47 ± 0.18 cm in MHA using streptomycin as a positive control and sterile water as a negative control.

Brahmaputra River floodplain is rich in plant bioresource. Plant species are considered as the key indicators of soil fertility and ecosystem health. Plant species have high ethnobotanical importance, especially plants are valued for their commercial and medicinal values. Considering Brahmaputra River floodplain as a huge repository of naturally occurring indigenous plants having high ethnobotanical significance, green synthesis of NPs was emphasized using plant extracts obtained from Brahmaputra floodplain i.e. Majuli and Kamrup. This application fulfilled the bioresource utilization aspect in a successful way. Synthesis and characterization of gold and silver NPs. with economically valued plants has been motivated in research trends since the last century. Especially green synthesized AgNPs have significant application in water filtration devices due to their efficient antimicrobial and metal chelating properties. Smaller size and capping of the NPs by phytochemicals during their synthesis masks the toxicity of otherwise toxic NPs and make them desirable for use in even biomedical applications. These useful traits of green synthesized NPs represent them as potential candidate in therapeutic uses.

CHAPTER 6

Summary

&

Future prospects

6.1 SUMMARY

The present investigation focused on ecological assessment of Brahmaputra River floodplain in Majuli River Island and Kamrup (Amingaon and Umananda), divided into two parts, (a) ***ecosystem functions*** and (b) ***bioresource utilization***. Part A included physicochemical and geochemical monitoring of water and soil samples in Majuli River Island and geochemical characterization of soil samples from Kamrup. Part B included utilization of plant resources to synthesize AuNPs and AgNPs and check applicability of AgNPs, emphasizing the ecosystem service perspective. Majuli is a huge river island representing characteristics of a mainland as well as an isolated island ecosystem. Amingaon is a mainland at the bank of Brahmaputra River and Umananda River Island represents a rather small island ecosystem. In a broader sense, Majuli represents a combination of both a mainland and an island ecosystem. The gradient of Brahmaputra River is expected to distinguish the ecological properties of Majuli from Amingaon and Umananda. Thus depending on the topography and geographical separation, floodplain characteristics of Majuli River Island was studied as a comparative consideration with those of Amingaon and Umananda River Island.

6.1.1 Analysis of floodplain characteristics vis-à-vis ecosystem support mechanism and evaluation of soil productivity as a function of nutrient cycling

This chapter described the ecosystem functions of Majuli River Island and their comparison to a low lying area in Brahmaputra floodplain, Kamrup (Amingaon and Majuli). This section covered experimental analyses monitoring the physical, chemical and biological components in selected areas of Majuli River Island and Kamrup in two

study periods, pre-monsoon and monsoon. Ecological parameters of major concern in an ecosystem are water and soil. A healthy environment reflects a good water and soil quality. Thus correlation between the abiotic and biotic parameters was emphasized in this study.

Physicochemical characterization of water samples in Majuli reflected the potability and usability perspective. Water sampling was carried out in pre-monsoon period (April, 2011) and monsoon period (August, 2011). Water samples were collected from 12 wetlands, 2 water bodies, 4 ground water samples and 2 river water samples (Brahmaputra River at two banks i.e. Kamalabari and Nimatighat). Samples were further grouped as a) residential area, b) grassland, c) agricultural field, d) ground water and e) river water based on land use activities and geomorphic origin. pH in water samples was neutral to alkaline in both the seasons. All parameters were within permissible limits given by BIS, WHO and EPA. Higher values of physicochemical parameters in Group A (residential area) were attributed to household activities like waste disposal, washing and cleaning activities. Leaching events in addition may contribute to significant concentration of PO_4^{3-}, Cl^- and F^- in ground water samples (Group C). River water samples (Group E) exhibited low concentration of all parameters analysed except DO, COD. Though seasonal variance was minimum, Cl^- concentration was notably higher in monsoon season. Overall investigation showed that DO, COD and ammonia were comparatively higher in monsoon season. Origin of these physicochemical parameters is multifarious, grouping at the time of sampling delimited a source dependent outcome of experimental analyses. Among trace elements, Na, K, Ca and Mg were used to determine water indexing parameters for usability of water in

irrigation activities. SAR was within the critical limits, SSP was higher in S7 (Group A) and Kelly's ratio was exceeding critical limits in S10 (Group A). SSP and Kelly's ratio were remarkable in water samples collected from residential areas. Presence of faecal coliform was evident in S9 (Magurmara welatalnd) (5 cells/100 mL sample in pre-monsoon and 2.2 cells/100 mL sample in monsoon) and S18 (Missing Gaon Water Body) (2.2 cells/100 mL in pre-monsoon only).

Soil sampling was performed at 12 sampling sites and 2 river banks in Brahmaputra River in pre-monsoon period (April, 2011) and monsoon period (August, 2011). Soil boring was performed at 5 different depths, from surface to 100 cm respectively at an interval of 20 cm. Like water samples, soil samples were also categorized into 4 groups on the basis of land use activities, a) residential, b) grassland, c) agriculture and d) bank sediments. Geochemical characterization was prominent in Group C (agricultural fields) in Majuli. Agricultural samples (Group C) indicated possibility of transformation of organic matter into humus which lower the pH by absorbing the basic cations. In Kamrup (Amingaon and Umananda) soil was sampling was performed in pre-monsoon (April, 2012) and monsoon (August, 2012), like in Majuli, soil samples were grouped as a) disturbed, b) undisturbed and c) bank sediments.

Experimental analyses revealed that geochemical parameters were more pronounced in undisturbed soil samples (Group A). Soil pH was acidic to alkaline in Majuli and slightly acidic to slightly alkaline in Kamrup (Amingaon and Umananda). CEC was higher in Kamrup soil samples. Vegetation study revealed that *Hemarthria*

sp. was the most abundant species present in all the quadrats studied in Majuli, followed by *Cynodon dactylon*. The plant species recorded in Majuli were also present in Kamrup. SOM, MB, microbial populations (bacterial and fungal) were more prominent in Kamrup soil samples. Infact overall CNP stoichiometry was higher in Kamrup soil samples. In addition to CNP status, soil enzyme activities revealed similar trend. The activities of enzyme in ascending order followed a trend, cellulase > amylase > invertase > urease > protease > dehydrogenase > phosphatases in Majuli as well as in Kamrup. Correlation studies and regression analyses projected SOM and MB as two dependent variables having functional relationship. Correlation studies also projected enzyme activities as an important function of nutrient mineralization. Depthwise variation (0 – 100 cm) was evident in soil samples in Majuli. Group C (agricultural fields) in Majuli and Group A (undisturbed area) in Kamrup showed significant activity as a response to physicochemical and geochemical characterization of ecological parameters. Seasonal variance was minimal but effective in both Majuli and Kamrup. Overall experimental analyses summarize Kamrup as a more productive ecosystem in comparison to Majuli.

6.1.2 Assessment of metal status and pollution indices in water and soil in Brahmaputra River floodplain

This section discussed assessment of metal status and related pollution indices in Brahmaputra River floodplain. Investigations extensively highlighted the pollution scenario and ecological risk assessment due occurrence of metals in water and soil in Majuli and soil in Amingaon and Umananda. Grouping of water samples in Majuli and

soil samples in Majuli and Kamrup (mentioned in section 6.1.1) were kept into consideration during the evaluation process\High enrichment of Cu and Fe was observed in the study areas.

Fe, Cu, Mn and Pb were found within permissible limits in water samples. Integrated pollution indexing, NPI in water samples showed high risk of pollution due to elevated levels of turbidity in S9 (Group A) and S2 (Group B). It was obvious that pollution risk was triggered due to turbidity, metal existence had a passive effect on water samples. Occurrence of *Eichornia crassipes* (vegetation profile in Chapter 2), may possibly facilitate phytoremediating influence on the lower concentration of metals in water as compared to the soil samples.

In Majuli, relative abundance was observed in an ascending order, total Fe > Cu > Zn specifically. Abundance of other metals varied accordingly. Terrestrial sediments showed significant metal concentration, whereas bank sediments displayed relatively lower metal concentration. Ni concentration was elevated in bank sediments. Total Fe presented high values for C_f followed Cu, Cu, Mn, Cd, Zn, Ni and Cr. Location wise and depth wise variation was minimal yet significant, which resulted in fluctuation of geochemical parameters and metal concentration. On the safe side, ER showed low ecological risk due to metal enrichment in soil. Low but remarkable levels of PLI, C_d, I_{geo} and PERI in soil were attributed to Cu and Cd. Cu and Cd levels were above world average background metal concentration. Most of the pollution indices were substantial in S10 (Sakali wetland under Group C). Cd, Cr and Pb in Majuli were

expected to originate from subordinate sources. Fe, Cu, Mn, Zn and Ni were among the naturally occurring elements, based on lithogenic origin.

In Kamrup soil samples, relative abundance of metals was highest for total Fe followed by Cu, Zn, Mn, Pb, Ni, Cr and Cd in all the places. Bank sediments exhibited lower metal concentration than the terrestrial sediments. Total Fe concentration was significantly lower in Umananda. C_f was higher for Fe, Cu and Cd. Cu and Cd concentration were prominent in Kamrup, acting as the root cause of dominant levels of PLI, Cd and NPI. Potential pollution risk was distinguished in Group A and Group B. Like in Majuli, ER and PERI due to metals present were within low risk.

Overall analysis showed that Cd, Cr and Pb concentration were higher in Kamrup. Majuli soils showed higher levels of total Fe. Integrated pollution indices like NPI, PERI, PLI and C_d was greater for samples in Kamrup soil samples. Correlation studies showed the coexistence of metals in soil and water. Moreover metals showed positive and significant correlations with most of the geochemical parameters. Metal association with SOM, soil enzymatic activities and soil microbial population indicates a synergistic effect, concerned with soil biochemical processes.

6.1.3 Comparative assessment of geochemical parameters in two soil typologies i.e. Majuli in the middle stretch and Kamrup in the lower stretch of Brahmaputra River floodplain

This chapter demonstrated a comparative assessment of upper and lower Brahmaputra floodplain characteristics based on geochemical parameters. Linear comparison statistics included frequency distribution statistics, measurement of dispersion and co-

efficient of variation. Multivariate statistics included PCA and geostatistical analysis. Results confirmed that the concentration of soil parameters like SOM, soil MB, enzyme activities and metal concentration were relatively higher in Kamrup (Amingaon and Umananda). This observation was partially discussed in Chapter 2, but statistical analyses validated the comparative evaluation.

Skewness and kurtosis distribution showed that the experimental data was asymmetrical in Majuli as well as in Kamrup. Spatial variability was projected to influence the geochemical parameters in the three sampling locations – Majuli, Amingaon and Umananda. In this context, CV (%), quartile distribution statitistics and PCA linked skewed nature data to some kind of spatial variability among Majuli, Amingaon and Umananda. PCA extracted geochemical parameters in Majuli and Amingaon were extracted into 7 principal components (PC) in pre-monsoon and 8 components in monsoon season respectively and in Umananda, 6 components were extracted in in pre-monsoon and monsoon season. These PCs stratified and decomposed the asymmetrical data and correlated them to establish a link between the geochemical parameters. 2D PC loading plots demarcated the sampling sites in each study location based on weightage of geochemical parameters. PC loadings also revealed that bank sediments have properties different from the terrestrial sediments. PCA to some extent visualized the spatial variability perspective.

The spatial variability and its influence on geochemical parameters was explained by geostatistical analysis. Semivariogram spherical model involving Range, Nugget and Sill as major components in a semivariance plot demonstrated the spatial

variability principle. Degree of spatial dependence (DSD) or DSD (%) provided a weightage to spatial variability depending to the Nugget to Sill ratios. Geoposition, or in a broader sense, geographical location of place tend to influence soil properties in that region. With this consideration, geochemical parameters may vary from place to place depending on geographical location and regionalized soil properties. Semivariogram model outputs showed that EC, TN, MBP, amylase and invertase enzymatic activities, Zn and Pb showed strong DSD (%), other geochemical parameters showed moderate to weak spatial dependence.

6.1.4 Green synthesis of gold and silver nanoparticles using plant extracts from indigenous plants in Majuli and Kamrup and antimicrobial studies of silver nanoparticles obtained by green synthesis

This chapter discussed the bioresource utilization perspective in Brahmaputra River floodplain. Bioresource utilization was fulfilled by screening of native plants from Majuli River Island and Kamrup to synthesize AuNPs and AgNPs with a scope of application in therapeutic studies. Utilization of indigenous plants for synthesizing AuNPs and AgNPs or biologically mediated NP synthesis includes two important requirements, a) the reducing and b) capping efficiency. AuNPs and AgNPs were synthesized from local plants of medicinal importance. Flowers of *Nyctanthes arbortristis and* leaves of *Amaranthus spinosus* have been used to synthesize AuNPs while AgNPs were synthesized from *Nyctanthes arbortristis* flowers extract. AgNPs synthesized from *Nyctanthes arbortristis*, were employed in antibacterial studies against pathogenic strain of *Escherichia coli* MTCC 443.

Experimental analyses revealed a novel application of ethanolic flower extract of *Nyctanthes arbortristis* and ethanolic leaf extract of *Amaranthus spinosus* to synthesize gold and silver nanoparticles. Green synthesis of AuNPs and AgNPs has been adopted as ecofriendly and cost effective method of screening plant material for bioresource utilization. Optical and physical properties of the synthesized AuNPs and AgNPs were characterized through a series of standardized protocols. UV-visible spectroscopy and Transmission electron microscopy (TEM) proved reduction of metallic ions to NPs. Crystalline nature of the NPs was determined by X-ray diffraction (XRD). Phytochemicals present in the EFE were adsorbed on the surface of the NPs, evident as distinct IR bands in the Fourier Transform Infra-Red (FTIR) spectrum. TEM micrographs showed that AuNPs synthesized from *Nyctanthes arbortristis* (AuNPs) and *Amaranthus spinosus* (AuNPs) were around 19.8 nm and 10.74 nm respectively. In case of AgNPs synthesized from *Nyctanthes arbortristis* EFE the size range was 5 – 20 nm. The size range and biofunctionalization of AuNPs and AgNPs synthesized through green synthesis method makes them desirable for therapeutic applications and water treatment processes respectively.

Finally this chapter demonstrated an environmentally safe and non – toxic method of synthesis of AuNPs and AgNPs. Biologically mediated nanoparticle synthesis facilitates capping or adsorption of stabilizing agents on the surface of the nanoparticles that prevents the particles from agglomerating. Sustainable surface adsorption chemistry, stability and non-toxicity of nanoparticles are the desirable traits in biomedical applications. Thus phytochemicals present in plant extracts are rationalized towards green chemistry of reduction of metallic salts to NPs and

sustainability of an environment friendly process of synthesis. Green synthesis of NPs was successfully accomplished as an eco-friendly and sustainable method of plant bio resource utilization in the study areas in Brahmaputra River floodplain.

6.2 FUTURE PROSPECTS

Analysis of floodplain characteristics for ecosystem support mechanism in Brahmaputra River floodplain opened sources for further exploration of ecological components in Majuli and Kamrup. In this context, there is a possibility for further research on ecological perspective in Majuli and Kamrup. While summarizing the outcomes of this investigation, probable implications of certain unmapped ideas could be foreseen in Section A and in Section B. These ideas could yield potentially new and beneficial information as summarized below:

- Soil microfauna contributing to wetland productivity can be screened for metagenomics, research findings in Majuli River Island and Kamrup showed activities of some important enzymes as cellulase, phosphatase, amylase, dehydrogenase, invertase, protease and urease.

- Bioresource utilization areas have scope for further exploration of indigenous plants for green synthesis of nanoparticles and check their antimicrobial activities. The synthesized AuNPs could be fabricated with natural polymers for potential drugs carriers for the treatment of the cancer.

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List of Publications

List of Publications

Manuscripts in communication

1. **Gogoi N**, Talukdar NC, Mahanta C, Bora U*. Nutrient cycling and enzyme activities as a function of soil productivity in wetland ecosystems in Brahmaputra river floodplain-a case study in Majuli River Island, Assam, India (Research article submitted to *Geoderma*)

Manuscripts under preparation

2. **Gogoi N**, Talukdar NC, Mahanta C, Bora U*. Assessment of metal status and pollution indices in water and soil for evaluation of ecological risk in wetlands in Majuli River Island, Assam, India (Research article)

3. **Gogoi N**, Talukdar NC, Mahanta C, Bora U*. Geochemical parameters as a function of soil productivity and fertility in an industrial area and a river island in lower Brahmaputra floodplain (Research article)

Manuscripts published

1. **Gogoi N**, Babu PJ, Mahanta C, Bora U* (2014) Green synthesis and characterization of silver nanoparticles using alcoholic flower extract of *Nyctanthes arbortristis* and in vitro investigation of their antibacterial and cytotoxic activities. Materials Science & Engineering C. 46(1): 463 – 469

2. Das RK, **Gogoi N**, Babu PJ, Sharma P, Mahanta C, Bora U* (2012) The Synthesis of gold nanoparticles using *Amaranthus spinosus* leaf extract and study of their optical properties. Advances in Materials Physics and Chemistry. 2:275 – 281 (Equal contribution)

3. Das RK, **Gogoi N**, Bora U* (2010) Green synthesis of gold nanoparticles using *Nyctanthes arbortristis* flower extract. Bioprocess and Biosystems Engineering. 34(5):615 – 9 (Equal contribution)

Other publications

1. Das RK, Babu PJ, **Gogoi N**, Sharma P, Bora U* (2012) Microwave mediated rapid synthesis of gold nanoparticles using *Calotropis procera* latex and study of optical properties. ISRN Nanomaterials. Article ID 650759, 6 pages

List of Presentations

Oral Presentations

1. Gogoi N, Mahanta C, Bora U*. Microbial diversity in soil and its role in nutrient mineralization, a case study in Brahmaputra River Floodplain, Guwahati. **International Conference on Harnessing Natural Resources for Harnessing for Sustainable Development – Global Trend** (2014)
2. Dhar A, Tashmi HH, Gogoi N, Fahmi NH. Water bank: an initiative for water communities. **Water Futures: A Dialogue for Young Scholars and Professionals, An Indo-Bangladesh dialogue** (2013)
3. Gogoi N, Mahanta C, Bora U*. Ecological perspective of Brahmaputra River floodplain. **International Conference on Environmentally Sustainable Urban Ecosystems** (2012)

Poster Presentations

1 Gogoi N, Mahanta C, Bora U*. An ecological risk assessment of metals in Majuli River Island and Kamrup, a comparative case study. **Disease Biology And Therapeutics (ICDBT)** (2014)

2 Gogoi N, Mahanta C, Bora U*. Use of geostatistical tools in environmental analysis, a case study in Majuli River Island**. National Conference on Sustainable Development of Environmental Systems** (2014)

3 Gogoi N, Kumar A, Mahanta C, Bora U*. Development of Majuli bioresource database. **International Symposium on Bioengineering** (2012)

4 Gogoi N, Mahanta C, Bora U*. Life cycle assessment and ecology. **One Day Symposium on Environment and Us** (2012)

5 Gogoi N, Mahanta C, Bora U*. Nutrient cycling in wetland ecosystems**. Young Ecologists Talk and Interact** (2011)

6 Gogoi N, Mahanta C, Bora U*. Evaluation of floodplain characteristics of Brahmaputra River for sustainable development and best management practices. **Climate Change and Water: Assessing vulnerability, impact and adaptation in the Eastern Himalayas** (2011)

7 Gogoi N, Mahanta C, Bora U*. Biodiversity of the Ganga River. **International Conference on "Biodiversity and Climate Change** (2010)

Workshops

1. Workshop on **Next Generation Sequencing and Data Analysis** supported by IITG Biotech Hub, Centre for the Environment, IIT Guwahati, Guwahati, Assam, India (2014)
2. Workshop on **Water Futures: A Dialogue for Young Scholars and Professionals**, jointly supported by Centre for North East Studies and Policy Research, Jamia Milia Islamia, New Delhi and Department of International Relations, University of Dhaka, Bangladesh in Association with the Ecosystems for life: A Bangladesh-India Initiative, IUCN (International Union for Conservation of Nature (2013)
3. Workshop on **IEEE Workshop on Compressive Sensing and Technical Writing** supported by IEEE Student Branch IIT Guwahati, Guwahati, Assam, India (2013)
4. **A National Level Workshop cum Training Programme on Advanced Techniques and Technologies in Sericulture (A training course for college, university students and young researchers)** supported by Institutional Biotech Hub, Central Muga Eri Research and Training Institute (CMER & TI), Central Silk Board, Ministry of Textiles, Govt. of India, Lahdoigarh, Assam, India (2013)
5. **Summer School in Efficient Fossil Energy Technologies** supported by University of Nottingham, Nottingham, UK and IIT Guwahati, Guwahati, Assam, India (2011)
6. **Hands on Training on Mammalian Cell Culture Techniques for Toxicity Studies** supported by IITG Biotech Hub, Centre for the Environment, IIT Guwahati, Guwahati, Assam, India (2011)
7. Quality Improvement Programme, **AICTE Sponsored Short Term Course on Tools for Bioresources Conservation** supported by the Department of Biotechnology, IIT Guwahati, Guwahati, Assam, India (2011)

Biography

BIOGRAPHY

Nayanmoni Gogoi was born and brought up in Moranhat, Assam India. She completed her Secondary School Certificate (10th Std.) in 2001 from Saint Joseph's School, Moranhat and her Intermediate education (12th Std.) in 2003 from Moran Higher Secondary School, Moranhat. She completed her Bachelor's degree in Botany, in 2007, from Moran College, affiliated to Dibrugarh University and was the 6th rank holder in university along with distinction. She obtained her Master's degree in Environmental Science, in 2009, from Tezpur Central University.

She qualified GATE and ICAR-NET, and joined Centre for the Environment, IIT Guwahati in August 2009 for her doctoral studies under joint supervision of Dr. Utpal Bora and Professor Chandan Mahanta. Her Ph. D. work focuses on ecological study of riverine floodplain mainly concentrated on assessment of ecological parameters as an important function of ecosystem support. Her thesis work also emphasizes on bioresource utilization perspective where synthesis of gold green and silver nanoparticles from plant extracts and antimicrobial activity of sliver nanoparticles have been adopted as an ecofriendly and sustainable method of utilizing plant resources. She has published 3 papers at the time of compilation of this thesis, 1 manuscript is in communication and 2 manuscripts are under preparation. She represented India in a transboundary dialogue, "Water Future," sponsored by IUCN. She is currently a life member of Association of Microbiologists of India (AMI).

