SILTATION PATTERN AND PEDOGENESIS IN THE COASTAL ZONE OF BANGLADESH

A DISSERTATION

BY

Md. Mahiuddin

B.Sc. (Hons), M.Sc in Soil Science (DU)
Registration No: 130
Session: 2012-2013

For the fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

IN

SOIL SCIENCE

DEPARTMENT OF SOIL, WATER AND ENVIRONMENT

UNIVERSITY OF DHAKA

OCTOBER, 2017

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OCTOBER, 2017

Dedicated To My Parents

DECLARATION

I hereby declare that the research presented in this thesis entitled "*Siltation Pattern and Pedogenesis in the Coastal Zone of Bangladesh*" was carried out by me for the degree of Doctor of Philosophy (Ph.D) in Soil Science under the supervision of **Prof. Dr. Md. Aminur Rahman Mazumder and Prof. Dr. Md. Zakir Hossain Khan** of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh.

I further declare that the thesis is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged at the respective place in the text.

Place: Dhaka

Date:

Md. Mahiuddin

Ph.D Research Student
Registration no 130/ 2012-2013
Session: 2012-2013
Dept. of Soil, Water and Environment
University of Dhaka
Dhaka- 1000, Bangladesh
E-mail: uddinmd40@gmail.com

CERTIFICATE

Certified that Mr. Md. Mahiuddin has submitted this thesis entitled ***"SILTATION PATTERN AND PEDOGENESIS IN THE COASTAL ZONE OF BANGLADESH"*** *in partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy(Ph.D) in Soil Science under the faculty of Biological Science, University of Dhaka, Bangladesh. Mr. Md. Mahiuddin successfully completed his course work and carried out his field study as well as laboratory work meticulously during the session 2102- 2013.*

This thesis has been prepared on the basis of original research work carried out in the laboratory of the Department of Soil, Water and Environment, University of Dhaka by Mr. Md. Mahiuddin under our supervision. So far my knowledge goes; no part of this thesis has been submitted elsewhere for any other degree or diploma.

We also certify that it is a bonafied research work of Md. Mahiuddin and the thesis is found satisfactory for submission to the Department of Soil, Water and Environment University of Dhaka, Bangladesh.

(Prof. Dr. Md. Aminur Rahman Mazumder)
Supervisor
Department of Soil, Water and Environment
University of Dhaka
Bangladesh

(Prof. Dr. Md. Zakir Hossain Khan)
Supervisor
Department of Soil, Water and Environment
University of Dhaka
Bangladesh

ACKNOLEDGEMENT

With the remembrance of almighty ALLAH, the author has the immense pleasure to express his sincere and heartiest appreciation, deep sense of gratitude , indebtedness and best regard to his honorable teacher **Dr. Aminur Rahman Mazumder**, M. Sc. (Dhaka),Ph. D (Dhaka), Ex-Chairman & Professor, Department of Soil, Water and Environment, University of Dhaka for his valuable instruction, scholastic and enthusiastic supervision, constant encouragement, excellent co-operation, worthy suggestions, advice and stimulating discussions, critical comments, affectionate feelings and keen interest throughout the period of the research work and during the preparation of the manuscript.

The author wishes to express his deepest sense of gratitude and appreciation to Professor **Md. Zakir Hossain Khan**, Ph. D (Vienna), University of Dhaka, Bangladesh for continuous encouragement, valuable guidance and fruitful suggestions for the successful completion of this program me. He guided me in every step in writing the report in systematic ways. The guidance was very much helpful to me to prepare scientific research and general report. This type of report will be a guideline in my professional life and will also help me to achieve the overall goals and objectives this research work.

The author expresses his heartfelt thanks and gratitude to **Honourary Professor Dr. Mohammad Sultan Hussain,** University of Dhaka for keen interest, valuable advice and insightful suggestions in this research work and preparation. He took the pains of going through the draft of this thesis for which I am grateful to him.

The author wishes to express his ever gratefulness and indebtedness to **Dr. S.M. Ullah**, retired professor, Department of Soil, water and Environment for his spontaneous encouragement, advice, valuable suggestions and help during the whole period of research work. The author is also grateful to all other members of teaching staff of the same department for their encouragement and inspiration.

The author expresses his indebtedness to Professor S.M. Imamul Huq and at present Vice Chancellor, University of Barisal for his heartfelt cooperation, necessary help and suggestions.

The author wishes to extend his gratification to Professor Dr. M. Sirajul Hoque, Chairman, Department of Soil, Water and Environment, University of Dhaka, Professors Dr. R. Mandal, Dr.M. Didarul Alam, Dr. Md. Khalilur Rahman, Dr. Akter Hossain, Dr. Mahbubur

Rahman and Dr. Zakia Parveen for providing him laboratory and research facilities whenever required during the whole period of research work.

The author gratefully acknowledge his elder brother Md. Ikhtiar Uddin, Senior Scientific Officer, Soil Resource Development Institute, Barisal for help and co-operation in the selection of soil sampling sites and collection of soil samples in the field in spite of him all problems to pursue this study.

The author expresses his cordial thanks to Professor Abu Zofar Md. Moslehuddin, Department of Soil Science, Bangladesh Agricultural University, Mymensingh, for his generous help and assistance in the X-ray diffraction analysis.

The author expresses his indebtedness and gratitude to the Ministry of Education, Govt. of Bangladesh for giving deputation for awarding him scholarship and research grant to complete Ph,D programme in Soil Science.

The author also remembers the kind consent and cooperation of Prof. Dr. Shin Ichiro Wada, Department of Agro-environmental Science, Faculty of Agriculture, Kyushu University, Fukuoka 812-8581, Japan for assistance in carrying out the X-ray diffraction analysis of clay samples.

The author wishes to express his gratefulness to Mr. Kazi M. Idris, former Principal Scientific officer, Soil Resources Development Institute, Dhaka and National Consultant, FAO and DANIDA, who helped in interpreting the morphological properties of the soils and also in their characterization.

The author is also grateful to Mohammad Ibrahim, technical officer, GIS Lab, Department of Soil, Water and Environment, University of Dhaka, for his support and good wishes during the completion of the studies.

The author expresses his cordial thanks to Prof. Dr. Md. Mahmudul Islam, Department of Soil Science, Govt. B M College, Barisal for kind co-operation and help.

Last but not the least, the author likes to expresses his deep sense of gratitude and appreciation to his wife Mrs. Afsana Shakhi and his offspring whose encouragement and help have always been a source of inspiration during the period of this work.

The author also wants to acknowledge the local people for their support during the sampling period.

October, 2017 **Author**

ABSTRACT

Siltation pattern and pedogenesis in the coastal zone of Bangladesh were studied. Suspended sediment load carried by the two rivers, the Bishkhali and the Arial Khan rivers of the coastal zone in Bangladesh was determined on seasonal basis for three consecutive years in order to observe siltation pattern. Suspended sediment load in the Bishkhali river was very high (9.4 kg per sq. meter per month) in the dry season as compared to that in the wet season (4.6 kg per sq. meter per month) whereas in the Arial Khan River the suspended sediment load was low in dry season (4.1 kg per sq. meter per month) as compared to that in the wet season (13.06 kg per sq. meter per month) due to severe water turbulence of the rivers. The mechanical, chemical, physico-chemical and elemental compositions of the sediments were determined and the importance of siltation in soil genesis was also studied.

Eight soil profiles from eight extensive soil series viz. Bhola, Nilkamal, Pirojpur, Hogla ,Muladi, Barisal, Jhalakati, and Ramgati occurring in the coastal floodplains of Bangladesh were studied morphologically in the field, and soil samples were collected on genetic horizon basis for their laboratory analyses. All these soils remain seasonally flooded for varying *periods during the monsoon months and develop some unique morphological features. Development of a cambic horizon is the most notable morphogenetic property in these soils. Particle size distribution showed wide variations in their clay fractions in the soil profiles. The quantity of clay was higher in the basin soils than in the ridge soils. Silt was the dominant size fraction in the sediment of the Bishkhali and the Arial Khan rivers.*

The chemical properties of the soils such as pH, organic carbon, total nitrogen, cation exchange capacity, exchangeable bases, free oxides of Fe and Mn, free lime and the fusion analysis of the sediments, whole soils and their clays were determined.

Results of fusion analyses of the sediments, soils and their clay fractions were presented. Both in soils and sediments silica was the most abundant element comprising a large part (58 to 65%) of the elemental composition of them. The other dominant elements were in decrasing order of abundance: $SiO_2 > Al_2O_3 > Fe_2O_3 > MgO > CaO > K_2O > TiO_2 > P_2O_5 > MnO_2$.

The vertical distribution pattern of silica, alumina, and ferric oxide were not uniform. The silica: sesquioxide molar ratios of the soils indicated that the soil parent materials were heterogeneous.

Illite was the dominant mineral in the clay fraction of Muladi, Barisal, Jhalakati and Ramgati soils, whereas the other soils had mixed mineralogical composition consisting of mica, smectite, chlorite, kaolinite and trace amount of vermiculite.

Gleization seemed to be the major pedogenic process of soil formation. Composition of parent material (sediments) and the associated aquic moisture regime dominantly influenced the genesis of these soils. All the soils meet the criteria of the Inceptisols order of the US Soil Taxonomy. The soils were characterized at the family category level according to the US Soil Taxonomy and correlated with World Reference Base (WRB) system. The studied soils were classed as six families which will be useful for their management implication as well as agro-technology transfer program.

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LIST OF ACRONYMS

AD	:	Air dry
AEZ	:	Agro-ecological Region
Av	:	Average
BARC	:	Bangladesh Agricultural Research Council
BARI	:	Bangladesh Agricultural Research Institute.
BBS	:	Bangladesh Bureau of Statistics
BCAS	:	Bangladesh Centre for Advance Studies
BRAC	:	Bangladesh Rural for Advancement Committee
BRRI	:	Bangladesh Rice Research institute
CEC	:	Cation Exchange Capacity
cm	:	Centimeter
cmol/kg	:	Centimoles per killogram
CZPo	:	Coastal Zone Policy
Db	:	Bulk Density
Dp	:	Particle Density
EC	:	Electrical conductivity.
f	:	Porosity
FAO	:	Food and Agricultural Organization
g	:	Gram
g/cc	:	Gram/ cubic centimeter
GBM	:	Ganges – Brahamaputra- Meghna river system.
GPS	:	Global Positioning System

ha	:	Hectare
HM	:	Hygroscopic moisture
HYV	:	High Yielding Variety
ICEAB	:	International conference on Environmental Aspects of Bangladesh.
IRRI	:	International Rice Research Institute
Kg	:	Killogram
Km	:	Killometer
LOI	:	Loss on Ignition
m^2/m	:	Square meter per month
mmhos/cm	:	Millimhos per centimeter
OC	:	Organic carbon
OM	:	Organic matter
PET	:	Potential evapo-transpiration
Ppm	:	Parts per million
Sq.km	:	Square kilometer
SRDI	:	Soil Resources Development Institute
TEB	:	Total exchangeable bases
UNDP	:	United Nations Development Program
USDA	:	United States Department of Agriculture
XRD	:	X-ray diffraction

CHAPTER-1

INTRODUCTION

CHAPTER - 1

INTRODUCTION

Bangladesh, a floodplain delta, is a land of rivers and canals covering an area of 147,570 sq. km (Sarwar, 2005) and lying across the tropic of cancer. The country is sloping gently from the north to the south, meeting the Bay of Bengal at the southern end. Bangladesh has around 710 km long coastline covering 2.85 million hectares of coastal floodplain which lies between 21-23º N latitudes and 89 - 90º E longitudes (Karim *et al.* 1990). Coastal zone of Bangladesh consists of 19 districts comprising 147 upazillas (CZPo, 2005) and accommodates more than 35 million people (MoWR, 2006). It encompasses parts of eight agro-ecological zones of the country (FAO- UNDP, 1988). This coastal floodplain has a fragile environment with some unique natural features. Most of the land in the coastal floodplains has an elevation of less than one meter above mean sea level and is subjected to flooding by tides which enter through the numerous creeks, canals, rivers and estuaries. Both tidal and wind actions in the coastal zone are strong and the tropical cyclones and their associated storm surges are the common natural calamities.

Bangladesh occupies a unique geographic location spanning a relatively short stretch of land between the mighty Himalayan mountain chain and the open ocean. It is virtually the only drainage outlet for a vast river basin complex made up the Ganges, Brahmaputra, Jamuna and Meghna rivers and their network of tributaries.

Most of the rivers of Bangladesh are meandering and braided in nature which are favorable for bank erosion (Elahi, 1991). Bank erosion and channel migration depends on hydro-morphological factors such as flood, water discharge, water velocity etc. Every year floods cause tremendous morphological change along their banks of courses of these rivers around the coastal zone of Bangladesh during the pre and post inundation period.

A vast network of rivers and cannels, an enormous discharge of river waters heavily laden with sediments are the most important features in the coastal morphology of Bangladesh. Sediments are dominant feature in the geo-morphological dynamics of the coastal area. Nearly a billion ton of sediments enter through the Ganges- Brahmaputra-Meghna (GBM) river systems. The combined flow of these rivers is as close to 200,000 m^3/s. Annual load of suspended sediments received by the GBM river systems is estimated to 2.5×10^9 tons (Rahman, 1989). About two-third of these sediments discharge into the Bay of Bengal. A portion of this is deposited in the coastal zone.

Bangladesh has a total land surface of 12.31 million hectares of which presently 7.85 million hectares are under agriculture (NAP, 2006).Out of about 1.689 million hectares of coastal land, 1.056 million hectares of land are affected by soil salinity of various degrees. About 0.328, 0.274, 0.189, 0.161 and 0.101 million hectares of land are affected by very slight, slight, moderate, strong and very strong salinity respectively (SRDI Staff, 2010). Some of the new land of coastal districts is affected by different degrees of salinity, which reduces agricultural productivity remarkably. The area of the salinity affected soils is increased to 21% in the last four decades in this region. This situation is expected to become worse further because of the effects of climate change (Salauddin and Asikuzzaman, 2012).

Farmers mostly cultivate low yielding traditional rice varieties during the wet season in the coastal zone. Most of the land remains fallow in the dry season (January- May) because of soil salinity, lack of good quality irrigation water and late draining condition (Karim *et al*. 1990; and SRDI, 2001). Crop production of the salt affected areas in the coastal regions differs considerably from non saline areas. At the same time food demand in the area is increasing with the steady increase in human population. The cropping patterns practiced in the coastal areas are mainly Fallow-Fallow-T. Aman Rice.

Faced with the task of providing food to the burgeoning population of coastal zone, the Government of East Pakistan implemented the coastal embankment project during the 1960's under which 4000 km of high embankments were built to enclose the entire tidal floodplains in the coastal areas within 90 polders (Firoze, 2003). After the construction of polders, the daily inflow of tidal water reduced and consequently the active sedimentation and erosion process has almost ceased except in brackish water shrimp cultivation area. Within the polders, sedimentation and inundation process are still active with saline water in the coastal area. At present, northern part of the area within the polder is flooded mainly with rain water. The most significant feature of hydrology in relation to agricultural development is the seasonal shallow flooding. In the coastal regions of Bangladesh highland, medium highland, medium lowland, lowland and very lowland occupies about 5%, 50%, 10%, 4% and 1% land respectively, in coastal areas (SRDI Staff, 2010).

Different rivers bring different alluvial materials having varying mineralogical compositions. Soil forming agencies working on these materials produce distinctive soils. Knowledge about the chemical and mineralogical compositions of the sediments is of prime importance for understanding the pedogenesis in the coastal zone and their productivity. The chemical and mineralogical composition of soils depends on the nature of sediments over which they have developed. Minerals are indicators of the extent of weathering that has taken place, and the presence or absence of particular mineral gives clues to how soils have been formed (Schulze,1989). The inherent potentiality of soil can be estimated from the nature and amounts of minerals in soils (Kawagauchi and Kyuma, 1977). Quite a few research works are carried out on mineralogy of coastal soils so far (Egashira and Yasmin, 1990; Moslehuddin and Egashira, 1996).

Basic understanding of the soil is a prerequisite for sound and sustainable land management. Unfortunately soils of the coastal belt of Bangladesh as a whole have been subjected to the least amount of scientific study. Only a few research works have been done on the problems and prospects of crop production in the coastal areas of Bangladesh (Karim *et al.* 1990). Our present knowledge on the genesis and characterization of the coastal soils in Bangladesh is very limited. Hence, more physical, chemical and mineralogical characterization of the soils of the coastal zone of Bangladesh is needed to understand the mineralogical impact on soil productivity and also to understand the mineral transformation, degree of weathering and soil development. Moreover sediment dynamics and siltation patterns have had significant role in the accretion and erosion of land in the coastal regions and also have profound influence on the genesis of the soils.

Therefore the present research work has been undertaken on eight pedons belonging to the eight extensive soil series forming on the floodplain of the nearby rivers of Bishkhali and Arial Khan rivers in the coastal zone Bangladesh with the following aims and objectives:

1. To determine the suspended sediment load of two rivers (Bishkhali and Arial Khan River) in the coastal zone of Bangladesh in order to investigate the siltation patterns.
2. To study the morphological and physical characteristics of the selected pedons.
3. To furnish basic information on the chemical and mineralogical properties of the sediments and soils.
4. To determine the chemical composition of the sediments and soils.
5. To through light on the probable genetic processes that were responsible for the formation of these soils.
6. Finally to characterize the soils at the family level according to US Soil Taxonomy and some other system of soil classification to provide a scientific data base for national land use planning.

CHAPTER-2

REVIEW OF LITERATURE

CHAPTER - 2

REVIEW OF LITERATURE

It was felt essential to know the findings of research work carried out elsewhere on coastal sediments, especially on their siltation pattern and soil genesis in the coastal zone of Bangladesh. Literatures dealing with the properties of sediments and soils in the coastal zone are presented below.

2.1 Coastal zone and coastal sediments

Coastal zone is a geographically delineated area which is distinctly characterized by the aggregation of interacting coastal environments and corresponding natural and man-maid structural systems. The southern part of Bangladesh falls under coastal zone that receives discharge of numerous rivers, including Ganges-Brahmputra-Meghna (GBM) river system, creating one of the most productive ecosystems of the world. Except Chittagong-Cox's Bazar, all parts of the coastal zone are plain land. However, the shape of the coastal zone is quite unstable and changing time to time due to erosion and accretion.

The coast of Bangladesh is about 710 km in long and can be broadly divided into three regions: the deltaic eastern region, the deltaic central region, and the stable deltaic western region. According to the coastal zone policy (CZPo, 2005) of the Government of Bangladesh, 19 districts out of 64 belong to the coastal zone covering a total of 147 upazillas (Fig.1) of the country. Out of these 19 districts, only 12 districts meet the sea or lower estuary directly. It covers about 47,201 square kilometer land area, which is 32 percent of total landmass of the country (Islam, 2004). It is characterized by a vast network of rivers covering an area of 9380 km^2, a large number of islands between channels, a submarine canyon, the funnel shaped part of the northern Bay of Bengal , low relief and horrendous tropical cyclones.

The characteristics of the coastal region of Bangladesh have been studied by the UN-ESCAP (1988). According to them the coastal morphology of Bangladesh can be characterized by the following features:

- A vast network of rivers;
- An enormous discharge of river water heavily loaded with sediments, both suspended and bed load;
- A large number of channels in between the channels;

- "The Swatch of No Ground" running NE-SW partially across the continental shelf about 24 kilimeters to the south of the Bangladesh coast;
- A funnel- shaped and shallow northern Bay of Bengal to the north of which the coastal area of Bangladesh is located;
- Strong tidal and wind actions especially during the monsoon months;
- Devastating tropical cyclones and their associated storm surges.

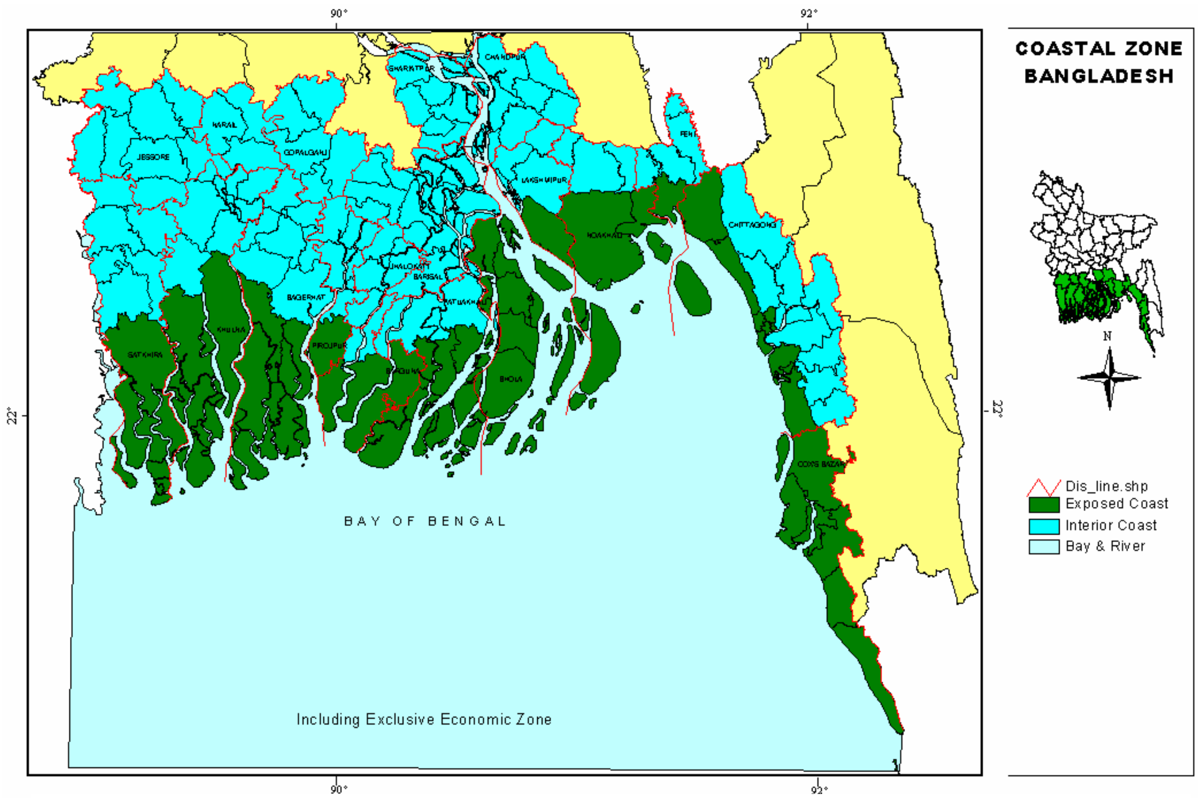

Fig.1. Map of Bangladesh showing coastal zone. (Source: Islam, 2004)

It has been widely quoted that 1.5 to 2.4 billion tons of sediments are carried by the water of the rivers whose combined flood level water can exceed 140,000 m^3/second and about two- third of the sediments goes into the Bay of Bengal and thus sediments become a dominant feature in the geo-morphological dynamics of the coastal areas of Bangladesh (Siddiqi, 1989 and Nishat, 1989).