Appendices

Appendix 1

Table A 1.1 *Details of ecological monitoring of lakes and rivers worlwide*

Sl. No.	Place	Name	Subject	References
1	India	Chambal River	Water quality and pollution status	Saksena et al., 2008
2	India	Chandola Lake	Physicochemical characterization to assess water quality	Verma et al., 2012
3	India	Gorewada Lake	Physicochemical characterization of water	Puri et al., 2010
4	India	Kotitirtha Lake, New Palace Lake and Lakshatirth Lake	Physicochemical characterization of water	Pawar, 2012
5	India	Katraj Lake	Physicochemical characterization of water	Shaikh et al., 2013
6	India	Lakes in Bangalore	Perspective on pollution, restoration and management	Jumbe et al., 2008
7	India	Lidder River	Impact of anthropogenic activities on water quality	Rashid et al.. 2013
8	India	Lotus Lake	Seasonal variation of diatoms and their correlation with physicochemical parameters	Patil et al., 2013
9	India	Mansar Lake	Physicochemical characterization and seasonal variability	Al-Mikhlafi et al., 2003
10	India	Mansar Lake	Water quantity and quality	Kumar et al,. 2006
11	India	Mansar Lake and Surinsar Lake	Assessment of water quality and eutrophication of lakes	Singh et al., 2013
12	India	Mansar Lake, Dal Lake, Tsokar Lake, Tsomoriri Lake, Surinsar Lake and Renuka Lake	Water quality and eutrophication status	Singh et al., 2007
13	India	Mansar Lake, Tsokar Lake, Tsomoriri Lake, Surinsar Lake and Renuka Lake	Hydrological profile	Anuradha et al., 2013
14	India	Musi River	Impact of pollution on health and economic conditions	Cheepi, 2012
15	India	Periyar Lake	Water quality parameters	Krishnan, 2013
16	India	Manasbal Lake	Water quality	Sarah et al., 2011

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Sl. No.	Place	Name	Subject	References
17	India	Porur Lake and Vihar Lake	Water quality	Chandra et al., 2012
18	India	Pushkar	Water quality status	Sharma et al., 2011
19	India	Major rivers in India	Water quality and pollution status	Central Water Commission, 2011
20	India	Saptakosi River, Saptagandaki River and Karnali River	Water quality	Sharma et al., 2005
21	India	Sawanga Lake	Physicochemical characterization of water	Wankhade et al., 2013
22	India	Shahpura Lake	Physicochemical characterization of water to check water quality	Trivedi et al., 2012
23	India	Small Lake	Water quality	Tandel et al., 2011
24	India	Futala Lake, Ambazari Lake and Gandhisagar Lake	Surface water (lakes) quality	Puri et al., 2011
25	India	Upper Lake	Water quality	Rahul et al., 2013
26	India	Vrishabavathi River and Byramangala Lake	Water quality	Madhukar et al., 2013
27	India	Wular Lake	Physicochemical characterization of water	Shah et al., 2012
28	China	Chagan Lake	Water quality monitoring	Song et al., 2011
29	China	Chao Lake	Analysis of water pollution and ecosystem health	Hong et al., 2007
30	China	Lake Puzhehei	Water quality improvement	Wang et al., 2011
31	China	Taihu Lake	Relationship between landscape pattern and river water quality	Zhang et al., 2010
32	China	Xiaohu Lake	Lake water environment capacity analysis based on steady-state model	Chang et al., 2013
33	China	Yellow River	Physicochemical characterization of water and assessment of ecological risk assessment	Wang et al., 2009
34	Nigeria	Mada River	Physicochemical characterization of water	Tukura et al., 2012
35	Nigeria	Oguta Lake	Assessment of the physical and environmental aspects	Ahiarakwem et al., 2012
36	Kenya	Elementaita Lake	Physicochemical characterization of water to check water quality	Adeka et al., 2007
37	Kenya, Uganda and Tanzania	Victoria Lake	Physicochemical characterization of water to check pollution load	Okungu et al., 2012

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Sl. No.	Place	Name	Subject	References
38	Australia	Murray-Darling Basin	Physicochemical characterization of water to check toxicity associated with commonly occurring cyanobacteria in surface waters	Baker et al., 1994
39	Cambodia, Vietnam	Mekong and Red River	Arsenic pollution	Berg et al., 2007
40	Mexico	Calcasieu Lake	Physicochemical characterization of water to check water quality	Waldon, 1996
41	Colorado, North Carolina	Rivers and Lakes in Colorado and North Carolina	Physicochemical characterization of water as an approach to valuing clean lakes, rivers, and streams	Magat et al., 2000
42	Michigan	Michigan Lake	Physicochemical characterization of water river load for total phosphorus	Dolan et al., 1981
43	New York	Three Rivers system in New York extending to Ontario Lake	Physicochemical characterization of water to check water quality	Effler et al., 2010
44	USA	Erie Lake	Physicochemical characterization of water to check re-eutrophication	Scavia et al., 2014
45	Arkansas	Coffee creek, Mossy Lake, and the Ouachita River	Physicochemical characterization of water to check water quality	Parsons Austin, TX and the University of Arkansas Ecological Engineering Group Fayetteville, AR, 2007
46	Arctic	River Lena, Ob (Yenisei) rivers in Russia, rivers in Northern Hemisphere, Toolik Lake (Alaska) and Ice Caps Greenland)	Assessment of recent climate change impacts by physicochemical characterization of water	Hinzman et al., 2005
47	Canada	Missisquoi Bay	Water quality monitoring by physicochemical characterization of water	De Boutray et al., 2005
48	Iraq	Dokan Lake	Assessment of water quality index by physicochemical characterization of water	Alobaidy et al., 2010
49	Iran	Zerebar Lake	Physicochemical characterization of water to check eutrophic status of lake	Rahmani et al., 2013
50	Iran	Zarivar Lake	Water quality assessment	Sharifinia et al., 2013

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Sl. No.	Place	Name	Subject	References
51	Armenia	Sevan Lake	Water quality assessment	Kachvoryan et al., 2008
52	Macedonia	Lipkova River and an Artificial Lake	Physicochemical characterization of water and evaluation of bacteriological parameters in water	Iseni et al., 2013
53	Greece	Aliakmon River, Axios River, Loudias River, Strymon River and Gallikos River	Assessment of the surface water quality	Simeonov et al., 2003
54	Mississippi	Mississippi River and Pepin Lake	Water quality modelling by determination of physicochemical characteristics of water	Lung et al., 1995
55	Mississippi	Mississippi River	Influence of physicochemical characteristics on fishes	Rutherford et al., 1995
56	Worldwide	Rivers and lakes worldwide	Water quality monitoring	Palaniappan et al., 2010
57	Turkey	Porsuk Stream	Assessment of seasonal variations of surface water quality	Altm et al., 2009
58	Northern Hemisphere	lake and river ice cover in Northern Hemisphere	Water quality monitoring in lake and river ice cover	Magnuson et al., 2000
59	Southern Hemisphere	Water in Southern Hemisphere	Hydrology profile	Alexander, 1985
60	Scotland	Lakes and rivers in Scotland	Water quality evaluation	Miller et al., 2013
61	Zimbabwe	Ruwa River	Impact waste water disposal on cations	Nyakungu et al., 2013
62	Philippines	Taal Lake	Water quality evaluation	Martinez et al., 2011
63	Philippines	Taal Lake	Evaluation of nutrient loading and efficiency of tilapia cage culture	Vista et al., 2006
64	Egypt	Nalser Lake	Physicochemical characteristics of water quality	Toufeek et al., 2009
65	Egypt	Nalser Lake	Physicochemical characteristics and distribution of some metals	Soltan et al., 2005
66	Egypt	Northern Delta Lakes	Assessment of heavy metals pollution in water and sediments and their effect on *Oreochromis niloticus*	Saeed et al., 2008

Appendix 1

Table A 1.2 *Details of ecological evaluation of microorganisms in water from lakes and rivers in different parts of the world*

Sl. No.	Place	Name	Subject	References
1	Poland	Kamionka, Maniowka, Wiatrotuza and Piertanka Rivers	Bacteriological monitoring for river water quality	Niewolak, 2000
2	Serbia	River Tisa	Microbiological evaluation of water quality	Kolarević et al., 2011
3	Nigeria	Perennial rivers in Kaduna Metropolis, Nigeria	Microbial for coliform species	Garba, 2014
4	Nigeria	Njaba River	Comparative assessment of the physico-chemical and microbial parameters	Ahiarakwem et al., 2011
5	Turkey	Biga Stream	Assessment of physico-chemical and microbiological parameters	Hacioglu et al., 2009
6	Brazil	Rio Doce basin	Assessment of microbial community	Petrucio et al., 2005
7	India	Singanallur Lake and Theneri Lake	Evaluation of cyanobacteria population	Jeyachitra et al., 2013
8	Thailand	Hot springs: San Kamphaeng, Pong Dued, Teppanom, Mae Fang, Doi Saket, Jae Son, Tha Pai, Mae Jun and Huai Mak Lium	Distribution of cyanobacteria in hot springs	Sompong et al., 2005)
9	Germany	Schussen River	Assessment of pathogenic bacteria in water	Triebskorn et al., 2013
10	Serbia	Velika Morava river	Seasonal variations of microbiological parameters in water	Kolarević et al., 2012
11	India	Udaipur Lakes	Microbiological evaluation of water	Sharma et al., 2008
12	Africa	Buffalo River	Bacteriological evaluation of water	Chigor et al., 2013
13	Africa	Tyume River	Spatio-temporal distribution of faecal-indicator bacteria	Sibanda et al., 2013

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Sl. No.	Place	Name	Subject	References
14	Egypt	Nile	Evaluation of Microbial quality	Sabae et al., 2007
15	Egypt	Nile	Assessment of Mutual Relations between Bacteria and Zooplankton	Khalifa et al., 2012
16	Egypt	El-Salam Canal	Assessment of Microbial Pollution	Yehia et al., 2011
17	Nigeria	Awba Lake	Microbiological Assessment of water	Tijani et al., 2005
18	Turkey	Golbasi lake	Assessment of Microbial Pollution	Toroglu et al., 2009
19	Nigeria	Awedele spring	Bacteriological evaluation	Odeyemi et al., 2010
20	India	North Indian lakes	Evaluation of bacteria as faecal pollution indicators	Sharma et al., 2010
21	Iceland	Lake Ellidavatn	Assessment of microbial diversity	Guðmundsdóttir, 2012
22	Congo	Lake Eduard and its majors tributaries rivers	Bacteriological	Bagalwa et al., 2014
23	Nigeria	Kainji Lake	Microbiological evaluation	Ajibade et al., 2008
24	Baghdad	Tigris River	Bacteriological evaluation	Al-Bayatti et al., 2012
25	Baghdad	Tigris River	Effect of pollution onbacterial population	Maalah et al., 2014
26	Macedonia	Lipkova's River	Evaluation of Bacteriological Parameters	Iseni et al., 2013
27	Arctic	Stamukhi lake	Assessment of Microbial diversity and heterotrophic production	Galand et al., 2008a
28	Arctic	Arctic shelf	Distribution of Heterogeneous archaeal communities	Galand et al., 2008b
29	California	San Joaquin River	Evaluation of risk assessment of pathogenic bacteria	Parkin et al., 2003
30	Kenya	Nairobi river and Athi river	Assessment of bacterial pathogens	Musyoki et al., 2013

Appendix 1

Table A 1.3 *Details of ecological evaluation of microorganisms in sediments and soils in lakes and rivers in different parts of the world*

Sl. No.	Place	River	Study	References
1	United States	Illinois River	Assessment of soil microbial communities	Kelly et al., 2007
2	United States	Upper Arzobispo River basin	Microbial activity in soil and sediments	Cerón et al., 2011
3	Italy	Mulargia River	Ecological evaluation of benthic microbial community	Zoppini et al., 2010
4	Nigeria	Ochanni, and Nsinkele, Ogon streams	Physicochemical and microbiological assessment of oil-impacted sediment	Akani et al., 2008
5	Italy	Southern Adriatic Sea: Brindisi, S. Cataldo, Otranto and Santa Maria di Leuca	Microbial assessment as pollution indicator	Stabili et al., 2011
6	Arctic	Canadian Eastern sub-Arctic and Arctic along the Resolution Island, Northwest Territories	Microbial assessment in polychlorinated biphenyl soil	Mohn et al., 1997
7	Arctic	Lake basin in the Arctic coastal plain near Barrow, Alaska	Metagenomic study in peat soil	Lipson et al., 2013
8	Arctic	Permafrost areas	Microbial evaluation in permafrost areas	Jansson et al., 2014
9	Arctic	Wetlands in Canadian High Arctic, permafrost areas	Assessment of microbial diversity in permafrost areas	Wilhelm et al., 2011
10	Antarctic and Arctic	Ice-cores Antarctic and Arctic circles	Evaluation of terrestrial, psychrophilic microorganisms in frozen habitats	Kirby et al., 2011
11	Belgium	North Sea	Microbial diversity and metal fluxes in contaminated sediments	Gillan et al., 2012
12	Pakistan	Indus River	Assessment of microbial flora for utilization in microbial fuel	Hayat et al. 2014
13	France	Scheldt River	Faecal contamination in sediments	Ouattara et al., 2011
14	France	Seine River	Ecological assessment of bacteria in a polluted river sediments	Garnier et al., 1992

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Sl. No.	Place	Name	Subject	References
15	Antarctic	West Antarctic	Bacterial evaluation in ice sheet	Lanoil et al., 2009
16	China	Pearl River	Diversity and vertical distributions of bacteria in sediments	Yang et al., 2013
17	Switzerland	Lake Geneva	evaluation of bacterial and archaeal communities in sediments	Haller et al., 2011
18	California	California salt marsh	Assessment of diversity geographical distribution of microbial communities	Córdova-Kreylos et al., 2006
19	Antarctic and Arctic	Polar ice caps	Microbiological evaluation in ice covered regions	Rampelotto, 2014
20	Canada	Mackenzie River basin	Microbiological evaluation	Boyd et al., 1971
21	Siberia	Permafrost areas	Characterization of viable bacteria from permafrost	Shi et al., 1997
22	Canada	Mackenzie Valley	Microbiological evaluation in permafrost soils	Ivarson, 1965
23	Antarctic	Antarctic Dry Valley	Microbiological evaluation in arid soils	Cary et al., 2010
24	Arctic	Arctic tundra tussock	Bacterial and fungal evaluation in tundra tussock and shrub soils	Wallenstein et al., 2007
25	Antarctic	Antarctic terrestrial habitats	Ecological evaluation of patterns of bacterial diversity	Yergeau et al., 2007

Appendix 2

Table A 2.1 (A) *Details of water sampling sites and wetlands studied in Majuli River Island*

Sample code	Type	Place	Geographic location	Locality [a]	Flooding [b]	Erosion [c]
Group A (Water from wetlands in residential area)						
S4	Wetland	Gakhojuwa Bil	N26°54'58.32" E94°17'25.88"	Residential land and river dyke	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S6	Wetland	Tuni Bil	N26°57'1.01" E94°17'56.89"	Residential land	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S7	Wetland	Barbil	N26°56'13.06" E94°15'58.60"	Agricultural land, grassland and residential	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion
S9	Wetland	Magurmara Bil	N26°55'11.97" E94°14'57.95"	Residential land	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion
S10	Wetland	Kharjan Bil	N26°57'58.99" E94° 9'30.29"	Grassland and residential	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S16	Wetland	Kharkhari Bil	N26°57'12.61" E94°10'18.27"	Residential land	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion

Appendix 2

Sample code	Type	Place	Geographic location	Locality [a]	Flooding [b]	Erosion [c]
Group B (Water from wetlands in grassland)						
S2	Wetland	Water body	N26°54'58.97" E94°16'0.24"	Grassland	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S3	Wetland	Sarala Bil	N26°58'55.06" E94°17'57.43"	Grassland and river dyke	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S12	Wetland	Daria Bil	N26°57'34.47" E94° 9'46.60"	Residential land and grassland	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion
S18	Water body	Missing Gaon	N26°55'38.49" E94° 9'56.78"	Residential land and grassland	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
Group C (Water from wetlands in agricultural field)						
S13	Wetland	Bhereki Bil	N26°55'37.65" E94° 8'14.81"	Agricultural land	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion
S14	Wetland	Kakarikata Bil	N26°55'58.37" E94° 5'39.82"	Agricultural land	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion

Appendix 2

Sample code	Type	Place	Geographic location	Locality [a]	Flooding [b]	Erosion [c]
Group C (Water from wetlands in agricultural field)						
S15	Wetland	Sakali Bil	N26°56'31.66" E94° 8'16.17"	Agricultural land	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion
S17	Wetland	Garukhuti Bil	N26°58'24.78" E94°11'5.25"	Residential, agricultural land and grassland	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion
Group D (Ground water)						
S1	Ground water	Aphalamukh	N26°55'0.50" E94°16'44.40"	Residential land	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S5	Ground water	Bongaon Chariali	N26°57'17.73" E94°17'15.01"	Residential land in market place	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S8	Ground water	Barbil Gaon	N26°56'10.01" E94°16'1.32"	Agricultural and residential land	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion
S11	Ground water	Garmur Chariali	N26°58´42.9´´ E94°08´54.3´´	Residential land in Garmur Satra	Flooding due to rainfall and water from rivers	Flood and rainfall driven erosion

Appendix 2

Sample code	Type	Place	Geographic location	Locality [a]	Flooding [b]	Erosion [c]
			Group E (River water)			
Kmb Bank	River	Kamalabari (Brahmaputra river)	N26°55'16.81" E94° 9'57.03"	Grassland	Monsoon and rain fed flood	Bank erosion
Nim Bank	River	Nimatighat (Brahmaputra river)	N26°51'40.45" E94°14'38.95"	Grassland	Monsoon and rain fed flood	Bank erosion

Here, Kmb=Kamalabari; Nim= Nimatighat

a – locality of the sampling sites were noted down prior to sampling

b, c – data based on a questionnaire asked to local people

Appendix 2

Table A 2.1 (B) *Details of field study, soil sampling sites and wetlands in Majuli River Island, Assam, India*

Sample Code	Geo Position	Place	Soil Type[a]	Locality [b]	Vegetation Type [c]	Vegetation at the time of First Sampling [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
Group A (Residential area)									
S1	N26°55'0.50" E94°16'44.40"	Aphalamukh	Sandy Clay Loam	Residential and River Dyke	Herbs, shrubs and large trees	*Dichanthium annulatum*, *Colocasia* sp. *Diplazium esculentum*, *Hemarthria* sp., *Imperata cylindrica*, *Cyperus rotundus*, *Cynodon dactylon*, *Gossypium* sp., *Cassia* sp., *Scoparia dulcis*, *Chrysosogon aciculatus*, *Erianthus* sp. and *Centella asiatica*	No record of synthetic fertilizer other than cow dung	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S5	N26°55'11.97" E94°14'57.95"	Magurmara	Sandy Clay Loam	Residential	Herbs, shrubs and large trees	*Mimosa pudica*, *Mentha* sp., *Hemarthria* sp., *Chrysopogon aciculatus*, *Ageratum conyzoides* and *Imperata cylindrica*	No record of synthetic fertilizer other than cow dung	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion
S6	N26°57'58.99" E94° 9'30.29"	Kharjan Bil	Sandy Clay Loam	Residential and grassland	Herbs, shrubs and large trees	*Mikania* sp., *Solanum nigrum*, *Polygonum hydropiper*, *Hemarthria* sp., *Centella asiatica*, *Dichanthium annulatum*, *Commelina benghalensis*, *Hydrocotyle rotundifolia*, *Diplazium esculentum*, *Ageratum conyzoides* and *Imperata cylindrica*	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from rainfall and connected wetlands	Flood and rainfall driven erosion

Appendix 2

Sample Code	Geo Position	Place	Soil Type[a]	Locality [b]	Vegetation Type [c]	Vegetation at the time of First Sampling [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
Group A (Residential area)									
S11	N26°57'12.61" E94°10'18.27"	Kharkhari Bil	Sandy Clay Loam	Residential	Herbs, shrubs and large trees	*Colocasia* sp., *Canella asiatica, Hydrocotyle rotundifolia*, *Oxalis repens*, *Dichanthium annulatum*, *Setaria flavidium*, *Cynodon dactylon, Diplazium esculentum*, *Polygonum hydropiper*, *Andrographis paniculata*, *Scoparia dulcis*, *Spilanthes paniculata* and *Daucas carota*	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from rainfall and connected wetlands	Flood and rainfall driven erosion
Group B (Grassland)									
S2	N26°58'55.06" E94°17'57.43"	Sarala Bil	Sandy Clay Loam	Grassland	Herbs, shrubs and large trees	*Cyperus esculentus*, *Hemarthria* sp., *Cynodon dactylon*, *Dichanthium annulatum*, *Ipomea aquatica* and *Eichornia crassipes*	No record of synthetic fertilizer other than cow dung	Flooding due to direct entry of water from rainfall and connected wetlands	Flood and rainfall driven erosion
S3	N26°57'1.01" E94°17'56.89"	Tuni Bil	Sandy Clay Loam	Grassland and river Dyke	Herbs, shrubs and large trees	*Hemarthria* sp., *Solanum nigrum, Xanthium strumarium, Eichornia crassipes, Imperata cylindrica, Diplazium esculentum, Oxalis repens* and *Colocasia esculenta*	No record of synthetic fertilizer other than cow dung	Flooding due to direct entry of water from the river and rainfall	Flood and rainfall driven erosion

Appendix 2

Sample Code	Geo Position	Place	Soil Type[a]	Locality [b]	Vegetation Type [c]	Vegetation at the time of First Sampling [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
S4	N26°56'13.06" E94°15'58.60"	Barbil	Sandy Clay Loam	Grassland and River Dyke	Herbs, shrubs and large trees	*Scoparia dulcis, Imperata cylindrica, Diplazium esculentum, Ficus religiosa, Daucas carota, Alternathera* sp. and *Commelina benghalensis*	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from river and rainfall	Flood and rainfall driven erosion
Group C (Agricultural field)									
S7	N26°57'34.47" E94° 9'46.60"	Daria Bil	Sandy Clay Loam	Residential, agricultural land and grassland	Herbs, shrubs and large trees with traces of mustard field at vicinity	*Scparia dulcis, Imperata cylindrica, Dichanthium annulatum, Lantana camara, Solanum nigrum, Carica papya, Spilanthes paniculata* and *Gossypium* sp.	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from river and rainfall	Flood and rainfall driven erosion
S8	N26°55'37.65" E94° 8'14.81"	Bhereki Bil	Sandy Clay Loam	Residential, agricultural land and grassland	Herbs, shrubs and large trees with traces of paddy cultivation at vicinity	*Chryosopogon aciculatus, Hemarthria* sp., *Cassia occidentalis, Setaria flavidium, Mikania* sp., *Dichanthium annulatum, Centella asiatica, Diplazium esculentum, Ageratum conyzoides* and *Imperata cylindrica*	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from rainfall and connected wetlands	Flood and rainfall driven erosion

Appendix 2

Sample Code	Geo Position	Place	Soil Type[a]	Locality [b]	Vegetation Type [c]	Vegetation at the time of First Sampling [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
Group C (Agricultural field)									
S9	N26°55'58.37" E94° 5'39.82"	Kakarikata Bil	Sandy Clay Loam	Agricultural land and grassland	Herbs and shrubs with traces of paddy cultivation at vicinity	*Daucas carota, Abelmoschus esculentus, Oxalis repens, Centella asiatica, Solanum nigrum, Andrographis paniculata, Polygonum hydropiper, Eichornia crassipes, Imperata cylindrica, Spilanthes paniculata Hemarthria* sp., *Commelina benghalensis, Hydrocotyle rotundifolia, Ageratum conyzoides* and *Ficus reliogiosa*	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from rainfall and connected wetlands	Flood and rainfall driven erosion
S10	N26°56'31.66" E94° 8'16.17"	Sakali Bil	Sandy Clay Loam	Agricultural land and residential	Herbs, shrubs and large trees with traces of paddy cultivation at vicinity	*Centella asiatica, Imperata cylindrica, Andrographis paniculata, Hemarhtria* sp., *Daucas carota, Scoparia dulcis, Chrysopogon aciculatus, Andropogon* sp. and *Commelina benghalensis*	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from rainfall and connected wetlands	Flood and rainfall driven erosion
S12	N26°58'24.78" E94°11'5.25"	Garukhuti Bil	Sandy Clay Loam	Residential, agricultural land and grassland	Herbs, shrubs and large trees with traces of paddy cultivation at vicinity	*Amaranthus spinosus, Polygonum hydropiper, Andrographis paniculata, Solanum torvum, Hemarthria* sp., *Daucas carota, Dichanthium annulatum, Diplazium esculentum, Eichornia crassipes* and *Ipomoea aquatica.*	No record of synthetic fertilizer other than cow dung	Flooding due to rainfall and water from rainfall and connected wetlands	Flood and rainfall driven erosion

Appendix 2

Sample Code	Geo Position	Place	Soil Type[a]	Locality [b]	Vegetation Type [c]	Vegetation at the time of First Sampling [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
Group D (Bank sediment)									
Kmb Bank	N26°55'16.81" E94° 9'57.03"	Kamalabari (Brahmaputra river)	Sandy	River	NA	NA	No record	Monsoon and rain fed flood	Bank erosion
Nim Bank	N26°51'40.45" E94°14'38.95"	Nimatighat (Brahmaputra river)	Sandy	River	NA	NA	No record	Monsoon and rain fed flood	Bank erosion

Here, Kmb=Kamalabari; Nim= Nimatighat

a – soil type was evaluated at a depth of 0 – 20 cm in laboratory

b – locality of the sampling sites were noted down prior to sampling

c – type of vegetation was documented at the time of soil sampling

d – vegetation was recorded at the sampling site by quadrat method, quantifying the abundance and density of the mentioned plant species

e, f, g – data based on questionnaire asked to local people

Appendix 2

Table A 2.1 (C) *Details of soil sampling sites, study area in Amingaon and Umananda River Island in pre-monsoon and monsoon season*

Sample Code	Geopostion	Place	Locality [a]	Nature of soil [b]	Soil type [c]	Vegetation Type [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
Group A (Disturbed)									
A1	N26°10'56.79" E94°41'23.84"	Near bank, residential area	Residential area	Disturbed	Sandy clay loam	Grass	No record of fertilizer and pesticide application	Flash floods due to heavy rainfall and increase in level of river water	Minor bank erosion due to increase in water level
A2	N26°10'54.18" E94°40'45.75"	Roadside traversed by trespassers	Market area	"	"	Grasses and shrubs	"	"	Surface erosion due to rainfall
A4	N26°10'51.44" E94°40'22.25"	Near old factory	Residential area	"	"	Grasses and herbs	"	"	Surface erosion due to rainfall
A6	N26°10'57.41" E94°40’38.50"	Roadside and residential area	Residential area	"	"	Grasses, herbs, shrubs and large trees	"	"	Surface erosion due to rainfall
A8	N26°10'50.03" E94°40'43.23"	Roadside	Market and residential area	"	"	Grasses and herbs	"	"	Surface erosion due to rainfall
A10	N26°10'54.80" E94°41'46.18	Roadside	Market and residential area	"	"	Grasses and herbs	"	"	Surface erosion due to rainfall

Appendix 2

Sample Code	Geopostion	Place	Locality [a]	Nature of soil [b]	Soil type [c]	Vegetation Type [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
				Group A (Disturbed)					
U2	N26°11'46.18" E94°44'42.18"	Near bridge disturbed by trespassers	Non-residential area	Disturbed	Sandy clay loam	Grasses, herbs, shrubs and large trees	No record of fertilizer and pesticide application	Floods due to heavy rainfall	Surface erosion due to rainfall
U3	N26°11'47.26" E94°44'42.26"	Near temple	Temple area	"	"	"	"	"	"
U5	N26°11'47.06" E94°44'41.31"	Near shops at the basement of temple	Non-residential area	"	"	"	"	"	"
U7	N26°11'48.39" E94°44'44.47"	Near resting place	Non-residential area	"	"	"	"	"	"
U9	N26°11'46.71" E94°44'41.93"	Near park	Non-residential area	"	"	"	"	"	"

Appendix 2

Sample Code	Geopostion	Place	Locality [a]	Nature of soil [b]	Soil type [c]	Vegetation Type [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
Group B (Undisturbed)									
A3	N26°10'51.34" E94°40'27.80"	Amingaon field	Market area	Undisturbed	Sandy clay loam	Grasses	No record of fertilizer and pesticide application	Flash floods due to heavy rainfall and increase in level of river water	Surface erosion due to rainfall
A5	N26°10'57.05" E94°40'27.12"	Near army camps	Residential area	"	"	Grasses, herbs and shrubs	"	"	Minor bank erosion due to increase in water level
A7	N26°10'53.94" E94°40'38.15"	Residential area	Residential area	"	"	Grasses, herbs, shrubs and large trees	"	"	Surface erosion due to rainfall
A9	N26°10'57.19" E94°40'57.50"	Roadside	Industrial area	"	"	Grasses and herbs	"	"	Surface erosion due to rainfall

Appendix 2

Sample Code	Geopostion	Place	Locality [a]	Nature of soil [b]	Soil type [c]	Vegetation Type [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
				Group B (Undisturbed)					
U1	N26°11'46.11" E94°44'43.14"	Near bank	Non-residential area	Undisturbed	Sandy clay loam	Grasses, herbs, shrubs and large trees	No record of fertilizer and pesticide application	Floods due to heavy rainfall	Surface erosion due to rainfall
U4	N26°11'47.73" E94°44'42.17"	Near temple	Temple area	"	"	"	"	"	"
U6	N26°11'48.09" E94°44'40.23"	Near bank with large trees	Non-residential area	"	"	"	"	"	"
U8	N26°11'49.39" E94°44'43.24"	Near the footpath	Non-residential area	"	"	"	"	"	"
U10	N26°11'48.06" E94°44'45.49"	Near Bank	Non-residential area	"	"	"	"	"	"

Appendix 2

Sample Code	Geopostion	Place	Locality [a]	Nature of soil [b]	Soil type [c]	Vegetation Type [d]	Fertilizer and Pesticides application [e]	Flooding [f]	Erosion [g]
Group C (Bank sediments)									
AB1	N26°10'55.55" E94°41'33.78"	IIT Bank	River bank	Disturbed by water flow	Sandy*	Greases near the banks	No record of fertilizer and pesticide application	Floods due to heavy rainfall and increase in level of river water	Minor bank erosion due to increase in water level
AB2	N26°10'50.23" E94°40’22.47"	Saraighat bank	River bank	"	"	"	"	"	"
U Bank	N26°11'45.84" E94°44'43.06"	Umananda bank	River bank	"	"	"	"	"	"
K Bank	N26°11'20.86" E94°44'30.65"	Kachari bank	River bank	"	"	"	"	"	"

A – place and locality of the sampling sites were noted down prior to sampling

c – soil type was evaluated at a depth of 0 – 20 cm in laboratory

d, e, f, g – data based on questionnaire asked to local people

*confirmed by basic soil analysis method

Appendix 2

Table A 2.2 *Physicochemical parameters of water samples analysed in Majuli, in pre – monsoon and monsoon seasons*

Sample code	Season	pH	EC (µS/cm)	Turbidity (NTU)	DO (mg/L)	COD (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Ammonia (mg/L)	Phosphate (mg/L)	Chloride (mg/L)
Group A (Water from wetlands in residential area)											
S4	PM	8.70	138.87	2.9	7.26	90.67	0.51	10.47	0	0.09	16.57
	M	7.77	95.30	1.4	8.57	74.67	0.28	6.15	0	0.07	9.47
S6	PM	7.63	360.90	1.6	10.34	30.93	0.40	5.87	0.10	0.17	33.13
	M	7.27	92.13	1.1	9.72	160.00	0.48	5.15	0	0.08	23.67
S7	PM	8.10	91.17	3.5	8.35	90.67	0.31	0.48	0	0.20	18.93
	M	7.10	112.13	1.5	7.72	74.67	0.42	0.63	0	0.09	9.47
S9	PM	7.20	144.03	139.6	8.42	58.67	0.50	2.68	0.30	0.19	11.83
	M	8.00	434.90	6.5	9.79	58.67	0.77	1.82	0.18	0.13	9.47
S10	PM	7.53	316.17	10.2	8.36	74.67	0.74	6.81	0.10	0.60	26.03
	M	7.53	77.90	7.7	7.63	186.67	0.86	7.06	0.14	0.18	16.57
S16	PM	7.80	173.00	10.6	7.73	90.67	0.40	5.35	0	0.22	18.93
	M	7.63	144.60	4.2	8.66	144.00	0.38	5.61	0	0.14	11.83

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Sample code	Season	pH	EC (µS/cm)	Turbidity (NTU)	DO (mg/L)	COD (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Ammonia (mg/L)	Phosphate (mg/L)	Chloride (mg/L)
Group B (Water from wetlands in grassland)											
S2	PM	7.90	353.33	13.3	7.75	122.67	0.14	23.86	0	0.24	18.93
	M	7.07	84.63	9.9	7.06	154.67	0.24	16.05	0	0.06	11.83
S3	PM	7.87	141.30	5.1	9.24	69.33	0.37	17.87	0	0.20	11.83
	M	7.73	117.30	3.4	8.74	58.67	0.45	15.22	0	0.10	9.47
S12	PM	7.87	192.90	1.1	7.24	58.67	0.51	3.26	0	0.20	26.03
	M	7.13	112.87	1.3	6.47	117.33	0.43	2.42	0	0.12	14.20
S18	PM	7.83	124.77	1.6	7.76	58.67	0.21	27.34	0	0.24	18.93
	M	7.73	89.30	1.1	6.33	138.67	0.28	20.62	0	0.10	9.47
Group C (Water from wetlands in agricultural field)											
S13	PM	8.17	272.97	20.6	8.22	69.33	0.52	62.48	0	0.25	11.83
	M	8.23	90.63	5.5	8.35	240.00	0.63	48.40	0	0.12	18.93
S14	PM	8.40	316.70	3.3	7.48	58.67	0.44	3.65	0	0.26	18.93
	M	7.55	92.73	1.2	7.14	128.00	0.53	2.58	0.04	0.10	26.03
S15	PM	8.10	358.00	5.2	6.82	112.00	0.37	8.38	0	0.18	30.77
	M	7.53	105.90	3.7	8.36	186.67	0.35	6.20	0.09	0.08	23.67

Appendix 2

Sample code	Season	pH	EC (µS/cm)	Turbidity (NTU)	DO (mg/L)	COD (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Ammonia (mg/L)	Phosphate (mg/L)	Chloride (mg/L)
Group C (Water from wetlands in agricultural field)											
S17	PM	7.43	186.03	7.0	7.50	69.33	0.40	10.99	0	0.26	11.83
	M	7.83	104.63	3.1	7.96	186.67	0.36	7.22	0.08	0.16	23.67
Group D (Ground water)											
S1	PM	7.50	386.00	1.7	6.39	218.67	0.23	16.28	0	0.71	30.77
	M	7.37	95.83	1.3	7.15	133.33	0.35	11.65	0.21	0.30	11.83
S5	PM	7.13	330.80	1.5	6.60	90.67	0.85	8.51	0.21	0.85	37.87
	M	7.13	115.50	0.9	7.35	138.67	0.71	8.34	0.07	0.37	9.47
S8	PM	7.33	340.40	1.0	8.67	58.67	0.86	26.41	0	0.37	40.23
	M	7.70	120.40	0.5	9.15	96.00	0.82	20.86	0	0.14	18.93
S11	PM	7.80	357.87	5.5	6.76	58.67	0.87	8.27	0	0.09	47.33
	M	7.27	105.53	3.4	7.22	149.33	0.91	8.61	0	0.23	9.47
Group E (River water)											
Kmb Bank	PM	7.43	133.63	15.7	8.18	69.33	0.28	26.55	0	0.29	11.83
	M	7.83	106.90	5.6	8.72	176.00	0.19	18.36	0	0.14	11.83
Nim Bank	PM	7.29	144.14	17.1	7.77	74.67	0.36	29.50	0	0.28	16.57
	M	7.41	120.46	9.0	9.06	160.00	0.31	23.25	0	0.15	18.93

Here, PM = pre – monsoon; M = monsoon; EC = Electrical conductivity; NTU = Nephelometric Turbidity Unit; Kmb = Kamalabari; Nim = Nimatighat

Appendix 2

Table A 2.3 *Concentration of trace elements and water quality indexing in water samples in Majuli, in pre – monsoon and monsoon seasons*

Sample code	Season	Na (mg/ L)	Ca (mg/ L)	Mg (mg/L)	K (mg/ L)	Fluoride (mg/L)	SAR	SSP (%)	KR
Group A (Water from wetlands in residential area)									
S4	PM	3.36	24.42	5.96	2.28	0.10	0.86	15.68	0.11
	M	2.89	14.92	3.64	2.80	0.10	0.95	23.44	0.16
S6	PM	4.14	25.11	6.13	13.73	0.11	1.05	36.39	0.13
	M	5.28	3.98	0.97	4.15	0.11	3.36	65.60	1.07
S7	PM	4.54	16.78	4.10	4.94	0.10	1.41	31.23	0.22
	M	2.98	2.79	0.68	14.48	0.11	2.26	83.41	0.86
S9	PM	4.43	21.63	5.28	3.79	0	1.21	23.42	0.16
	M	2.34	44.25	10.80	9.32	0	0.45	17.48	0.04
S10	PM	7.78	31.29	7.64	11.23	0.12	1.76	32.82	0.20
	M	8.37	2.35	0.57	3.43	0.12	6.93	80.15	2.87
S16	PM	6.35	30.57	7.46	4.35	0	1.46	21.96	0.17
	M	7.24	8.57	2.09	3.04	0	3.14	49.10	0.68

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Sample code	Season	Na (mg/ L)	Ca (mg/ L)	Mg (mg/L)	K (mg/ L)	Fluoride (mg/L)	SAR	SSP (%)	KR
Group B (Water from wetlands in grassland)									
S2	PM	8.78	26.70	6.51	8.38	0.10	1.93	32.86	0.24
	M	5.15	9.86	2.41	2.35	0.09	2.08	37.96	0.42
S3	PM	2.70	17.67	4.31	3.31	0.08	0.81	21.47	0.12
	M	1.57	14.38	3.51	2.88	0.08	0.52	19.90	0.09
S12	PM	4.47	21.26	5.19	3.10	0.11	1.23	22.27	0.17
	M	3.24	9.25	2.26	3.55	0.12	1.35	37.10	0.28
S18	PM	3.32	21.04	5.13	19.58	0	0.92	46.69	0.13
	M	2.39	12.75	3.11	1.26	0	0.85	18.71	0.15
Group C (Water from wetlands in agricultural field)									
S13	PM	9.64	21.36	5.21	10.30	0.14	2.64	42.88	0.36
	M	8.04	14.24	3.47	2.17	0.14	2.70	36.55	0.45
S14	PM	7.35	34.83	8.56	5.12	0	1.57	22.23	0.17
	M	5.82	4.72	1.15	4.27	0	3.40	63.21	0.99

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Sample code	Season	Na (mg/ L)	Ca (mg/ L)	Mg (mg/L)	K (mg/ L)	Fluoride (mg/L)	SAR	SSP (%)	KR
Group C (Water from wetlands in agricultural field)									
S15	PM	6.13	23.94	6.01	11.78	0.10	1.57	36.88	0.20
	M	4.56	5.05	1.23	4.62	0.15	2.58	59.41	0.73
S17	PM	6.15	25.61	6.24	5.06	0.10	1.54	26.06	0.19
	M	4.47	5.62	1.37	2.55	0.09	2.39	50.11	0.64
Group D (Ground water)									
S1	PM	4.11	12.94	3.18	1.85	0.25	1.44	26.91	0.25
	M	2.75	9.41	2.30	1.16	0.25	1.14	25.06	0.24
S5	PM	9.43	20.58	5.01	19.88	0.30	2.64	53.45	0.37
	M	7.59	15.31	3.73	11.40	0.28	2.46	49.93	0.40
S8	PM	9.26	14.91	3.63	4.16	0.31	3.05	42.05	0.50
	M	10.84	11.09	2.71	5.28	0.29	4.13	53.88	0.79
S11	PM	5.89	17.82	4.35	6.46	0.28	1.77	35.77	0.27
	M	4.24	11.96	2.92	2.97	0.26	1.56	32.67	0.29

Appendix 2

Sample code	Season	Na (mg/ L)	Ca (mg/ L)	Mg (mg/L)	K (mg/ L)	Fluoride (mg/L)	SAR	SSP (%)	KR
Group D (Water from river at two banks)									
Kmb Bank	PM	3.58	20.47	5.08	2.33	0	1.00	18.61	0.14
	M	2.14	1.84	0.45	3.29	0	2.00	70.39	0.94
Nim Bank	PM	5.13	17.86	4.36	3.24	0	1.54	27.36	0.23
	M	6.23	15.57	3.80	2.98	0	2.00	32.23	0.32

Here, PM = pre – monsoon; M = monsoon; SAR = Sodium Absorption ratio; SSP = Soluble Sodium Percentage; KR = Kelly's Ratio; Kmb = Kamalabari; Nim = Nimatighat

Appendix 2

Table A 2.4 (A) *Details of geochemical parameters in Majuli in pre – monsoon and monsoon seasons, at a depth of 20 cm and a depth >20 cm*

Sample Code	Season	pH range		EC µ S cm^{-1}		MC (%)		CEC $cmol_c kg^{-1}$		Nitrate (mg/kg)		Ammonia (mg/kg)		Nitrite (mg/kg)		Sulphate (mg/kg)		Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	> 20 cm	(0 – 20 cm)	(0 – 20 cm)	> 20 cm	Fine Sand (%)	Silt (%)	Clay (%)
Group A (Residential area)																				
S1	PM	8.06	7.98-7.70	128.5	96.2-72.3	30.91	28.26-32.12	53.87	41.38-21.60	24.31	28.09-16.49	3.06	3.93-3.58	1.06	1.12-0.66	0.038	0.032-0.011	64.79	22.19	12.54
	M	8.14	8.15-7.72	128.28	117.07-89.22	32.69	30.42-33.21	34.86	37.15-13.05	12.95	10.23-10.13	2.72	2.30-1.74	1.04	1.03-0.71	0.032	0.026-0.006			
S5	PM	7.94	8.08-8.00	92.7	138.2-270.3	27.94	30.17-33.08	29.87	27.89-42.75	24.66	26.88-14.34	2.02	2.65-1.75	2.18	2.25-1.20	0.035	0.155-0.463	60.76	24.11	14.34
	M	8.24	8.35-8.17	146.97	211.98-166.02	29.61	31.66-34.47	22.36	20.34-9.67	22.96	24.83-8.37	1.21	1.27-1.75	0.83	0.74-0.56	0.034	0.051-0.218			

Appendix 2

Sample Code	Season	pH range		EC μ S cm^{-1}		MC (%)		CEC $cmol_c kg^{-1}$		Nitrate (mg/kg)		Ammonia (mg/kg)		Nitrite (mg/kg)		Sulphate (mg/kg)		Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm
Group A (Residential area)																				
S6	PM	7.77	7.74-7.68	52.4	52.4-160.2	17.98	21.36-33.14	5.45	8.51-20.34	28.81	25.26-21.97	2.74	2.85-2.36	2.09	2.22-1.19	0.041	0.143-0.173	60.25	20.89	18.62
	M	8.21	8.27-8.30	87.52	96.41-153.40	20.14	23.62-39.22	12.67	13.76-8.15	21.92	25.66-9.23	1.72	1.99-1.36	1.12	0.98-0.78	0.160	0.180-0.032			
S11	PM	6.57	6.58-6.94	48.6	21.4-23.1	28.87	27.76-32.45	48.16	44.04-46.09	26.97	21.54-16.37	1.09	1.14-1.46	1.76	1.59-1.25	0.007	0.119-0.149	65.28	20.57	13.12
	M	7.09	7.17-6.72	85.76	97.11-33.90	25.01	28.77-38.60	45.75	52.10-15.71	11.39	9.51-7.50	1.90	1.26-1.03	1.11	1.11-0.86	0.067	0.100-0.015			

Appendix 2

Sample Code	Season	pH range		EC μ S cm^{-1}		MC (%)		CEC $cmol_c kg^{-1}$		Nitrate (mg/kg)		Ammonia (mg/kg)		Nitrite (mg/kg)		Sulphate (mg/kg)		Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	> 20 cm	(0 – 20 cm)	> 20 cm
Group B (Grasslands)																				
S2	PM	8.24	8.17-7.99	121.3	79.8-76.6	27.40	29.64-35.95	59.93	60.77-57.63	36.56	35.11-22.20	4.31	4.41-4.18	1.87	1.73-0.67	0.054	0.012-0.008	55.89	27.79	15.30
	M	8.17	7.99-8.27	162.64	94.48-68.27	31.75	33.37-38.13	49.73	43.54-22.02	17.50	24.72-9.59	3.03	2.73-1.25	1.53	1.12-0.91	0.041	0.023-0.004			
S3	PM	5.55	7.15-6.10	142.0	80.6-21.2	33.81	30.46-37.37	21.07	22.50-6.64	22.11	26.21-16.72	4.69	4.68-4.12	2.70	2.20-0.74	0.162	0.091-0.022	60.72	22.77	16.17
	M	6.22	6.13-6.17	119.92	87.48-54.51	35.58	34.35-38.33	12.17	12.75-5.26	17.46	20.60-9.72	4.60	4.22-3.45	1.31	1.19-0.92	0.120	0.100-0.031			
S4	PM	5.79	6.74-6.73	62.6	23.7-16.4	28.78	30.26-37.78	23.62	25.84-8.61	33.58	32.53-21.10	2.88	2.53-2.08	1.25	1.28-0.89	0.158	0.146-0.068	63.41	20.61	15.37
	M	6.86	7.12-7.13	96.05	89.05-39.65	31.77	33.18-38.83	16.49	24.43-8.18	29.73	19.45-9.04	2.48	1.65-1.96	0.90	0.97-0.65	0.167	0.143-0.047			

Appendix 2

Sample Code	Season	pH range		EC µ S cm^{-1}		MC (%)		CEC $cmol_c kg^{-1}$		Nitrate (mg/kg)		Ammonia (mg/kg)		Nitrite (mg/kg)		Sulphate (mg/kg)		Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm
Group C (Agricultural fields)																				
S7	PM	5.49	6.59-6.97	89.3	46.8-20.9	23.35	25.36-32.81	19.12	15.12-19.12	18.57	25.27-21.75	1.93	2.49-1.83	1.06	1.31-0.68	0.011	0.075-0.200	57.18	24.44	18.05
	M	6.15	6.65-7.07	115.48	122.95-26.14	25.53	28.37-36.29	15.54	20.27-4.26	11.46	19.63-12.51	2.20	2.00-1.42	1.19	1.23-0.85	0.079	0.083-0.028			
S8	PM	6.83	6.85-7.10	90.2	34.5-22.4	20.12	24.76-30.10	33.69	15.21-12.40	20.07	22.33-16.39	1.97	1.45-1.19	1.14	1.07-0.63	0.025	0.072-0.107	55.84	23.98	19.42
	M	7.24	7.07-7.16	115.49	78.41-31.68	22.91	25.36-31.03	25.41	25.47-14.42	9.71	17.39-9.52	1.41	1.12-0.94	1.19	1.04-0.84	0.038	0.042-0.016			
S9	PM	5.19	7.06-7.74	267.1	76.7-49.2	24.08	26.97-33.67	24.09	44.94-39.41	20.04	27.33-15.72	1.86	1.48-1.52	1.44	1.57-0.74	0.008	0.011-0.0005	48.58	32.95	17.97
	M	6.69	7.16-7.57	118.71	225.49-34.82	27.27	29.83-35.82	13.42	14.73-6.90	9.49	13.97-9.22	1.24	1.48-0.74	1.04	1.04-0.86	0.029	0.024-0.002			

Appendix 2

Sample Code	Season	pH range		EC μ S cm^{-1}		MC (%)		CEC $cmol_c kg^{-1}$		Nitrate (mg/kg)		Ammonia (mg/kg)		Nitrite (mg/kg)		Sulphate (mg/kg)		Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm	> 20 cm	(0 – 20 cm)	> 20 cm
Group C (Agricultural fields)																				
S10	PM	7.33	8.08-7.92	90.4	87.7-78.3	26.50	28.81-33.98	28.40	37.20-47.49	38.20	34.27-22.09	1.91	3.28-2.50	1.64	1.67-1.23	0.207	0.079-0.175	45.58	28.21	25.58
	M	7.65	8.28-8.14	350.79	104.18-91.48	31.20	33.57-37.22	33.77	35.77-20.88	30.23	22.87-9.74	1.76	1.87-1.03	1.25	1.11-0.78	0.236	0.153-0.086			
S12	PM	5.10	6.81-6.72	164.7	30.7-17.5	32.45	29.86-36.66	36.84	40.30-37.22	37.07	33.56-19.65	2.33	2.97-2.69	2.07	1.88-1.64	0.062	0.055-0.241	50.86	26.09	22.79
	M	6.76	6.88-7.01	222.38	190.01-68.74	36.88	36.82-40.13			33.04	26.35-10.96	2.38	2.39-1.33	1.27	1.21-1.06	0.098	0.116-0.143			
Group D (Bank sediments)																				
Kmb Bank	PM	7.77	ND	114.9	ND	94.20	ND	69.84	ND	19.72	ND	1.30	ND	1.11	ND	0.003	ND	ND	ND	ND
	M	7.93		124.92		94.49		23.86		20.42		1.32		1.13		0.003				
Nim Bank	PM	7.42	ND	100.2	ND	93.81	ND	66.54	ND	11.21	ND	1.29	ND	1.24	ND	0.005	ND	ND	ND	ND
	M	7.66		99.89		95.78		24.50		11.17		1.57		1.24		0.006				