2.1.1 physico- chemical properties of sediments

Bangladesh is considered as the largest deltaic plain of the world of three mighty rivers, namely the Ganges, the Brahmaputra, and the Meghna commonly known together as GBM. Along with GBM, the major river systems in Bangladesh are mainly originated from the Himalayas which are situated in the north to the Bengal delta. GBM carries a total of about 2.4 billion tons of sediments per year (Coleman, 1969) into the Bay of Bengal. These sediments interact with dynamic process in the Bay of Bengal leading to coastal geomorphologic changes (Ali, 1989).

The floodplain soils of Bangladesh have developed on unconsolidated sediments. These sediments are not homogenous in age, texture and mineralogy (FAO, 1971). The major rivers in Bangladesh carry earthy materials of different geological origin, and consequently the floodplain soils differ in their chemical and mineralogical composition. The floodplain soils are continuously enriched by fresh siltation during flooding and rapid profile development takes place with clear morphological features as influenced by their typical hydrological situation (Brammer, 1971).

The suspended solids in the water of the Mckong River serve to enrich annually the soils of the Mckong delta by adding phosphorus and potassium bearing minerals (Uehera *et al*. 1979). In the Ganges River water the increase in calcium is attributed to the addition of calcium from the carbonate rich terrain through which the river passes (Abbas and Subranium, 1984).

Ghimire *et al.* (1990) have carried out an experiment on the causes and effects of siltation on the environment of Nepal based upon about 20 years of river discharge data (1960s to 1980s) on three important river systems in Nepal and remarked that the greatest mean annual suspended sediment load was 1.434 g/L.

Bangladesh occupies the greater part of a large delta formed by the fluvial sediments. The combined annual sediment flow through the big rivers in Bangladesh has been estimated to be about 2.5 billion tons (Hossain, 1992). All these sediments come from the upper reaches and most of them come during the monsoon season.

The three rivers: the Ganges, the Brahmaputra and the Meghna (GBM) carry nearly 6 million cusecs of water and 13 million tons of suspended sediment loads per day during the flood season to the Bay of Bengal, nearly three times the quantity borne by the Missisippi River (Anwar, 1989).

Martinelli *et al.* (1992) have conducted a research on the chemical and mineralogical composition of Amazon River floodplain sediments in Brazil and observed that the average elemental composition (wt %) decreased in the order: Si>Al>>Fe>Na>Ca>k>Mg>>Ti. Silicon was the most abundant element varying (as SiO_2) from 63.4% to 97.1%. On average Calcium (11 meq/100 g of sediment) was the dominant exchangeable basic cation followed by Mg (2.58 meq/100g) and then by K (0.22 meq/100) and Na (0.11 meq/100g) respectively. They also suggest six principal minerals were assumed to be present: Na-plagioclase; Ca-plagioclase; Illite; Smectite- Vermiculite; Kaolinite and Quartz.

Many authors showed the scenarios of sedimentation in the Bay of Bengal. The various factors involving the hydrodynamics of the estuary such as deformation of tides, bottom layer sedimentation and concentration, water depth, tectonic subsidence ete. Individually or in combination with others jeopardize the settlement process of the sediments.

Table 1: Scenarios of sedimentation in the Bay of Bengal

Name of river system	Sedimentation rate	Sources
Ganges-Brahmaputra-Meghna	2.46 billion tons/ year	Coleman, 1969
Ganges-Brahmaputra-Meghna	1.5-2.4 billion tons/ year	Siddiqi, 1989 & Nishat, 1989
Ganges-Brahmaputra-Meghna	1.3 billion tons / year	Anwar, 1989
Ganges-Brahmaputra-Meghna	1.0-2.1 billion tons / year	Barua, 1991 & Milliman and Meade, 1983
Ganges-Brahmaputra-Meghna	2.5 billion tons/ year	Hossain, 1992

The suspended materials of the Nile river water contain a number of nutrients element in appreciable amounts, which supply the soils with micronutrients in farm lands (Hamdi, 1979). Recent sediments deposited by the Mississippi river enriched the fertility and productivity of the soils of the Mississippi river plains (Brady, 1994). Sediment sometimes may degrade land when fertile land is filled with infertile sandy deposition (Saheed *et al*. 1992).

Hossain (1992) studied on the loose sediments of some coastal river of Bangladesh and revealed that over all the sites, the clay content mostly ranged in between 20 and 35%, the silt content around 50% and the fine sand content ranged between 15 and 20%., pH around 8.0 and mostly poor organic matter and nitrogen content.

From the study of the texture and mineralogy of sediments from the Ganges-Brahmaputra-Meghna river system in the Bengal Basin, Bangladesh, Datta and Subramanian (1996) indicated that the sediment load of the GBM river system consists exclusively of fine sand, silt and clay and is deposited under uniformly fluctuating, unidirectional energy conditions. The sediments have a close similarity in grain size with the sediments of the surrounding floodplain. The mineral assemblage is dominated by quartz and feldspars. Illite and Kaolinite are the major clay minerals. The heavy mineral assemblage is dominated by unstable minerals which are mostly derived from metamorphic rocks. The sediments show lower concentration of Pb, Hg and As and higher value of Cd. They pointed out that the textural, mineralogical and chemical nature of the sediments thus has an important bearing on the environmental quality of the basin as well as the Bay of Bengal.

Chakrapani (2005) studied the sediment discharge in some large rivers in the world as well as factors controlling variations in river sediment loads and found that sediment in the river water is 1200 t/yr in Amazon; 1060 ton/yr in Ganges/ Brahmaputra; 1050 t/yr in Huang He and 210 t/yr in Mississippi river and factors like relief, channel slope, basin size, seasonality of rains, human perturbations, water flow and tectonic activities control sediment loads in river.

The sediment load of the Ganges and the Brahmaputra river water in Bangladesh was examined by Rahman *et al*. (2009) and concluded that in dry season the average content of sediment of the river water is 75 mg/l and that in wet season is 705 mg/l. They also elucidated that sand and silt together was the dominant size fractions in the sediments of both the Ganges and Brahmaputra rivers. The textural classes of the sediments in the waters of the Ganges and the Brahmaputra rivers vary from silt loam to loam. There was no appreciable difference in the textural classes between the sediments of two rivers. The pH of the sediments ranged from 6.95 to 7.9. The electrical conductivity of the sediments was low which indicates they are non-saline sediments. The cation exchange capacity of the sediments ranged from 10 to12.2 cmol/kg. The highest value (CEC) is found in the sediments of Ganges River and lowest in the sediments of Brahmaputra River. Lime content in the Ganges sediments is higher which indicates their calcarious nature than the Brahmaputra sediments. The average content of organic matter in the Ganges river sediments is 0.65 percent and Brahmaputra river sediments is 0.62 percent , did not show much variation among the sediments. The C/N ratio is slightly higher (9.3) in the sediments of Ganges River than the Brahmaputra River. This may be due to the higher lime contents.

Jalal *et al*. (2009) have studied the physico-chemical characteristics of the coastal water sediments in Pulau Tuba River, Langkawi, Malaysia from four stations and remarked that the silt was the dominant size fraction followed by sand and clay. pH of the sediment is around 7.8. The organic carbon content ranged from 1.92 to 3.00 percent; Fe content 19.6 to 366.9 µg per gram; Mn content 18.2 to 39.75 µg per gram and Pb content is 1.10 to 3.15 µg per gram. Specific conductivity (49.83- 51.63 mS/cm) did not show sharp variation among the stations.

Particle size analysis of a growing sand bar at Sonadia Island, Bangladesh has studied by Hoque *et al*. (2013) .Sediment samples were collected from 9 (nine) stations and texture analysis of sediment had done . The percentage of sediment weight was 0.05, 0.11, 19.07, 70.27, 7.94 and 2.56% and concluded that particle size distribution of sediment is a fundamental property of sediment as it influences other fundamental properties of sediment.

2.2 Soils of the coastal zone

A brief literature review on the findings of research works carried out elsewhere by different scientists on pedological aspects of soils in the coastal environments is given below.

2.2.1 General characteristics of coastal soils

The areas are subject to flooding in the monsoon season and water logging in parts of basin areas in most parts of the dry season. Tidal flooding through a network of tidal creaks and drainage channels connected to the main river system inundates the soil and impregnates them with soluble salts thereby rendering the topsoil and subsoil salinity. After the construction of polders, the daily inflow of tidal water reduced and consequently the active sedimentation and erosion process has almost ceased except in brackish water shrimp cultivation area. Within the polders, sedimentation and inundation process are still active with saline water. At present, northern part of the area within the polder is flooded mainly with rain water. The most significant featureof hydrology in relation to agriculture development is the seasonal shallow flooding.Highland, medium highland, medium lowland, lowland and very lowland occupies about 5%, 50%, 10%, 4% and 1% land respectively, in coastal areas.In these areas, flood water recedes from about 20% areawithin October, from 30% in November to mid December and from 20% area in late December or in early January.

All soils contain some water soluble salts. Plants absorb essential plant nutrients in the form of soluble salts, but excessive accumulation of soluble salts suppresses plant growth. Salt affected soils are common in coastal area. Out of about1.689 million hectares of coastal land 1.056 million hactares are affected by soil salinity of various degrees which has been studied by a number of workers on their various aspects (Hassan and Razzaq 1981, Karim *et al.* 1982, Hussain and Rahman 1983, Hussain *et al*. 1989). Most of these tidally flooded soils are suitable for aman rice cultivation as the rainfall during monsoon is adequate for washing the soils below a safer limit. Physiographically floodplain landscapes are not always really flat. Often a number of micro-relief features occur there which include a succession of broad ridges (levees) and depressions (black swamps or old channels). Often the sandy or silty materials occupy the ridges and clayey materials occupy the depressions, but the relative proportions of the different textured materials vary considerably between and within the floodplains.

Development of soil profile can be extraordinarily rapid, except in permeability wet sites on active floodplains receiving regular addition of new alluvium. Ripening and oxidation of raw alluvium apparently take place within 2-3 years, and homogenization by soil fauna destroys alluvial stratification to 20-50 cm within about 25 years (Brammer, 1971). In materials heavier than light silt loams, prismatic structure developed in the sub-soil under the influence of seasonal wetting and drying whereas claey materials may develop a blocky structure. Ped faces quickly become coated with gleyans comprising unorianted clay, fine silt and humus eluviated from the top soil. Brammer (1971) pointed out that within span of 25 years; a cambic horizon may form in floodplain sediments.

Soil Resources Development institute (SRDI, 2010) noted that in almost all the coastal belt soils, salinity is highest in the top soil in the dry season and is appreciably less in the sub-soil but often shows an increasing trend below a depth of one meter. About 0.328, 0.274, 0.189, 0.161, and 0.0101 million hactares of land are affected by very slight (S_1), slight (S_2), moderate (S_3), strong (S_4) and very strong salinity (S_5) , respectively.

2.2.2 Morphological properties of soils

Studies of the morphological features of soils during the field work are of prime importance for their identification and classification, because they are believed to have resulted from the pedogenic processes. The morphological characteristics of soils that have been included in this review are colour, structure, concretions and mottlings, gleys, plough pan and flood coatings.

Horizon Boundary

Khan *et al.* (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and remarked that all the soil profiles showed abrupt to clear and smooth horizon boundaries that reflecting young soil development or rejuvenation processes.

Soil colour

Color is the most conspicuous feature of any soil and is one of the most important and useful characteristics for its identification. Soil Scientists commonly use grey colours (Chroma< 2) as an indicator of seasonally/permanently saturated and reduced soil conditions.

Various studies have indicated that reducing conditions result in greyish color in poorly drained soils or horizons and oxidizing conditions are responsible for the brighter colors in better drained soils. Studies of water table fluctuations in soils have shown that soil colors can be used as a general indicator of saturated and reduced conditions, as well as movement of ground water table (Mackintosh and Vander Hust, 1978; Zobek and Ritche, 1984; Pickering and Venemen, 1984; Evans and Franzmeier, 1986).

Sinha *et al.* (1965) in their study of some heavy textured soils in the Gangetic plains of Bihar, distinguished soils that remained under water for 3 to 4 months in a year from those that were under water for a shorter period. The former have chroma of 2 or less with mottles, whereas the latter have chroma of more than 2. A chroma of 2 or less has been used to indicate a water saturation regime free of oxygen, when the soil temperature exceeds 5°C for some part of the year (Soil Survey Staff, 1998).

The relationship between water saturation and sol color has been explained primarily by the oxidation reduction states of Fe and Mn compounds, which regulate the distribution and forms of these elements within the soil profile (Mc.keague, 1965; Bonner and Relston, 1968). Reduction of Fe requires exclusion of oxygen for a prolonged period of time, a population of (micro-organisms and organic matter as a source of energy for the micro-organisms (Jenny, 1980).

SRDI Staff (1965-86) surveyed the soils of the Brahmaputra floodplain area and noted that soils formed in the seasonally flooded old Brahmaputra floodplain have surface soils colour ranging from olive to grey and olive grey in ridges and grey to dark grey in lower slope of ridges and basins. Subsoil colour ranges from grey to dark grey in ridges and grey to mixed dark grey in basins.

Brammer (1971) noted that the textures of soils are known to affect the brightness of colour in some soils of Bangladesh. Usually the light textured soils tend to have lighter colour and the heavy textured soils tend to have darker colours. The reduction and segregation of iron in the channel soil, however, had been intense enough to produce horizons dominated by grey or olive grey colour with chroma of 2 or less. In the heavy textured soils, organic matter might have a role in producing grey colour.

Stoops and Eswaran (1985) noted that with increasing hydomorphism iron hydroxide segregations appear in the groundmass and low chromas in the peds, Morphological characteristics of wet soils: In: Wetland Soils Characterization, Classification and Utilization.

During flooding there is a net loss of iron from these soils which helps in developing a grey to dark grey hue. Gleization is thus a general soil forming process in these soils (Hussain, 1992).

Mokma and Cremans (1991) made an attempt to establish a relationship between saturation and B horizon color patterns in soils of three hydrosequences in south- central Michigan. They found that the matrix colors of these B horizons changed with duration of saturation as follows: hues became more yellow or olive as duration of saturation increased; chromas tended to decrease with increasing duration of saturation at temperature exceeding 5ºC, duration of saturation increased as the proportion of grey (≤2 chroma) mottles increased.

Szogi and Hudnall (1992) emphasized that in studying the seasonally wet soils the terms "epi saturation" and "endosaturation" must be differentiated because the different nature and duration of perched and ground water tables. The endosaturation conditions are related to the occurrence of horizons with oxidizing conditions above reduced horizons. In saturated zones of soils that have true water tables, the redox potentials are low, particularly if the water table is not very mobile.

Okusami and Rust (1992) studied the hydromorphic soils from some inland depressions, alluvial plains and coastal sediments. A 10YR hue was observed in addition to other typical morphological features of hydromorphic soils. Redder hues within a 10YR matrix colour indicated an iron accumulation zone which reflected the aerobic or anaerobic fluctuation zones.

Begum *et al*. (2004) found that the colour of the Manpura Island soils of Bangladesh vary from grey to dark grey because of organic matter accumulation in the soils.

Akter *et al.* (2004) point out that the soils had mixture of grey, olive grey and dark grey developmental colours with values ranging from 3 to 6 in the some seasonally flooded soils of Bangladesh. They also mentioned that the chromas are lower than 2 in all horizons, indicating evidence of prolonged submergence and subsequent development of reducing condition during the flooding season.

Nizam Uddin *et al.* (2009 b) studied some soils of the Surma-Kushiyara floodplain of Bangladesh and found that the colour of top soil was generally grey to very dark grey.

Mazumder *et al.* (2010) postulated that the soil matrix had a mixture of olive grey, grey and dark grey colours with values ranging from 4 to 5 of the old Brahmaputra floodplain soils in Bangladesh. The chrma was 1 in all soils except the Sherpur peon (4), which aws caused by prolonged submergence during the monsoon season.

Hossain *et al.* (2011) reported that in the intensively cultivated soils of Ganges River Floodplain of Bangladesh, the soil matrix had a mixture of Olive brown (2.5 Y 4/4), light olive brown (2.5 Y 5/4; 2.5 Y 5/6), grayish brown (2.5 Y 5/2) and dark grey colors. Seasonal flooding ranging from 2 to 3 months, the soils have developed redoxi-morphic features. The redox depletion at the surface contributed to the development of dark grey color of the surface soils.

Khan *et al.* (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and found that the soils exhibit grey matrix colour with value 3 to 5 and chroma 1 to 3 possibly due to prolonged submergence and subsequent development of reducing conditions during the flooding season. A low chroma of the matrix is generally associated with the gleying phenomena of the soils.

Mottlings

Mottlings are important property in the seasonally flooded soils in the floodplain areas. Joffe (1968) noted that the presence of mottles near the surface horizon indicate fluctuation of ground water table while the presence of gleys in the lower zone is an unfailing indication of perennial hydromorphism.

Akter *et al.* (2004) concluded from the study of some seasonally flooded soils of Bangladesh that all the soils have strong brown to dark brown yellowish brown colour patterns in the subsoils and fine distinct mottles have developed along root channels and pores created by crabs and other aquatic creatures that facilitate air to enter into the soil mass when the flood water recedes.

Begum *et al.* (2004) studied some soils from the Manpura Island in the coastal zone of Bangladesh and found that mottles were usually absent in the surface horizon of the soils. However prominent mottles were found in the subsurface horizons of the studied soils which varied in abundance size and contrast.

Nizam Uddin *et al.* (2009a) postulated that due to alternate wetting and drying conditions abundant quantities of mottles have been formed in all the soil profiles of the Surma-Kushiyara floodplain of Bangladesh. They also mentioned that colours of mottles were a combination of dark redish brown to dark yellowish brown and mottled horizon occurred in the subsoil zone.

Mazumder *et al.* (2010) elucidated from the study of some representative soil profiles developed on the Brahmaputra alluvium that the alternate wetting and drying conditions in these soils resulted in the reduction and subsequent release of iron oxides which are accumulated in the form of dark brown to dark yellowish brown mottles in the middle zone of the profiles.

Hassan *et al.* (2012) point out that due to alternate wetting and drying condition abundant quantities of mottles have been formed in all the soil profiles of the Ganges floodplain of Bangladesh and the colours of mottles were a combination of yellowish brown to dark brown.

Khan *et al.* (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and observed that all the soils have dark brown to dark yellowish brown mottles, prominent in the middle zone of the profiles. Alternate wetting and drying conditions in the soils resulted in release of Fe from iron bearing minerals which in turn was precipitated and fixed in the form of mottles in the sub-surface horizon. Surface gleying (pseudogleys) and sub-surface grayization (gleys) are the most notable morphometric features in these soils.

Flood coatings

Flood coatings are formed mainly in the seasonally flooded lands of Bangladesh. Brammer (1971) defined flood coatings as the shiny surface of soil cracks and pores formed by deposition of material washed from the soil surface or the top soil under seasonally flooded conditions, These coatings are typically continuous, thick and of a grey color. These shiny materials are composed of clay, fine silt and humus. Flood coatings is clearly different from clay skins (argilans), which comprise well oriented fine clay and which are generally regarded as indicating long continued soil development.

Khan *et al.* (2012) elucidated from the study of three surface-water gley soils from the Meghna floodplain of Bangladesh that all the soils have continuous, thick, grey to dark grey flood coatings on the structural ped faces due to mechanical down washing of unoriented clay, fine silt and humus when the soils get flooded and ploughed (Brammer, 1971).

Gleys

Brammer and Brinkman (1977) observed that surface water gleys are extensively developed on the seasonally wet landscapes. These gley soils are hydromorphic soils with albic horizon and the upper horizons contain less clay than the deeper ones. The pH values in these soils changes due to fluctuation of ground water. Surface water gley soils indicate loss of clay in the surface layer. Ferrolysis involves reduction of soils in the wet season producing ferrous iron, which displaces part of the exchangeable basic cations and aluminium.

Akter *et al.* (2004) studied some seasonally flooded soils of Bangladesh and reported that the surface water gley or pseudogley is a special morphogenetic formation in soils that have an impervious clay pan and developed under aquic moisture regime. Soils under aquatic rice cultivation for a long time acquire some specific morphological features which are called aquarizems (Kyuma, 1978).

Plough pan

The formation of a plaugh pan is the outcome of field operations like tillage. By passing over the field frequently the plaughing equipments compact the soil and encourage the development of a compact zone (plaugh pan) immediately bellow the palughed layer.

Joshua *et al.* (1983) studied some representative Ganges river floodplain soils of Bangladesh and found the bulk densities varying from 1.35 to 1.5 gm/cc. He reported that the higher bulk densities are frequently associated with the surface horizons of the medium textured soils of the levve areas. This condition could be attributed to the structural breakdown and compaction of the soils due to ploughing under wet conditions.

SRDI Staff (1965-1986) found that the lower bulk density in clay loam soils ranges from 1.26 to 1.46 gm/cc and the higher bulk density which ranges from 1.52 to 1.62 gm/cc are associated with plough pan which are mostly silt loam in the soil of old Brahmaputra floodplains. It was also reported that lower bulk density has been encountered in heavy textured soil and density increases with depth in the soils.

Khan *et al.* (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and observed that ploughpan was a special morphogenetic (anthropogenic) feature in these soils. Ploughpan- a compact slowly permeable layer- below the Ap horizon has been formed due to puddling by using traditional ploughs to which the soils were subjected to for transplanted paddy cultivation. On all landscape puddling for rice cultivation apparently accelerates the processes giving rise to the albic horizon and concentrate them in the ploughed layer and ploughpan.

2.2.3 Physical properties of soils

Physical properties of soils do not change their pattern easily in comparison to the chemical properties of soils and hence impart the stable and most useful contribution in soil classification purposes and in the diagnosis, management and improvement of cultivated soils.

Paticle density

Khan *et al.* (1997) found that particle density of the soils of Madhupur Tract in the surface horizons varies from 2.66 to 2.69 g/cm^3 and increased in the underlying horizons. The highest recorded value was 2.73 g/cm^3.

According to Rahman *et al.* (1992) the particle density values at different depth of the profiles of Ganges- kobadak project ranged between 2.56 and 2.73 g/ cm^3. No definite order in the change of particle density values with increasing depth of horizons in a given profile was observed.

Bulk density

SRDI Staff (1965- 1986) studied some soils of Old Brahmaputra floodplain and reported that bulk density ranging from 1.26 to 1.40 g/cm^3 occur in the surface soils and the bulk density ranging from 1.54 to 1.62 g/cm^3 are associated with ploughpans. They also indicated that bulk densities from 1.41 to 1.48 g/cm^3 have been encountered in heavy textured soil, and density tends to increase with depth in these soils.

Joshua *et al.*, (1983) and Rahman et *al*. (1992) elucidated that the bulk densities of Ganges river floodplain generally vary between 1.15 and 1.56 g/cm^3 at different depths. They also reported that the higher bulk densities were frequently associated with the surface horizons of the medium textured soils of the upper slopes. This condition has been attributed to the structural breakdown and compaction of the soils due to ploughing under wet conditions.

Hannan (1995) stated that the bulk density values ranged between 1.27 and 1.41 g /cm^3 in Old Brahmaputra alluvium; 1.32 to 1.53 g/cc in Madhupur Tract. It was observed that bulk density of the soils had significant negative correlation with silt, organic matter content and state of micro-aggregate.

Soil texture

Soil texture is one of the most fundamental and permanent characteristics that has direct bearings on structure, porosity, adhesion, consistency and physico-chemical behavior of soils.

SRDI Staff (1965-1986) working on the soils of Dhaka and Comilla districts stated that the soils developed on the Meghna and Brahmaputra floodplains almost everywhere showed a distributional pattern of friable silt loams to silty clay loams on the ridges and clays in the basins. Some clay in older floodplain areas were very heavy and cracked widely when dry and flood coatin

Brammer (1971) reported that silt loams and silty clay loams predominate on the old Meghna Estuarine floodplain, whereas silty clays and clays occur extensively on the old Brahmaputra floodplain. He noted that loam was the dominant textural class in Bangladesh soils followed by clay.

Toreent and Nettleton (1979) showed that chemical weathering affects the particle distribution.They found significant correlation between weathering index (fine silt: total silt) and temperature which could be useful in assessing the uniformity of parent material.

Hassan and Razzzaque (1981) observed that silt was the dominant size fraction in the soils of the Sundarbans.

Joshua *et al.* (1983) mentioned that the soils of the Tista floodplain, in general, contained a high percentage of silt and this property appears to be characteristic for the soils of this floodplain. The silt content was usually higher than 50 percent, but occasionally may be as high as 90%. The clay content in these soils was mostly less than 30%.

Okusami and Rust (1992) pointed out that the soil texture varied quite widely with land types in their study of hydromorphic soils from inland depressions, alluvial plains and coastal sediments.

Begum *et al.* (2004) have studied the morphological features of some soils from the Manpura Islad in Bangladesh and concluded that the dominant texture of the soils is silt loam.

Nizam Uddin *et al.* (2009a) concluded from the study of the Surma-Kushiyara floodplain soils of Bangladesh that the texture of the soil was mostly silt loam up to a depth of 120 cm. and mechanisms such as sedimentary discontinuities where *in situ* weathering of primary minerals and neo-formation of clay minerals might be the causes of this differentiation.

Mazumder *et al.* (2010) found that the texture of the old Brahmaputra floodplain soils of Bangladesh varied from silt loam to clay. The soils contained large quantity of silt, ranged from 8 to 80% with an average of 51%. The average clay content 28%. This high silt content is a characteristic property of the floodplain soils of Bangladesh. The vertical and horizontal variation in texture is due to sedimentation rather tha weathering.Akter *et al.* (2011), also reported the same results from the study of some seasonally flooded soils of Bangladesh and point out that the soils are fine-textured show textural variations ranging from silt loam to clay.

Hassan *et al.* (2012) also found the same result from the study of some soils from the Ganges floodplain of Bangladesh.

Khan *et al*. (2013) studied nine surface (0-15 cm depth) soil samples representing nine typical soil series from the Ganges, Brahmaputra and Meghna floodplains of Bangladesh and observed that the Gangetic soil had the highest clay content (17-77%) among the studied soils. As all the soils have developed on alluvial materials there is wide variation in clay content. This kind of variation is common in sedimentary environments.

Hussain *et al.* (2013) examined the three surface soils of Urir Char of Meghna Estuay floodplain and found that silt is the dominant fraction ranged from 54 to 58% followed by clay and sand. Soils are young, loamy textured in nature.

Soil structure

SRDI Staff (1965-86) found that the moderately well to imperfectly drained sub soils have weak to moderately strong prismatic and blocky structure in the old Brahmaputra floodplain area. The imperfectly to poorly drained soils have moderately strong to very strong prismatic structure; and the poorly to very poorly drained soils have strong prismatic and blocky structures.

Akter *et al.* (2004) concluded from the study of some seasonally flooded soils of Bangladesh that the structure is massive in the surface horizon of all the soils. Any stable structure did not developed in the surface horizon as it has been ploughed for many years with puddling. A moderate medium to course prismatic and blocky structure has developed in the B horizons of all the soils. The same results also found by Nizam Uddin *et al.* (2009a) in the Surma-Kushiyara floodplain, Khan *et al.* (2012) in the Meghna floodplain soils in Bangladesh.

Khan *et al.* (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and observed that the soil structure is massive in the surface horizons because of ploughing for many years with puddling. A moderate medium to coarse prismatic and blocky structure has developed in the B horizons. Brammer (1996) also found the same result from the study of some soils from the Ganges floodplain of Bangladesh. The structure is massive in the surface horizons because of ploughing for many years with puddling. Structurelessness in the lower most horizons was also observed in these soils.

Soil moisture

Soil moisture retention is strongly related to the surface area per unit mass of the soil. It is also related to the texture of the soil and the clay mineral types.

Das *et al.* (1974) studied water retention characteristics of 12 alluvial soil profiles from West Bengal. Soil series varying in textures from sandy loam to sandy clay loam showed increasing trend of water holding capacity with depth (42.9-58.7%). Availability of water ranged from 7.1 to 23.3 percent in Gheora and from 7.7 to 16.0 percent in Mehrauli profile.

Velayutham and Raj (1977) stated that the assessment of water requirement, planning of irrigation schedules and prediction of probable crop response to irrigation depend very much upon differences in available water capacity of soils. They found that loamy soils had maximum available water capacity followed by sandy loam and clay loam.

Joshua and Rahman (1983) studied soil moisture characteristics in four profiles in Ganges river floodplain of Bangladesh. They reported that in the moisture retention graphs of the loamy soils, the moisture contents decreased sharply with increase in tension above 50 cm of H_2O (pF 1.65). This sharp decrease in moisture content persist upto one atmosphere tension during which most of the stored moisture was released. The silty clay loam soils, which have more clay than the silt loam soils, do not exhibit the sharp moisture release at the tension of 50 cm water.

Diwakar and Singh (1992) suggested that clay fractions might be dominant modifier of the water content at higher energies of retention. Soil water tension at higher tension is mainly a function of amount and nature of clay (Joshua and Rahman, 1983).

Nizam Uddin *et al.* (2009b) reported that the hygroscopic moisture in the Surma-Kushiyara floodplain soils of Bangladesh ranged from 1.37 to 6.1 percent. The mean value of hygroscopic moisture in the soils is 4.03 percent. Such variation in moisture content retained by air dry soils is possibly due to the difference in their clay and organic matter contents.

2.2.4 Chemical and physico-chemical properties of soils

Electrical conductivity (EC)

EC is an excellent and rapid method for obtaining an estimate of total salt content in any suspension. If excessive quantities of soluble salts accumulate in the root zone, the crop has extra difficulty in extracting enough water from the soil salty solution, thereby affecting yield adversely. So it is important to determination of electrical conductivity in evaluating soil and water quality in terms of salinity hazard (ASCE, 1990, Somani, 1991). The EC of aqueous salt solution increases at the rate of about 2% per degree Celcius rise in temperature. The standard temperature for reporting EC is 25 ^{0} C (USSL Staff, 1954).

SRDI Staff (1967) noted that in almost all the coastal belt soils, EC is highest in the top soil in the dry season and is appreciably less in the sub-soil but often shows an increasing trend below a depth of one meter.

Hossain *et al*. (2011) studied on some soils from the coastal area of Bangladesh and reported that the EC of the soils ranged from 1.0 to 5.5 mmhos/cm at 25 ^{0} C. The vertical distribution pattern of EC is irregular. In some pedons, there is a trend of decreasing EC value with depth is noticed.

Hussain *et al*. (2013) elucidated that the electrical conductivity of the Meghna Estuay floodplain soils ranged from 5.8 to7.5 dS/m that indicates the saline nature of the soil. They also reported that most plants suffer salt injury at an electrical conductivity of the soil saturation extract of 4 dS/m or higher.

Soil reaction (pH)

Soil reaction is the most important single chemical characteristic which has a great influence on many physico-chemical, chemical and mineralogical properties of a soil. Suitability of soil as a medium for plant growth and desirable micro-organisms depends upon whether the soil is acid, neutral or alkaline and, therefore, this property receives special attention in pedogenesis and classification study of soils.

Ponnamperuma (1985) observed that when an aerobic soil was submerged, its pH decreased during the first few days, reached a minimum and then increased asymptotically to a fairly stable value of 6.7 to 7.2 a few weeks later in a 1: 1 soil water suspension. He reported that the overall effect of flooding is an increase in pH of most acid mineral soils which was due to the reduction of Fe^{3+}; and a decrease in pH of alkaline soils which was due to CO_2 accumulation.

Walia and Chamuah (1992) reported that the seasonally flooded soils of the Brahmaputra valley in Assam were slightly acidic to neutral in reactions and the pH increased with depth. Ali (1994) postulated that the Ganges alluvium have higher pH values than the soils of the Brahmaputra alluvium from his study on the effects of alternate wetting and drying cycles on some representative Bangladesh soils.

Begum *et al.* (2004) conducted a research on the Monpura Island, located in coastal area of Bangladesh from the pedological and edaphological aspect and pointed out that the reaction of the soils are alkaline with a mean value of 8.0.

Islam *et al*. (2008) concluded from their study of some low land rice soils of the lower Atrai basin of Bangladesh that the pH of the soils ranges from 6.2 to 6.9 with a mean value of 6.5. Nizam Uddin *et al*. (2009a) studied some Surma-Kushiyara floodplain soils of Bangladesh and found slightly acidic in reaction and the pH of the soils increased with depth of soil profile.

Mazumder *et al*. (2010) carried out pedogenic study of some soil profiles from the old Brahmaputra floodplain of Bangladesh and observed that the soils of the Brahmaputra floodplain were acidic to neutral with pH values ranging from 5.3 to 7.8. He also reported that in all soil profiles, there was a trend of increasing pH with depth.

Hossain *et al*. (2011) found that the soils were neutral to alkaline with pH values ranging from 6.9 to 7.9 from the characterization and classification of some intensively cultivated soils from the Ganges river floodplain of Bangladesh.

Akter *et al.* (2011) have conducted an experiment on pedogenic study of the seasonally flooded soils of Bangladesh and reported that that the pH values of the soils ranges from 5.4 to 7.0, a feature common in seasonal flooded soils in Bangladesh and the values shows increasing trends with the increase of depth. These soils were slightly acidic to neutral and are negatively charged with ΔpH values ranging between – 0.2 and -1.2. The ΔpH values are presumed to be due to the difference in reserve acidity.

Khan *et al.* (2012) elucidated from the study of three surface-water gley soils from the Meghna floodplain of Bangladesh that the soils were moderately acidic to neutral with pH values ranging from 5.07 to 7.32 and also reported that there was a trend of increasing pH up to a certain depth. The ΔpH values were all negative and ranged from -0.90 to -2.01, presumed to be difference in reserve acidity.

Hussain *et al*. (2013) revealed that the Meghna estuarine floodplain soils were alkaline in reaction. The pH (H_2O) value ranged from 7.5 to 7.7.

Organic matter

Hussain *et al.* (1989) studied chemical properties of four pedons from Bhola district of Bangladesh and noted that in those soils the organic matter content was higher at the surface soils and showed a gradual decreasing pattern with depth. Saheed and Hussain (1992) reported that both organic carbon and total nitrogen contents in the wet mineral soils in Bangladesh were low. More than half of the soils had organic carbon content in the range of 0.5 to 1.0 percent.

Walia and Chamuah (1992) reported that the flood affected soils of Brahmaputra valley have moderate quantity of organic matter (more than 1%). Sidhu *et al.* (1994) remarked that the organic carbon content of the floodplain Entisols of Punjab decreased irregularly with depth indicating their stratified nature.

Nizam Uddin *et al.* (2009a) found the low amount of organic matter content of the Surma-Kushiyara floodplain soils of Bangladesh. Low content of organic matter may be caused by rapid decomposition of organic residues because of high temperature and rainfall, higher cropping intensity under tropical condition.

Mazumder *et al*. (2010) Carried out pedogenic study of some soil profiles from the old Brahmaputra floodplain of Bangladesh and observed that the organic carbon content in the soils is low and range from 0.20 to 1.07%. Low organic carbon content is a problem of Bangladesh soils, which is possibly due to rapid decomposition of organic matter under hyperthermic temperature regime. Hossain *et al.* (2011) also found the same results of the Ganges river floodplain soils of Bangladesh.

Akter *et al.* (2011) have conducted an experiment on pedogenic study of the seasonally flooded soils of Bangladesh and reported that organic matter content in the surface horizons of the studied soils ranged from 1.76 to 2.05 percent that decreased steadily with depth.

Khan *et al.* (2012) elucidated from the study of three surface-water gley soils from the Meghna floodplain of Bangladesh that the organic carbon contents is low and ranges from 0.21 to 1.83 percent. These results are in agreement with those reported for soils from the floodplains of Bangladesh.

Hussain *et al*. (2013) revealed that organic carbon content in the Meghna Estuay floodplain soils were up to the mark and ranged from 1.79 to 1.95 percent.

Total nitrogen

Rahman (2001) studied the chemical and mineralogical composition of major river sediments of Bangladesh and their impact on genesis and nutrient status of soils and found that the total nitrogen of the soil ranges from 0.04 to 0.12% and surface soil of the pedon contains the higher amount of nitrogen than the underlying horizon. From the study of some hydromorphic soils from the Ganges delta in Bangladesh Ferdous *et al.* (2005) concluded that the total nitrogen content ranges from 0.01 to 0.71 percent with a mean value of 0.11 percent and total nitrogen content shows decreasing trend with depth.

Mazumder *et al*. (2010) carried out pedogenic study of some soil profiles from the old Brahmaputra floodplain of Bangladesh and observed that the total nitrogen content in the soil ranged from 0.02 to 0.10% and vertical distribution pattern is irregular.

Akter *et al.* (2011) suggest from the pedogenic study of the seasonally flooded soils of Bangladesh that the total nitrogen content of the soils ranges from 0.05 to 0.19% and the values shows decreasing trends with the increase of depth. Mazumder (1996) also reported similar trend for some seasonally flooded Brahmaputra floodplain soils.

Khan *et al.* (2012) pointed out from the study of three surface-water gley soils from the Meghna floodplain of Bangladesh that the total nitrogen contents of the soils ranges from 0.02 to 0.18 percent with an average of 0.07 percent. The seasonally flooded soils of Bangladesh are presently puddle using the mechanical or traditional ploughs to cultivate transplanted paddy. Consequently paddy straws are smeared in the top soil in large quantity and C/N ratio increases. The microbial activities in top soil are augmented as the microbes can derive adequate energy from the added paddy straw. The phenomenon depletes the soil nitrogen content as the microbes derive the needed nitrogen for cell formation from the soil humus.

Cation exchange capacity (CEC)

SRDI Staff (1965-86) reported that the CEC of the top soil of most of the Brahmaputra floodplain area having less than 2 percent organic matter ranged from 9- 23 cmol/kg soil. The CEC of subsoils was usually slightly higher ranging from 10 - 28 cmol/kg of soil. The values of CEC slightly increased with depth due to their increased clay content.

Chatterjee and Dalal (1976) reported that the CEC value of some soils from Bihar and West Bengal decreased with depth from 4.1 to 10.2 cmol/kg soil.

Pathak and Patel (1980) studied some physic-chemical characteristics of salt affected soils of India and observed that CEC values showed increasing trend with clay content and soil depth. They reported a range of CEC from 2.1 to 11 cmol/kg when the clay content in soils ranged from 25 to 55 percent.

In a study on the physic-chemical characteristics of some coastal saline soils of Bangladesh, Hussain and Rahman (1983) observed that the cation exchange capacity of these soils was relatively low ranged from 12.6 to 20.6 cmol/kg of soil.

Thawale *et al.* (1991) found that the CEC of the soils of agricultural school farm sawangi ranges from 35.7 to 62.8 cmol/kg soil indicating montmorillonite type of clay minerals.

Walia and Chamuah (1992) reported that the CEC of the floodplain soils of Brahmaputra valley in Assam ranged between 6.6 and 18.0 cmol/kg of soil.

Mazumder (1996) in a study of some soils from the Brahmaputra floodplain of Bangladesh obtained significant positive correlation between cation exchange capacity and percent clay and also with the organic matter.

Nizam Uddin *et al.* (2009a) reported that the cation exchange capacity of the Surma-Kushiyara floodplain soils of Bangladesh ranges from 13.14 to 24.56 cmol/kg soil. The variation of CEC of the soils reflects the important influence of both the clay and organic matter content of these soils.

Rahman *et al.* (2009) found that the CEC of Ganges and Brahmaputra river sediments ranges from 10 to 12 cmol/kg soil. They also noted that CEC is higher in Ganges river sediment than the Brahmaputra river sediment.

Mazumder *et al*. (2010) Carried out pedogenic study of some soil profiles from the old Brahmaputra floodplain of Bangladesh and observed that the CEC of the soil ranged from 3.14 to 21.84 cmol/kg with an average of 10.10 cmol/kg and found significant positive correlation with the clay content. Hossain *et al.* (2011) found high cation exchange capacity of the Ganges river floodplain soils of Bangladesh.

Akter *et al.* (2011) conclude from the pedogenic study of the seasonally flooded soils of Bangladesh that the CEC of the soils ranges from 9 to 33 with a mean value of 14.9 cmol/kg and also point out that there was a highly significant positive correlation with clay and organic matter. Khan *et al.* (2012) found the CEC of the Meghna floodplain soils ranges from 3.53 to 14.8 cmol/kg with an average of 10.10 cmol/kg.

Khan and Ottner (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and noted that the CEC of the soils ranged from 3.53 to

14.08 cmol/kg with an average of 10.10 cmol/kg. The CEC in these soils bears a significant positive correlation with the clay contents (r= 0.87**).

Khan *et al*. (2013) studied nine surface (0-15 cm depth) soil samples representing nine typical soil series from the Ganges, Brahmaputra and Meghna floodplains of Bangladesh and observed that the CEC was comparatively higher in the Gangetic soilsthan that in the non-Gangetic soils. The CEC varied between 12.96 and 27.66 for Gangetic soils and between 7.08 and 12.08 for non-Gangetic soils. They claimed that the type and amount of clay minerals and organic matter content regulates the CEC of these soils.

Hussain *et al*. (2013) showed that the cation exchange capacity in the Meghna Estuay floodplain soils were high and ranged from 19.88 to 20.45 cmol/ kg.

Exchangeable cations

In the study of hydromorphic soils from inland depressions, alluvial plains and coastal sediments, Okusami and Rust (1992) stated that the general cation distribution are Ca > Al > H > Mg > K$\geq$ Na (inland depressions); Ca > Mg $\geq$ Al > Na > H > K (alluvial plains) and Al > Mg > Ca > H $\geq$ Na (coastal plains).

Khan (1995) Determined exchangeable bases such as Ca^{++}, Mg^{++}, Na^{+}, and K^{+} in some floodplain soils of Bangladesh and also calculated their percentage composition. Calcium was found to be by far the most dominant metal cation in most of the soils. Next to calcium comes the magnesium. The exchangeable Ca^{++}/Mg^{++} ratio in the soils ranged from 1.4 to 9.4.

Buol *et al.* (2001) reported that the Ca++/ Mg++ ratio in the soil decreases with increasing maturity.

Nizam Uddin *et al.* (2009a) studied some soils of the Surma-Kushiyara floodplain of Bangladesh and reported that the exchangeable Ca^{++}/Mg^{++} ratio varied from 1.2 to 1.9.

Mazumder *et al*. (2010) found that calcium was the dominant cation in the exchange phase followed by Mg^{++} and K^{+} of the old Brahmaputra floodplain soils of Bangladesh. Akter *et al.*, (2011) found Ca^{++} is the dominant cation in the colloidal complex followed my Mg^{++}, Na^{+}, and K^{+}.

Khan *et al.* (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and observed that the Mg^{++} in some horizons of the profiles was the dominant cation in the exchange phase of these soils followed by Ca^{++} and K^{+} ion. The Mean Ca^{++}/ Mg^{++} ratio was 0.85 which is less than unitu indicating loss of Ca^{++} due to Gleization in these soils.

Hussain *et al.* (2013) examined the three surface soils of Urir Char of Meghna Estuay floodplain and found that magnesium was the dominant exchangeable cation followed by calcium, sodium and potassium.

Base saturation percentage

Ali (1994) observed that high degree of saturation in some alluvial soils of Brahmaputra and Gangetic floodplains is noticed.

Khan (1995) found the base saturation percentage of Brahmaputra floodplain soils was ranged from 53 to 100 and the mean value was 77 percent. Hossain *et al.* (2011) found high base saturation percentage of the Ganges river floodplain soils of Bangladesh. Akter *et al.* (2011) mentioned high base saturation percentage of the seasonally flooded soils of Bangladesh. Hussain *et al*. (2014) revealed that percent base saturation (BSP) of surface soils of Urir Char of Meghna Estuay floodplain was very high ranged from 90 to 92%.

Mazumder *et al*. (2010) carried out pedogenic study of some soil profiles from the old Brahmaputra floodplain of Bangladesh and observed that calcium is the dominant cation in the exchange phase of these soils followed by $mg2^{+}$ and K^{+}. The sols had very high percentage of base saturation 52 to 80%.

Khan *et al.* (2012) have studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and reported that the soils have very high percent base saturation ranged from 59 to 87%.

Free iron and manganese oxides

Juo *et al.* (1974) reported that the active Fe decreases with the increases of profile depth suggesting that the larger portion of Fe oxides are present as crystalline forms in the upper horizons of well drained profiles. They also reported the co-migration of clay and Fe oxides from A to B horizon in some Nigerian soils.