Here, PM = pre – monsoon, M = monsoon; EC = Electrical Conductivity, CEC = Cation Exchange Capacity, MC = Moisture Content, ND = No Data

Appendix 2

Table A 2.4 (B) *Details of geochemical parameters in Amingaon and Umananda in pre-monsoon and monsoon seasons, at a depth of 20 cm*

Sample Code	Season	pH	EC	MC (%)	Nitrate (mg/kg)	CEC $cmol_c kg^{-1}$	Ammonia (mg/kg)	Nitrite (mg/kg)	Sulphate (mg/kg)	Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)								Fine Sand (%)	Silt (%)	Clay (%)
Group A (Disturbed)												
A1	PM	7.00	69.97	21.82	12.25	46.58	3.15	1.72	0.15	67.41	21.80	10.40
	M	7.05	65.85	17.95	11.00	32.30	2.70	1.58	0.14			
A2	PM	7.18	118.40	28.20	12.84	46.67	2.45	1.78	0.16	61.36	28.57	9.84
	M	7.22	112.88	21.68	10.72	35.61	2.05	1.71	0.12			
A4	PM	7.12	62.70	24.18	11.07	45.49	3.02	1.92	0.16	65.68	26.53	7.69
	M	7.08	56.12	22.91	10.01	41.72	2.41	1.49	0.10			
A6	PM	7.22	111.90	25.39	16.56	37.42	3.63	2.03	0.18	66.79	23.33	9.61
	M	7.14	66.94	23.71	13.30	32.07	2.59	1.94	0.14			
A8	PM	7.07	88.70	23.82	24.81	34.79	2.90	2.34	0.20	67.19	20.70	11.70
	M	7.04	77.21	17.74	14.00	27.80	2.77	2.52	0.09			

Appendix 2

Sample Code	Season	pH	EC	MC (%)	Nitrate (mg/kg)	CEC $cmol_c kg^{-1}$	Ammonia (mg/kg)	Nitrite (mg/kg)	Sulphate (mg/kg)	Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)								Fine Sand (%)	Silt (%)	Clay (%)
Group A (Disturbed)												
A10	PM	6.98	76.57	27.38	15.35	38.07	2.79	2.33	0.21	62.77	25.22	11.80
	M	7.07	99.08	24.28	24.45	35.64	3.54	2.20	0.18			
U2	PM	7.26	90.69	23.99	23.15	42.81	3.12	2.38	0.16	58.44	28.27	13.18
	M	7.33	68.20	21.42	19.70	65.35	2.54	2.17	0.12			
U3	PM	7.16	34.73	26.59	20.13	36.69	3.58	2.25	0.15	60.00	22.50	16.80
	M	7.23	30.77	23.51	18.42	37.45	2.95	1.92	0.10			
U5	PM	7.58	66.67	26.44	18.53	48.47	3.06	1.86	0.20	55.48	28.38	15.62
	M	7.09	72.57	22.98	16.91	35.32	2.50	1.83	0.16			
U7	PM	7.11	75.46	27.44	21.20	54.94	3.55	2.63	0.19	63.10	22.67	13.95
	M	7.33	66.62	24.28	21.74	45.09	4.37	2.63	0.18			
U9	PM	6.95	81.19	21.14	23.98	39.35	3.95	2.48	0.21	60.12	23.54	15.59
	M	7.04	70.86	20.01	22.10	43.73	3.04	2.57	0.17			

Appendix 2

Sample Code	Season	pH	EC	MC (%)	Nitrate (mg/kg)	CEC $cmol_c kg^{-1}$	Ammonia (mg/kg)	Nitrite (mg/kg)	Sulphate (mg/kg)	Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)								Fine Sand (%)	Silt (%)	Clay (%)
Group B (Undisturbed)												
A3	PM	7.35	142.40	26.61	17.14	29.04	4.05	2.13	0.20	M 63.69	22.25	13.52
	M	7.28	131.97	23.27	15.98	25.49	3.25	2.27	0.17			
A5	PM	7.36	121.60	24.20	25.46	42.29	3.83	2.27	0.19	54.95	29.17	15.18
	M	7.06	110.03	20.29	25.33	36.34	2.66	2.38	0.15			
A7	PM	7.32	157.93	24.94	28.49	43.21	4.26	2.48	0.24	61.02	21.92	16.56
	M	7.24	123.56	22.26	23.44	35.71	3.56	2.47	0.17			
A9	PM	7.28	251.33	23.59	27.05	36.88	4.49	2.45	0.26	63.99	20.36	15.00
	M	7.23	180.04	20.52	26.82	31.14	4.07	2.34	0.21			
U1	PM	7.87	115.17	24.63	22.40	51.16	5.11	2.04	0.27	59.17	22.09	18.23
	M	7.54	84.58	22.59	29.80	29.72	3.42	1.74	0.17			
U4	PM	7.60	88.92	25.73	29.93	35.78	5.61	1.92	0.25	47.25	27.31	25.01
	M	7.56	75.29	23.34	26.64	24.97	4.49	2.10	0.20			

Appendix 2

Sample Code	Season	pH	EC	MC (%)	Nitrate (mg/kg)	CEC $cmol_c kg^{-1}$	Ammonia (mg/kg)	Nitrite (mg/kg)	Sulphate (mg/kg)	Particle Size Distribution (0 – 20 cm)		
		(0 – 20 cm)								Fine Sand (%)	Silt (%)	Clay (%)
U6	PM	7.98	92.79	23.55	27.27	33.81	5.02	2.58	0.23	58.23	23.57	18.18
	M	7.61	94.23	22.87	30.80	29.29	4.66	2.56	0.23			
U8	PM	7.65	75.97	26.92	29.86	57.61	4.70	2.70	0.25	58.67	22.00	18.81
	M	7.49	86.88	23.06	25.11	48.00	4.76	2.55	0.21			
U10	PM	7.83	121.56	25.88	26.99	45.00	4.95	2.37	0.24	57.45	25.35	16.53
	M	7.73	112.45	24.43	27.04	32.07	4.31	2.40	0.19			
Group C (Bank sediments)												
AB1	PM	6.87	49.63	89.58	23.17	53.80	1.71	1.84	0.14	ND	ND	ND
	M	7.02	34.17	89.14	20.07	50.70	1.39	1.55	0.11			
AB2	PM	7.13	60.87	84.13	26.41	70.46	1.80	1.52	0.13	ND	ND	ND
	M	7.03	55.66	88.47	22.21	36.69	1.61	1.41	0.09			
U Bank	PM	7.46	50.46	90.41	24.96	61.26	2.06	2.21	0.17	ND	ND	ND
	M	7.32	44.44	87.79	25.45	63.04	1.46	2.00	0.12			
K Bank	PM	7.34	86.29	87.19	26.08	72.87	1.93	2.31	0.18	ND	ND	ND
	M	7.18	72.98	84.27	26.26	66.65	1.87	2.13	0.15			

Here, PM = pre – monsoon; M = monsoon; EC = Electrical Conductivity, CEC = Cation Exchange Capacity, MC = Moisture Content, ND = No Data

Appendix 2

Table A 2.5 (A) *Details of microbial population in soil samples in Majuli in pre-monsoon and monsoon seasons respectively, at a depth of 20 cm*

Sample Code	Sampling sites	Season	BCFU cm^{-2} (0 – 20 cm)	FCFU cm^{-2} (0 – 20 cm)
Group A (Residential area)				
S1	Residential	PM	0.15	0.14
		M	0.28	0.23
S5	Residential	PM	0.073	0.055
		M	0.28	0.04
S6	Residential and grassland	PM	0.084	0.065
		M	0.31	0.042
S11	Residential	PM	0.055	0.073
		M	0.053	0.11
Group B (Grasslands)				
S2	Grassland	PM	0.14	0.12
		M	0.29	0.19
S3	Grassland	PM	0.053	0.13
		M	0.26	0.16
S4	Grassland	PM	0.083	0.015
		M	0.24	0.07

Appendix 2

Sample Code	Sampling sites	Season	BCFU cm^{-2} (0 – 20 cm)	FCFU cm^{-2} (0 – 20 cm)
Group C (Agricultural fields)				
S7	Residential, agricultural land and grassland	PM	0.07	0.055
		M	0.35	0.22
S8	Residential, agricultural land and grassland	PM	0.23	0.12
		M	0.23	0.10
S9	Residential, agricultural land and grassland	PM	0.065	0.09
		M	0.37	0.13
S10	Residential, agricultural land and grassland	PM	0.43	0.12
		M	0.34	0.075
S12	Residential, agricultural land and grassland	PM	0.048	0.053
		M	0.088	0.072
Group D (Bank sediments)				
Kmb Bank	Kamalabri bank	PM	ND	ND
		M		
Nim Bank	Nimatighat bank	PM	ND	ND
		M		

Here, PM = pre – monsoon; M = monsoon; BCFU = Bacterial Colony Forming Unit; FCFU = Fungal Colony Forming Unit, ND = No Data

Appendix 2

Table A 2.5 (B) *Details of microbial population in soil samples in Amingaon and Umananda in pre – monsoon and monsoon seasons respectively, at a depth of 20 cm*

Sample Code	Sampling sites	Season	BCFU cm^{-2}	FCFU cm^{-2}
			(0 – 20 cm)	
Group A (Disturbed)				
A1	Near bank, residential area	PM	1.02	0.40
		M	1.12	0.45
A2	Roadside traversed by trespassers	PM	0.77	0.46
		M	0.98	0.47
A4	Near old factory	PM	0.36	0.41
		M	0.62	0.47
A6	Residential area	PM	0.98	0.33
		M	1.04	0.38
A8	Roadside	PM	0.70	0.31
		M	0.79	0.36
A10	Roadside	PM	0.61	0.36
		M	0.66	0.41
U2	Near bridge disturbed by trespassers	PM	1.08	0.83
		M	1.15	0.84
U3	Near temple	PM	1.23	1.18
		M	1.10	1.21
U5	Near shops at the basement of temple	PM	1.39	0.96
		M	1.46	1.00

Appendix 2

Sample Code	Sampling sites	Season	BCFU cm^{-2}	FCFU cm^{-2}
			(0 – 20 cm)	
U7	Near resting place	PM	1.29	0.90
		M	1.35	0.84
U9	Near park	PM	1.30	0.74
		M	1.27	0.83
Group B (Undisturbed)				
A3	Amingaon field	PM	0.84	0.56
		M	0.95	0.63
A5	Near army camps	PM	0.65	0.53
		M	0.84	0.55
A7	Residential area	PM	0.68	0.34
		M	0.82	0.41
A9	Roadside	PM	0.37	0.47
		M	0.64	0.53
U1	Near bank	PM	0.90	0.87
		M	0.98	0.90
U4	Near temple	PM	1.70	0.43
		M	1.63	0.50
U6	Near bank with large trees	PM	1.36	1.07
		M	1.40	1.09
U8	Near the footpath	PM	1.24	0.65
		M	1.21	0.69

Appendix 2

Sample Code	Sampling sites	Season	BCFU cm^{-2}	FCFU cm^{-2}
			(0 – 20 cm)	
U10	Near Bank	PM	0.75	0.70
		M	0.84	0.73
Group D (Bank sediments)				
AB1	IIT bank	PM	ND	ND
		M		
AB2	Saraighat bank	PM	ND	ND
		M		
U Bank	Umananda bank	PM	ND	ND
		M		
K Bank	Kachari bank	PM	ND	ND
		M		

Here PM = pre – monsoon; M = monsoon; BCFU = Bacterial Colony Forming Unit; FCFU = Fungal Colony Forming Unit, ND = No Data

Appendix 2

Table A 2.6 (A) *Red field like ratio observed in CNP mineralization process in soil as well soil microbial biomass in Majuli River Island, CNP ratios at a depth of 0 – 20 cm shown in one column and the range of CNP ratio at depths > 20 cm shown in separate column (after Cleveland et al., 2011)*

Sample Code	Season	C:N:P		MBC:MBN:MBP	
		(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm
Group A (Residential area)					
S1	PM	17:2:1	12:1:1-15:1:1	24:2:1	22:2:1-30:2:1
	M	25:3:1	18:2:1-26:2:1	29:2:1	23:2:1-38:1:1
S5	PM	11:2:1	15:2:1-23:2:1	21:2:1	22:2:1-38:2:1
	M	20:3:1	19:2:1-25:1:1	29:3:1	27:2:1-37:2:1
S6	PM	11:2:1	10:1:1-21:2:1	12:2:1	13:1:1-36:2:1
	M	13:2:1	14:1:1-33:3:1	15:2:1	20:1:1-45:3:1
S11	PM	14:2:1	16:2:1-30:3:1	17:2:1	18:2:1-33:3:1
	M	16:2:1	14:1:1-17:2:1	16:2:1	17:1:1-26:1:1
Group B (Grassland)					
S2	PM	14:2:1	14:2:1-16:2:1	20:2:1	18:1:1-39:2:1
	M	19:2:1	16:3:1-25:2:1	27:2:1	25:3:1-40:2:1
S3	PM	14:2:1	15:2:1-17:1:1	18:2:1	20:1:1-29:2:1
	M	12:1:1	15:2:1-25:1:1	14:1:1	18:1:1-25:1:1
S4	PM	13:2:1	12:2:1-33:4:1	17:2:1	16:1:1-57:4:1
	M	15:2:1	14:2:1-26:4:1	16:2:1	22:2:1-33:3:1

Appendix 2

Sample Code	Season	C:N:P		MBC:MBN:MBP	
		(0 – 20 cm)	> 20 cm	(0 – 20 cm)	> 20 cm
Group C (Agricultural fields)					
S7	PM	13:3:1	15:2:1-20:2:1	15:3:1	18:2:1-34:2:1
	M	19:3:1	28:2:1-29:4:1	29:4:1	37:2:1-48:4:1
S8	PM	11:2:1	14:2:1-23:2:1	17:2:1	15:2:1-29:2:1
	M	15:2:1	16:2:1-20:2:1	15:2:1	18:3:1-18:1:1
S9	PM	12:3:1	11:2:1-17:2:1	14:3:1	15:2:1-18:2:1
	M	15:3:1	17:3:1-16:1:1	15:3:1	19:3:1-26:1:1
S10	PM	11:2:1	10:2:1-33:6:1	16:2:1	13:2:1-61:7:1
	M	14:3:1	12:3:1-23:5:1	19:2:1	13:3:1-35:4:1
S12	PM	10:2:1	13:3:1-8:1:1	12:2:1	19:3:1-35:2:1
	M	16:3:1	17:4:1-29:3:1	20:3:1	21:4:1-40:3:1
Group D (Bank sediments)					
Kmb Bank	PM	22:3:1	ND	17:1:1	ND
	M	19:3:1		22:2:1	
Nim Bank	PM	19:3:1	ND	16:1:1	ND
	M	15:3:1		23:2:1	

Here, PM = pre – monsoon; M = monsoon

Appendix 2

Table A 2.6 (B) *Red field like ratio observed in CNP mineralization process in soil as well soil microbial biomass CNP ratios in Amingaon and Umananda in pre – monsoon and monsoon seasons, at a depth of 0 – 20 cm (after Cleveland et al., 2011)*

Sample Code	Season	C:N:P	MBC:MBN:MBP
		(0 – 20) cm	
Group A (Disturbed)			
A1	PM	16:3:1	18:2:1
	M	13:3:1	20:4:1
A2	PM	16:3:1	22:3:1
	M	16:3:1	22:3:1
A4	PM	17:4:1	19:3:1
	M	13:3:1	23:2:1
A6	PM	20:4:1	23:2:1
	M	16:3:1	28:3:1
A8	PM	16:5:1	23:3:1
	M	17:4:1	21:4:1
A10	PM	17:2:1	21:1:1
	M	15:2:1	22:2:1
U2	PM	14:41	28:6:1
	M	18:5:1	18:4:1
U3	PM	15:4:1	17:3:1
	M	12:4:1	18:4:1
U5	PM	15:4:1	20:3:1
	M	13:3:1	21:4:1

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Sample Code	Season	C:N:P	MBC:MBN:MBP
		(0 – 20) cm	
Group A (Disturbed)			
U7	PM	18:4:1	22:3:1
	M	14:3:1	21:3:1
U9	PM	19:4:1	17:2:1
	M	13:3:1	23:3:1
Group B (Undisturbed)			
A3	PM	12:3:1	20:3:1
	M	14:3:1	16:3:1
A5	PM	13:4:1	19:4:1
	M	14:5:1	19:4:1
A7	PM	13:3:1	24:4:1
	M	20:6:1	18:3:1
A9	PM	13:4:1	22:4:1
	M	20:7:1	17:4:1
U1	PM	11:4:1	24:6:1
	M	19:6:1	17:4:1
U4	PM	13:4:1	31:5:1
	M	18:5:1	16:3:1

Appendix 2

Sample Code	Season	C:N:P	MBC:MBN:MBP
		(0 – 20) cm	
Group B (Undisturbed)			
U6	PM	13:3;1	32:4:1
	M	24:5:1	16:2:1
U8	PM	16:3:1	29:4:1
	M	20:4:1	21:3:1
U10	PM	13:3:1	27:4:1
	M	19:4:1	20:3:1
Group C (Bank sediments)			
AB1	PM	19:2:1	21:1:1
	M	22:4:1	23:1:1
AB2	PM	17:2:1	28:1:`1
	M	24:4:1	20:2:1
K Bank	PM	22:3:1	17:1:1
	M	19:3:1	22:2:1
U Bank	PM	19:3:1	16:1:1
	M	15:3:1	23:2:1

Here, PM = pre – monsoon; M = monsoon

Appendix 2

Table A 2.7 (A) *Representation of Pearson correlation matrix showing correlation between the soil parameters analyzed in Majuli in pre – monsoon and monsoon seasons. (+) represents positive correlation and (–) represents negative correlation between the parameters, at a depth of 0 – 20 cm*

(A) Parameters	TOC		TN		TP		MBC		MBN		MBP		CEC		pH		Cond		BCFU		FCFU		Fine Sand (%)		Silt (%)		Clay (%)	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
TOC	+	+	-	+	+	+	(+)**	(+)**	+	+	+	+	+	+	+	-	-	+	+	-	+	+	-	ND	-	ND	-	ND
TN	-	+	+	+	(+)*	+	+	+	(+)**	(+)**	(+)*	+	-	+	-	+	+	+	+	+	-	-	+	ND	(+)*	ND	(+)*	ND
TP	+	+	(+)*	+	+	+	(+)*	-	+	(+)*	(+)**	(+)**	-	-	+	-	-	-	+	-	-	-	-	ND	+	ND	+	ND
MBC	(+)**	(+)**	+	+	(+)*	-	+	+	+	+	+	-	+	+	+	+	-	+	+	-	+	-	-	ND	+	ND	-	ND
MBN	+	+	(+)**	(+)**	+	+	+	+	+	+	(+)*	+	-	+	-	+	+	+	+	+	-	-	+	ND	+	ND	(+)*	ND
MBP	+	+	(+)*	+	(+)**	(+)**	+	-	(+)*	+	+	+	-	+	-	-	-	-	+	-	-	-	-	ND	-	ND	+	ND
CEC	+	+	-	+	-	+	+	+	-	+	-	+	+	+	+	+	-	-	+	-	+	+	-	ND	+	ND	-	ND
pH	+	+	-	+	+	-	+	+	-	+	-	-	+	+	+	+	+	+	+	+	+	-	+	ND	-	ND	+	ND
Cond	-	-	+	+	-	-	-	+	+	+	-	-	+	-	-	+	+	+	-	+	+	-	+	ND	+	ND	-	ND
Fine Sand (%)	-	-	(+)*	+	+	-	-	-	(+)*	+	+	+	-	-	-	-	-	+	+	+	-	-	+	ND	+	ND	+	ND

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(A) Parameters	TOC		TN		TP		MBC		MBN		MBP		CEC		pH		Cond		BCFU		FCFU		Fine Sand (%)		Silt (%)		Clay (%)	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M		PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM
Silt (%)	+	-	(+)*	(+)**	(+)*	+	+	+	(+)*	(+)**	+	+	-	+	+	+	+	+	(+)*	+	-	-	+	ND	(+)*	ND	(+)*	ND
Clay (%)	-	+	-	-	-	-	+	+	-	-	-	-	+	-	-	-	+	+	-	+	(+)*	+	-	ND	-	ND	-	ND

Here, PM = Pre – monsoon; M = Monsoon

Table A 2.7 (B) *Representation of Pearson correlation matrix showing correlation between the soil parameters analyzed in Amingaon pre – monsoon and monsoon seasons. (+) represents positive correlation and (–) represents negative correlation between the parameters, at a depth of 0 – 20 cm*

(B) Parameters	pH		EC		CEC		TOC		MBC		TN		MBN		TP		MBP		BCFU		FCFU		Fine Sand (%)		Silt (%)		Clay (%)	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	+	+	(+)*	(+)**	-	-	(+)**	(+)*	(+)*	(+)*	(+)**	+	(+)*	+	(+)**	+	(+)**	+	+	+	+	+	+	ND	+	ND	(+)*	ND
EC	(+)*	(+)**	+	+	-	-	+	(+)*	+	(+)*	(+)*	(+)*	(+)**	(+)*	(+)**	+	(+)**	+	-	+	+	+	+	ND	+	ND	(+)*	ND
CEC	-	-	-	-	+	+	(-)*	-	(-)**	(-)*	(-)*	-	-	-	-	-	-	-	-	-	-	+	(-)**	ND	(-)*	ND	(-)*	ND

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(B) Parameters	pH		EC		CEC		TOC		MBC		TN		MBN		TP		MBP		BCFU		FCFU		Fine Sand (%)		Silt (%)		Clay (%)	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M		PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM
TOC	(+)**	(+)*	+	(+)*	(-)*	-	+	+	(+)**	(+)**	(+)**	(+)*	+	(+)*	(+)*	(+)**	+	(+)**	+	+	-	-	(+)**	ND	(+)**	ND	(+)**	ND
MBC	(+)*	(+)*	+	(+)*	(-)**	(-)*	(+)**	(+)**	+	+	(+)**	+	(+)*	+	(+)*	(+)*	(+)*	(+)*	+	+	+	-	(+)**	ND	(+)**	ND	(+)**	ND
TN	(+)**	+	(+)*	(+)*	(-)*	-	(+)**	(+)*	(+)**	+	+	+	(+)**	(+)**	(+)**	+	(+)**	+	+	+	+	+	(+)*	ND	(+)*	ND	(+)**	ND
MBN	(+)*	+	(+)**	(+)*	-	-	+	(+)*	(+)*	+	(+)**	(+)**	+	+	(+)**	+	(+)**	(+)*	+	+	+	+	(+)*	ND	+	ND	(+)**	ND
TP	(+)**	+	(+)**	+	-	-	(+)*	(+)**	(+)*	(+)*	(+)**	+	(+)**	+	+	+	(+)**	(+)**	+	+	+	-	+	ND	+	ND	(+)**	ND
MBP	(+)**	+	(+)**	+	-	-	+	(+)**	(+)*	(+)*	(+)**	+	(+)**	(+)*	(+)**	(+)**	+	+	-	+	+	+	+	ND	+	ND	(+)**	ND
BCFU	+	+	-	+	-	-	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	-	+	ND	+	ND	+	ND
FCFU	+	+	+	+	-	+	-	-	+	-	+	+	+	+	+	-	+	+	-	-	+	+	-	ND	+	ND	+	ND
Fine Sand (%)	+	ND	+	ND	(-)**		(+)**	ND	(+)**	ND	(+)*	ND	(+)*	ND	+	ND	+	ND	+	ND	-	ND	+	ND	(+)**	ND	(+)**	ND
Silt (%)	+	ND	+	ND	(-)*		(+)**	ND	(+)**	ND	(+)*	ND	+	ND	+	ND	+	ND	+	ND	+	ND	(+)**	ND	+	ND	(+)**	ND
Clay (%)	(+)*	ND	(+)*	ND	(-)*		(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	+	ND	+	ND	(+)**	ND	(+)**	ND	+	ND

* Correlation is significant at the 0.05 level (2 – tailed)

** Correlation is significant at the 0.01 level (2 – tailed)

Here, PM = Pre – monsoon; M = Monsoon

Appendix 2

Table A 2.7 (C) *Representation of Pearson correlation matrix showing correlation between the soil parameters analyzed in Umananda in pre – monsoon and monsoon seasons. (+) represents positive correlation and (–) represents negative correlation between the parameters, at a depth of 0 – 20 cm*

(C) Parameters	pH		EC		CEC		TOC		MBC		TN		MBN		TP		MBP		BCFU		FCFU		Fine Sand (%)		Silt (%)		Clay (%)	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	+	+	+	(+)*	-	-	+	+	+	+	+	+	+	+	(+)*	(-)*	(+)*	(-)*	+	-	+	-	-	ND	+	ND	+	ND
EC	+	(+)*	+	+	-	-	+	+	+	+	+	+	+	+	+	-	+	-	(-)*	-	-	-	+	ND	+	ND	+	ND
CEC	-	-	-	-	+	+	(-)*	(-)*	-	(-)**	(-)*	-	(-)*	-	(-)*	-	(-)*	-	-	+	-	+	(-)**	ND	(-)**	ND	(-)**	ND
TOC	+	+	+	+	(-)**	(-)*	+	+	(+)**	(+)**	(+)**	(+)**	(+)**	(+)**	(+)**	+	(+)**	-	-	-	+	+	(+)**	ND	(+)**	ND	(+)**	ND
MBC	+	+	+	+	-	(-)**	(+)**	(+)**	+	+	(+)**	(+)**	(+)**	(+)**	(+)**	+	(+)**	+	-	+	+	+	(+)**	ND	(+)**	ND	(+)**	ND

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(C) Parameters	pH		EC		CEC		TOC		MBC		TN		MBN		TP		MBP		BCFU		FCFU		Fine Sand (%)		Silt (%)		Clay (%)	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M		PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM
TN	+	+	+	+	(-)*	-	(+)**	(+)**	(+)**	(+)**	+	+	(+)**	(+)**	(+)**	+	(+)**	+	-	-	+	+	(+)**	ND	(+)**	ND	(+)**	ND
MBN	+	+	+	+	(-)*	-	(+)**	(+)**	(+)**	(+)**	(+)**	(+)**	+	+	(+)**	+	(+)**	+	-	-	+	+	(+)**	ND	(+)**	ND	(+)**	ND
TP	(+)*	(-)*	+	-	(-)*	-	(+)**	+	(+)**	+	(+)**	+	(+)**	+	+	+	(+)**	(+)**	-	+	+	+	(+)*	ND	(+)**	ND	(+)**	ND
MBP	(+)*	(-)*	+	-	(-)*	-	(+)**	-	(+)**	+	(+)**	+	(+)**	+	(+)**	(+)**	+	+	+	-	+	+	+	ND	(+)*	ND	(+)**	ND
BCFU	+	-	(-)*	-	-	+	-	-	-	+	-	-	-	-	-	+	+	-	+	+	+	-	-	ND	-	ND	+	ND
FCFU	+	-	-	-	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	-	+	+	+	ND	+	ND	+	ND
Fine Sand (%)	-	ND	+	ND	(-)**	ND	(+)**	ND	(+)**	ND	(+)*	ND	(+)**	ND	(+)*	ND	+	ND	-	ND	+	ND	+	ND	(+)**	ND	(+)**	ND
Silt (%)	+	ND	+	ND	(-)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)*	ND	-	ND	+	ND	(+)**	ND	+	ND	(+)**	ND
Clay (%)	+	ND	+	ND	(-)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	(+)**	ND	+	ND	+	ND	(+)**	ND	(+)**	ND	+	ND

* Correlation is significant at the 0.05 level (2 – tailed)

** Correlation is significant at the 0.01 level (2 – tailed)

Here, PM = Pre – monsoon; M = Monsoon

Appendix 2

Table A 2.8 (A), (B) *Representation of Pearson correlation matrix showing correlation between the soil parameters and soil enzymes* ***(A)*** *without toluene treatment,* ***(B)*** *with toluene treatment, analyzed in Majuli, in pre – monsoon and monsoon seasons. (+) represents positive correlation and (–) represents negative correlation between the parameters, at a depth of 0 – 20 cm*

Parameters	(A) Samples without toluene															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	+
Cond	+	-	+	+	+	-	+	+	-	+	-	+	+	+	+	+
CEC	-	+	+	+	+	+	+	+	+	+	(-)**	+	+	-	+	+
TOC	+	+	+	+	+	+	+	+	+	(+)**	+	(+)*	+	(+)**	+	(+)*
TN	(+)*	(+)**	(+)**	(+)*	+	(+)*	(+)*	(+)*	+	+	(+)*	+	+	-	(+)*	+
TP	(+)*	+	(+)*	+	+	+	(+)*	+	+	+	(+)*	+	+	+	(+)*	+
MBC	+	+	+	+	+	+	+	+	+	(+)**	+	+	+	(+)**	+	(+)**
MBN	(+)*	(+)**	(+)**	(+)*	+	(+)*	(+)*	(+)*	+	+	+	+	+	+	(+)*	(+)*
MBP	(+)**	(+)*	(+)**	+	(+)**	(+)*	(+)*	+	(+)*	+	(+)**	+	+	+	(+)*	+
BCFU	+	-	+	-	+	-	+	-	-	-	+	-	-	-	-	-

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(A) Samples without toluene

Parameters	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
FCFU	-	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-
Fine Sand	-	ND	+	ND	+	ND	+	ND	-	ND	+	ND	-	ND	-	ND
Silt	+	ND	+	ND	+	ND	+	ND	-	ND	+	ND	-	ND	-	ND
Clay	+	ND	+	ND	+	ND	+	ND	-	ND	+	ND	-	ND	-	ND

(B) Samples with toluene treatment

Parameters	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	-	-	-	-	-	-	-	-	-	+	+	+	-	+	-	+
Cond	+	-	+	+	+	-	+	+	+	+	+	+	-	+	+	+

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Parameters	(B) Samples with toluene treatment															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
CEC	-	+	+	-	+	+	+	+	+	+	-	+	-	+	-	+
TOC	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	(+)**
TN	(+)*	(+)**	(+)*	(+)*	+	(+)*	(+)*	+	+	+	(+)**	(+)*	+	-	+	+
TP	(+)*	+	(+)*	+	(+)*	+	+	+	+	+	(+)*	-	+	+	(+)**	+
MBC	+	(+)*	+	+	+	+	+	+	+	+	+	+	-	+	+	(+)**
MBN	(+)*	(+)**	(+)*	(+)**	+	(+)*	(+)*	+	+	+	(+)**	(+)*	+	-	+	+
MBP	(+)**	+	(+)**	+	(+)*	(+)*	(+)*	+	(+)*	+	+	-	-	+	(+)**	+
BCFU	+	-	+	+	+	-	+	-	+	+	-	-	-	(-)*	+	-
FCFU	-	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-
Clay	-	ND	+	ND	+	ND	+	ND	-	ND	-	ND	-	ND	-	ND
Silt	+	ND	+	ND	+	ND	+	ND	-	ND	-	ND	-	ND	-	ND
Fine Sand	+	ND	+	ND	+	ND	+	ND	-	ND	-	ND	-	ND	-	ND

** Correlation is significant at the 0.01 level (2 – tailed)

* Correlation is significant at the 0.05 level (2 – tailed)

Here, PM = Pre – monsoon; M = Monsoon

Appendix 2

Table A 2.9 (A), (B) *Representation of Pearson correlation matrix showing correlation between the soil parameters and soil enzymes* ***(A)*** *without toluene treatment,* ***(B)*** *with toluene treatment, analyzed in Amingaon, in pre – monsoon and monsoon seasons. (+) represents positive correlation and (–) represents negative correlation between the parameters, at a depth of 0 – 20 cm*

Parameters	(A) Samples without toluene															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	(+)**	(+)*	(+)**	+	+	+	(+)**	+	(+)**	-	(+)*	+	(+)*	+	(+)*	+
EC	+	+	+	+	+	-	+	-	(+)*	-	+	+	+	-	(+)*	+
CEC	-	-	(-)*	-	-	+	-	+	(-)*	+	(-)**	-	(-)*	+	(-)**	-
TOC	(+)*	(+)**	(+)*	+	(+)*	+	(+)**	+	(+)*	+	(+)**	+	(+)**	-	(+)**	+
MBC	(+)*	+	(+)**	-	(+)**	-	(+)**	-	(+)**	-	(+)**	-	(+)**	-	(+)**	+
TN	(+)**	(+)*	(+)**	+	(+)**	+	(+)**	+	(+)**	+	(+)**	+	(+)**	+	(+)**	+
MBN	+	(+)**	(+)**	+	(+)**	+	(+)**	+	(+)**	+	(+)**	+	(+)**	+	(+)*	+
TP	(+)*	+	(+)**	+	+	+	(+)**	+	(+)**	+	(+)*	+	(+)**	-	(+)*	-
MBP	+	+	(+)**	+	+	+	(+)**	+	(+)**	+	(+)*	+	(+)*	-	(+)*	-
BCFU	+	+	+	(+)*	+	+	+	+	+	+	+	+	+	+	+	+

Appendix 2

Parameters	(A) Samples without toluene															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
FCFU	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-
Fine Sand	+	ND	(+)*	ND	(+)**	ND	(+)*	ND	(+)*	ND	(+)**	ND	(+)**	ND	(+)**	ND
Silt	+	ND	(+)*	ND	(+)*	ND	(+)*	ND	(+)*	ND	(+)**	ND	(+)*	ND	(+)**	ND
Clay	+	ND	(+)**	ND	(+)*	ND	(+)*	ND	(+)**	ND	(+)**	ND	(+)*	ND	(+)**	ND
* Correlation is significant at the 0.05 level (2 – tailed)																
** Correlation is significant at the 0.01 level (2 – tailed)																

Parameters	(B) Samples with toluene treatment															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	(+)*	+	(+)**	+	(+)*	+	(+)**	+	(+)**	-	(+)*	+	(+)*	+	(+)*	+
Cond	+	+	+	-	+	-	+	-	(+)*	-	+	+	+	+	(+)*	+
CEC	-	-	(-)*	+	(-)*	+	(-)*	+	-	+	(-)*	-	-	-	(-)*	-
TOC	(+)*	(+)**	(+)**	+	(+)*	+	(+)**	+	(+)**	-	(+)**	+	(+)*	+	(+)**	+

Appendix 2

Parameters	(B) Samples with toluene treatment															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
MBC	(+) *	+	(+) **	-	(+) **	-	(+) **	-	(+) **	-	(+) **	-	(+) **	+	(+) **	+
TN	(+) **	(+) **	(+) **	+	(+) **	+	(+) **	+	(+) **	+	(+) **	(+) *	(+) **	+	(+) **	+
MBN	+	(+) **	(+) **	+	(+) **	+	(+) **	+	(+) **	+	(+) **	+	(+) *	+	(+) *	+
TP	(+) *	+	(+) **	+	(+) *	+	(+) **	+	(+) **	-	(+) *	+	+	+	(+) *	-
MBP	+	+	(+) *	+	(+) *	+	(+) **	+	(+) **	-	(+) *	+	+	+	(+) *	-
BCFU	+	+	+	(+) *	+	+	+	(+) *	+	+	+	+	+	+	+	+
FCFU	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-
Fine Sand	+	ND	(+) *	ND	(+) *	ND	(+) *	ND	(+) *	ND	(+) **	ND	(+) *	ND	(+) **	ND
Silt	+	ND	(+) *	ND	(+) *	ND	(+) *	ND	(+) **	ND	(+) **	ND	(+) *	ND	(+) **	ND
Clay	+	ND	(+) *	ND	(+) **	ND	(+) **	ND	(+) **	ND	(+) **	ND	(+) *	ND	(+) **	ND

* Correlation is significant at the 0.05 level (2 – tailed)

** Correlation is significant at the 0.01 level (2 – tailed)

Here, PM = Pre – monsoon; M = Monsoon

Appendix 2

Table 2.10 (A), (B) *Representation of Pearson correlation matrix showing correlation between the soil parameters and soil enzymes* ***(A)*** *without toluene treatment,* ***(B)*** *with toluene treatment, analyzed in Umananda, in pre – monsoon and monsoon seasons. (+) represents positive correlation and (–) represents negative correlation between the parameters, at a depth of 0 – 20 cm*

Parameters	(A) Samples without toluene															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	+	+	+	+	+	-	+	-	+	-	+	+	+	+	+	+
Cond	+	+	+	+	+	-	+	-	+	-	+	-	+	+	+	+
CEC	(-)*	+	(-)**	-	-	-	(-)*	-	-	-	-	-	(-)**	-	-	-
TOC	(+)*	+	(+)**	(+)*	(+)**	(+)**	(+)**	+	(+)**	+	+	+	(+)**	(+)*	(+)*	+
MBC	+	+	(+)**	+	(+)**	(+)**	(+)**	+	+	(+)*	(+)*	+	(+)**	+	(+)*	+
TN	+	(+)*	(+)**	+	(+)*	(+)**	(+)**	+	+	+	+	+	(+)**	+	+	+
MBN	+	(+)*	(+)**	+	(+)*	(+)**	(+)**	(+)**	+	+	(+)*	+	(+)**	+	+	+
TP	+	+	(+)**	+	(+)**	+	(+)**	+	(+)*	+	+	-	(+)**	+	+	+

Appendix 2

Parameters	(A) Samples without toluene															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
MBP	+	-	(+) **	+	(+) **	+	(+) **	+	(+) *	+	+	+	(+) *	+	+	+
Fine Sand	+	-	(+) **	-	(+) **	-	(+) **	-	+	+	(+) **	-	(+) **	-	+	-
Silt	(+) **	+	(+) **	(+) *	(+) **	+	(+) **	(+) *	+	+	(+) *	-	(+) **	+	+	+
Clay	(+) *	ND	(+) **	ND	(+) **	ND	(+) **	ND	(+) *	ND	+	ND	(+) **	ND	(+) *	ND
BCFU	+	ND	-	ND	-	ND	+	ND	+	ND	(-) **	ND	-	ND	-	ND
FCFU	+	ND	+	ND	+	ND	+	ND	-	ND	+	ND	+	ND	+	ND

* Correlation is significant at the 0.05 level (2 – tailed)

** Correlation is significant at the 0.01 level (2 – tailed)

Here, PM = Pre – monsoon; M = Monsoon

Appendix 2

Parameters	(B) Samples with toluene treatment															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
pH	+	+	+	-	(+)*	-	+	-	+	-	-	+	+	+	+	+
Cond	+	+	+	+	+	-	+	+	(+)*	-	+	-	+	+	+	+
CEC	(-)*	-	(-)**	-	-	-	(-)*	-	-	-	-	-	(-)**	-	-	-
TOC	(+)*	+	(+)**	+	(+)**	(+)*	(+)**	+	(+)*	-	+	+	(+)**	(+)*	(+)*	+
MBC	+	+	(+)**	+	(+)**	(+)*	(+)**	+	(+)*	+	+	+	(+)**	+	(+)*	+
TN	+	(+)*	(+)**	+	(+)**	(+)**	(+)**	+	+	+	+	(+)*	(+)**	+	+	+
MBN	+	(+)*	(+)**	+	(+)**	(+)**	(+)**	(+)*	+	+	(+)*	+	(+)**	+	+	+
TP	+	-	(+)**	+	(+)**	+	(+)**	+	(+)**	+	+	-	(+)**	+	+	+
MBP	+	-	(+)**	+	(+)**	+	(+)**	+	(+)*	(+)*	+	-	(+)*	+	+	+
Fine Sand	+	-	(+)**	-	(+)**	-	(+)**	-	+	+	+	-	(+)**	-	+	+

Appendix 2

Parameters	(B) Samples with toluene treatment															
	Acid Phosphatase		Alkaline Phosphatase		Cellulase		Amylase		Invertase		Urease		Protease		Dehydrogenase	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
Silt	(+) **	+	(+) **	+	(+) **	+	(+) **	(+) *	+	+	(+) *	-	(+) **	+	+	+
Clay	(+) *		(+) **		(+) **		(+) **		(+) *		+		(+) **		(+) *	
BCFU	+		-		-		+		-		(-) *		-		-	
FCFU	+		+		+		+		-		+		+		+	

* Correlation is significant at the 0.05 level (2 – tailed)

** Correlation is significant at the 0.01 level (2 – tailed)

Here, PM = Pre – monsoon; M = Monsoon

Appendix 3

Table A 3.1 *Grades of integrated pollution indices defined by researchers*

C_d (Abrahim et al., 2008)		I_{geo} (Muller, 1969)			NPI (Qingjie et al., 2008)		ER (Hakanson, 1980)		PERI (Hakanson, 1980)	
Values	Extent of contamination	Values	Class	Sediment quality	Values	Soil quality	Values	Grades	Values	Grades
$C_d < 1.5$	Nil to very low degree of contamination	> 5	6	Extremely contaminated	NPI < 0.7	Safety domain	ER <40	Low risk	PERI < 150	Low risk
$1.5 \leq C_d < 2$	Low degree of contamination	4 – 5	5	Strongly to extremely contaminated						
$2 \leq C_d < 4$	Moderate degree of contamination	3 – 4	4	Strongly contaminated	0.7 ≤ NPI < 1.0	Precaution domain	40 ≤ ER < 80	Moderate risk	150 ≤ PERI < 300	Moderate risk
$4 \leq C_d < 8$	High degree of contamination	2 – 3	3	Moderately to strongly contaminated	1.0 ≤ NPI < 2.0	Slightly polluted domain	80 ≤ ER < 160	Considerable risk	300 ≤ PERI < 600	Considerable risk
$8 \leq C_d < 16$	Very high degree of contamination	1 – 2	2	Moderately contaminated	2.0 ≤ NPI < 3.0	Moderately polluted domain	160 ≤ ER < 320	High risk		
$16 \leq C_d < 32$	Extremely high degree of contamination	0 – 1	1	Uncontaminated to moderately contaminated	NPI > 3.0	Seriously polluted domain	ER ≥ 320	Very high risk	PERI ≥ 600	Very high risk
$C_d \geq 32$	Ultra high degree of contamination	0	0	Uncontaminated						

Here, C_d = Contamination degree; I_{geo} = Geoaccumulation index; NPI = Nemerow's Pollution Index; ER = Ecological Risk; PERI = Potential Ecological Risk Index

Appendix 3

Table A 3.2 *Concentration of metals in water samples analyzed in Majuli, in pre – monsoon and monsoon seasons*

Sample code	Season	Total Fe (mg/ L)	Cu (mg/ L)	Zn (mg/ L)	Mn (mg/ L)	Pb (mg/ L)
Group A (Water from wetlands in residential area)						
S4	PM	1.28	0.04	0	0.62	0
	M	1.97	0.12	0.22	0.42	0
S6	PM	2.48	0.02	0	0.59	0
	M	3.23	0.08	0.002	0.42	0
S7	PM	0.58	0.03	0	0.59	0
	M	3.08	0.04	0	0.63	0
S9	PM	1.98	0.06	0.006	0.58	0
	M	3.48	0.04	0.009	0.61	1.23
S10	PM	3.62	0.03	0.05	0.75	0
	M	1.38	0.05	0	0.64	0
S16	PM	2.58	0.11	0	0.32	0
	M	2.42	0.05	0	0.28	0

Appendix 3

Sample code	Season	Total Fe (mg/ L)	Cu (mg/ L)	Zn (mg/ L)	Mn (mg/ L)	Pb (mg/ L)
Group B (Water from wetlands in grassland)						
S2	PM	3.65	0.04	0	7.59	0
	M	1.30	0.04	0.013	1.26	0
S3	PM	1.94	0.01	0	11.74	0
	M	2.29	0.04	0.024	10.39	0
S12	PM	3.41	0.06	0	0.61	0
	M	1.80	0.02	0.004	0.52	0
S18	PM	2.30	0.05	0.004	0.68	8.10
	M	3.45	0.04	0.13	0.51	0
Group C (Water from wetlands in agricultural field)						
S13	PM	1.28	0.05	0.01	0.60	0
	M	2.64	0.07	0.001	0.43	0
S14	PM	1.86	0.06	0	0.68	0
	M	2.34	0.08	0.007	0.50	0

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Sample code	Season	Total Fe (mg/ L)	Cu (mg/ L)	Zn (mg/ L)	Mn (mg/ L)	Pb (mg/ L)
Group D (Ground water)						
S15	PM	3.79	0.05	0	0.50	0
	M	1.16	0.01	0	0.37	0.01
S17	PM	1.26	0.09	0.001	0.59	7.77
	M	2.19	0.04	0.07	0.66	0
S1	PM	4.67	0.05	0	0.85	0
	M	5.86	0.02	0	0.22	0
S5	PM	7.88	0.04	0	1.02	0
	M	4.18	0.02	0	0.55	0
S8	PM	3.60	0.02	0	0.30	0
	M	5.19	0.02	0	0.22	0
S11	PM	28.90	0.06	0	0.83	0
	M	22.66	0.06	0.001	0.63	0

Appendix 3

Sample code	Season	Total Fe (mg/ L)	Cu (mg/ L)	Zn (mg/ L)	Mn (mg/ L)	Pb (mg/ L)
Group E (River water)						
Kmb Bank	PM	1.77	0.03	0	0.57	0
	M	0.03	0.04	0	0.49	0
Nim Bank	PM	1.56	0.04	0	0.62	0
	M	0.04	0.03	0	0.52	0

Here, PM = pre – monsoon; M = monsoon; Kmb = Kamalabari; Nim = Nimatighat

Appendix 3

Table A 3.3 *Single pollution indices calculated for soil samples in Majuli, in pre – monsoon and monsoon seasons*

Sample code	Locality	Soil type	Period	Ascending order of RA	Ascending order of C_f	Ascending order of ER
				Group A (Residential area)		
S1	Residential and river dyke	Sandy clay loam	PM	Fe>Mn>Zn>Cu>Ni>Cr>Cd	Fe>Cu>Mn>Zn>Cd>Ni>Cr	Cu>Cd>Ni>Zn>Cr
			M	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Zn>Cd>Ni>Cr	Cd>Cu>Ni>Zn>Cr
S5	Residential		PM	Fe>Mn>Cu>Pb>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Pb>Cr	Cu>Cd>Ni>Zn>Pb>Cr
			M	Fe>Mn>Cu>Pb>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Cr>Pb	Cu>Cd>Ni>Zn>Cr>Pb
S6	Residential and grassland		PM	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Pb>Ni>Cr	Cu>Cd>Pb>Ni>Zn>Cr
			M	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Pb>Zn>Ni>Cr	Cu>Cd>Pb>Ni>Zn>Cr
S11	Residential	"	PM	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Zn>Cd>Ni>Cr	Cu>Cd>Ni>Zn>Cr
			M	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Cr	Cd>Cu>Ni>Zn>Cr

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Sample code	Locality	Soil type	Period	Ascending order of RA	Ascending order of C_f	Ascending order of ER
				Group B (Grassland)		
S2	Grassland	Sandy clay loam	PM	Fe>Mn>Zn>Cu>Ni>Cr>Cd	Fe>Cu>Mn>Zn>Cd>Ni>Cr	Cu>Cd>Zn>Ni>Cr
			M	Fe>Mn>Zn>Cu>Ni>Cr>Cd	Fe>Cu>Mn>Zn>Cd>Ni>Cr	Cu>Cd>Zn>Ni>Cr
S3	Grassland and river dyke		PM	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Cr	Cd>Cu>Ni>Zn>Cr
			M	Fe>Cu>Zn>Cu>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Cr	Cd>Cu>Ni>Zn>Cr
S4	Grassland and river dyke		PM	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Pb>Ni>Cr	Cu>Cd>Pb>Ni>Zn>Cr
			M	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Pb>Cr	Cu>Cd>Ni>Pb>Zn>Cr
				Group C (Agricultural field)		
S7	Residential, agricultural land and grassland	Sandy clay loam	PM	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Pb>Cr	Cu>Cd>Ni>Zn>Pb>Cr
			M	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Pb>Cr	Cu>Cd>Ni>Zn>Pb>Cr