Schwertmann and Taylor (1977) reported that the weathering of iron-bearing primary minerals in soils is known to release structural iron through hydrolytic oxidation. In the pH range that usually occurs in soils, the released iron is precipitated as oxides, hydrooxides, or oxyhydroxides (Gartels and Christ, 1965). Soils contain variable amount of free oxides and amorphous or x-amorphous constituents (Ghabru *et al.* 1990). Schwertmann and Taylor (1977) further noted that even at low concentration in a soil, iron oxides have a high pigmentation power and determine the colour of many soils.

Hussain *et al.* (1989) stated that the free iron oxide content in the soils of Bhola is low due to loss of iron with draining water. He reported that at a depth of around 40-80 cm in all the studied pedons an enrichment of free iron oxide occurred which was due to their fixation in the profiles in the form of mottles.

Orlov (1992) stated that the contents and forms of Fe and Mn in soil and then vertical distribution in the profiles reflected the trend and peculiarity of the soil formation process.

Hussain *et al.* (1992) found that the free iron oxide content in the soils of Bhola was low due to loss of iron when reduced during the wet season along with draining water. They reported that at a depth of around 40-60 cm in the soil pedon an enrichment of free iron oxide occurs which was probably due to their fixation in the soils in the form of mottles. Mottles, therefore, were prominent at the middle zone of the soil profiles where oxidation reduction condition alternates (Saheed and Hussain, 1992).

The movement of manganese oxide and its distridution in soil profile were significant criteria in pedogenic study as it behaves like iron oxide (Joffee, 1966). Mandal (1960) however stated that the course of manganese transformationin soil was somewhat different from that of iron.

Khan (1995) and Muzib (1969) studied some seasonally flooded soils of Bangladesh and reported that free Fe_2O_3 contents in these soils were low. The average free Fe_2O_3 content in the soils was around one percent in the Ganges and Brahrnaputra floodplain but it was surprisingly lower in the Meghna floodplain soils.

Rahman (2001) found 1.38 percent mean free iron oxide and 0.038 percent mean free manganese oxide in soils of Brahmaputra and Ganges river floodplain in Bangladesh.

2.2.5 Total analysis of sediments and soils

Silicon is the most abundant element in the earth's crust and in most soils. Wilding *et al.* (1977) stated that silicon occurs as six distinct minerals: quartz, tridymite, cristobalite, coesite, stishovite and opal. Due to its strong resistance to weathering and ubiquitous nature, quartz is the most abundant mineral in the coarser fractions of most soils and occurs in nearly every locality on the earth's surface. Recent aquatic sediments show decrease in silica content with particle size. The primary silica content is generally concentrated in the sand and silt fractions with secondary minerals in the clay fraction. The sand and silt fractions of the most soils are dominantly silicates (Borchardt *et al.* 1968; Huizing, 1971). Silicate minerals exert a secondary influence on most physic-chemical properties in soils including surface area, ion exchange, moisture retention, plasticity, cohesion and adhesion, as well as, shrinkage and swelling.

Hussain *et al*. (2014) studied the chemical composition of clay fraction of some selected soils developed on various parent materials in Bangladesh and found that the silica percentage was 53.40%, 53.70%, 54.10%, 52.40% and 52.80% in Brahmaputra alluvial soil, Ganges alluvial soil, Meghna alluvial soil, Tista alluvial soil and Madhupur clay soil respectively and concluded that silicate clay minerals were dominant in these soils. More than 50% SiO_2 in the clay fraction indicated quite stable clay minerals and the pedochemical weathering processes were slow as there was virtually little amount of iron and magnesium in the clay fraction.

Aluminium

Dolout *et al.* (1987) reported that there exist a relationship between the pedochemical reactions and the forms of aluminium. Forms and amounts of aluminium have influence on flocculation, pH, surface area, surface charge and also pedogenic process of the soil profile. Karim (1984) reported that formation of goethite took place at pH 5.8. Van Mensvoort *et al.* (1985) reported that aluminium concentrations were directly related to soil pH and toxic concentration can occur only below pH 5.0.

Mazumder *et al*. (2010) carried out pedogenic study of some soil profiles from the old Brahmaputra floodplain of Bangladesh and observed that aluminium is the second abundant element in these soils with the mean value was 12.8%. Vertical distribution pattern showed little variation.

Hussain *et al*. (2014) studied the chemical composition of clay fraction of some selected soils developed on various parent materials in Bangladesh and found that the alumina percentage was 20.90%, 19.00%, 17.97%, 18.70% and 18.25% in Brahmaputra alluvial soil, Ganges alluvial soil, Meghna alluvial soil, Tista alluvial soil and Madhupur clay soil respectively and indicated the presence of high quantities of ferroaluminosilicate minerals in these soils.

Potassium

Potassium in soil is classified in three forms: unavailable, slowly available, and readily available or exchangeable.Unavailable potassium comprises approximately 90-98% of the total potassium (Khan *et al.* 2013). Slowly available potassium, which is fixed and non-exchangeable, is the form trapped between the layers of sheets of certain kind of clay minerals. Readily available potassium is a dissolved form of potassium or held on the surface of clay particles. A dynamic equilibrium exists between the different forms of potassium in soils. Availability of K for plants therefore depends on weathering of potassium bearing minerals in soils, exchangeable K from the inorganic colloidal complexes.

Potassium status of soils depends largely on soil parent material as well as the degree of weathering (Graham, 1953). Potassium is low in highly weathered soil and in Histosols. Young soils derived from materials rich in K-bearing minerals contain abundant potassium. Hussain *et al.* (1983) reported that the vertical distribution of K_2O in the soil shows an irregular distribution pattern and further noted that it is quite an expected feature in alluvial soils when the parent materials are derived from distant and varied sources.

Hussain *et al*. (2014) studied the chemical composition of clay fraction of some selected soils developed on various parent materials in Bangladesh and found that the potassium (K_2O) percentage was 2.71%, 2.95%, 2.70%, 2.70%, and 2.68% in Brahmaputra alluvial soil, Ganges alluvial soil, Meghna alluvial soil, Tista alluvial soil and Madhupur clay soil respectively and assumption that the quantity of potassium ion depletion in soil clays is not appreciable.

Phosphorus

Mazumder *et al*. (2010) carried out pedogenic study on some soil profiles from the Old Brahmaputra floodplain of Bangladesh and observed that the P_2O_5 contents vary widely ranging from 500 to 1700 ppm with a mean value of 1000 ppm. The vertical distribution pattern of P_2O_5 in the soil profiles were abrupt indicating an alluvial character of the soil material.

Iron

Chatterjee and Dalal (1976) indicated that the alluvial soils in Bihar and West Bengal were higher in total Fe_2O_3 content near the surface than that in the lowers layers. No definite sequence in the distribution of iron with depth was noted probably due to young nature of the alluvial deposits.

Jha *et al.* (1984) examined the distribution of micronutrients in some calcarious soils and found that the total iron had been accumulated in low land soils. Fraction of the total iron in available form was also the highest in the low land profile apparently due to prolonged submergence and reducing conditions and high clay content while higher pH and calcareousness reduced the availability of iron in upland soil profile. Total iron showed a positive relationship with total Mn and available P. No definite sequence in the distribution of Fe was noted probably due to young nature of the alluvial deposits.

Titanium

From a study of the distribution of titanium in the clay fraction of some Bangladesh soils Karim and Hussain (1963) reported that the average value of TiO_2 in clay fraction of the soil was 1.5 percent.

Hussain and Swindale (1974) reported that TiO_2 in soils ranged from 0.6 to 5.0 percent. The TiO_2 content was higher in the calcarious soils and was uniformly distributed within the profile

Mazumder (1976) worked on some deep water rice soils of Bangladesh and noted that the TiO_2 content of the clay fraction of the soils was around 1.49 percent. He observed that the distribution of TiO_2 from the surface downward followed closely the sequence of sand/silt ratio which was irregular in nature.

Hussain and Islam (1979) studied the TiO_2 content of a number of whole soils and clays from Bangladesh and reported the mean TiO_2 contents as 0.67 and 1.14 percent for the whole soils and clays, respectively.

Sharma and Dev (1985) reported that TiO_2 content of the whole soils in the northeast of Punjub ranged from 0.27 to 2.16 percent. The irregular distribution pattern of titanium content indicated wide-spread stratifications.

Singh and Mishra (1994) stated that the TiO_2 content of the soils of the Indo-Gangetic Plain of Bihar ranged from 0.6 to 1.1 percent. It has been observed that TiO_2 occurred in the finer fraction of soils.

Islam (2014b) determined TiO_2 in the clay fractions of some soils of Bangladesh and found the average value of TiO_2 as 0.84 percent.

SiO_2/R_2O_3 molar ratio

Hussain and Swindale (1974) stated that in Hawaiian Gray Hydromorphic Soils the SiO_2/R_2O_3 and SiO_2/Al_2O_3 molar ratios of the soils increased with increasing degree of hydromorphism. The SiO_2/R_2O_3 and SiO_2/Al_2O_3 molar ratios of the fine clay fraction of the soils increased with increasing drainage impedance.

Hussain *et al*. (2014) investigated the chemical composition of clay fraction on some selected soils developed on various parent materials in Bangladesh and found that the SiO_2/R_2O_3 molar ratio in Brahmaputra alluvial soil is 3.42; 3.69 in Ganges alluvial soil, 3.86 in Meghna alluvial soil; 3.73 in Tista alluvial soil and 3.68 in Madhupur clay soil and indicated that the minerals in the clay complex are of 2:1 layer silicate types such as illite, vermiculite, montmorrilonite, and mixed layer minerals etc. are dominant in these soils.

2.2.6 Mineralogical properties of sediments and soils

Mineralogical composition of soils is very important to have an idea on genesis, physico-chemical properties, nutrient behavior as well as inherent potentiality of soils.

Hassan and Razzaq (1981) investigated four soil profiles from the Sunderban forest area on Ganges Tidal Floodplain and found that all soils were dominated by mica and smectite with some kaolinite, chlorite, vermiculite and interstratified minerals.

White (1985) reported qualitative estimates of clay mineralogical composition of a large number of soils of Bangladesh and opined that mica (muscovite) and kaolinite were the predominant minerals in the clay fraction of the most floodplain soils. He speculated that mica was transformed to vermiculite under acidic condition in the Brahmaputra, Meghna and Tista Floodplain soils; while under neutral to alkaline reaction and poor drainage conditions mica was transformed to smectite in Ganges Floodplain soils.

The mineralogy of silt and fine and coarse clays of four soil profiles was studied by Islam and Lotse (1986) using X-ray diffraction (XRD), ion exchange and selective dissolution techniques. Mica and smectite were found to be dominant in Batara and Ghior series of Ganges River Floodplain, whereas mica and Kaolinite were dominant in Naraibag and Ghatile series of Old Meghna Estuarine Floodplain and Old Brahmaputra Floodplain respectively.

Hussain *et al.* (1989) reported high contents of mica, kaolinite and smectite in the clay fraction of some Gangetic alluvium soils of the coastal belt of Bangladesh. The variation in the content of smectite with depth was insignificant which led them to conclude that this mineral was allogenic in origin.

Egashira and Yasmin (1990) reported the mineralogy of some floodplain soils. Mica and chlorite were found to be dominant in Tista and Old Brahnaputra floodplain soils, and the latter also contained large amounts of vermiculite; the calcareous part of Ganges floodplain soils was composed of smectite and mica while the noncalcareous or decalcified part contained mica and chlorite. A terrace soil was dominated by mica and interstratified kaolinite-smectite and mica-vermiculite-smectite.

Mall and Mishra (1994) stated that the fine sand mineralogy of the Gangetic alluvial soils of Bihar is dominated by light minerals in the order: quartz > feldspar > muscovite. Heavy fraction contains mainly opaque minerals, biotite and garnet, although zircon, apatite, rutile and chloritized mica are also present in some soils. Biotite and feldspars are the weatherable minerals. Fine sand fraction from the river beds contains garnet, opaque minerals, quartz, feldspar and muscovite.

Egashira *et al.* (1994) stated that the mineralogy of paddy soil in southern Fukuoka prefecture, Japan was related to the geological characteristics of the sediment from which they were derived. He also stated that the mineralogical differences were reflected in soil fertility.

Silt and clay mineralogy of ten soil series, three from terrace areas and seven from floodplains, were studied by Moslehuddin and Egashira (1996). They reported that silt fractions were dominated by quartz in all soils while terrace soils contained relatively higher quartz and lower mica, chlorite and plagioclase. Mica was present in large amount in the clay fraction of all the soils.

Khan *et al.* (1997) studied five benchmark soil profiles from different floodplains of Bangladesh and found that mica was the dominant mineral in the clay fractions of most of those soils. The other minerals in the clay fraction of those soils were kaolinite, vermiculite, chlorite and interstratified minerals. The clay minerals appear to be inherited from parentmaterials with very little *in situ* mineral transformation.

Mineralogical study of some Meghna Floodplain soils was carried out by Moslehuddin *et al.* (1998b) to determine the contribution of different river sediments as the parent material In general; mica, smectite, vermiculite; chlorite and kaolinite were the major clay minerals in these soils. Soils of Lower Meghna River Floodplain were dominated by mica, vermiculite and chlorite, and were estimated to be developed from the Jamuna (Brahmaputra) sediments while the contribution of the Meghna/Old Brahmaputra sediments increased towards the surface. The Ganges sediments had apparently no contribution. In contrast, soils of Young Meghna Estuarine Floodplain contained good amounts of smectite and chlorite in addition to mica, and were estimated to be developed from the Ganges and Meghna/Old Brahnaputra sediments.

Iftekhar *et al.* (2004) elucidated from mineralogical characterization of clay fraction of some Ganges floodplain soils of Bangladesh that mica was the dominant clay minerals in all the soils. Although high content of smectite was found in Ghior and Ishwardi soils, it was minor in other three cases which might be because of disappearance of smectite from top soils.

The mineralogy of ten soils consisting of nine representative soil series of Low Ganges River Floodplain studied by Rahman *et al.* (2005). The clay content of the surface soil ranged from 18.6 to 35.7%. They reported that mica and smectite were the dominant minerals in the clay size fraction.

Hussain *et al.* (2006) pointed out from their mineralogical study of some hydromorphic soils of the Ganges delta in Bangladesh that smectite was the dominant mineral with weathered mica and chlorite along with small quantities of kaolinite and mixed layer minerals.

Hussain *et al.* (2011) concluded from the characterization and classification of some intensively cultivated soils from the Ganges river floodplain of Bangladesh that smectite was the dominant clay minerals followed by mica and kaolinite with small quantities of vermiculite and interstratified minerals. The minerals in the clay fraction of the soils appear to be inherited from individual parent materials with very little *in situ* mineral transformation (Khan and Ottner, 2011).

From the study of bulk and clay composition of some Benchmark soils of Bangladesh Khan and Ottner (2012) indicated the smectite mineral , with peak intensity at 17Å in the Mg-saturated-ethylene glycol (ME) and in the K-saturated- ethylene glycol (KE) solvated sampales. Vermiculite can be distinguished as true vermiculite and soil vermiculite, considering that the true vermiculite is a rock forming mineral or 14Å vermiculite, while soil vermiculite is of pedogenic origin and sometimes called or 18Å vermiculite (Moore and Reynolds. 1997). They also reported that the occurance of considerable quantities of 18 Å vermiculite in the clay fraction of the soils of Bangladesh was not detected by the earliar workers (Islam and Lotse, 1986; Moslehuddin and Egashira, 1997). Soil vermiculite (18Å) might have been misinterpreted for smectite in the soils of the Gangetic floodplain. When the peak at 14Å in the Mg- saturated specimen expands to 17Å in the ME solvated specimen then, it is absolutely smectite but if contracted to 10 Å in the K- saturated specimen and KE solvated specimen then it is 18 Å vermiculite or soil vermiculite.

Khan *et al.* (2012) studied the mineralogical composition of three soil series from the Meghna floodplain of Bangladesh and noted that illite was the dominant mineral in the clay fraction, soil vermiculite was the second dominant clay minerals followed by kaolinite and chlorite. They also found small quantities of smectite and primary vermiculite minerals. They further mentioned that most minerals in the clay fraction of floodplain soils are assumed to be inherited rather than *in situ* transformation.

Hussain *et al*. (2013) revealed that in the bulk soils of Meghna estuarine floodplain of Urir Char soils, layer silicates and quartz were the dominant minerals while the quantity of feldspars was around ten percent. Quantity of weatherable minerals was very high in the soils. Illite is the dominant mineral in the clay fraction of the soils followed by smectite. Mixed layer minerals were absent in these soils.

Reza *et al.* (2013) elucidated from their mineralogical study of some soils of lower Purnabhaba floodplain in Bangladesh and reported that clay fraction was commonly dominated by mica followed by interstratified mica–vermiculite–smectite and kaolinite–smectite minerals, accompanied with small amounts of kaolinite, chlorite, interstratified mica–chlorite, vermiculite, quartz, feldspars and lepidocrocite. The soils of the lower Purnabhaba floodplain (AEZ 6) included in the mineralogical suite of mica–mixed layer minerals–kaolinite along with terrace soils in Bangladesh (Moslehuddin *et al.*1999).

Khan *et al.* (2013) studied nine surface (0-15 cm depth) soil samples representing nine typical soil series from the Ganges, Brahmaputra and Meghna floodplains of Bangladesh and observed that the gangetic floodplain soils predominated with 18 A vermiculite> illite>smectite minerals contained higher amount of all forms of potassium compared to the Brahmaputra and Meghna floodplain soils in which illite and Kaolinite predominated.

Akter *et al.* (2015) studied twenty four soils from three representative soil series (Ramgati, Hatiya and Silonia) of AEZ -18: Young Meghna Estuarine Floodplain soils of Bangladesh in context of mineralogical characterization of clay fraction of these soils and remarked that clay fraction was dominated by mica. Chlorite and kaolinite were also identified as dominant mineral in almost all soils. Smectite, and vermiculite and/or vermiculite–chlorite intergrade minerals were also detected in most soils. The variation in the mineralogical composition was supposed to be attributed from the difference in the proportion of parent sediments from three major rivers (GBM) of Bangladesh.

Kader *et al.* (2015) conducted a research on the mineralogical composition of twenty four widely distributed paddy soils from different agro-ecological regions (AEZ 9, 10, 12 , 17, 22, 25, 28) of Bangladesh using x-ray diffraction (XRD) and postulated that five layer silicate (mica, smectite, chlorite, vermiculite and Kaolinite) and four complex minerals (quartz, feldspar, goethite and lepidocrocite) and two interstratified minerals (Vermiculite- chlorite and mica- chlorite)were contained in the <2 µm clay fraction. Mica (20 to 50%) was the most predominant mineral identified in the studied soils. Next to mica, chlorite (5 to 20%) and Kaolinite (2-37%) were present in all the soils. Other than layer silicates quartz (4-21%) was the predominant non-silicate mineral identified in all the studied soils. According to the clay mineralogical composition, most of the studied soils were found to the initial stage of weathering.

2.2.7 Genesis and classification of floodplain soils

2.2.7.1 Genesis of floodplain soils

Brammer and Brinkman (1977) correlated surface water gley soils in Bangladesh with the hydromorphic soils developed on the floodplain landforms occurring widely in south east Asia, the degraded rice soils of Burma (Karmanov, 1968); the "aquarizems" of Japan (Kyuma and Kawaguchi, 1966), and the "anthrasols"(Dudal and Moorman, 1964) that form in areas long used for seasonal wetland rice cultivation. Hydromorphism is the common soil forming process in all these soils.

Surface water gley or pseudogley or inverted gleys are the principal morphological properties of soils that developed under aquic moisture regime. Dudal (1965) reported the existence of inverted gley in well drained soils that was used for wetland rice cultivation. When soils that have a non-aquic moisture regime are brought under wetland rice cultivation by irrigation, the surface horizons of such soil develop a gleying phenomenon that cultivated gley. In this case, the morphological properties of an aquic soil moisture regime are imposed on the upper part of the profiles while the lower horizons reflect the free drainage of the original profile (Saheed and Hussain, 1996).

Moorman (1980) reported that a large proportion of the rice soils in the major and minor alluvial plains of south and East Asia belong to various great groups of the Aquents and Aquepts suborders. He stated that alteration of diagnostic characteristics of may, however, take place locally in the pedons of wet rice lands which remain submerged for long periods. Moorman (1978) also noted that in flood plain soils the subsurface horizon may develop neutral grey colours due to continuous waterlogging and absence of oxygen. This is seen in double and triple-croped irrigated rice land on fine clayey Inceptisols. Such soils may lose the characteristics required to classify them as Inceptisols, particularly the diagnostic cambic horizon, and they may become Aquents.

Moorman (1980) further postulated that the changes in soil moisture regine under paddy cultivation is most fundamental in moderately well drained soils, where a surface and subsurface gley developed which is not connected continuously with a subsoil gley. Moorman and Van Breemen (1978) termed this specific soil moisture regime as anthraquic. In Taxonomic terms it can be defined as periodic man-induced water saturation of the solum to depth of at least 40 cm without corresponding periodic water saturation and reduction in the horizons below. The soil material in the surfacial horizons, submitted to an anthraquic moisture regime shows the same colours of low chroma in the matrix or in the mottles as defined for the aquic suborder in soil taxonomy (Soil Survey Staff, 1975). The lower horizons, however, do not, show these low chroma colours, indicating the absence of longer period of water saturation and reduction. Moorman (1978) made a formal proposal to introduce the term ***"anthraquic"*** soil moisture regime in soil taxonomy.

Hussain and Chowdhury (1980) studied pedochemical properties and genesis of some soils from the Moribund Ganges delta in Bangladesh. Based on Fe and Mn contents the studied soils were grouped into two distinct classes. About twenty percent of the total Fe and Mn were found to occur as free oxides. The mean SiO_2/R_2O_3 molar ratio in these soils was 4.6 which indicated that the 2:1 minerals are dominant in the clay fraction. Mica constituted one third of the clay fraction. Pedogenic processes in the soils appeared to be relatively weaker; decalcification was considered to be the dominant pedogenic process.

Hassan (1984) studied the soil formation in the floodplain areas of Bangladesh and observed that the soil formation in this region takes place in several stages. Initially, the sediments have low bulk density and high water content. In the ripening stage moisture is lost irreversibly resulting in an increase in bulk density. Subsequently, the sediments become homogenized due to bioturbations. At this stage the formation of soil structure begins due to alternate seasonal shrinking and swelling caused by wetting and drying in the wet and dry seasons, respectively soils of this region possess either A-C type profile, or locally an A-(B)-C type profile. Biotic factors, depending on the duration of dry and wet periods, contribute to the soil structure formation. Effects of other soil forming factors become diffused due to high ground water table and jubenility of these soils. It is interesting to note that in most cases, the attributes of the parent materials dominate the soil properties.