Appendix 3

Sample code	Locality	Soil type	Period	Ascending order of RA	Ascending order of C_f	Ascending order of ER
			Group C (Agricultural field)			
S8	Residential, agricultural land and grassland	Sandy clay loam	PM	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Pb>Cr	Cd>Cu>Ni>Zn>Pb>Cr
			M	Fe>Mn>Cu>Zn>Pb>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Pb>Cr	Cd>Cu>Ni>Pb>Zn>Cr
S9	Agricultural land and grassland	"	PM	Fe>Mn>Cu>Pb>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Pb>Cr	Cd>Cu>Ni>Zn>Pb>Cr
			M	Fe>Mn>Cu>Pb>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Cr>Pb	Cd>Cu>ni>Zn>Cr>Pb
S10	Agricultural land and grassland	"	PM	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Cd>Zn>Mn>Ni>Cr	Cu>Cd>Ni>Zn>Cr
			M	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Cd>Mn> Zn>Ni>Cr	Cu>Cd>Ni>Zn>Cr
S12	Agricultural land and grassland	"	PM	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Zn>Cd>Ni>Cr	Cu>Cd>Zn>Ni>Cr
			M	Fe>Mn>Cu>Zn>Ni>Cr>Cd	Fe>Cu>Mn>Cd>Zn>Ni>Cr	Cu>Cd>Zn>Ni>Cr

Appendix 3

Sample code	Locality	Soil type	Period	Ascending order of RA	Ascending order of C_f	Ascending order of ER
				Group D (Bank sediment)		
Kmb Bank	Grassland	Sandy clay loam	PM	Fe>Mn>Cu>Zn>Pb>Ni>Cd>Cr	Fe>Cu>Mn>Zn>Cd>Pb>Ni>Cr	Cu>Cd>Pb>Ni>Zn>Cr
			M	Fe>Mn>Cu>Zn>Pb>Ni>Cd>Cr	Fe>Cu>Mn>Cd>Zn>Pb>Ni>Cr	Cd>Cu>Pb>Zn>Ni>Cr
Nim Bank	Grassland	"	PM	Fe>Mn>Zn>Cu>Ni>Pb>Cr>Cd	Fe>Cu>Mn>Zn>Cd>Ni>Pb>Cr	Cu>Cd>Ni>Pb>Zn>Cr
			M	Fe>Mn>Zn>Cu>Ni>Pb>Cd>Cr	Fe>Cu>Mn>Zn>Cd>Pb>Ni>Cr	Cd>Cu>Pb>Zn>Ni>Cr

Here, PM = pre – monsoon; M = monsoon; RA = Relative Abundance, C_f = Contamination Factor; ER = Ecological Risk; Kmb = Kamalabari; Nim = Nimatighat

Appendix 3

Table A 3.4 *Depth wise and group wise analytical results of contamination factors due to individual metal concentration in Majuli, in pre – monsoon and monsoon seasons*

Sample code	Season	C_f Total Fe range		C_f Ni range		C_f Cd range		C_f Mn range		C_f Cr range		C_f Cu range		C_f Zn range		C_f Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group A (Residential area)																	
S1	PM	1420.00	1757.35-2214.47	0.123	0.115-0.133	0.370	0.377-0.331	0.94	1.05-0.66	0.003	0.003-0.003	1.68	2.68-2.57	0.362	0.382-0.310	0	0
	M	1338.04	1397.23-1145.71	0.127	0.093-0.129	0.350	0.386-0.275	0.72	0.98-0.39	0.003	0.002-0.002	1.08	2.66-0.63	0.325	0.359-0.252	0	0
S5	PM	3545.55	4634.78-5105.39	0.064	0.040-0.073	0.338	0.311-0.329	0.56	0.65-0.74	0.003	0.003-0.003	3.91	2.54-2.55	0.139	0.080-0.182	0	0.146
	M	2874.82	4498.97-4024.71	0.070	0.051-0.054	0.301	0.316-0.248	0.47	0.65-0.50	0.001	0.001-0.002	2.82	3.09-2.46	0.154	0.048-0.129	0	0
S6	PM	5017.92	5392.13-5229.08	0.080	0.075-0.069	0.114	0.358-0.189	0.64	0.90-0.75	0.002	0.002-0.0002	3.38	3.70-2.10	0.293	0.212-0.301	0	0.128-0.101
	M	5400.43	4452.81-3033.85	0.082	0.062-0.059	0.219	0.268-0.204	0.57	0.50-0.29	0.002	0.001-0.001	2.81	2.01-1.35	0.365	0.382-0.294	0	0

Appendix 3

Sample code	Season	C_f Total Fe range		C_f Ni range		C_f Cd range		C_f Mn range		C_f Cr range		C_f Cu range		C_f Zn range		C_f Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group A (Residential area)																	
S11	PM	2842.29	2975.03-2031.26	0.060	0.081-0.064	0.531	0.618-0.510	0.50	0.53-0.49	0.001	0.001-0.002	2.24	2.32-2.31	0.044	0.380-0.256	0	0
	M	2032.39	1303.83-1243.79	0.067	0.075-0.052	0.204	0.209-0.173	0.30	0.36-0.29	0.0005	0.0004-0.0003	1.35	1.04-0.86	0.159	0.118-0.023	0	0.437-0.309
Group B (Grassland)																	
S2	PM	3561.70	3933.15-3361.90	0.124	0.112-0.117	0.411	0.373-0.451	0.97	1.17-0.86	0.001	0.002-0.002	3.45	2.78-2.53	1.027	0.637-0.655	0	0
	M	3025.12	2270.84-2213.56	0.125	0.101-0.091	0.366	0.321-0.454	0.82	1.11-0.89	0.003	0.003-0.002	2.87	1.39-1.26	0.819	0.577-0.391	0	0.142
S3	PM	3210.89	3511.24-3232.25	0.108	0.105-0.071	0.324	0.273-0.313	0.96	0.87-0.55	0.002	0.0001-0.001	1.92	2.04-1.63	0.418	0.319-0.197	0	0
	M	2796.75	2185.51-2573.84	0.108	0.099-0.059	0.334	0.248-0.236	1.14	0.82-0.38	0.002	0.002-0.001	1.52	1.43-0.76	0.600	0.285-0.216	0	0.124-0.095

Appendix 3

Sample code	Season	C_f Total Fe range		C_f Ni range		C_f Cd range		C_f Mn range		C_f Cr range		C_f Cu range		C_f Zn range		C_f Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group B (Grassland)																	
S4	PM	4050.34	4660.60-3927.01	0.112	0.130-0.079	0.326	0.345-0.373	0.65	0.63-0.55	0.002	0.002-0.001	3.50	3.79-1.44	0.390	0.323-0.062	0	0.459-0.307
	M	3396.85	4488.36-1581.94	0.104	0.123-0.088	0.268	0.323-0.311	0.56	0.53-0.32	0.001	0.001-0.001	2.19	2.53-2.39	0.075	0.247-0.040	0	0.208
Group C (Agricultural field)																	
S7	PM	5196.76	5573.66-5376.42	0.118	0.055-0.089	0.246	0.086-0.371	0.72	0.93-0.52	0.001	0.0001-0.0001	2.79	2.81-2.37	0.238	0.128-0.363	0	0.221
	M	5890.81	4219.35-3599.26	0.105	0.060-0.070	0.186	0.216-0.198	0.64	0.68-0.31	0.001	0.001-0.001	2.58	2.56-1.29	0.191	0.093-0.334	0	0.168
S8	PM	6660.81	5697.01-5402.80	0.126	0.130-0.053	0.645	0.573-0.697	0.97	0.92-0.85	0.001	0.001-0.001	3.29	3.17-2.43	0.405	0.025-0.044	0	0.163
	M	5210.21	4836.52-3912.07	0.098	0.095-0.049	0.590	0.534-0.556	0.87	0.87-0.46	0.002	0.002-0.001	2.46	2.96-1.96	0.342	0.210-0.035	0	0.270

Appendix 3

Sample code	Season	C_f Total Fe range		C_f Ni range		C_f Cd range		C_f Mn range		C_f Cr range		C_f Cu range		C_f Zn range		C_f Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group C (Agricultural field)																	
S9	PM	6061.51	5810.56-4649.16	0.075	0.107-0.062	0.604	0.629-0.898	0.98	0.84-0.57	0.001	0.002-0.002	3.87	2.79-2.07	0.258	0.222-0.094	0	0.183
	M	4493.70	5096.11-3021.12	0.065	0.087-0.047	0.524	0.489-0.913	0.67	0.74-0.50	0.002	0.002-0.002	3.62	3.20-1.59	0.223	0.181-0.111	0	0
S10	PM	5610.37	5328.54-4332.33	0.076	0.093-0.106	0.673	0.709-0.728	0.53	0.63-0.51	0.001	0.001-0.002	5.21	4.45-6.36	0.475	0.738-0.944	0	0
	M	3794.99	4587.01-4032.74	0.092	0.086-0.101	0.586	0.710-0.647	0.62	0.55-0.45	0.001	0.002-0.002	6.11	6.17-2.93	0.306	0.364-0.221	0	0
S12	PM	4467.60	4781.45-4396.68	0.050	0.056-0.041	0.476	0.541-0.286	0.58	0.65-0.60	0.001	0.001-0.0002	3.07	3.25-2.58	0.766	0.634-0.418	0	0
	M	3019.22	4324.35-4169.89	0.041	0.067-0.041	0.494	0.516-0.303	0.44	0.48-0.54	0.001	0.001-0.0005	2.69	3.32-1.80	0.592	0.576-0.249	0	0

Appendix 3

Sample code	Season	C_f Total Fe range		C_f Ni range		C_f Cd range		C_f Mn range		C_f Cr range		C_f Cu range		C_f Zn range		C_f Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group D (Bank sediment)																	
Kmb Bank	PM	1264.81	NA	0.069	NA	0.371	NA	0.75	NA	0.001	NA	2.64	NA	0.506	NA	0.188	NA
	M	877.65	NA	0.058	NA	0.580	NA	0.58	NA	0.005	NA	1.57	NA	0.327	NA	0.233	NA
Nim Bank	PM	2445.13	NA	0.231	NA	0.261	NA	0.57	NA	0.001	NA	1.90	NA	0.552	NA	0.130	NA
	M	1035.25	NA	0.062	NA	0.319	NA	0.68	NA	0.006	NA	1.76	NA	0.411	NA	0.148	NA

Here, PM = pre – monsoon; M = monsoon; C_f = Contamination Factor; Kmb = Kamalabari; Nim = Nimatighat

Appendix 3

Table A 3.5 *Group wise analytical results of contamination factors due to individual metal concentration in Amingaon and Umananda, in pre – monsoon and monsoon seasons*

Sample Code	Season	C_f Fe	C_f Ni	C_f Cd	C_f Mn	C_f Cr	C_f Cu	C_f Zn	C_f Pb
		(0 – 20) cm							
Group A (Disturbed)									
A1	PM	6383.95	0.14	2.52	0.87	0.005	5.99	2.51	0.25
	M	3082.84	0.15	2.48	0.86	0.004	5.59	2.44	0.25
A2	PM	7843.39	0.23	3.03	0.77	0.007	7.23	1.09	0.22
	M	6716.38	0.21	3.22	0.89	0.005	3.68	1.10	0.20
A4	PM	5066.62	0.21	2.68	0.75	0.004	8.15	2.32	0.27
	M	5320.93	0.22	2.44	0.59	0.004	3.03	2.28	0.28
A6	PM	5440.10	0.20	2.63	0.61	0.002	4.09	2.04	0.29
	M	4432.30	0.18	2.62	0.54	0.003	3.49	2.24	0.27

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Sample Code	Season	C_f Fe	C_f Ni	C_f Cd	C_f Mn	C_f Cr	C_f Cu	C_f Zn	C_f Pb
		(0 – 20) cm							
		Group A (Disturbed)							
A8	PM	4369.90	0.19	2.87	0.60	0.005	4.37	1.70	0.27
	M	5448.58	0.20	3.34	0.61	0.005	4.85	1.18	0.24
A10	PM	4836.50	0.15	2.54	0.49	0.003	1.39	0.75	0.20
	M	4386.88	0.12	2.36	0.32	0.003	4.18	1.86	0.18
U2	PM	1744.14	0.26	2.47	0.73	0.004	4.43	2.95	0.22
	M	2546.12	0.22	2.72	0.62	0.003	4.13	3.41	0.20
U3	PM	1276.41	0.18	2.38	0.99	0.006	3.37	4.05	0.24
	M	1740.37	0.18	3.01	1.08	0.005	5.58	4.30	0.23
U5	PM	2433.63	0.18	2.58	0.65	0.003	3.58	3.70	0.20
	M	1462.39	0.14	2.68	0.64	0.003	4.54	3.86	0.19

Appendix 3

Sample Code	Season	C_f Fe	C_f Ni	C_f Cd	C_f Mn	C_f Cr	C_f Cu	C_f Zn	C_f Pb
		(0 – 20) cm							
Group A (Disturbed)									
U7	PM	1799.46	0.21	2.25	0.65	0.003	5.35	4.33	0.15
	M	1796.19	0.21	2.49	0.51	0.003	4.30	3.85	0.13
U9	PM	1562.87	0.26	2.09	0.50	0.004	3.57	4.23	0.13
	M	1334.68	0.23	2.37	0.42	0.003	4.36	4.30	0.12
Group B (Undisturbed)									
A3	PM	5071.43	0.25	2.85	0.74	0.001	6.08	1.59	0.25
	M	5623.02	0.24	2.86	0.76	0.003	3.65	1.54	0.24
A5	PM	5860.97	0.19	2.78	0.68	0.004	9.87	1.74	0.23
	M	5774.45	0.16	2.87	0.74	0.004	2.41	2.07	0.23
A7	PM	4767.66	0.22	2.74	0.68	0.003	3.53	2.27	0.27
	M	6758.15	0.23	3.10	0.49	0.003	4.10	1.87	0.26

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Sample Code	Season	C_f Fe	C_f Ni	C_f Cd	C_f Mn	C_f Cr	C_f Cu	C_f Zn	C_f Pb
		(0 – 20) cm							
		Group B (Undisturbed)							
A9	PM	3641.41	0.17	2.53	0.62	0.004	3.21	1.79	0.25
	M	5723.30	0.18	2.52	0.68	0.004	5.45	1.71	0.25
U1	PM	2670.52	0.19	2.67	0.95	0.004	5.56	2.05	0.25
	M	1959.54	0.20	2.84	0.82	0.005	4.87	2.01	0.24
U4	PM	1877.01	0.19	2.65	0.62	0.003	5.02	3.05	0.27
	M	1724.97	0.16	1.91	0.62	0.004	5.67	3.00	0.31
U6	PM	1514.87	0.18	2.54	0.70	0.004	4.95	4.72	0.17
	M	1187.89	0.20	2.56	0.61	0.003	3.66	4.47	0.16
U8	PM	2243.93	0.20	2.32	0.56	0.004	4.13	3.74	0.19
	M	1577.67	0.20	2.65	0.61	0.004	5.05	3.71	0.18
U10	PM	1718.23	0.21	2.20	0.42	0.005	4.22	3.00	0.15
	M	1208.31	0.22	2.36	0.49	0.004	2.91	3.60	0.14

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Sample Code	Season	C_f Fe	C_f Ni	C_f Cd	C_f Mn	C_f Cr	C_f Cu	C_f Zn	C_f Pb
		(0 – 20) cm							
		Group C (Bank sediment)							
AB1	PM	3619.21	0.19	1.83	0.65	0.003	2.85	0.84	0.13
	M	3420.93	0.18	1.85	0.67	0.003	3.74	0.86	0.13
AB2	PM	1937.28	0.14	2.20	0.39	0.003	1.69	0.57	0.11
	M	1336.01	0.14	1.36	0.45	0.003	3.74	1.20	0.11
U Bank	PM	401.28	0.08	1.59	0.20	0.003	1.46	0.40	0.13
	M	493.65	0.09	1.39	0.16	0.003	1.48	0.38	0.13
K Bank	PM	529.00	0.09	1.49	0.16	0.003	2.26	0.40	0.15
	M	475.99	0.08	1.36	0.21	0.004	1.68	0.41	0.14

Here, PM = pre – monsoon; M = monsoon; C_f = Contamination Factor; AB = Amingaon Bank; U Bank = Umananda Bank; K Bank = Kachari Bank

Appendix 3

Table A 3.6 *Depth wise and location wise details of ecological risk index in Majuli, in pre – monsoon and monsoon seasons*

Sample code	Season	ER Zn range		ER Cu range		ER Cr range		ER Cd range		ER Ni range		ER Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group A(Residential area)													
S1	PM	0.36	0.38-0.31	8.38	11.80-12.85	0.013	0.13-0.13	11.10	11.30-9.94	0.62	0.57-0.67	0	0
	M	0.32	0.36-0.25	5.38	13.28-3.15	0.013	0.011-0.008	10.51	11.58-8.26	0.63	0.47-0.64	0	0
S5	PM	0.14	0.08-0.18	19.56	12.72-12.76	0.015	0.013-0.015	10.15	9.33-9.87	0.32	0.20-0.37	0	0.73
	M	0.15	0.05-0.13	14.11	15.43-12.30	0.004	0.007-0.009	9.03	9.49-7.44	0.35	0.25-0.27	0	0
S6	PM	0.29	0.21-0.30	16.91	18.52-10.52	0.011	0.003-0.04	3.42	10.74-5.66	0.40	0.37-0.34	0	0.64-0.51
	M	0.37	0.38-0.29	14.03	10.05-6.74	0.008	0.008-0.001	6.58	8.05-6.11	0.41	0.31-0.29	0	0

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Sample code	Season	ER Zn range		ER Cu range		ER Cr range		ER Cd range		ER Ni range		ER Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group A(Residential area)													
S11	PM	0.04	0.38-0.26	11.22	11.59-11.57	0.004	0.009-0.009	15.92	18.53-15.30	0.30	0.40-0.32	0	0
	M	0.16	0.12-0.02	6.74	5.19-4.32	0.002	0.002-0.001	6.13	6.28-5.19	0.33	0.38-0.26	0	2.18-1.54
Group B(Grassland)													
S2	PM	1.03	0.64-0.65	17.23	13.88-12.64	0.004	0.006-0.011	12.33	11.19-13.53	0.62	0.56-0.58	0	0
	M	0.82	0.58-0.39	14.36	6.96-6.30	0.017	0.014-0.012	10.97	9.64-13.61	0.63	0.51-0.55	0	0.71
S3	PM	0.42	0.32-0.20	9.61	10.20-8.13	0.011	0.0003-0.004	9.71	8.19-9.38	0.54	0.53-0.35	0	0
	M	0.60	0.29-0.22	7.61	7.16-3.79	0.012	0.011-0.004	10.03	7.44-7.08	0.54	0.50-0.29	0	0.62-0.48
S4	PM	0.39	0.32-0.06	17.51	18.97-7.22	0.008	0.004-0.004	9.77	10.36-11.19	0.56	0.65-0.40	0	2.29-1.53
	M	0.07	0.25-0.04	10.93	12.64-11.95	0.007	0.006-0.004	8.04	9.69-9.33	0.52	0.62-0.44	0	1.04

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Sample code	Season	ER Zn range		ER Cu range		ER Cr range		ER Cd range		ER Ni range		ER Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group C(Agricultural field)													
S7	PM	0.24	0.13-0.36	13.93	14.06-11.86	0.001	0.009-0.0003	7.37	2.59-11.13	0.59	0.28-0.44	0	1.10
	M	0.19	0.09-0.33	12.89	12.79-6.44	0.004	0.004-0.003	5.58	6.47-5.94	0.53	0.30-0.35	0	0.84
S8	PM	0.41	0.03-0.04	16.45	15.84-12.17	0.005	0.003-0.006	19.34	17.20-20.91	0.63	0.65-0.26	0	0.81
	M	0.34	0.21-0.04	12.29	14.82-9.80	0.008	0.009-0.005	17.70	16.03-16.68	0.49	0.47-0.25	0	1.35
S9	PM	0.26	0.22-0.09	19.37	13.95-10.33	0.008	0.008-0.007	18.11	18.86-26.93	0.37	0.53-0.31	0	0.92
	M	0.22	0.18-0.11	18.11	16.01-7.94	0.008	0.009-0.008	15.71	14.67-27.39	0.32	0.43-0.24	0	0
S10	PM	0.48	0.74-0.94	26.06	22.26-31.80	0.007	0.009-0.011	20.20	21.26-21.85	0.38	0.47-0.53	0	0
	M	0.31	0.36-0.22	30.57	30.84-14.66	0.005	0.010-0.008	17.57	21.31-19.42	0.46	0.43-0.50	0	0
S12	PM	0.77	0.63-0.42	15.34	16.26-12.88	0.005	0.004-0.001	14.29	16.24-8.57	0.25	0.28-0.21	0	0
	M	0.59	0.58-0.25	13.44	16.60-9.02	0.006	0.004-0.002	14.83	15.49-9.10	0.21	0.33-0.21	0	0

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Sample code	Season	ER Zn range		ER Cu range		ER Cr range		ER Cd range		ER Ni range		ER Pb range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group D(Bank sediment)													
Kmb Bank	PM	0.51	NA	13.18	NA	0.003	NA	11.12	NA	0.35	NA	0.94	NA
	M	0.33	NA	7.86	NA	0.002	NA	17.40	NA	0.29	NA	1.17	NA
Nim Bank	PM	0.55	NA	9.49	NA	0.003	NA	7.82	NA	1.15	NA	0.65	NA
	M	0.41	NA	8.81	NA	0.003	NA	9.56	NA	0.31	NA	0.74	NA

Here, PM = pre – monsoon; M = monsoon; ER = Ecological Risk; Kmb = Kamalabari; Nim = Nimatighat

Appendix 3

Table A 3.7 *Location wise details of ecological risk index in Amingaon and Umananda, in pre – monsoon and monsoon seasons*

Sample Code	Season	ER Zn	ER Cu	ER Cr	ER Cd	ER Ni	ER Pb
		(0 – 20) cm					
Group A (Disturbed)							
A1	PM	2.51	29.94	0.02	75.49	0.72	1.24
	M	2.44	27.93	0.02	74.29	0.77	1.27
A2	PM	1.09	36.15	0.04	90.84	1.16	1.09
	M	1.10	18.41	0.02	96.73	1.06	0.98
A4	PM	2.32	40.74	0.02	80.27	1.05	1.33
	M	2.28	15.17	0.02	73.08	1.10	1.42
A6	PM	2.04	20.46	0.01	79.02	1.02	1.43
	M	2.24	17.43	0.01	78.55	0.91	1.37
A8	PM	1.70	21.85	0.03	86.22	0.97	1.33
	M	1.18	24.24	0.03	100.15	1.00	1.20

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Sample Code	Season	ER Zn	ER Cu	ER Cr	ER Cd	ER Ni	ER Pb
		(0 – 20) cm					
		Group A (Disturbed)					
A10	PM	0.75	6.96	0.02	76.32	0.73	1.00
	M	1.86	20.88	0.02	70.65	0.62	0.89
U2	PM	2.95	22.13	0.02	74.04	1.31	1.08
	M	3.41	20.63	0.02	81.66	1.12	1.02
U3	PM	4.05	16.87	0.03	71.41	0.88	1.21
	M	4.30	27.88	0.03	90.25	0.90	1.17
U5	PM	3.70	17.91	0.01	77.37	0.92	1.00
	M	3.86	22.72	0.02	80.28	0.70	0.93
U7	PM	4.33	26.76	0.02	67.48	1.05	0.76
	M	3.85	21.52	0.01	74.74	1.07	0.66
U9	PM	4.23	17.86	0.02	62.71	1.32	0.66
	M	4.30	21.80	0.02	71.20	1.13	0.58

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Sample Code	Season	ER Zn	ER Cu	ER Cr	ER Cd	ER Ni	ER Pb
		(0 – 20) cm					
		Group B (Undisturbed)					
A3	PM	1.59	30.38	0.01	85.57	1.25	1.27
	M	1.54	18.27	0.01	85.89	1.18	1.19
A5	PM	1.74	49.34	0.02	83.38	0.95	1.13
	M	2.07	12.06	0.02	86.15	0.78	1.15
A7	PM	2.27	17.64	0.02	82.30	1.10	1.37
	M	1.87	20.52	0.02	93.05	1.16	1.29
A9	PM	1.79	16.05	0.02	75.77	0.83	1.23
	M	1.71	27.25	0.02	75.65	0.92	1.26
U1	PM	2.05	27.79	0.02	79.99	0.95	1.25
	M	2.01	24.35	0.02	85.26	1.00	1.22

Appendix 3

Sample Code	Season	ER Zn	ER Cu	ER Cr	ER Cd	ER Ni	ER Pb
		(0 – 20) cm					
		Group B (Undisturbed)					
U4	PM	3.05	25.10	0.02	79.62	0.93	1.37
	M	3.00	28.36	0.02	57.26	0.80	1.57
U6	PM	4.72	24.76	0.02	76.08	0.92	0.86
	M	4.47	18.32	0.02	76.69	1.00	0.81
U8	PM	3.74	20.68	0.02	69.67	0.98	0.94
	M	3.71	25.24	0.02	79.38	0.98	0.91
U10	PM	3.00	21.10	0.02	66.00	1.07	0.77
	M	3.60	14.53	0.02	70.90	1.09	0.70

Appendix 3

Sample Code	Season	ER Zn	ER Cu	ER Cr	ER Cd	ER Ni	ER Pb
		(0 – 20) cm					
Group C (Bank sediment)							
AB1	PM	0.85	14.26	0.01	54.81	0.95	0.65
	M	0.86	18.69	0.02	55.65	0.89	0.67
AB2	PM	0.57	8.47	0.01	66.08	0.70	0.56
	M	1.20	18.69	0.01	40.87	0.68	0.57
U Bank	PM	0.40	7.28	0.02	47.67	0.40	0.67
	M	0.38	7.42	0.02	41.62	0.44	0.66
K Bank	PM	0.40	11.32	0.02	44.68	0.47	0.75
		0.41	8.42	0.02	40.87	0.42	0.70

Here, PM = pre – monsoon; M = monsoon; ER = Ecological Risk; AB = Amingaon Bank; U Bank = Umananda Bank; K Bank = Kachari Bank

Appendix 3

Table A 3.8 *Depth wise and location wise details of integrated pollution indices in Majuli, in pre – monsoon and monsoon seasons*

Sample code	Season	PLI range		Cont. degree range		NPI range		PERI range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group A (Residential area)									
S1	PM	0.25	0.27-0.25	0.50	0.61-0.57	1.28	1.78-1.91	20.46	24.07-23.78
	M	0.22	0.26-0.17	0.37	0.64-0.24	0.85	1.98-0.51	16.87	25.70-12.31
S5	PM	0.21	0.17-0.22	0.72	0.52-0.55	2.86	1.87-1.89	30.19	22.35-23.19
	M	0.17	0.15-0.17	0.55	0.59-0.48	2.07	2.26-1.81	23.64	25.24-20.15
S6	PM	0.20	0.23-0.15	0.64	0.77-0.50	2.48	2.73-1.57	21.03	30.50-17.34
	M	0.21	0.18-0.14	0.58	0.46-0.31	2.07	1.49-1.00	21.39	18.80-13.44
S11	PM	0.14	0.24-0.21	0.48	0.56-0.52	1.66	1.73-1.72	27.49	30.92-27.45
	M	0.12	0.12-0.08	0.30	0.32-0.24	1.00	0.80-0.66	13.37	14.15-11.34

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Sample code	Season	PLI range		Cont. degree range		NPI range		PERI range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group B (Grassland)									
S2	PM	0.28	0.27-0.29	0.85	0.72-0.66	2.58	2.09-1.91	31.21	26.28-27.42
	M	0.31	0.26-0.25	0.72	0.50-0.44	2.15	1.10-1.00	26.79	17.69-20.87
S3	PM	0.25	0.14-0.16	0.53	0.52-0.39	1.46	1.53-1.22	20.29	19.24-18.07
	M	0.26	0.21-0.13	0.53	0.43-0.25	1.20	1.10-0.59	18.79	16.01-11.86
S4	PM	0.24	0.22-0.14	0.71	0.81-0.40	2.58	2.80-1.10	28.24	32.60-20.40
	M	0.17	0.21-0.13	0.46	0.54-0.48	1.61	1.87-1.76	19.58	23.19-22.81
Group C(Agricultural field)									
S7	PM	0.15	0.16-0.14	0.59	0.57-0.56	2.06	2.07-1.77	22.13	17.07-24.90
	M	0.17	0.15-0.14	0.53	0.51-0.31	1.90	1.88-0.96	19.19	19.65-13.08
S8	PM	0.27	0.17-0.17	0.78	0.69-0.58	2.45	2.34-1.82	36.84	33.72-33.40
	M	0.26	0.24-0.14	0.62	0.71-0.44	1.85	2.21-1.45	30.83	32.89-26.77

Appendix 3

Sample code	Season	PLI range		Cont. degree range		NPI range		PERI range	
		(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm	(0 – 20) cm	> 20 cm
Group C (Agricultural field)									
S9	PM	0.25	0.25-0.19	0.83	0.68-0.53	2.86	2.09-1.55	38.12	34.49-37.66
	M	0.23	0.23-0.18	0.73	0.67-0.45	2.66	2.36-1.21	34.38	31.31-35.69
S10	PM	0.26	0.31-0.34	1.00	0.95-1.24	3.82	3.29-4.66	47.13	44.73-55.13
	M	0.25	0.28-0.23	1.10	1.13-0.62	4.46	4.50-2.16	48.91	52.95-34.82
S12	PM	0.23	0.22-0.14	0.71	0.73-0.56	2.28	2.41-1.91	30.65	33.42-22.07
	M	0.21	0.22-0.15	0.61	0.71-0.42	2.00	2.45-1.34	29.07	33.01-18.57
Group D (Bank sediment)									
Kmb Bank	PM	0.210	NA	0.646	NA	1.97	NA	26.10	NA
	M	0.173	NA	0.479	NA	1.21	NA	27.04	NA
Nim Bank	PM	0.213	NA	0.520	NA	1.44	NA	19.66	NA
	M	0.174	NA	0.483	NA	1.34	NA	19.83	NA

Here, PM = pre-monsoon; M = monsoon; PLI = Pollution Load Index; Cont. degree = Contamination Degree; NPI = Nemerow's Pollution Index; PERI = Potential Ecological Risk Index; Kmb = Kamalabari; Nim = Nimatighat

Appendix 3

Table A 3.9 *Location wise details of integrated pollution indices in Amingaon and Umananda, in pre – monsoon and monsoon seasons*

Sample Code	Season	PLI	Cont. deg	NPI	PERI
		(0 – 20) cm			
Group A (Disturbed)					
A1	PM	0.58	1.75	4.58	109.92
	M	0.56	1.68	4.29	106.72
A2	PM	0.61	1.80	5.42	130.35
	M	0.53	1.33	2.92	118.30
A4	PM	0.61	2.05	6.12	125.72
	M	0.51	1.26	2.49	93.07
A6	PM	0.48	1.41	3.22	103.97
	M	0.47	1.33	2.80	100.51
A8	PM	0.53	1.43	3.41	112.11
	M	0.53	1.49	3.74	127.79
A10	PM	0.35	0.79	1.96	85.77
	M	0.42	1.29	3.22	94.92

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Sample Code	Season	PLI	Cont. deg	NPI	PERI
		(0 – 20) cm			
Group A (Disturbed)					
U2	PM	0.59	1.58	3.51	101.54
	M	0.56	1.61	3.33	107.85
U3	PM	0.61	1.60	3.28	94.44
	M	0.68	2.05	4.45	124.52
U5	PM	0.53	1.56	3.04	100.90
	M	0.54	1.72	3.65	108.50
U7	PM	0.58	1.85	4.21	100.39
	M	0.53	1.64	3.46	101.85
U9	PM	0.56	1.54	3.36	86.79
	M	0.54	1.69	3.51	99.02
Group B (Undisturbed)					
A3	PM	0.47	1.68	4.61	120.06
	M	0.50	1.33	2.90	108.09
A5	PM	0.60	2.21	7.32	136.56
	M	0.48	1.21	2.36	102.23

Appendix 3

Sample Code	Season	PLI	Cont. deg	NPI	PERI
		(0 – 20) cm			
Group B (Undisturbed)					
A7	PM	0.52	1.39	2.85	104.68
	M	0.51	1.44	3.24	117.89
A9	PM	0.48	1.22	2.58	95.69
	M	0.53	1.54	4.15	106.82
U1	PM	0.58	1.67	4.27	112.03
	M	0.58	1.57	3.78	113.86
U4	PM	0.56	1.69	3.93	110.10
	M	0.54	1.67	4.34	91.02
U6	PM	0.61	1.90	3.98	107.35
	M	0.55	1.67	3.58	101.31
U8	PM	0.55	1.59	3.33	96.02
	M	0.58	1.77	3.98	110.23
U10	PM	0.53	1.46	3.32	91.96
	M	0.52	1.39	2.90	90.84

Appendix 3

Sample Code	Season	PLI	Cont. deg	NPI	PERI
		(0 – 20) cm			
Group C (Bank sediment)					
AB1	PM	0.40	0.93	2.22	71.54
	M	0.42	1.06	2.85	76.76
AB2	PM	0.32	0.73	1.40	76.40
	M	0.37	1.00	2.83	62.02
U Bank	PM	0.24	0.55	1.25	56.44
	M	0.23	0.52	1.17	50.54
K Bank	PM	0.25	0.65	1.73	57.63
	M	0.25	0.56	1.32	50.85

Here, PM = pre – monsoon; M = monsoon; PLI = Pollution Load Index; Cont. deg = Contamination Degree; NPI = Nemerow's Pollution Index; PERI = Potential Ecological Risk Index; AB = Amingaon Bank; U Bank = Umananda Bank; K Bank = Kachari Bank

Appendix 3

Table A 3.10 *Results of integrated pollution indices analyzed in soil and water samples in Majuli, in pre – monsoon and monsoon seasons respectively. Sampling sites are arranged in ascending order of values of the indices measured.*

Indices	Season	Ascending order of values in soil sampling sites	Indices	Season	Ascending order of values in water sampling sites
PLI	PM	S10>S2>S1>S9>Nim Bank>S5>Kmb Bank>S11>S12>S8>S6>S4>S3>S7	NPI	PM	Nim Bank>S6>S2>S3>S8>S9>S10>S13>Kmb Bank >S7>S16>S18>S17>S14>S4>S12>S15>S11>S5>S1
	M	S10>S2>S1>S9>S8>S3>S12>Nim Bank>Kmb Bank>S4>S6>S5>S7>S11			
C_d	PM	S10>S2>S12>S6>S8>S9>S5>S4>S7>Kmb Bank>S1>S11>Nim Bank>S3			
	M	S10>S12>S9>S8>S2>S5>S4>Nim bank>Kmb bank>S7>S6>S1>S3>S11			
NPI	PM	S10>S12>S5>S6>S4>S2>S9>S8>S7>Kmb Bank>S11>S1>Nim Bank>S3		M	S9>S2>S6>NimBank>S8>S19>S3>S16>S13>S4>S15> S10>S17>S7>S11>S5>S1>S14>S12>Kmb Bank
	M	S10>S12>S9>S5>S4>S8>S6>S7>S2>Nim Bank>Kmb Bank>S1>S3>S11			
PERI	PM	S10>S9>S8>S12>S11>S2>S4>S5>S6>Kmb Bank>S7>S1>Nim Bank>S3			
	M	S10>S8>S9>S12>Kmb Bank>S4>S2>S5>Nim Bank>S6>S1>S7>S3>S11			

Here, PM = pre – monsoon; M = monsoon; PLI = Pollution Load Index; C_d = Contamination Degree; ER = Ecological Risk; PERI = Potential Ecological Risk Index; NPI = Nemerow's Pollution Index; Kmb = Kamalabari; Nim = Nimatighat

Appendix 3

Table A 3.11 *Representation of Karl Pearson correlation matrix among metals to show association between metals and soil physicochemical and biological properties in Majuli and Kamrup, in pre – monsoon and monsoon seasons*

Parameters	Season	Fe	Cu	Mn	Zn	Cd	Cr	Ni	Pb
pH	PM	-	+	-	+	+	+	-	+
	M	(-)*	+	+	+	+	+	+	+
Cond	PM	+	+	+	-	+	-	+	+
	M	+	+	+	-	+	+	+	+
CEC	PM	-	-	(-)**	-	(-)**	-	(-)**	(-)**
	M	(-)*	(-)**	(-)*	-	(-)*	-	-	(-)**
TOC	PM	+	(+)**	(+)**	(+)**	(+)**	+	(+)**	(+)**
	M	+	(+)*	(+)*	(+)**	(+)**	+	(+)**	(+)**
MBC	PM	+	(+)**	(+)**	(+)**	(+)**	+	(+)**	(+)**
	M	+	(+)**	(+)*	(+)**	(+)**	+	(+)**	(+)**
TN	PM	+	(+)**	(+)**	(+)*	(+)**	+	(+)**	(+)**
	M	+	(+)*	(+)**	+	(+)**	(+)*	(+)*	(+)**
MBN	PM	+	(+)*	(+)**	(+)*	(+)**	+	(+)*	(+)**
	M	+	(+)*	(+)**	(+)*	(+)**	(+)*	(+)*	(+)**

Appendix 3

Parameters	Season	Fe	Cu	Mn	Zn	Cd	Cr	Ni	Pb
TP	PM	+	(+) *	(+) **	+	(+) **	+	(+) *	(+) **
	M	+	+	+	(+) *	(+) *	+	+	+
MBP	PM	-	+	(+) **	(+) *	(+) **	+	+	(+) *
	M	(+) *	+	(+) *	+	(+) *	+	+	(+) *
ACP	PM	+	(+) **	+	(+) **	(+) **	+	(+) **	+
	M	(+) **	-	+	-	(+) **	+	(+) **	(+) *
ACP_T	PM	+	(+) **	(+) *	(+) **	(+) *	+	(+) **	+
	M	(+) **	-	+	-	(+) **	+	(+) *	(+) **
AKP	PM	+	(+) *	(+) **	(+) **	(+) **	+	(+) **	(+) **
	M	(+) *	+	(+) **	+	(+) **	+	(+) **	+
AKP_T	PM	+	(+) **	(+) **	(+) **	(+) **	+	(+) **	(+) *
	M	(+) **	+	+	+	(+) *	-	(+) *	+
Amy	PM	-	+	(+) *	(+) **	+	+	(+) *	+
	M	+	+	(+) **	(+) *	(+) **	+	(+) **	+

Appendix 3

Parameters	Season	Fe	Cu	Mn	Zn	Cd	Cr	Ni	Pb
Amy_T	PM	-	+	(+)*	(+)**	+	+	(+)**	+
	M	+	+	(+)**	(+)*	(+)**	+	(+)**	+
Cell	PM	+	(+)*	(+)**	(+)**	(+)*	+	(+)*	(+)*
	M	(+)**	+	+	-	(+)*	+	+	(+)**
Cell_T	PM	+	(+)**	(+)**	(+)**	(+)*	+	(+)*	(+)*
	M	(+)**	+	+	-	+	+	+	(+)**
Deh	PM	+	+	+	(+)**	+	+	+	+
	M	(+)**	+	+	-	+	+	+	+
Deh_T	PM	+	+	+	(+)**	(+)*	+	+	+
	M	(+)**	+	+	-	+	+	+	+
Inv	PM	(+)**	(+)**	+	+	(+)**	-	+	(+)**
	M	(+)**	+	+	-	+	+	+	(+)*
Inv_T	PM	(+)*	(+)**	(+)*	+	(+)**	+	+	(+)**
	M	+	+	+	-	+	+	+	+

Appendix 3

Parameters	Season	Fe	Cu	Mn	Zn	Cd	Cr	Ni	Pb
Pro	PM	+	(+)**	(+)**	+	(+)**	+	(+)**	(+)**
	M	+	+	(+)**	+	+	(+)*	+	+
Pro_T	PM	+	(+)**	(+)**	+	(+)**	+	(+)**	(+)**
	M	(+)**	(+)*	(+)*	-	+	+	+	(+)**
Urea	PM	(+)*	(+)**	(+)**	(+)**	(+)**	+	(+)**	(+)**
	M	(+)*	(+)*	(+)**	+	(+)**	+	(+)**	+
Urea_T	PM	(+)*	(+)**	(+)**	(+)**	(+)**	+	(+)**	(+)**
	M	(+)*	+	(+)**	+	(+)**	+	(+)**	+
BCFU	PM	(-)**	-	-	(+)*	-	-	-	-
	M	(-)*	+	-	(+)*	-	-	-	-
FCFU	PM	(-)**	-	+	(+)**	-	+	+	-
	M	(-)**	+	+	(+)**	+	+	+	-
Fe	PM	+	(+)**	(+)*	-	(+)**	+	+	(+)**
	M	+	+	+	-	(+)**	+	+	(+)**

Appendix 3

Parameters	Season	Fe	Cu	Mn	Zn	Cd	Cr	Ni	Pb
Cu	PM	(+)**	+	(+)**	+	(+)**	+	(+)*	(+)*
	M	+	+	(+)**	(+)*	(+)*	+	+	(+)*
Mn	PM	(+)*	(+)**	+	(+)*	(+)**	+	(+)*	(+)**
	M	+	(+)**	+	+	(+)**	(+)*	(+)*	(+)*
Zn	PM	-	+	(+)*	+	+	+	(+)*	+
	M	-	(+)*	+	+	+	+	(+)*	-
Cd	PM	(+)**	(+)**	+	+	+	+	(+)**	(+)**
	M	(+)**	(+)*	+	+	+	(+)*	(+)**	(+)*
Cr	PM	+	+	+	+	+	+	+	+
	M	+	+	(+)*	+	(+)*	+	+	(+)*
Ni	PM	+	(+)*	(+)*	(+)*	(+)**	+	+	+
	M	+	+	(+)*	(+)*	(+)**	+	+	+
Pb	PM	(+)**	(+)*	(+)**	+	(+)**	+	+	+
	M	(+)**	(+)*	(+)*	-	(+)*	(+)*	+	+

Here, PM = pre – monsoon; M = monsoon

Appendix 4

Table A 4.1 *Measurement of distribution and dispersion of geochemical parameters in Majuli, in pre – monsoon and monsoon seasons respectively*

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q1	Q2	Q3	
pH	PM	5.35	8.23	7.14	0.23	7.09	0.87	-0.56	-0.45	6.60	7.09	7.89	12
	M	6.02	8.19	7.46	0.18	7.55	0.67	-0.65	-0.31	6.99	7.55	8.08	9
EC	PM	26.64	207.34	85.26	13.20	83.90	49.39	1.10	1.68	43.85	83.90	102.46	58
	M	59.29	231.62	108.33	11.17	104.29	41.78	2.02	5.88	73.90	104.29	123.53	39
CEC	PM	15.05	69.84	36.46	4.79	36.46	17.93	0.61	-0.54	18.48	36.46	46.21	49
	M	10.02	39.88	21.85	2.48	22.55	9.28	0.50	-0.51	12.34	22.55	27.60	42
TOC	PM	2146.28	3044.49	2533.21	78.37	2580.41	293.23	0.17	-1.34	2264.83	2580.41	2776.98	12
	M	1928.24	2737.54	2320.62	58.92	2326.74	220.44	-0.002	-0.29	2157.42	2326.74	2464.67	9
MBC	PM	162.56	322.34	245.50	11.20	253.78	41.92	-0.16	0.14	215.86	253.78	271.12	17
	M	144.17	418.39	224.32	22.91	202.86	85.73	1.74	2.30	174.68	202.86	232.11	38
TN	PM	282.80	709.30	426.13	33.67	392.47	125.97	1.11	0.62	338.10	392.47	483.93	30
	M	234.27	704.67	372.93	37.71	315.47	141.10	1.25	0.98	269.03	315.47	454.07	38

Appendix 4

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q1	Q2	Q3	
MBN	PM	10.83	42.17	23.80	2.33	22.42	8.73	0.79	0.39	18.63	22.42	27.63	37
	M	9.17	34.00	19.69	2.09	19.17	7.81	0.66	-0.30	13.29	19.17	24.88	40
TP	PM	151.23	530.09	408.21	32.22	431.93	120.54	-1.32	0.67	378.27	431.93	497.12	30
	M	87.51	376.00	282.39	22.87	311.60	85.59	-1.59	1.95	263.32	311.60	332.09	30
MBP	PM	16.97	34.78	27.26	1.25	27.77	4.69	-0.77	0.87	25.31	27.77	30.64	17
	M	12.56	25.37	19.22	1.05	19.86	3.92	-0.05	-0.61	16.39	19.86	21.79	20
ACP	PM	0.01	4.47	1.73	0.29	1.75	1.10	0.73	2.35	1.24	1.75	2.22	64
	M	0.07	3.87	1.72	0.28	1.64	1.05	0.38	0.002	1.12	1.64	2.38	61
ACP_T	PM	0.02	4.78	1.94	0.32	1.91	1.19	0.62	1.92	1.50	1.91	2.35	61
	M	0.06	3.63	1.73	0.29	1.58	1.09	0.25	-0.65	1.08	1.58	2.45	63
AKP	PM	0.07	0.93	0.58	0.07	0.61	0.25	-1.01	1.01	0.50	0.61	0.73	44
	M	0.03	1.17	0.79	0.09	0.88	0.34	-1.58	2.08	0.74	0.88	0.95	42
AKP_T	PM	0.06	0.95	0.55	0.07	0.55	0.25	-0.70	0.72	0.48	0.55	0.70	46
	M	0.03	1.15	0.81	0.09	0.91	0.33	-1.78	2.47	0.77	0.91	0.97	42
Amy	PM	43.70	986.01	348.44	79.44	273.71	297.25	1.50	1.53	130.30	273.71	466.23	85
	M	278.00	2184.28	704.20	131.13	579.12	490.64	2.34	6.53	368.02	579.12	847.01	70

Appendix 4

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Amy_T	PM	140.36	1130.88	455.17	82.75	343.90	309.63	1.48	1.30	246.64	343.90	588.45	68
	M	237.66	2766.99	1219.53	159.58	1057.49	597.08	1.15	2.78	918.88	1057.49	1562.36	49
Cell	PM	420.56	2043.96	941.73	128.37	910.78	480.32	1.01	0.65	523.69	910.78	1174.73	51
	M	658.44	2301.52	1197.87	120.35	1076.46	450.32	1.30	1.60	840.45	1076.46	1400.63	38
Cell_T	PM	374.83	2186.86	1028.60	129.13	983.07	483.14	1.06	1.42	712.70	983.07	1229.41	47
	M	916.23	2851.83	1545.82	153.30	1441.96	573.60	1.06	0.69	1056.98	1441.96	1919.13	37
Deh	PM	2.28	21.41	9.36	1.23	9.59	4.59	1.05	3.38	7.39	9.59	10.34	49
	M	1.36	21.74	10.46	1.33	10.93	4.97	0.10	2.02	9.00	10.93	11.76	48
Deh_T	PM	1.87	18.94	8.78	1.20	7.58	4.48	0.57	0.93	6.68	7.58	11.97	51
	M	1.47	26.99	11.38	1.67	10.87	6.26	0.79	2.45	8.91	10.87	13.64	55
Inv	PM	0.94	2404.70	1359.49	198.55	1587.92	742.90	-0.88	-0.12	978.35	1587.92	1848.59	55
	M	885.54	2331.74	1717.87	112.52	1755.62	421.02	-0.55	-0.20	1466.96	1755.62	2076.60	25
Inv_T	PM	111.76	1975.67	907.60	156.00	762.27	583.70	0.55	-0.86	475.47	762.27	1508.62	64
	M	207.68	1683.91	967.67	113.67	999.74	425.33	-0.03	-0.65	608.74	999.74	1312.35	44