Ali (1994) noted that an anthraquic epipedon forms in the floodplain soils of Bangladesh under an imposed aquic moisture regime having rice cultivation for a long time.

Mazumder *et al.* (2010) elucidated from the morphogenesis and characterization of some soils from the Brahmaputra floodplain of Bangladesh that seasonal submergence and drying set the conditions of the alternate oxidation and reduction which are the most striking features of the pedochemical environment in these soils. These alternate wetting and drying situations hasten the processes of soil profile development. The alternation of wetting and drying conditions also resulted in the release of iron and manganese from Fe-bearing minerals. Subsequently, these oxide minerals are accumulated in the form of mottles in various horizons. They noted that this kind of mobilization and fixation of iron oxide minerals in the form of mottles in the soils indicates that gley horizon occur in the deeper zone of the soils in the permanent ground water zone. Gleization can possibly be designated as the major pedogenic processes in these soils. Nizamuddin *et al.* (2009b), Hossain *et al.* (2011) also concluded that gleization seems to be the dominant pedogenic processes in the floodplain soils of Bangladesh.

Khan *et al.* (2012) studied the three surface-water gley soils from the Meghna floodplain of Bangladesh and concluded that the presence of gleys, mottles and flood coatings or gleyans indicates that there was hydromorphism in these soils. The process of hydromorphism in the soils was mainly attained due to the reduction and/ or loss of iron and manganese and the development of grey colours. Gley horizons occur in the deeper zone of the soils in the permanent ground water zone. Gleization ca possibly be designated as the major pedogenic process in these soils The low exchangeable Ca^{2+}/Mg^{2+} ratio, massive structure in the top soil and structurelessness in the lowermost horizon of these soils also support this fact.

2.2.7.2 Classification of floodplain soils

SRDI Staff (1965-86) while surveying the soils of Mymensingh district found that almost all floodplain soils have characteristic topsoils which are seasonally wet and gleyed and have prominent iron staining along root channels. These topsoils consist of a passive or cloddy plough layer at the surface underlain by a massive and compact Ploughpan. They observed that the ploughpan, formed in older soils often has strong iron stain at its base. These stains/iron cutans have been developed by continuous ploughing puddling for rice cultivation and prolonged seasonal flooding. They commented that these toosoils cannot be correlated satisfactorily with the diagnostic epipedons described is soil taxonomy.

The above authors further reported that the most of these soils have cambic B vnn which was identified on the basis of destruction of the alluvial stratification, development of prismatic or blocky structure, usually with the peds coated by the flood tans and strong oxidation within the peds. Because of grey mottling and moist colours on ped faces of the soils, they were classified as Haplaquepts according to the USDA classification system. The soils having 50% or more matrix colour chroma ≥ 2 within 75 cm depth were classified as Aeric subgroup. They observed that some profiles of Ghatail series have vertic properties. They are clayey down to 100 cm or deeper and have some slickensides and wedge shaped peds in the subsoil. These soils could not be classified in the vertic sub-group because slickensides were not close enough to intersect and cracks of one cm or more wide at a depth of 50 cm were not found to develop.

Inceptisols are usually moist and have weakly developed natural soil horizons that do not represent significant illuviation or eluviation or extreme weathering (Soil Survey Staff, 1975). Many of these soils are young, although they are always older than Entisol. These soils have no spodic, argillic, natric, calcic, gypsic, salic or oxic horizon, but have conductivity of the saturation extract of less than 2 mmhos/cm at 25°C and have one or more of the following: a histic, umbric or ochric epipedon; a cambic horizon, a fragipan or a duripan. These soils have an appreciable accumulation of organic matter and there must be some evidence that the parent materials have been 'sufficiently altered by Agenesis (Hussain, 1992; Soil Survey Staff, 1994).

Murthy *et al.* (1962) examined the morphological characteristics of four soil profiles from the alluvial soils in the Ganges river plains of Central Uttar Pradesh and ordering to the USDA soil classification system they put some of them in the great group and others into the Haplaquoll great group as these have very the pH due to their drainage impedance.

Floodplain soils that are used for rice cultivation have been considered as artificial hydromorphic soils (Kanno, 1962), an anthraquic great soil group (Dudal and Moormann, 1964), anthropic subgroup of the great soil groups (Dudal, 1965), aquorizems (Kyuma and Kawaguchi, 1966), land use phases of original hydraquic sub-groups (Ottowa, 1973) and lowland paddy soils (Mitsuchi, 1974). According to Mohr *et al.* (1972) the rice soils in south and Southeast Asia and Japan are diverse and have been classified into seven soil orders of US soil taxonomy, such as Entisols, Inceptisols, Vertisols, Alfisols, Ultisols, Oxisols and Histosols.

Kanno (1978) commented that the soils whose properties have been greatly changed by rice cultivation should be classified as independent great group, whereas the rice soils in which the inherent characteristics of the preceding soils have been dominantly maintained should be classified as the sub-groups of the preceding great group.

Paramananthan (1978) stated that the areas where wetland rice was traditionally cultivated were alluvial soils and floodplains or simply as rice growing areas. Rice grwoing soils in Malayasia have not been classified beyond subgroup level. According to the classification of Thorp and Smith (1949) most of the soils would be classified as Low gleys and in the Hydromorphous sub-order of Intrazonal soils

According to Paramananthan (1978), most of the rice soils of Malaysia fall into the two sub-orders of US Soil taxonomy. These sub-orders are: Aquent and Aquepts. A few of the soils fell into the order Ultisols.

SRDI Staff (1965-1986) correlated Melandaha and Dhamrai series as Typic Haplaquepts; Silmandi, Sonatala, Lokdeo and Ghatail series as Aerie Haplaquepts and Sherpur series as Aquic Ustochrepts in the USDA soil taxonomic system. Zijsvelt (1980) and Hussain, (1992) attempted to correlate the major soil series of Bangladesh into the family category.

Kyuma *et al.* (1988) stated that the soils utilized for aquatic rice cultivation, i.e. the Paddy soils, are either naturally or artificially waterlogged for at least three months every year or more. The effect of waterlogging is particularly drastic for those soils that do not have a naturally-occurring aquic moisture regime and in which an "inverted gley" morphology, induced by artificial submergence, is a readily visible change. This change should be taken into consideration when the soils are classified. An "Anthraquic" soil moisture regime has been proposed and defined to handle this situation. Soils with an anthraquic moisture regime should be classified at the subgroup level. A diagnostic surface horizon has also been proposed, to recognize morphological changes induced by artificial submergence. The "hydragric" horizon is defined in terms of the eluviation-illuviation pattern of iron and manganese. Soils with a hydragric horizon should be classified at the great group level. An irrigation induced pseudogleying or gray-ization is another feature that occurs in non-aquic, slowly permeable soils used for aquatic rice cultivation. This is yet to be defined in terms that differentiate it from natural pseudogleys.

Walia and Chamuah (1992) stated that the upland soils of the flood affected areas of rahmaputra valley showing the development of cambic horizon are keyed out as Inceptisols. Further, these soils qualify for Ochrepts sub-order due to Ochric epipedon and Dystrochrept great group as the base saturation is less than 60 percent. Similarly, soils of lowland, flat land and levee are also Inceptisols as they show the formation of gleyed structural Bg horizon. At great group level these soils are categorized as Aquepts as they exhibit characteristics associated with wetness such as greying colour and mottles but these soils lack sulphuric, umbric and mollic epipedons and fragipan and duripan horizons and are classified as Haplaquepts. Soils of flood channels and meandering scars are stratified and put under Entisols due to the absence of any diagnostic horizon. Flood channels soils are characterized by irregular distribution of organic carbon and classified as Fluvent at the suborder level and Udifluvent at great group level owing to udic moisture regime. Soils of meandering scars qualify for Aquents suborder due to aquic characteristics and Fluvaquents at great group level because of irregular distribution of organic carbon.

Hussain (1995) noted that the soils of the Brahmaputra alluvium have been used for rice and jute cultivation for centuries. These two crops have been grown in the past at the time the soils were naturally wet. Flooding during the rainy season was a natural feature for centuries. The formation of ploughpan in these soils is a long time phenomenon here. Another important feature of these soils is the flood coating. The composition and manner of orientation of flood coatings have not been subjected to any serious study. Properties of these flood coatings should be studied in closer detail (Hussain, 1995). The concept of "Aquarizems" was first developed in Japan (Kawaguchi and Kyuma, 1977). Bangladesh has a usually large area under paddy cultivations where soils may be quite similar to the Aquarizems. Refinement of the definition and critical properties of these kinds of soils can be formulated in this country.

Mazumder *et al.* (2010) elucidated from the morphogenesis and characterization of some soils from the Brahmaputra floodplain of Bangladesh. They revealed that except Melandaha pedon the other four pedon (Sonatala, Silmandi, Ghatail, and Sherpur) belong to the Inceptosol order because of having cambic horizon along with an ochric epipedon. Melandha soil was very young than the other pedons and signs of stratification were evident within 50 cm of the surface and have a very weak type of structure development, this soil could be classified in the Entisol order. At the suborder level the studied soils were placed into three sub-orders: Aquents, Aquepts and udepts on the basis of properties associated with wetness. The soil series namely Sonatala, Silmandi and Ghatail fall in the Aquept suborder due to their low chroma (chroma ≤ 2); while sherpur series due to its high chroma (chroma > 2) falls into the Udepts suboeder. Melandaha pedon under Aquent suborder may be placed into Fluvaquents great group because of irregular decrease in carbon contents with depth. The other three series (Sonatala, Silmandi and Ghatail pedons) belonging to the Aquepts suborder were placed into Endoaquepts Great group considering the mechanism by which the aquic moisture regime originated as the basis and the soils got wet. The Sherpur pedons belonging to the Udepts suborder can be placed into Eutrudepts great group because of a base saturation of 60% or more (by 1M NH_4OAc) in some horizon between 25 and 75 cm depths.

At the subgroup level Sonatala, Silmandi and Ghatail soil pedons are further characterized as Aeric Endoaquepts subgroup as these soils have 50% or more matrix colour chroma ≥ 2 within 75 cm depth while the Sherpur pedon fit into Aquic Eutrodepts subgroup because of the presence of grey mottles within 60 cm from the surface. Melandha soil may be classed as Typic Fluvaquents subgroup because of grey matrix color. Finally on the basis of textural class, clay mineralogical composition, soil reaction class and temperature regime with subgroup the soils have been classified at the family level of the US Soil Taxonomy.

Hossain *et al*. (2011) studied four representative pedons of Ganges river floodplain and classified them on the basis of morphological, physical, chemical, and clay mineralogical properties the studied soils. They classified the soils upto family categoric ledvel of USDA Soil Taxonomy. The family level classification may serve as useful vehicle for crop production and agro-technology transfer.

CHAPTER-3

MATERIALS AND METHODS

CHAPTER – 3

MATERIALS AND METHODS

This chapter includes relevant information about the sediments and soils collected for the investigation together with the short accounts of the sampling sites and experimental procedures.

3.1 Materials

3.1.1 Location and sediment sample collection

Two rivers in the coastal zone such as Bishkhali and Arial Khan were selected for sediment sample collection. Sediment sampling locations are marked in Figs. 2 & 3 and their latitudinal and longitudinal locations were presented in Table-2. Bishkhali river is situated in the district of Barguna, Bangladesh. It is a perennial river which is the branch of mighty GBM river system and flows to the south towards the Bay of Bengal. The total catchment area is 7430 km^2. The average evapotranspiration is around 10 mm/ day (BMD, 2012). Arial Khan river lies in Singerkhati Union under the sadar upazilla of Barisal district. It is situated in the eastern part of Barisal sadar upazilla. The total catchment area is 2341 Km^2. Photograph shows a riverine landscape of Bishkhali and Arial Khan River (Plate 1- 2).

Suspended sediments were collected from the Bishkhali and the Arial Khan river in the coastal zone once a month from May, 2013 to April, 2016. Three sampling locations in each river side were selected at regular interval (0.5 km) for sediment load collection. Sampling stations were selected along the one side of the river and collected individually. Three plastic buckets (30 liter capacity) in each location of the river were set up at a depth of 80 cm from the water surface. The sediments settled in the buckets were collected and weighted by digital weighing machine on wet basis. A portion of the collected sediments were air dried and preserved in plastic container for subsequent laboratory analysis.

3.1.2 Location and soil sample collection

The soils included in this investigation belong to the recent deltaic floodplain in the coastal zone of Bangladesh. The soil sampling sites under investigation were identified with the help of the senior scientific officers of Soil Resources Development Institute (SRDI). Upazilla land and soil resources utilization guide Reconnaissance Soil Survey (RSS) reports, toposheets and maps of the respected area were used as the base materials for field work. Location of soil sampling sites is shown in Fig. 4 and the environmental characteristics of the soils is shown in Table 3. Two pedons from Bhola district, one pedon from Barisal district, two pedons from Patuakhali district, one pedon from Jhalakati district, one pedons from Pirojpur district and one pedons from Barguna district were selected for this investigation.

Fig 2. Map showing the sampling points of sediment collection from Bishkhali River in Bangladesh.

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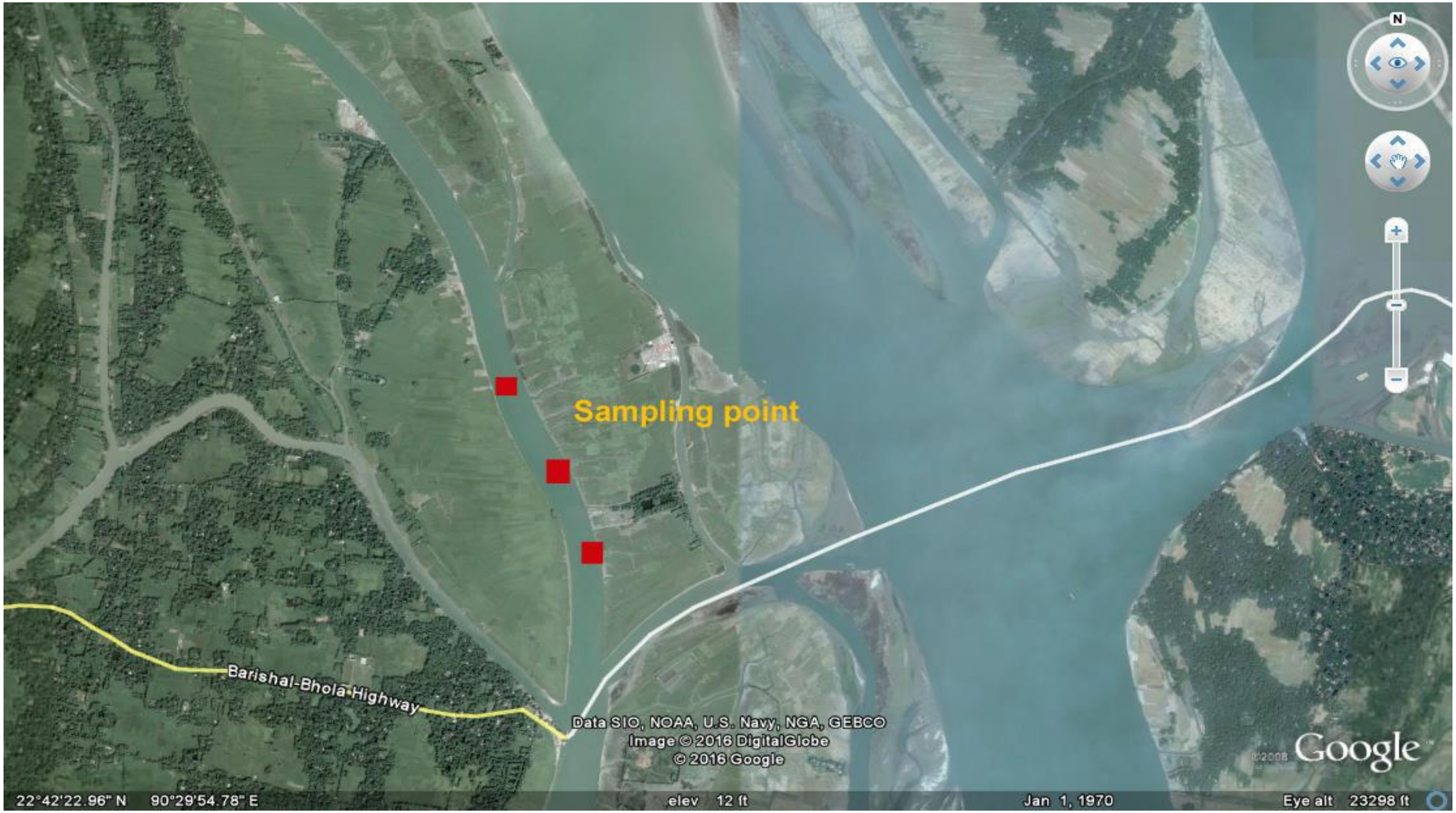


Fig 3 Map showing the sampling points of sediment collection from Arial Khan river in Bangladesh

Plate 1. A photograph depicting the typical riverine landscape of the Bishkhali river

Plate 2. A photograph depicting the typical riverine landscape of the Arial Khan river

Table 2. Sediment sampling location in two rivers of the coastal zone of Bangladesh

River Name	Coastal Zone	Location	Latitude & Longitude	River position
Bishkhali	Interior coastal zone	Vill -Baraitala Upa–Barguna Sadar Dist. -Barguna	22º 02′ 18.6″ N 89º 59′ 00.0″ E	Central Southern part of Bangladesh
	Interior coastal zone	Vill -Baraitala Upa–Barguna Sadar Dist. -Barguna	22º 01′ 18.6″ N 89º 58′ 55.0″ E	Central Southern part of Bangladesh
	Interior coastal zone	Vill -Baraitala Upa–Barguna Sadar Dist. -Barguna	22º 00′ 18.6″ N 89º 59′ 00.0″ E	Central Southern part of Bangladesh
Arial Khan	Exterior Coastal zone	Vill – Singerkhathi Upa –Barisal Sadar Dist. – Barisal	22º 41′ 51.4″ N 90º29′ 27.2″ E	Northern part of Barisal
	Exterior Coastal zone	Vill – Singerkhathi Upa –Barisal Sadar Dist. – Barisal	22º 42′ 30.4″ N 90º29′ 11.2″ E	Northern part of Barisal
	Exterior Coastal zone	Vill – Singerkhathi Upa –Barisal Sadar Dist. – Barisal	22º 43′ 03.4″ N 90º28′ 56.7″ E	Northern part of Barisal

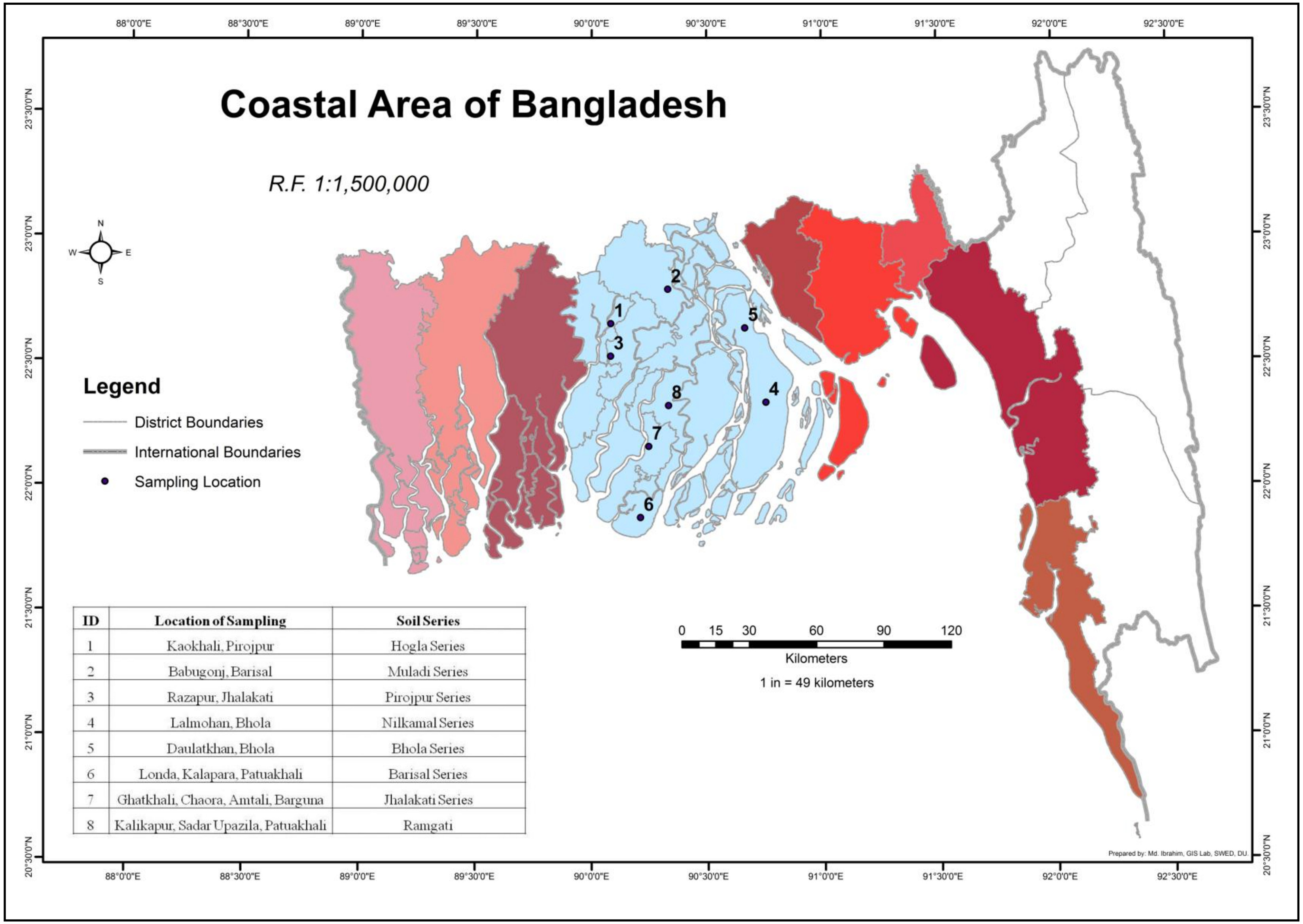
SRDI have identified about 31 soil series in the coastal floodplain in Bangladesh. Among them eight major soil series such as Bhola, Nilkamal , Pirojpur, Hogla, Muladi, Barisal, Jhalakati and Ramgati were selected for comprehensive morphological study in the field. A pit of 1m ×2m up to parent material was dug at each soil sampling site. For recording the detailed soil properties the soil profiles were studied and described morphologically *in situ* following the methods of Soil Survey Staff (2003).

The morphogenetic properties such as color, mottling, texture, structure, consistency, distribution of pores and roots, soil reaction, boundary, effervescence etc. were studied in the field. A total of 46 soil samples from the eight selected soil profiles were collected and analyzed. Undisturbed core samples and disturbed soil samples were collected on profile basis from each genetic horizon. The core samples were placed in transporting wooden boxes and the disturb soil samples were collected into polyethylene bags.

Table 3. Soil Sampling location and extent of the study area.

Soil Series	Area* (ha)	Location	Latitude & Longitude	Flooding (month)	Land Type	Parent Material	Drainage	Catena position
Bhola	28943	Vill -Charduani Upa - Daulatkhan Dist. -Bhola	22º 38′ 14.2″ N 90º 39′ 48.3″ E	3-4	MHL*	Ganges Tidal alluvium	Poorly drained	Low ridges and basin margins
Nilkamal	74335	Vill - Charbhuta Upa - Lalmohan Distr – Bhola	22º 20′ 19.4″ N 90º 45’ 14.1″ E	3-4	MHL	Meghna Estuarine alluvium	Poorly drained	Basin margin
Pirojpur	118691	Vill – Saturia Upa - Razapur Dist – Jhalakati	24º 32′ 0.05″ N 89º 00′ 40.4″ E	4-5	MHL	Ganges River alluvium	Poorly drained	Basin margin
Hogla	8895	Vill –Amrajuri Upa - Kawkhali Dist – Pirojpur	22º 39′ 19.4″ N 90º 04′ 59.2″ E	4-5	MHL	Ganges Tidal alluvium	Poorly drained	Basin margin
Muladi	35036	Vill –Chandpasha Upa-Babugonj Distr – Barisal	22º 47′ 35.7″ N 90º 19’ 48.4″ E	3-4	MHL	Ganges River Alluvium	Poorly drained	Basin Margin
Barisal	384305	Vill –Londa Upa - Kalapara Dist –Patuakhali	22º 04′ 59.9″ N 90º 14’ 32.8″ E	4-5	MHL	Ganges River alluvium	Poorly drained	Basin margin
Jhalakati	117712	Vill. Chalabhanga Upa - Amtali Distr-Barguna	21º 52′ 36.9″ N 90º 12′ 36.1″ E	3-4	MHL	Ganges alluvium	Poorly drained	Low ridges
Ramgati	209913	Vill - Kalikapur Upa - Sadar Dist - Patuakhali	22º 19′ 35.8″ N 90º 19′ 58.6″ E	3-4	Medium low land	Meghna Estuarine Alluvium	Imperfectly to poorly drained	Ridge

MHL = Medium highland Area (hectare) = SRDI Staff (1965-86)



ID	Location of Sampling	Soil Series
1	Kaokhali, Pirojpur	Hogla Series
2	Babugonj, Barisal	Muladi Series
3	Razapur, Jhalakati	Pirojpur Series
4	Lalmohan, Bhola	Nilkamal Series
5	Daulatkhan, Bhola	Bhola Series
6	Londa, Kalapara, Patuakhali	Barisal Series
7	Ghatkhali, Chaora, Amtali, Barguna	Jhalakati Series
8	Kalikapur, Sadar Upazila, Patuakhali	Ramgati

Fig 4. Map showing the soil sampling locations in the coastal area of Bangladesh.

Prior to laboratory analyses, the collected soil samples were spread on a piece of polythene paper and big lumps were broken and air dried under shade. The air dried soil samples were ground in a mortar and pestle and pass the ground soil sample through a 2 mm sieve and mixed thoroughly.

The sieved soil was then stored into a plastic container. Each container was labeled to show the location, depth, sample number and date of collection and stored the containers in a cool dry place in the laboratory for laboratory analysis.

3.2 Laboratory methods

Some important physical, chemical and mineralogical properties of the sediment and soil samples were analyzed. Most of the methods employed in the present study were published procedures. A brief outline of each procedure has been given in all cases.

3.2.1 Physical analyses of sediments and soils

i) Particle size analysis of sediments and soils: Particle size analysis of sediment and soil was carried out in the laboratory following the Hydrometer method as described by Day (1965). Marshall's triangular co-ordinate system as devised by the United States Department of Agriculture (USDA, 1951) was used to determine the textural class.

ii) Moisture content: The percentage of moisture in soil was determined by drying a known amount of soil in an oven at 105˚c for 24 hours until a constant weight was obtained and the moisture percentage was calculated from loss of moisture (Black, 1965).

iii) Particle density (Dp): Particle density of sediment and soil was determined by Pycnometer method as described by Black (1965).

iv) Total porosity (f): Total porosity of soil was calculated from the data of particle density and bulk density using the formula as described by Stricking (1956) which is stated below:

$$\% \text{ Porosity} = 1 - \left(\frac{\text{bulk density}}{\text{particle density}}\right) \times 100.$$

v) Hygroscopic moisture: Hygroscopic moisture content of the soils was determined in laboratory by drying the air-dry soil in an oven at 105°C for 24 hours.

3.2.2 Chemical analyses of sediments and soils

i) Soil reaction (pH): pH of the sediment and soil samples was determined with a Lovibond pH meter (model pH200) at a sediment/ soil: water ratio of 1:2.5. pH also was determined with 1 N KCl solution using the same soil : solution ratio as above. The ΔpH values were calculated by subtracting pH with water from pH with 1N KCl solution.

ii) Organic carbon: Organic carbon content of the sediment and soil sample was determined volumetrically by wet oxidation and rapid titration method of Walkley and Black (1934) as described by Jackson (1964). Total organic matter content was estimated by multiplying the percentage of organic carbon with the conventional "Van Bemmelen's factor of 1.723.

iii) Total Nitrogen: Total nitrogen in both the sediments and soils were determined by kjeldahl's distillation method as described by Page (1982).

iv) Free oxides of iron and manganese: Free oxides of iron (Fe_d) and manganese(Mn_d) were extracted by sodium dithionate-citrate system buffered with sodium bicarbonate as described by Mehra and Jackson (1960).The extracted iron and manganese were determined by atomic absorption spectrophotometer.

***v) Electrical conductivity*:** Electrical conductivity was determined with a ratio of soil: water 1:5 by using an EC meter (USSL Staff, 1954).

vi) Free $CaCO_3$: Rapid titration method was followed for the determination of the free calcium carbonate in both the sediments and soils (Piper, 1966).

vi) Loss on ignition (LOI): Loss on ignition of soils and clays samples was determined by using muffle furnace after ignition of soils and clay samples for 2 hours at 900˚ C (Piper, 1966).

3.2.3 Physico-chemical analyses of sediments and soils

i) Cation exchange capacity (CEC): Cation exchange capacity (CEC) was determined by 1N NH_4OAc solution buffered at pH 7.0 (Chapman and Pratt, 1965).

ii) Exchangeable bases: Exchangeable bases (Na^+, K^+, $Ca^{2+}$and $Mg^{2+)}$ were determined from the 1 N ammonium acetate leachate of the soils as described by Jackson (1962). The Ca^{2+} and Mg^{2+} ions were determined by atomic absorption spectrophotometer, while Na^+ and K^+ were analyzed by a Gallencamp flame photometer (Black, 1965).

iii) Base saturation percentage (BSP): The base saturation percentage was calculated by using the following formula.

$$BSP = \left(\frac{\text{Total exchangeable bases}}{\text{Cation exchange capacity}}\right) \times 100$$

3.2.4 Fusion analyses of sediments, whole soils and clay fractions

Fusion analysis entails the determination of the total elemental estimate of the inorganic components of the sediments, soils and clays by fusion method. This analysis was carried out by Na_2CO_3 fusion method as devised by Piper (1966) and Jackson (1967).

i) Silica (SiO_2): Silica in both sediment and soil samples was determined by the method of silicate analyses proposed by Jackson (1967), which involves sodium carbonate fusion, double evaporation of the HCl extract of the fuse and dehydrate, ignition and purification by HCl acid.

ii) Total phosphorus (P_2O_5): Total phosphorus content in the extract was determined by Shimadzu spectrophotometer (UV-120-02 model) at 460 mµ wavelengths, after developing yellow color with molybdate- vandate, as described by Jackson (1967).

iii) Total potassium (K_2O): Total potassium was determined by a Gallenkamp flame photometer (Jackson, 1967).

iv)Total titanium (TiO_2): Titanium was determined colorimetrically by developing yellow colour with 30% H_2O_2 (Black, 1965).

v) Total Aluminium, Iron, manganese, calcium and magnesium: Total aluminium, iron, .manganese, calcium and magnesium were determined from sodium carbonate fusion extract of the sediments, soils and clays as described by Jackson (1967).

3.2.5 Methods of mineralogical analyses of clay fraction

Soil sample representing Ap horizon (surface) from each soil profiles were selected for the mineralogical analysis of clay fraction. X-ray diffraction (XRD) analysis was done for the determination of mineralogical composition.

3.2.5.1 X-ray diffraction (XRD) analysis of clay fraction:

i) Dispersion and Separation of Clay fraction: To concentrate clay fraction the soil were thoroughly dispersed. To achieve successful dispersion the following pretreatments were used for the removal of flocculating and cementing agents.

- ***Removal of carbonate and organic matter:*** A weighed amount of soil sample was placed in a tall 600 ml beaker and treated with 30% H_2O_2 in order to decompose organic matter (Jackson, 1965). The soil samples were washed twice with 1N sodium acetate solution (pH 5.0) and once with alcohol.
- ***Removal of free silica and alumina:*** The soil sample in step 1 was further treated with 2% Na_2CO_3 solution to remove out both silica and alumina.
- ***Removal of iron and manganese oxides:*** Free oxides of Fe and Mn were removed from soils by citrate bicarbonate dithionite extraction method as described by

Jackson (1965). The soil sample was brought into suspension with distilled water and it was now ready for separation into different size fractions.

The clay fraction was separated by gravitational sedimentation method using sodium carbonate solution as the dispersing agent. The suspension was stirred and then allowed to stand for 8 hours for each separation (Day, 1965). The clay fraction was decanted by means of a siphon. This procedure was repeated until the remaining suspension appeared clear, after the time needed for silt to settle down to a fixed depth. The separated clay suspension was flocculated by the addition of 1 N NaCl solution.

ii) Preparation of slide and X-ray diffraction analysis: Specimens for X-ray diffraction of the clay fraction were prepared by taking duplicate clay sols containing 50 mg of clay were placed in 10 mL centrifugal tube. Washing by centrifugation and decantation was carried out twice with 8 ml of an equal mixture of 1 M NaCl and 1M $NaCH_3COOH$ (pH 5.0) in order to decrease the pH of the preserved clay sols. Of the duplicate sets, one was saturated with K and the other with Mg by washing 3 times with 8 ml of 1M KCl and 0.5 M $MgCl_2$, respectively. Excess salt was removed by washing once with water. Clay in the tube was thoroughly suspended with 1 ml of water. An aliquot of 0.4 ml of the suspension was dropped onto a glass slide (28×48 mm), covering two- third of the area, air dried and X-rayed (parallel powder mount). XRD patterns were obtained using a Rigaku diffractometer with Ni- filtered CuKα radiation at 40 kV, 20 mA and at a scanning speed of 2°2θ per minute over a range of 3 to 35º 2θ. In addition to the air dried specimen, the Mg- saturated clay specimen was X-rayed after salvation with glycerol, and the K- saturated clay specimen was x-rayed after heating at 300 and 550°C for 2 hours.

Identification of clay minerals was made mainly on the basis of their characteristic basal reflections (C- axis length) following the procedure of Jackson (1975). Approximate mineral composition of the < 2µm clay fraction was estimated based on the relative peak intensities in the XRD patterns of the random powder mount.The peak intensity was calculated by multiplying peak height with peak width at half height (Moslehuddin and Egashira, 1996). The intensity ratio of two components *P* and *Q* in a multi-component mixture can be related to their weight ratio as follows:

$$Ip/ Iq = Kp.q\ (w_p/w_q)$$

`Where, *Ip* and *Iq* are the intensities of the *P* and *Q* components, respectively in XRD, *Kp.q* is the constant and *wp* and *wq* are the weight proportions of the *P* and *Q* components, respectively (Islam and Lotse, 1986). Since mica was detected in all samples, all the other minerals were paired with mica and the intensity ratios of all the pairs were calculated. With application of appropriate values for *Kp.q* (Egashira and Yasmin, 1990; Egashira and Watanabe, 1994) listed in Appendix 24**,** the weight ratios of all the pairs were calculated. Assuming that the sum of the weight ratios is one, the weight proportions of all the minerals in the clay fraction were obtained.

Dispersion and separation of clay fraction was done in the Pedology Laboratory, Department of Soil, Water and Environment, University of Dhaka and slide preparation was done in the Laboratory of Soil Science Department, Bangladesh Agricultural University, Mymenshing. XRD patterns were obtained using a Rigaku X-ray diffractometer in the Laboratory of Environmental Geochemistry, Division of Bioproduction Environmental Science, Department of Agro-environmental Science, Faculty of Agriculture, Kyushu University, Fukuoka 812-8581, Japan.

CHAPTER-4

ENVIRONMENTAL SETTINGS

CHAPTER – 4

ENVIRONMENTAL SETTINGS AND FIELD INVESTIGATION OF THE SOILS

This chapter deals with different aspects of soil environment which is vitally necessary for the correct assessment of the finding of any pedological work. With this view an attempt has been made to trace the available environmental information. Brief morphological description of the soils studied in the field has also been included in this section.

4.1 Environmental settings of the soils

4.1.1 Climate

The climate of the investigated area has been characterized as tropical monsoon (Manalo, 1975) climate with three main seasons: (i) the monsoon or the rainy season from June to October. During this time more than 75 percent of the total annual rainfall is received (ii) the winter season extends from November to February and is cool and rainless. This season is dry (iii) the pre-monsoon or the hot season extends from March to May which has the highest temperature and evaporation rates of the year and during which occasional thunder showers happen.

Within the investigated areas Barisal, Bhola, patuakhali has weather recording station but Jhalakati, Barguna and Pirojpur has no weather recording station. Hence the climatic data of Khepupara and Barisal stations, recorded by meteorological department, can be taken into consideration for the area under investigation.

The climatic data for Barisal, Bhola, Patuakhali and Khepupara station are presented in Appendix 14 on yearly basis. This indicates that the mean annual rainfall (2012) of the area under Barisal District is about 1836 mm, Bhola District is about 1484 mm, Patuakhali District is about 1920 mm and Khepupara Upazila is about 2625 mm and the mean annual air temperature is about 26.11°C recorded for Barisal; 25.87°C for Bhola, 26.4°C for Patuakhali and 26.31°C for Khepupara are presented in Appendix 15. During the monsoon month’s rain is frequent and occasionally heavy. The heaviest rainfall occurs in the months of June to August. In December the area receives the lowest rainfall.

The mean monthly air temperatures vary between about 10.9°C in January and 34.2° C in May. The diurnal range in temperature is about 15°C in the dry season (Dec. to March) and about 6°C in the rainy season (June to September).During the months from May to October there is surplus of water and from November to April there is water deficit. Mean monthly humidity is highest during the monsoon months (Appendix 15). The soil temperature regime has not been determined but is believed to be Hyperthermic. Mean annual evaporation is 83.4 mm in Barisal, 87.88 mm in Patuakhali, 87.04 in Bhola and 90.41mm in Khepupara. There is thus an excess annual rainfall over evaporation.

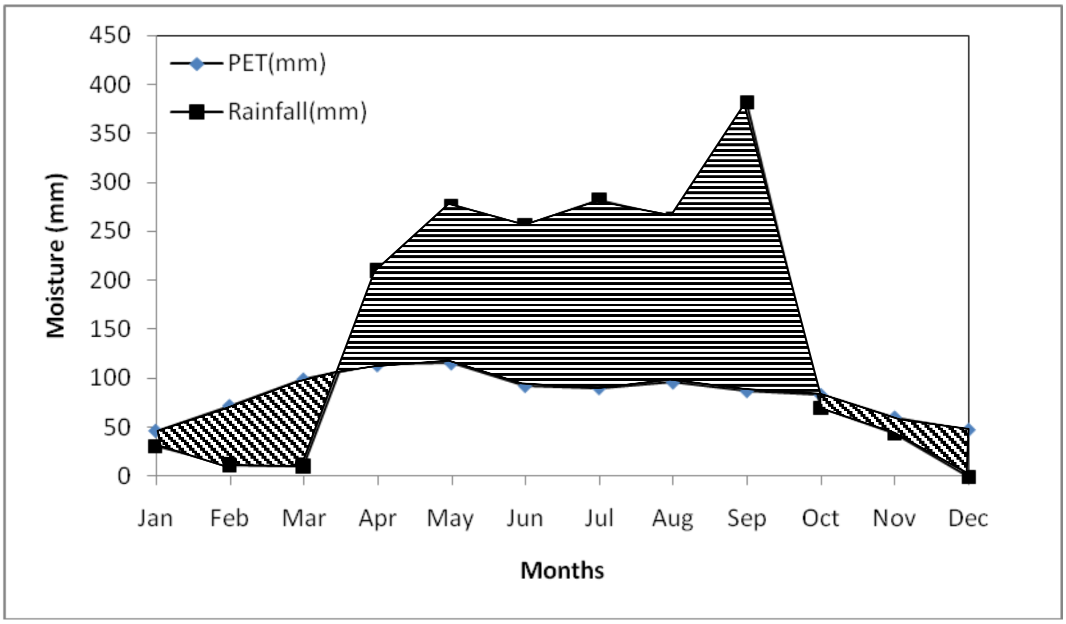


Fig 5. Climatic data and the soil water balance of Barisal.

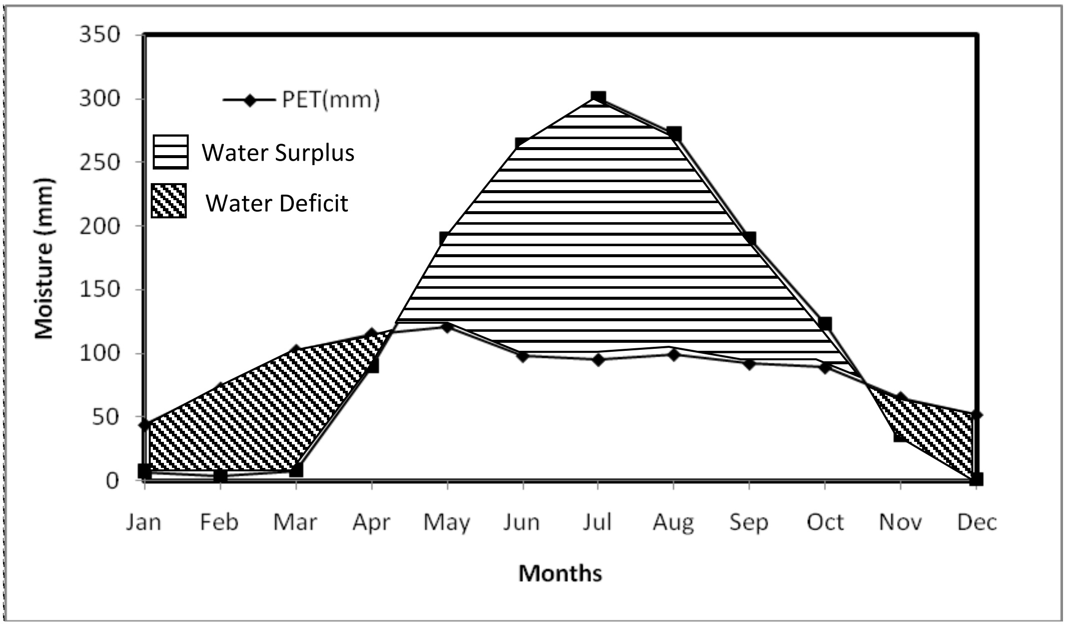


Fig 6. Climatic data and the soil water balance of Bhola.

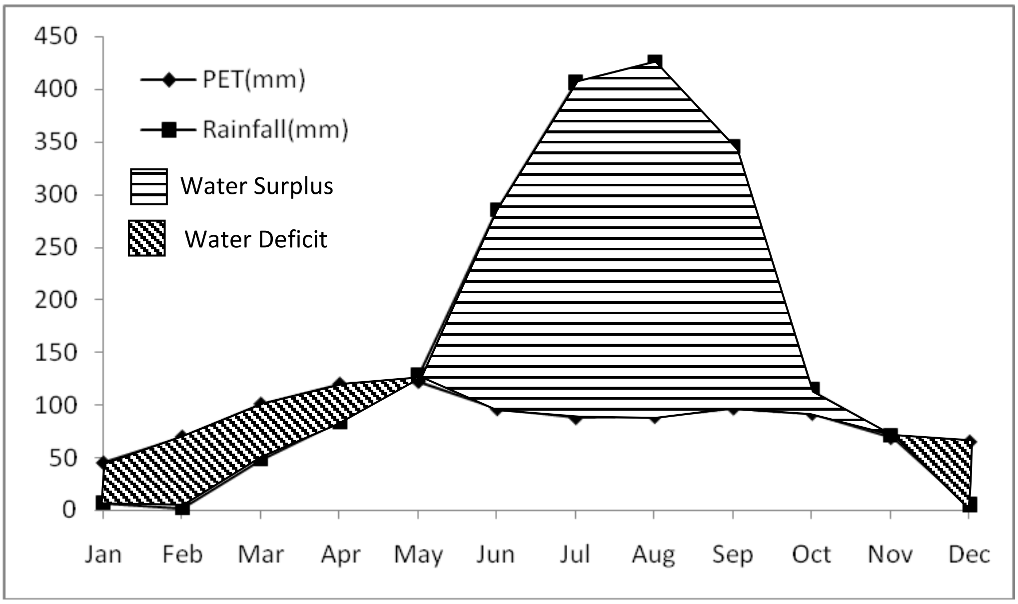


Fig.7. Climatic data and the soil water balance of Patuakhali

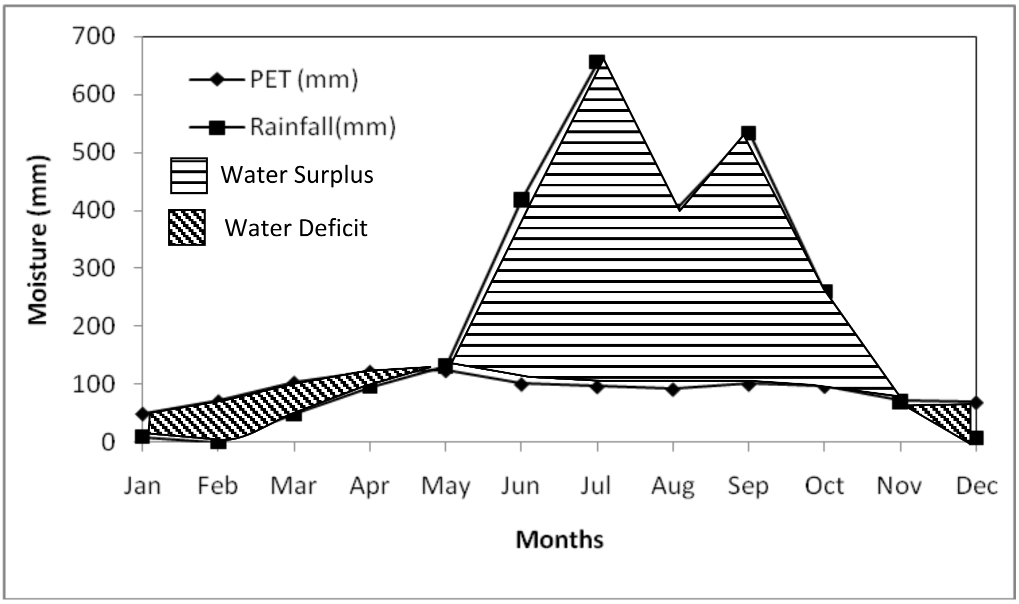


Fig.8. Climatic data and the soil water balance of Khepupara

4.1.2 Physiography and geomorphology

The major physiographic unit exists in the studied area were Old Meghna Estuarine Floodplain, Young Meghna Estuarine Floodplain, Ganges Tidal Floodplain, Ganges River Floodplain and Lower Meghna River Floodplain. It occupies level landscape with narrow floodplain ridges and broad shallow basins crisscrossed by an intricate network of tidal rivers and creeks. Estuarine land in the coastal belt is forming at present in the south of Noakhali mainland and in the islands of Meghna estuary. The land apparently originates as Char formations within the open estuary and builds up by slow tidal sedimentation. New alluvium is still being accumulated near the active river channels.