Appendix 4

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Pro	PM	20.63	560.95	267.54	41.97	216.30	157.04	0.22	-0.44	181.67	216.30	388.53	59
	M	255.73	1041.67	555.06	69.56	541.91	260.29	0.79	-0.27	323.08	541.91	685.35	47
Pro_T	PM	20.23	625.01	338.89	44.32	340.06	165.83	-0.42	0.28	270.85	340.06	422.89	49
	M	312.86	1070.25	667.23	60.55	664.13	226.56	0.37	-0.61	461.48	664.13	811.01	34
Urea	PM	35.35	525.10	382.03	43.64	449.69	163.29	-1.50	1.25	297.48	449.69	495.65	43
	M	130.21	1571.41	1103.51	120.06	1219.77	449.22	-1.25	0.89	933.32	1219.77	1441.26	41
Urea_T	PM	19.42	506.60	374.62	42.33	422.80	158.40	-1.70	2.08	336.42	422.80	490.12	42
	M	89.15	1689.57	1236.49	113.52	1397.70	424.75	-1.70	3.24	1038.09	1397.70	1507.59	34
BCFU	PM	0.05	0.44	0.12	0.03	0.08	0.10	2.56	7.05	0.06	0.08	0.14	89
	M	0.05	0.38	0.23	0.03	0.27	0.11	-0.58	-1.10	0.09	0.27	0.32	47
FCFU	PM	0.02	0.14	0.08	0.01	0.07	0.04	0.03	-1.00	0.06	0.07	0.12	45
	M	0.04	0.24	0.12	0.02	0.09	0.06	0.79	-0.57	0.07	0.09	0.17	56
Fe	PM	4540.65	21219.41	14398.79	1423.20	15726.66	5325.12	-0.51	-1.04	9429.96	15726.66	18843.43	37
	M	3150.75	17133.69	10751.78	1287.63	12207.51	4817.86	-0.45	-1.39	5173.23	12207.51	14694.32	45
Cu	PM	59.55	177.93	91.58	7.55	89.01	28.24	2.28	7.28	75.13	89.01	100.03	31
	M	29.80	158.92	69.80	8.15	65.87	30.48	1.90	5.69	53.91	65.87	80.56	44

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Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Mn	PM	372.33	700.22	522.70	26.94	529.20	100.79	-0.45	-1.05	413.37	529.20	596.11	19
	M	200.34	599.22	425.77	27.77	453.95	103.91	-0.63	0.66	371.47	453.95	480.91	24
Zn	PM	20.09	92.86	49.30	6.93	35.61	25.94	0.56	-1.23	27.82	35.61	72.58	53
	M	13.14	63.38	35.36	4.23	38.04	15.82	0.12	-1.13	20.67	38.04	49.64	45
Cd	PM	0.02	0.13	0.08	0.01	0.07	0.03	0.20	-0.60	0.06	0.07	0.11	40
	M	0.04	0.15	0.07	0.01	0.06	0.03	1.12	0.35	0.05	0.06	0.09	45
Cr	PM	0.05	0.27	0.13	0.02	0.12	0.07	0.79	-0.10	0.08	0.12	0.17	50
	M	0.04	0.25	0.12	0.02	0.13	0.06	0.45	-0.38	0.06	0.13	0.16	51
Pb	PM	2.86	17.00	4.01	1.32	2.98	4.93	1.56	2.99	0.02	2.98	6.75	123
	M	2.95	17.00	4.18	1.34	3.00	5.02	1.28	1.45	0.01	3.00	7.23	120
Ni	PM	2.62	11.31	4.55	0.57	3.95	2.14	2.70	8.62	3.37	3.95	5.00	47
	M	2.43	5.23	3.69	0.25	3.41	0.94	0.46	-1.23	2.84	3.41	4.48	26
Fine Sand (%)	PM	NA	65.28	49.22	5.79	56.53	21.67	-1.96	2.81	47.83	56.53	61.43	44
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silt (%)	PM	NA	32.95	21.04	2.55	23.37	9.54	-1.66	2.32	20.60	23.37	26.51	45
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Clay (%)	PM	NA	25.58	14.95	1.94	15.77	7.26	-1.13	1.33	12.97	15.77	18.82	49
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Here PM = pre – monsoon; M = monsoon

Appendix 4

Table A 4.2 *Measurement of distribution and dispersion of geochemical parameters in Amingaon, in pre – monsoon and monsoon seasons respectively*

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
pH	PM	6.87	7.36	7.16	0.05	7.16	0.16	-0.33	-0.85	7.02	7.16	7.31	2
	M	7.02	7.28	7.12	0.03	7.07	0.10	0.59	-1.50	7.04	7.07	7.23	1
Cond	PM	49.63	251.33	109.33	16.28	100.30	56.40	1.51	2.82	64.52	100.30	137.20	52
	M	34.17	180.04	92.79	11.88	88.14	41.15	0.66	0.25	58.55	88.14	120.89	44
CEC	PM	29.04	70.46	43.72	3.08	42.75	10.67	1.40	3.01	37.02	42.75	46.65	24
	M	25.49	50.70	35.10	1.89	35.62	6.54	1.05	2.25	31.37	35.62	36.61	19
TOC	PM	2396.98	3152.36	2928.95	63.41	2986.14	219.65	-1.40	1.99	2794.04	2986.14	3091.82	7
	M	2209.72	2961.92	2716.86	71.96	2783.51	249.28	-1.31	0.79	2630.89	2783.51	2917.71	9
MBC	PM	197.98	278.87	251.81	7.62	259.23	26.39	-1.14	0.33	237.29	259.23	271.90	10
	M	184.77	274.38	250.46	7.55	262.58	26.16	-1.59	2.67	232.90	262.58	268.72	10
TN	PM	289.30	1064.00	737.84	82.41	794.03	285.46	-0.54	-1.24	416.50	794.03	994.00	39
	M	382.67	1148.00	740.44	74.13	742.00	256.80	0.16	-0.60	486.50	742.00	906.50	35
MBN	PM	14.17	68.33	42.22	5.24	46.67	18.15	-0.12	-1.35	24.58	46.67	55.21	43
	M	9.17	64.17	36.08	5.25	37.08	18.19	-0.17	-0.88	16.67	37.08	47.29	50

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Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
TP	PM	327.57	678.14	495.21	30.33	460.69	105.06	0.34	-0.81	420.10	460.69	600.08	21
	M	240.85	555.47	434.12	30.95	470.87	107.22	-0.76	-0.59	364.78	470.87	527.91	25
MBP	PM	23.54	43.59	32.19	1.89	30.26	6.53	0.50	-1.00	26.69	30.26	38.67	20
	M	21.15	36.35	30.30	1.36	30.73	4.70	-0.74	-0.09	27.43	30.73	33.77	16
ACP	PM	0.07	6.04	3.27	0.60	2.94	2.07	0.01	-1.52	1.27	2.94	5.25	63
	M	0.13	7.86	3.53	0.77	3.70	2.67	0.10	-1.21	0.60	3.70	5.79	76
ACP_T	PM	0.07	6.20	3.50	0.63	3.46	2.19	-0.34	-1.15	1.89	3.46	5.36	63
	M	0.23	7.92	3.60	0.74	4.01	2.57	-0.01	-1.10	0.62	4.01	5.86	71
AKP	PM	0.07	5.33	2.66	0.49	2.97	1.71	-0.56	-0.55	0.76	2.97	3.76	64
	M	0.99	4.91	3.01	0.35	2.94	1.22	0.02	-0.50	2.30	2.94	3.93	41
AKP_T	PM	0.03	5.50	2.75	0.52	3.22	1.81	-0.49	-0.63	0.70	3.22	3.80	66
	M	0.92	5.77	3.27	0.43	3.11	1.48	0.18	-0.79	2.30	3.11	4.52	45
Amy	PM	111.65	1534.91	841.03	141.45	912.91	489.98	-0.29	-1.13	333.44	912.91	1279.08	58
	M	433.05	3221.13	2001.99	232.48	2153.60	805.32	-0.77	0.43	1656.05	2153.60	2542.32	40
Amy_T	PM	120.68	1750.91	958.62	152.89	1038.62	529.62	-0.28	-0.81	468.74	1038.62	1322.44	55
	M	764.07	3369.45	2333.99	233.98	2407.59	810.52	-1.06	0.62	2158.02	2407.59	2903.27	35

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Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Cell	PM	799.42	2522.77	1995.71	194.95	2246.97	675.34	-1.24	-0.33	1320.94	2246.97	2464.60	34
	M	727.57	3330.64	2143.85	204.01	2312.97	706.71	-0.89	1.31	2060.81	2312.97	2475.79	33
Cell_T	PM	857.64	2604.61	2066.07	203.99	2367.72	706.64	-1.26	-0.36	1330.21	2367.72	2528.87	34
	M	831.51	3663.21	2318.40	223.61	2412.49	774.61	-0.64	0.91	2099.42	2412.49	2813.98	33
Deh	PM	1.76	55.39	33.97	5.12	35.70	17.74	-0.79	-0.06	24.95	35.70	48.69	52
	M	16.37	104.48	44.35	8.46	31.46	29.31	1.25	0.32	23.71	31.46	65.20	66
Deh_T	PM	1.80	57.23	34.37	5.16	37.30	17.88	-0.80	-0.05	25.24	37.30	47.99	52
	M	16.47	102.74	43.66	8.38	30.47	29.04	1.25	0.28	23.08	30.47	64.44	67
Inv	PM	524.72	5590.23	2851.06	425.93	2877.70	1475.45	0.18	-0.49	1702.76	2877.70	3764.30	52
	M	748.48	7437.33	3892.31	666.29	3905.94	2308.10	0.15	-1.41	1639.39	3905.94	5910.36	59
Inv_T	PM	332.37	4161.20	2467.92	344.43	2796.66	1193.15	-0.53	-0.68	1586.77	2796.66	3418.17	48
	M	917.66	5644.49	2671.58	484.58	2018.57	1678.64	0.82	-0.81	1391.09	2018.57	4235.12	63
Pro	PM	78.48	1174.29	653.41	102.69	765.17	355.73	-0.76	-0.51	251.11	765.17	881.12	54
	M	584.70	1045.34	817.87	32.91	819.40	114.02	-0.26	1.74	782.33	819.40	865.91	14
Pro_T	PM	81.92	1069.11	688.78	103.74	831.21	359.35	-0.87	-0.84	268.64	831.21	960.84	52
	M	945.73	1207.53	1058.27	23.56	1054.31	81.61	0.43	-0.45	992.67	1054.31	1114.86	8

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Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Urea	PM	117.57	920.78	663.91	72.01	740.82	249.45	-1.56	1.60	614.25	740.82	802.27	38
	M	167.18	2112.07	1552.95	192.11	1854.70	665.48	-1.61	1.44	1392.47	1854.70	1984.61	43
Urea_T	PM	102.70	912.58	673.27	73.06	762.08	253.10	-1.66	1.81	616.83	762.08	822.29	38
	M	249.16	2185.27	1722.41	199.97	1991.05	692.72	-1.86	2.12	1708.46	1991.05	2123.27	40
BCFU	PM	0.36	1.02	0.67	0.06	0.67	0.21	0.15	-0.45	0.55	0.67	0.82	31
	M	0.60	1.12	0.81	0.05	0.81	0.18	0.39	-1.30	0.63	0.81	0.98	22
FCFU	PM	0.30	0.56	0.42	0.03	0.41	0.10	0.30	-1.44	0.33	0.41	0.52	23
	M	0.36	0.63	0.47	0.02	0.46	0.08	0.57	-0.68	0.41	0.46	0.54	18
Fe	PM	6954.84	28157.78	17602.49	1544.83	17776.10	5351.45	-0.02	1.17	13726.49	17776.10	20663.14	30
	M	4796.29	24261.75	17358.78	1648.08	19331.26	5709.10	-0.95	0.69	13148.07	19331.26	20684.35	33
Cu	PM	44.52	315.77	155.86	24.23	135.40	83.93	0.52	-0.54	94.15	135.40	222.11	54
	M	77.20	178.72	127.75	8.56	119.62	29.66	0.37	-0.05	112.90	119.62	149.74	23
Mn	PM	282.00	627.71	471.20	26.75	479.26	92.68	-0.51	0.64	434.57	479.26	537.74	20
	M	228.72	640.00	456.39	34.99	462.53	121.22	-0.23	-0.35	360.43	462.53	543.71	27
Zn	PM	73.83	323.69	206.43	24.20	221.62	83.83	-0.30	-1.20	116.86	221.62	284.98	41
	M	110.55	315.23	218.69	19.44	230.62	67.33	-0.17	-1.28	152.74	230.62	283.21	31

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Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Cd	PM	0.37	0.61	0.52	0.02	0.53	0.06	-1.29	2.09	0.50	0.53	0.57	12
	M	0.27	0.67	0.52	0.03	0.51	0.11	-0.82	0.73	0.48	0.51	0.61	22
Cr	PM	0.09	0.71	0.36	0.04	0.35	0.16	0.69	1.78	0.27	0.35	0.46	43
	M	0.25	0.49	0.34	0.02	0.33	0.08	0.55	-0.29	0.27	0.33	0.39	22
Pb	PM	7.00	12.00	9.33	0.50	9.44	1.74	-0.01	-0.89	7.43	9.44	10.63	19
	M	6.00	12.00	9.04	0.52	8.97	1.81	-0.15	-1.11	7.54	8.97	10.70	20
Ni	PM	2.25	5.71	4.54	0.32	4.93	1.10	-1.28	0.76	4.07	4.93	5.32	24
	M	2.29	5.68	4.42	0.31	4.78	1.09	-0.98	-0.08	3.64	4.78	5.14	25
Fine Sand (%)	PM	0.00	67.41	52.90	7.20	63.23	24.95	-1.97	2.42	56.47	63.23	66.51	47
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silt (%)	PM	0.00	29.17	19.99	2.82	22.09	9.78	-1.64	1.74	20.45	22.09	26.20	49
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Clay (%)	PM	0.00	16.56	10.11	1.55	11.05	5.38	-1.06	0.47	8.17	11.05	14.63	53
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Here PM = pre – monsoon; M = monsoon

Appendix 4

Table A 4.3 *Measurement of distribution and dispersion of geochemical parameters in Umananda, in pre – monsoon and monsoon season respectively*

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
pH	PM	6.95	7.98	7.48	0.09	7.52	0.33	-0.08	-1.06	7.18	7.52	7.79	4
	M	7.04	7.73	7.37	0.06	7.33	0.22	0.06	-1.01	7.19	7.33	7.55	3
Cond	PM	34.73	121.56	81.66	7.00	83.74	24.25	-0.26	0.38	68.87	83.74	92.26	30
	M	30.77	112.45	73.32	6.16	72.78	21.33	-0.32	0.96	67.02	72.78	86.31	29
CEC	PM	33.81	72.87	48.31	3.41	46.74	11.80	0.70	-0.01	37.35	46.74	56.94	24
	M	24.97	66.65	43.39	4.25	40.59	14.73	0.58	-1.07	30.31	40.59	59.28	34
TOC	PM	2294.63	3413.57	2935.22	90.12	3016.73	312.18	-1.04	1.12	2859.17	3016.73	3114.58	11
	M	2280.71	3165.61	2842.48	85.80	2850.05	297.21	-1.01	0.34	2765.28	2850.05	3097.99	10
MBC	PM	212.42	301.55	261.28	7.65	270.34	26.51	-0.72	0.10	249.64	270.34	278.73	10
	M	144.81	342.26	247.58	15.24	258.35	52.81	-0.82	1.63	245.37	258.35	266.68	21
TN	PM	373.30	1138.70	805.39	70.34	751.33	243.66	-0.11	-0.58	695.33	751.33	1064.00	30
	M	392.00	1115.33	800.72	66.32	756.00	229.74	-0.12	-0.60	686.00	756.00	1046.50	29
MBN	PM	18.33	78.33	51.04	5.57	50.83	19.29	-0.37	-0.63	38.96	50.83	68.96	38
	M	11.67	70.00	44.51	5.61	45.42	19.42	-0.41	-0.57	32.29	45.42	62.29	44

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Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
TP	PM	279.72	690.83	507.35	39.04	518.98	135.23	-0.30	-0.90	395.71	518.98	630.22	27
	M	316.47	590.89	446.94	26.48	426.98	91.72	0.33	-1.24	383.35	426.98	550.18	21
MBP	PM	23.79	46.93	35.47	2.18	35.36	7.54	0.04	-0.94	28.75	35.36	42.63	21
	M	20.49	39.66	28.15	1.74	26.44	6.04	0.76	-0.44	23.30	26.44	33.05	21
ACP	PM	1.25	5.85	3.68	0.42	3.67	1.44	-0.27	-0.43	2.88	3.67	4.88	39
	M	0.03	4.87	1.26	0.40	0.99	1.37	1.96	4.18	0.23	0.99	1.29	109
ACP_T	PM	1.59	6.18	4.07	0.40	3.93	1.37	-0.12	-0.20	3.41	3.93	5.25	34
	M	0.03	3.83	1.00	0.32	0.74	1.12	1.86	3.33	0.18	0.74	1.02	112
AKP	PM	0.10	6.28	3.91	0.60	4.16	2.07	-0.97	0.19	3.15	4.16	5.56	53
	M	0.06	4.16	2.38	0.42	2.80	1.46	-0.90	-0.61	0.71	2.80	3.40	61
AKP_T	PM	0.10	6.59	4.20	0.62	4.60	2.16	-1.14	0.48	3.39	4.60	5.84	51
	M	0.05	3.38	1.77	0.36	1.82	1.23	-0.29	-1.38	0.39	1.82	2.96	70
Amy	PM	91.82	3104.65	2179.53	296.17	2666.89	1025.97	-1.56	1.34	1963.93	2666.89	2832.53	47
	M	498.37	3765.03	2131.53	309.25	2411.34	1071.28	-0.46	-0.79	966.86	2411.34	2823.49	50
Amy_T	PM	85.56	3285.67	2220.64	306.91	2637.22	1063.17	-1.50	1.26	1966.19	2637.22	2920.78	48
	M	679.15	3871.09	2411.78	307.10	2640.54	1063.82	-0.65	-0.75	1255.33	2640.54	3194.43	44

Appendix 4

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Cell	PM	1205.76	3259.94	2463.61	193.34	2546.49	669.75	-0.82	-0.18	2081.17	2546.49	3056.68	27
	M	676.85	1201.73	980.39	46.46	1032.85	160.93	-0.81	-0.20	872.33	1032.85	1085.64	16
Cell_T	PM	1414.99	3406.34	2603.11	192.85	2700.38	668.06	-0.70	-0.47	2146.59	2700.38	3186.79	26
	M	756.77	1354.08	1054.92	54.98	1095.29	190.47	-0.28	-0.89	905.67	1095.29	1212.82	18
Deh	PM	15.40	73.19	38.73	4.88	35.74	16.92	0.62	0.24	29.25	35.74	49.90	44
	M	19.99	30.87	24.78	1.02	24.23	3.52	0.52	-0.78	22.02	24.23	28.26	14
Deh_T	PM	15.41	70.63	37.55	4.86	35.31	16.84	0.63	-0.08	26.59	35.31	46.73	45
	M	20.03	30.32	24.35	1.00	24.33	3.46	0.47	-0.95	21.56	24.33	27.80	14
Inv	PM	585.78	5742.33	2234.01	432.09	1945.04	1496.81	1.33	1.61	1154.04	1945.04	2681.66	67
	M	1248.80	2584.43	1800.54	119.25	1856.40	413.09	0.22	-0.62	1364.62	1856.40	2076.69	23
Inv_T	PM	183.94	4270.63	1919.24	394.56	1905.90	1366.81	0.36	-1.11	567.76	1905.90	3003.75	71
	M	750.89	3997.91	1809.46	234.61	1821.14	812.73	1.72	5.03	1480.62	1821.14	1860.22	45
Pro	PM	23.40	1187.70	611.85	111.74	709.04	387.08	-0.56	-0.74	165.44	709.04	856.46	63
	M	593.37	1009.07	815.12	33.66	803.63	116.59	0.05	0.14	749.50	803.63	913.52	14
Pro_T	PM	29.53	1155.88	618.36	119.90	613.20	415.34	-0.21	-1.14	183.56	613.20	1049.32	67
	M	717.89	1172.61	949.13	41.23	901.41	142.84	0.20	-1.08	844.93	901.41	1101.48	15

Appendix 4

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Urea	PM	24.52	852.05	591.72	80.41	666.37	278.53	-1.60	1.57	573.12	666.37	768.17	47
	M	84.73	1979.49	1346.72	197.19	1660.27	683.08	-1.21	-0.22	715.37	1660.27	1789.31	51
Urea_T	PM	37.18	874.96	611.32	80.45	685.32	278.68	-1.69	1.82	614.03	685.32	773.79	46
	M	135.65	2160.20	1454.59	219.24	1778.95	759.47	-1.24	-0.31	701.75	1778.95	1934.35	52
BCFU	PM	0.75	1.70	1.25	0.07	1.29	0.25	-0.48	1.10	1.12	1.29	1.37	20
	M	0.84	1.64	1.26	0.06	1.31	0.22	-0.42	0.13	1.12	1.31	1.40	17
FCFU	PM	0.43	1.18	0.80	0.06	0.79	0.21	0.07	-0.11	0.66	0.79	0.95	26
	M	0.50	1.21	0.84	0.06	0.83	0.20	0.25	0.08	0.70	0.83	0.97	24
Fe	PM	1440.59	9587.17	5914.92	704.06	6214.95	2438.94	-0.56	0.11	4796.32	6214.95	7726.41	41
	M	1708.81	9140.57	5237.74	605.91	5456.92	2098.92	-0.22	0.41	4282.84	5456.92	6398.23	40
Cu	PM	46.59	177.83	127.76	11.38	133.67	39.41	-0.79	0.21	109.54	133.67	160.11	31
	M	47.47	181.51	128.65	12.66	138.65	43.86	-0.86	-0.12	99.06	138.65	160.13	34
Mn	PM	116.83	714.76	428.69	52.52	455.41	181.95	-0.24	-0.14	315.95	455.41	523.08	42
	M	113.24	775.00	407.36	50.96	440.73	176.53	0.27	1.03	316.51	440.73	455.15	43
Zn	PM	51.46	608.65	393.56	53.56	435.16	185.53	-1.04	0.15	293.24	435.16	539.58	47
	M	49.57	577.20	400.92	53.14	471.12	184.09	-1.28	0.43	290.80	471.12	540.10	46

Appendix 4

Parameters	Season	Min.	Max.	Mean	SE	Median	Std. Dev.	Skewness	Kurtosis	Percentiles			CV %
										Q_1	Q_2	Q_3	
Cd	PM	0.30	0.53	0.45	0.02	0.47	0.08	-1.17	0.57	0.42	0.47	0.51	17
	M	0.27	0.60	0.47	0.03	0.50	0.11	-1.08	0.16	0.40	0.50	0.54	23
Cr	PM	0.27	0.56	0.38	0.02	0.38	0.08	0.92	1.32	0.32	0.38	0.42	21
	M	0.25	0.48	0.35	0.02	0.35	0.07	0.45	-0.47	0.30	0.35	0.40	20
Pb	PM	4.00	13.00	9.14	0.78	9.17	2.69	-0.71	0.68	8.73	9.17	10.42	29
	M	4.00	11.00	8.69	0.70	9.69	2.44	-1.08	-0.01	7.09	9.69	10.63	28
Ni	PM	2.64	5.49	3.77	0.28	3.61	0.96	0.52	-1.03	3.01	3.61	4.72	25
	M	2.30	6.29	3.64	0.34	3.44	1.18	1.08	0.84	2.69	3.44	4.52	32
Fine Sand	PM	0.00	63.10	48.16	6.59	58.33	22.81	-1.94	2.31	49.31	58.33	59.80	47
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silt	PM	0.00	28.38	20.47	2.84	23.11	9.84	-1.80	2.05	22.03	23.11	26.82	48
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Clay	PM	0.00	25.01	14.32	2.11	16.08	7.33	-1.23	1.34	13.37	16.08	18.22	51
	M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Here PM = pre – monsoon; M = monsoon; ND = no data