Rivers change their courses from time to time abandoning and reoccupying various parts of their floodplains and thus providing sediments of different ages in different areas and reflect important changes in the river courses that have taken place probably within the last 1000 years. The islands in the Meghna estuary are constantly changing shape and position as a result of erosion and new depositions takes place in the island of Bhola district. The area is under laid by recent and sub-recent alluvia brought down by the Ganges. Their lithologies are dominated by silt and clay sized particles. Most of the deposits appear to have been laid down under estuarine or tidal flat conditions and are very finely stratified. Elevations in the area under study are less than 1.5 m above mean sea level.

4.1.3 Hydrology

The rivers Ganges or Padma and the Brahamaputra or Jamuna and Meghna are the predominating factors controlling the hydrology of the area under the investigation. Bhola is virtually an island in the Bay of Bengal surrounded by water bodies on all sides. The rivers in the investigated areas are tidal throughout the dry season, the daily tidal range decreasing from south to north. Monsoon season floods push back the tidal limit to about the latitude of Barisal Town. Water in the rivers is fresh almost to their mouths at the height of the monsoon season floods, but saline water gradually penetrates inland up the rivers during the dry season (World Bank,2001).The coastal embankment is designed to prevent salt water flooding. Flooding is mainly by the accumulation of rain water as well as over- bank spilling from the rivers. High water level of the rivers prevents escape from extensive areas of flood water resulting from direct rainfall.

Almost all the areas under the investigation surplus water remained from the month of April to October (Figs.5 to 8) and are flooded in the rainy season and remain flooded for several months each year. Depth of flooding is controlled by rivers levels and the ground water table. In the rainy season the ground water table goes above the surface of the soil. In the rainy season the ground water table goes above the surface of the soil. The soils in the area are flooded up to 1-2 feet for up to 3 months on the ridges and up to 2-4 feet deep for

3-6 months in the basins. In the tidal and young estuarine floodplains the flooding is up to 1-3 feet deep for 3-6 months but flood levels are subject to daily tidal fluctuation.

Drainage in the coastal areas is mainly controlled and regulated by the rivers and creeks crisscrossing the landscape. These lands are inundated twice a day of varying depths during high tides. In addition to the protection against regular inundations and salt water intrusion, the embankments reduce the tidal dynamics. This has an adverse effect on the drainage conditions (siltation) and the ecosystems (water logging). These negative effects have already been visible in many places of the coastal belt (EGIS, 1998; BARC, 1996).

4.1.4 Present land use

No natural vegetation is present in the area under the investigation as the land is under cultivation. Monsoon rainfall is generally sufficient to reduce top soil salinity so that transplanted *aman* grown throughout the coastal zone when the salt is washed down below the rooting zone of the seasonally growing plants. During dry season, the salt comes up near the soil surface by capillary rise of water, when white crusts of salt appear at the surface soils.

Cultivation of winter rice (IRRI) has been introduced recently and is becoming popular gradually. Some Rabi crops like mustard, khesari, gram, lentils are grown on river bank soils during the winter season especially on the silty soils of Bhola. Present land use in the coastal areas is of extensive type with insufficient and unbalanced application of fertilizer. The yield as a result is low which is barely sufficient to meet the needs of the increasing population. Salinity in these soils varies with the season

4.1.5 Agroecological regions (AEZ)

Bangladesh has thirty agro ecological regions. Three major agro ecological regions (FAO-UNDP, 1988) have been identified in the studied area. Brief description of these AEZ is given below:

AEZ 11. Ganges River Floodplain

AEZ 12. Ganges Tidal Floodplain

AEZ 18. Young Meghna Estuarine Floodplain

Ganges River Floodplain

This region comprises the active floodplains of the Ganges river and part of the lower Meghna river (major subregion Active Ganges Floodplain), and the older and younger parts of the Ganges meander floodplain. The total area of the region is 23962 km^2 (Brammer, 2012). It comprises the greater district of Jessore, and Kustia and parts of Rajshahi, Pabna, Faridpur, Khulna, Barisal and Dhaka. In general the topography is smooth but it locally comprises rapidly alternating, linear low ridges and depressions, especially in the west. The Ganges River is consistently shifting its course, eroding its banks and depositing large volume of new alluvium on its beds banks, char lands and floodplains. The Ganges alluvium is calcareous. Clayey soils predominate in basins and on some ridges. The substratum is mainly silt, but is sandy in many places of the west. Flooding is mainly deep and long but becomes shallow and short in the west. Ganges sediments contain a high content of easily-weather able minerals. They have a high content of smectite in the clay fraction.

The floodplain is divided into active and moribund deltaic regions. It is a typical meander floodplain with broad ridges and basins and several large and deep oxbow lakes or cut- off channels. It locally has irregular relief of series of low narrow linear ridges and in filled channels. Bank erosion and deposition occur continuously in and around the active Ganges channels. The sediments are calcarious and rich in feldsper and biotite. The older soils are decalcified to varying depths.

Ganges Tidal floodplain

Tidal floodplain is formed under the influence of tidal flooding. The materials carried by the tidal rivers are predominantly fine. The land is flooded by the high tides. The landscape has a distinctive, almost level, criss-crossed by numerous inter connecting tidal creeks and rivers. It occupies an area of 16413km^2 (Brammer, 2012) covering the entire tidal coastal land of Barisal, Patuakhali and Khulna region. It differs from the adjoining meander floodplain in having lower relief of low narrow ridges and shallow broad basins. The sediments are mainly non-calcarious clays, becoming siltier in the east and have a burried peat layer in the west. The mangrove forest of sundarbans occupies about 5570 sk. km in the southwest. Flooding is shallow and tidally affected. Dry season salinity occurs in the southern part of Patuakhali and in most of khulna region. Acid sulphate soils occur in the southwest, in areas adjoining the sundarbans

Young Meghna Estuarine Floodplain

The young estuarine floodplain occupies an area 13120 km^2 covering the southeast district of Bhola to Brahamanbaria district. This landscape has been formed by the actions of the rivers of Meghna. It is almost level land within and adjoining the Meghna estuary including both island and mainland areas. Here new deposition and erosion are constantly taking place on the land margins, altering the shape of the land areas and channels. The sediments are predominantly silty and very fine sandy which are finely stratified and slightly calcareous.. It is mainly by rainwater or non-saline river water. Occasional storm surges associated with tropical cyclones affect the area.

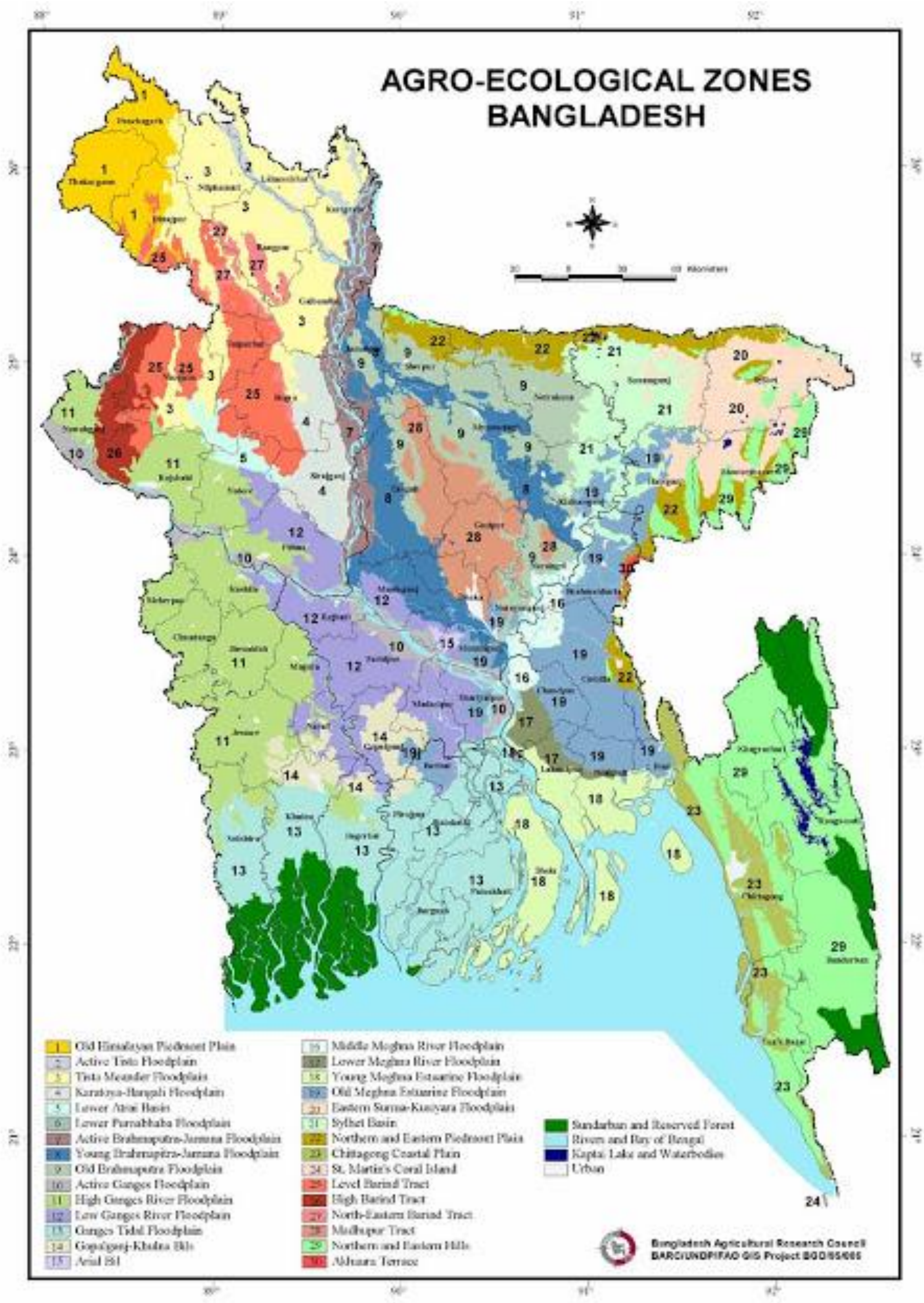


Fig 9. Map of Agro-ecological regions of Bangladesh showing study area.

4.2 Field Investigations of the Soils

The morphological properties of the soils were studied in the field and brief description of each of the pedon of soil series were given below. During the study of soils in the field, photographs of typical soil profile and its associated landscape were taken. These are also presented in Figures 10-25.

4.2.1 BHOLA SERIES

The Bhola series comprises seasonally flooded, poorly drained, olive grey to olive, finely mottled, silt loam with weak to moderate prismatic structure in the B horizon. They are usually non- calcareous but may be locally slightly calcareous.

<u>Typical Pedon</u>

Location: Village- Char Duany, Union- North Joynagar, Upazila- Daulatkhan, District: Bhola.

Topography: Upper slope of estuarine flat

Land use: Groundnut – T. Aus- Transplanted Aman

Drainage: poor. Flooded up to 30- 60 cm for 3-4 months in the rainy season.

Parent material: Meghna Alluvium

Horizon	Depth (cm)	Description
Ap	0-8	Grey (5Y 5/1) moist to grey (5Y 5/1) dry with common fine distinct dark yellowish brown mottles; silt loam; massive; friable moist ; common fine tubular pores; common fine roots; abrupt smooth boundary; no effervescence with HCl ; pH 6.53 (7.5)
Ad	8- 12	Dark grey (5Y 4/1) moist with few fine distinct olive brown mottles; silt loam; massive; friable moist ; few fine tubular pores; few fine roots ; abrupt smooth boundary; no effervescence with HCl ; pH 7.05 (8.3)
Bw1	12- 28	Olive grey (5Y 5/2) moist with common fine distinct dark yellowish brown mottles; silt loam, weak coarse prismatic structure; friable moist; thin patchy grey cutans along the vertical ped faces and pores; common fine tubular pores; common fine roots; clear smooth boundary ; slight effervescence with HCl;; pH 7.35 (8.3)
C1	28- 40	Olive grey (5Y 5/2) moist and olive brown (2.5Y 4/4) moist horizontal bands with common medium distinct yellowish red mottles; silt loam ; massive; friable moist ; common fine tubular pores; few fine roots; clear smooth boundary ; slight effervescence with HCl ; pH 7.42 (8.4)
C2	40- 90+	Olive grey (5Y 5/2) moist and olive brown (2.5Y 4/4) moist horizontal bands with few, medium and coarse distinct yellowish red mottles; silt loam ; massive; very friable moist ; common fine tubular pores; few fine roots; clear smooth boundary ; slight effervescence with HCl ; pH 7.75 (8.0)

Note: pH figures in bracket recorded in the field using a Hellige- Troug test kit.

Fig 10. Landscape and vegetation around Bhola soil profile site.

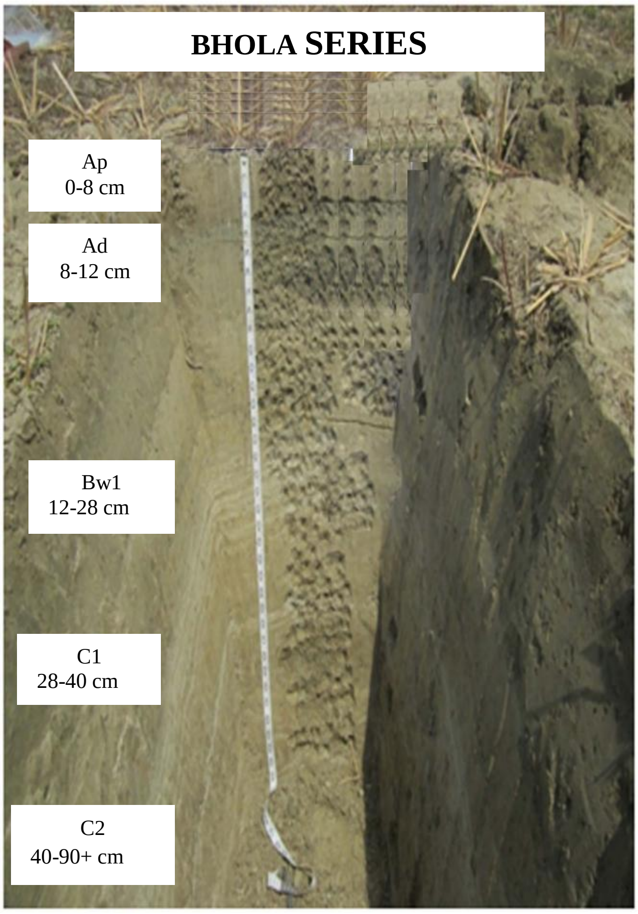


Fig 11 . Profile of the Bhola soil series.

4.2.2 NILKAMAL SERIES

The Nilkamal series comprises seasonally flooded, poorly drained, grey to olive grey, finely mottled, slightly calcarious silt loam topsoil overlying an olive, firm, silt loam to silty clay loam subsoil with weak to moderate very coarse prismatic structure and broken moderately thick grey cutans on vertical ped faces. They are non- saline to moderately saline.

Typical Pedon

Location: Village- Char Bhuta, Union- Char Bhuta, Upazila- Lalmohan, District: Bhola

Topography: Very gently undulating levee

Land use: T.Aman – fallow- Transplanted Aman

Drainage: poor. Flooded up to 60- 90 cm during low tide and 3- 4 feet during high tide for 3- 4 months in the rainy season.

Parent material: Meghna Alluvium

Horizon	Depth (cm)	Description
Ap	0-13	Grey (5Y 5/1) moist with few fine faint yellowish brown mottles; silt loam; massive; firm moist ; common fine tubular pores; common fine roots ; clear smooth boundary; slight effervescence with HCl ; pH 6.68 (8.2)
Ad	13- 18	Grey (5Y 5/1) moist to grey (5Y6/1) dry with many fine distinct olive brown mottles; silt loam; massive; firm moist ; common fine tubular pores; common fine roots ; abrupt smooth boundary; no effervescence with HCl ; pH 7.37 (8.0)
Bw1	18- 45	Olive (5Y 5/3) moist with common fine distinct dark yellowish brown mottles; silty clay loam, moderate very coarse prismatic; firm moist; broken moderately thick grey cutans; common fine tubular pores; few fine roots; clear smooth boundary ; slight effervescence with HCl;; pH 7.52 (8.2)
Bw2	45- 80	Alternate bonds of grey (5Y 5/2), olive grey (5 Y 3/2) and olive brown (2.5 Y 4/4) moist with common medium distinct dark reddish brown mottles; silt loam ; massive; friable moist ; patchy grey cutans ;few fine tubular pores; gradual smooth boundary ; slight effervescence with HCl ; pH 7.63 (8.2)
C1	80-105+	Alternate bonds of grey (5Y 5/1), olive grey (5 Y 5/2) and olive brown (2.5 Y 4/4) moist with few fine medium distinct dark brown mottles; silt loam ; massive; very friable moist ; patchy grey cutans ;few fine tubular pores; gradual smooth boundary ; slight effervescence with HCl ; pH 7.71 (8.2)

Note: pH figures in bracket recorded in the field using a Hellige- Troug test kit.

Fig 12. Vegetation and landscape around Nilkamal soil Profile.

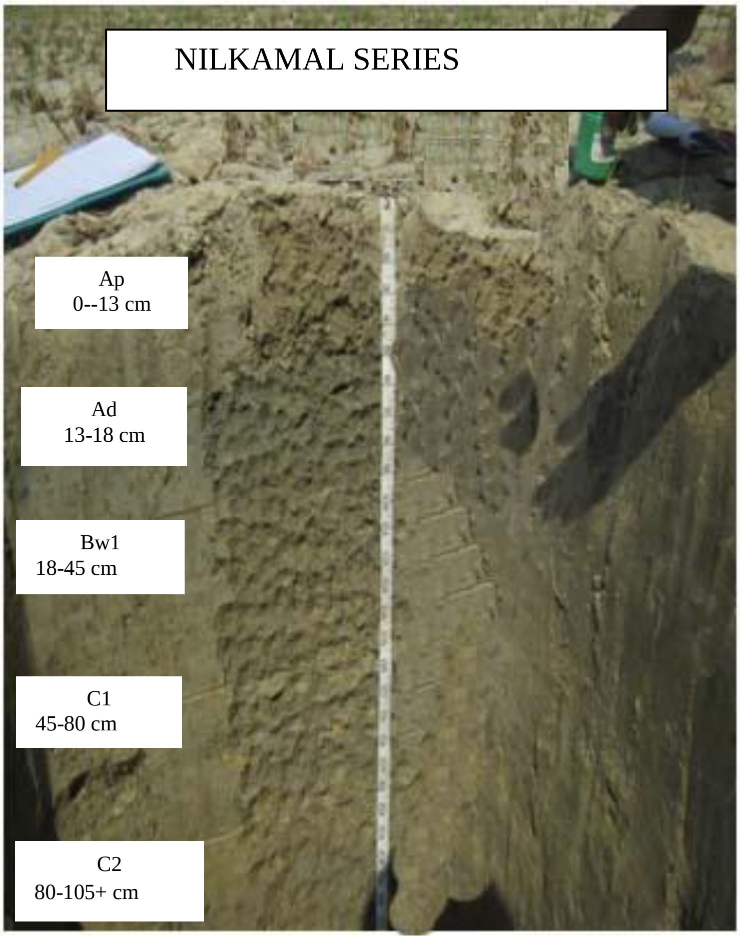


Fig 13. Profile of the Nilkamal soil series.

4.2.3 PIROJPUR SERIES

The Pirojpur series comprises seasonally flooded, poorly and very poorly drained, fine textured soils with a buried organic or humus layer below 20 inches but within a depth of 4 feet. The poorly drained phase has strong prismatic and angular blocky structure in the B horizon.

Typical Pedon

Location: Village- Garaiya, Union- Saturia, Upazila- Razapur, District: Jhalakati.

Topography: Nearly level basin bottom

Land use: fallow – fallow- Transplanted *Aman* (local)

Drainage: Poor. Flooded up to 3 feet for 4-5 months during the monsoon season.

Parent material: Ganges Tidal Alluvium

Horizon	Depth (cm)	Description
Ap	0-10	Dark grey (5Y 4/1) moist to grey (5Y 6/1) dry with common fine distinct yellowish brown mottles; clay; massive; very firm moist ; many fine tubular pores; common fine roots; abrupt smooth boundary; no effervescence with HCl; pH 6.34 (6.5.)
Ad	10-14	Dark grey (5Y 4/1) moist with common fine distinct yellowish brown mottles; clay; massive; extremely firm moist; broken thick very dark grey cutans along vertical faces of the crack; few fine pores; common fine roots; abrupt smooth boundary; no effervescence with HCl; pH 6.75 (7.5)
Bw1	14-28	Grey (5Y5/2) moist with common fine distinct yellowish brown mottles; clay; strong very coarse and coarse prismatic breaking into angular blocks. firm moist; continuous moderately thick grey cutans along vertical ped faces and pores; common fine tubular pores; common fine roots; clear smooth boundary; pH 7.07 (8.0.)
Bw2	28-50	Grey (5Y 5/1) moist with few fine distinct yellowish brown mottles; silty clay ; strong coarse prismatic structure breaking into angular blocky; very firm moist; very plastic moist; continuous moderately thick grey cutans along vertical ped faces and pores; common fine tubular pores; common fine roots; abrupt smooth boundary; pH 7.13 (8.0.)
C1	50-70	Dark grey (5Y 4/1) moist ; Silty clay ; massive; sticky plastic wet, abrupt smooth boundary; pH 7.19 (8.0)
C2	70-120	Dark grey (5Y 4/1) moist; silty clay; massive; presence of buried peat layer; pH 6.74 (8.0.)

Note : pH figures in bracket recorded in the field using a Hellige- Troug test kit.

Fig 14 . Landscape and vegetation around Pirojpur soil profile site.

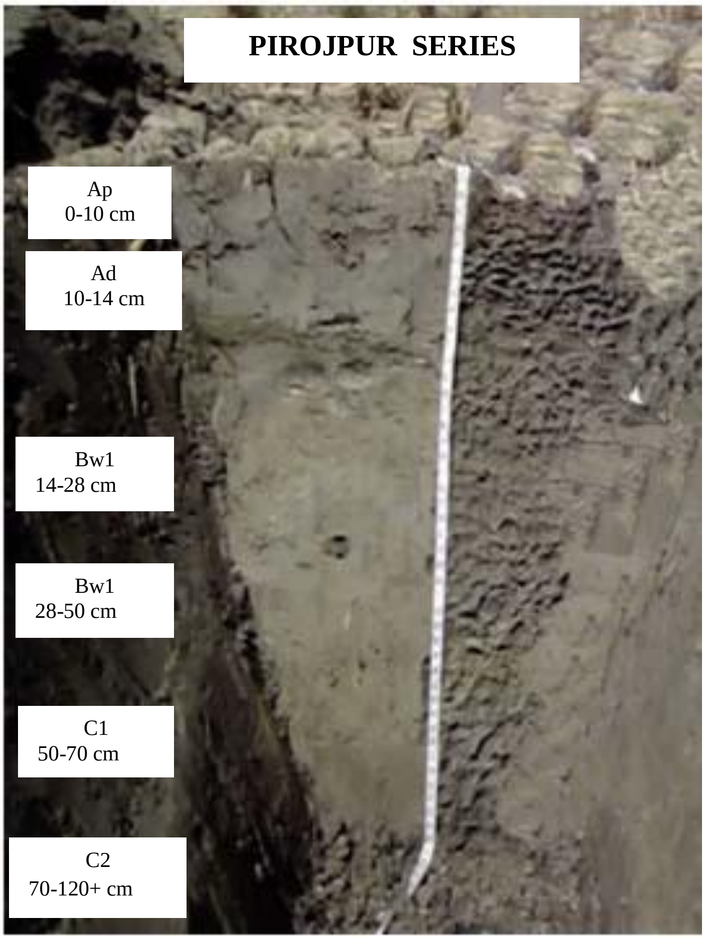


Fig 15 . Profile of the Pirojpur soil series.

4.2.4 HOGLA SERIES

The Hogla series comprises seasonally flooded, poorly to very poorly drained, grey to dark grey, silty clay loam containing a buried peat layer at a depth between 18 – 40 inches.

Typical Pedon

Location: Village- Ashoa Amrajuri, Union- amrajuri, Upazila- Kawkhali, District: Pirojpur.
Topography: basin margin.
Land use: Fallow – T. aus- Transplanted aman.
Drainage: Poor. Flooded up to 2-3 feet for 4-5 months during the rainy season.
Parent material: Ganges Tidal Alluvium

Horizon	Depth (cm)	Description
Ap	0-12	Grey (5Y 5/1) moist to grey (5Y 6/1) dry with common fine distinct yellowish brown mottles; silty clay loam ; massive; firm moist ; plastic and sticky wet; common fine tubular pores; many fine roots; abrupt smooth boundary; slight effervescence with HCl; pH 6.63 (8.0.)
Ad	12-15	Dark grey (5Y 4/2) moist with common fine distinct yellowish brown mottles; silty clay; massive; very firm moist; few very fine tubular pores; common very fine and fine roots; abrupt smooth boundary; very slight/ no effervescence with HCl; pH 6.40 (6.5)
Bw1	15-48	Dark Grey (5Y 4/2) moist with many fine distinct yellowish brown mottles; silty clay loam ; strong coarse prismatic breaking into angular blocky structure; firm moist; broken moderately thick dark grey cutans or vertical ped faces and along pores; common fine tubular pores; common fine roots; clear smooth boundary; slight effervescence with HCl; pH 6.71 (8.0).
Bw2	50-77	Dark Grey (5Y 4/2) moist with common fine distinct yellowish brown mottles; silty clay loam ; strong coarse prismatic structure; firm moist; broken moderately thick dark grey cutans along vertical ped faces and pores; common fine tubular pores; few fine roots; clear smooth boundary; slight effervescence with HCl; pH 6.90 (8.0.)
C1	60-85	Dark grey (5Y 4/2) moist ; silty clay ; massive; very firm moist; abrupt smooth boundary; slight effervescence with HCl; pH 6.95 (8.0)
C2	85-110+	Dark grey (5Y 4/2) moist; silty clay; massive; very firm moist; presence of buried peat layer; sticky and plastic wet; slight effervescence with HCl ; pH 6.61 (8.0.)

Note: pH figures in bracket recorded in the field using a Hellige- Troug test kit.

Fig 16 . Landscape and vegetation around Hogla soil profile site.

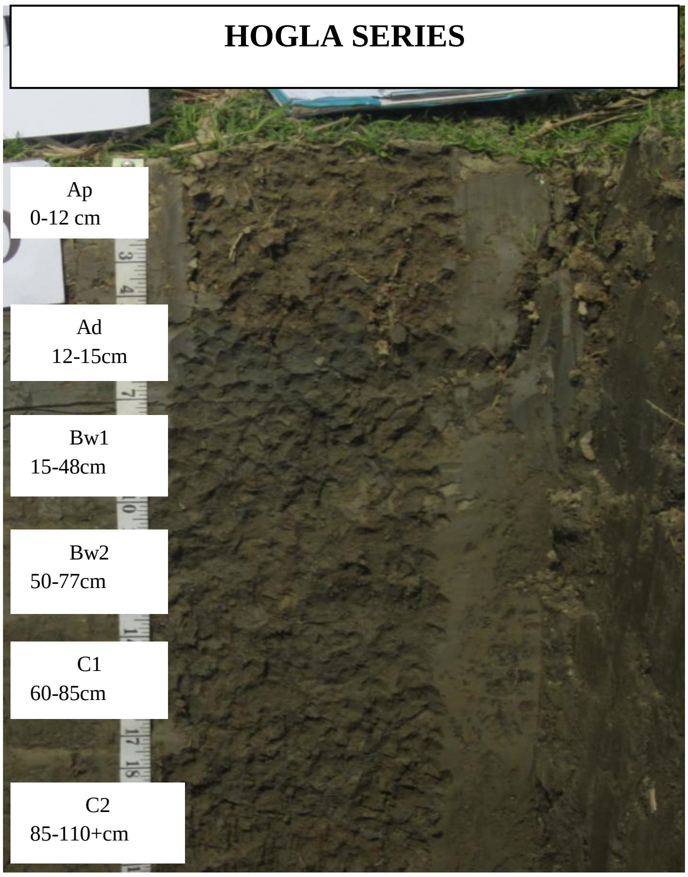


Fig 17. Profile of the Hogla soil series.

4.2.5 MULADI SERIES

The Muladi series includes seasonally flooded, poorly drained, olive grey to yellowish brown, finely mottled, calcareous silty clay loam with moderate to strong prismatic and blocky structure in the B horizon.

Typical Pedon

Location: Village- Kiswmat chandpasha, Union- Chandpasha, Upazila- Babugonj, District: Barisal

Topography: Nearly level basin margin

Land use: Mungbean – fallow- Transplanted Aman

Drainage: poor. Flooded up to 3 feet for 3-4 months during the monsoon season.

Parent material: Ganges Alluvium

Horizon	Depth (cm)	Description
Ap	0-10	Grey (5Y 5/1) moist to grey (5Y6/1) dry with common fine distinct dark yellowish brown and strong brown mottles; silty clay loam; massive; common fine tubular pores; common fine roots ; abrupt smooth boundary; no effervescence with HCl ; pH 6.43 (7.5)
Ad	10- 17	Olive grey (2.5 Y 5/2) moist to light olive grey (5Y6/2) dry with common fine distinct olive brown and strong brown mottles; silty clay loam; massive; common fine tubular pores; common fine roots ; abrupt smooth boundary; no effervescence with Hcl ; pH 6.68 (7.9)
Bw1	17- 34	Dark Grey (5Y 4/2) moist with common fine faint olive brown mottles; silty clay loam; strong coarse prismatic and angular blocky structure; firm moist; continuous thick dark grey cutans along vertical and horizontal ped faces and pores ; many very fine and fine tubular pores; common fine roots ; clear smooth boundary; strong effervescence with HCl ; pH 7.39 (8.0)
Bw2	34- 62	Dark Grey (5Y 4/2) moist with many fine distinct olive mottles; silty clay loam; strong coarse prismatic structure; firm moist; continuous moderately thick dark grey cutans along vertical ped faces and pores ; many very fine and common fine tubular pores; few fine roots ; clear smooth boundary; strong effervescence with HCl ; pH 7.61 (8.2)
C1	62- 94	Light olive brown (2.5Y 5/3) moist with many fine distinct dark brown mottles; ; silt loam ; massive; friable moist ; abrupt smooth boundary ; strong effervescence with HCl ; pH 7.68 (8.2)
C2	94-105+	Olive grey (5Y 5/2) moist with common medium distinct yellowish brown mottles; ; sandy loam ; massive; friable moist; strong effervescence with HCl ; pH 7.71 (8.2)

Note: pH figures in bracket recorded in the field using a Hellige- Troug test kit

Fig 18. Vegetation and landscape around Muladi soil profile site

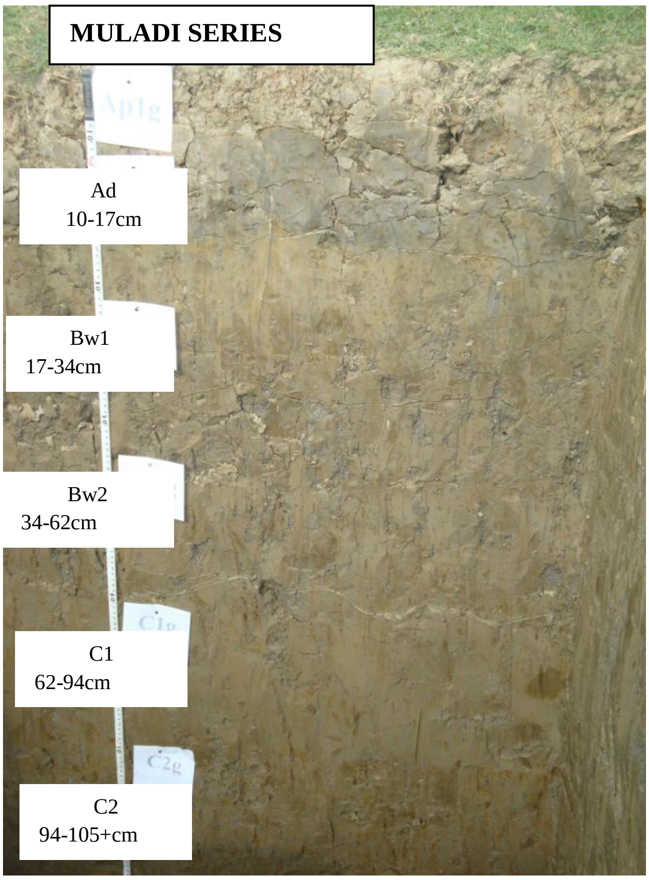


Fig 19. Profile of the Muladi soil series.

4.2.6 BARISAL SERIES

The Barisal tidal clays comprise nearly level, seasonally flooded, poorly and very poorly drained, dark grey to grey, silty clay and clay soils. They are non-calcaeous ranges between saline to non-saline.

Typical Pedon

Location: Village- chalabanga, Union- amtali, Upazila- amtali, District: Barguna.

Topography: Nearly level basin.

Land use: fallow – fallow- Transplanted Aman.

Drainage: Poor. Flooded up to 2.5 feet for 4- 5 months during the rainy season.

Parent material: Ganges Tidal Alluvium

Horizon	Depth (cm)	Description
Ap	0-10	Grey (5Y 5/1) moist grey (5Y 6/1) dry with common fine distinct dark yellowish brown and yellowish brown mottles; silty clay; massive; very hard dry ; patchy iron cutans along pores and on faces of clods; few fine tubular pores; common fine roots; abrupt smooth boundary; no effervescence with HCl; pH 5.09 (6..0.)
Ad	10-18	Dark grey (5Y 4/2) moist and grey (5Y 5/1) dry with few fine fine distinct yellowish brown and strong brown mottles; clay; massive; very firm moist; common fine tubular pores; few fine roots; abrupt smooth boundary; no effervescence with HCl; pH 5.15(6.0)
Bw1	18-50	Dark grey (5Y 4/2) moist with common fine distinct yellowish brown mottles; silty clay ; strong coarse prismatic breaking into angular blocky structure; very firm moist; continuous moderately thick dark grey cutans along vertical and horizontal ped faces and pores; many very fine tubular pores; common fine roots; clear smooth boundary; no effervescence with HCl; pH 5.83(8.0.)
Bw2	50-77	Dark grey (5Y 4/2) moist with few fine distinct yellowish brown mottles; silty clay ; strong coarse prismatic structure breaking into angular blocky; very firm moist; broken moderately thick dark grey cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; few fine roots; clear smooth boundary; no effervescence with HCl; pH 6.16(7.0.)
C1	77-110	Grey (5Y 5/2) moist with common fine and medium distinct yellowish brown mottles; clay ; massive; very firm moist; very plastic and very sticky wet; few fine tubular pores, clear smooth boundary; no effervescence with HCl; pH4.9 (6.0)
C2	110-125+	Grey (5Y 5/1) moist with common fine and medium distinct dark yellowish brown mottles; clay ; massive; very firm moist; very plastic wet; pH 4.74 (6.0)

Note: pH figures in bracket recorded in the field using a Hellige- Troug test kit

Fig 20. Landscape and vegetation around Barisal profile site.

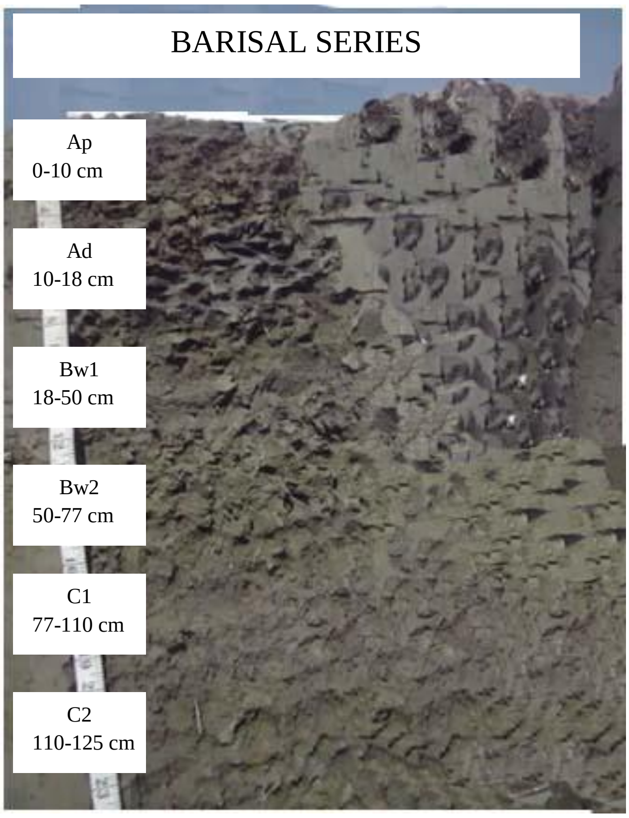


Fig 21 . Profile of the Barisal series.

4.2.7 JHALAKATI SERIES

The Jhalakati series comprises seasonally flooded, poorly drained soil; grey silty clay loams with moderate to strong prismatic and blocky structure in the B horizon. They are non-calcarious throughout and vary from non-saline to moderately saline.

Typical Pedon

Location: Village- kalibari, Union- kathaltali, Upazila- patharghata, District: Barguna.

Topography: Very gently un-dulating basin edge.

Land use: Khesari – T. aus- Transplanted Aman.

Drainage: Poor. Flooded up to 1 to 1.5 feet for 3- 4 months in the rainy season.

Parent material: Ganges Tidal Alluvium

Horizon	Depth (cm)	Description
Ap	0-9	Grey (5Y 5/1) moist to light grey (5Y 6/1) dry, common fine and distinct yellowish brown mottles; silty clay loam; massive; firm moist; common fine tubular pores; common very fine and fine roots; abrupt smooth boundary; no effervescence with HCl; pH 6.68 (7.6)
Ad	9-16	Grey (5Y 5/1) moist to light grey (5Y 6/1) dry, common fine and distinct yellowish brown mottles; silty clay; massive; very firm moist; common very fine tubular pores; common very fine and fine roots; abrupt smooth boundary; no effervescence with HCl; pH 7.51 (8.0)
Bw1	16-30	Olive Grey (5Y 5/2) moist; many fine and distinct yellowish brown mottles; silty clay loam; strong very coarse prismatic breaking into coarse angular blocky structure; firm moist; broken moderate thick cutans on vertical and horizontal ped faces; common fine and many very fine tubular pores; common very fine and fine roots; clear smooth boundary; no effervescence with HCl; pH 7.57 (8.0.)
Bw2	30-48	Olive Grey (5Y 5/2) moist; many fine and distinct yellowish brown mottles; silty clay loam; strong very coarse prismatic breaking into strong coarse angular blocky structure; firm moist; broken moderate thick grey cutans on vertical and horizontal ped faces; common very fine and fine tubular pores; clear smooth boundary; pH 7.46 (8.0.)
C1	48-69	Grey (5Y 5/1) moist; common medium and distinct yellowish brown and dark brown mottles; silty clay loam; massive; firm moist; clear smooth boundary; pH 7.41 (8.0.)
C2	69-100+	Olive grey (5Y 5/2) moist; ; common medium and distinct yellowish brown and dark brown mottles; silt loam; massive; friable moist; pH 7.13 (8.0)

Note: pH figures in bracket recorded in the field using a Hellige- Troug test kit

Fig 22. Vegetation and landscape around Jhalakati profile site

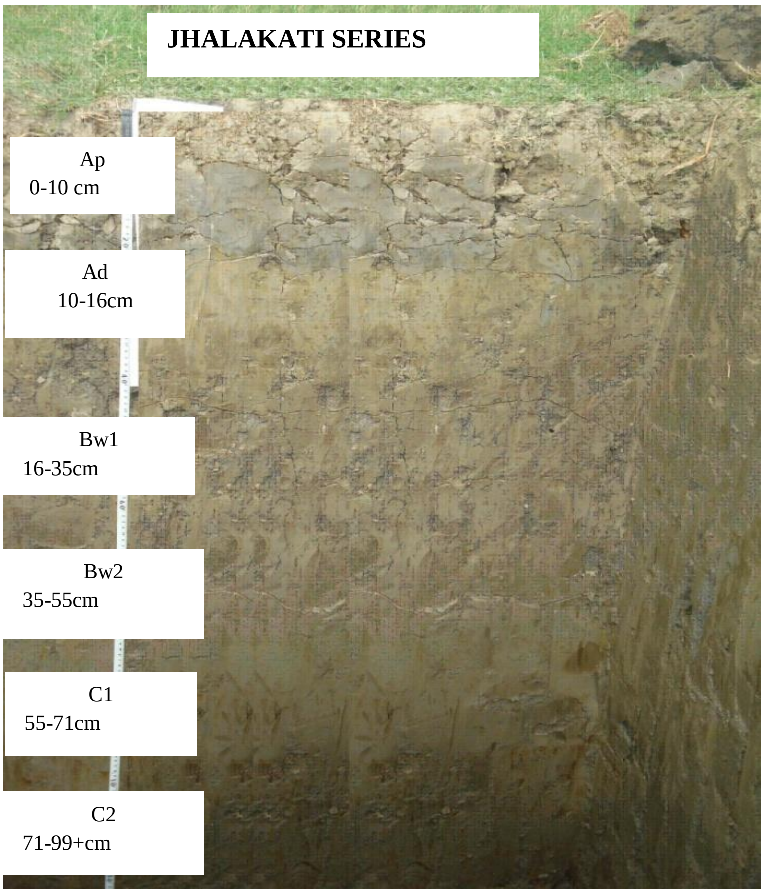


Fig 23. Profile of the Jhalakati soil series.

4.2.8 RAMGATI SERIES

The Ramgati series comprises seasonally tidally flooded, poorly drained soil developed in medium textured silt loams. They have an olive grey to grey, mottled yellowish brown to strong brown, silty loam subsoil with moderate prismatic structure in the B horizon. They are very slightly to moderately calcarious throughout and vary from non-saline to saline.

Typical Pedon

Location: Village- Ballavpur, Union- Kalikapur Upazila- Patuakhali Sadar District: Patuakhali

Topography: Very gently undulating levee/ nearly level tidal floodplain

Land use: Rabi crops (Khesari/ Mungbean/ Ground nut) – Fallow- Transplanted Aman.

Drainage: Poor. Flooded up to 30- 60 cm for 3- 4 months in the rainy season.

Parent material: Gangetic Alluvium

Horizon	Depth (cm)	Description
Ap	0-8	Grey (5Y 5/1) moist to grey (5Y 6/1) with many fine and distinct dark yellowish brown and greenish grey mottles; silt loam; massive; friable moist; iron coatings along common fine tubular pores; many fine roots; abrupt smooth boundary; no effervescence with HCl; pH 5.02 (6.5)
Ad	8-12	Grey (5Y 5/1) moist with many fine and distinct dark yellowish brown mottles; silt loam; massive; friable moist; common fine tubular pores; many fine roots; abrupt smooth boundary; no effervescence with HCl; pH 6.04 (7.0)
Bw1	12-35	Olive brown(2.5Y 4/3) moist with many fine and distinct yellowish brown mottles; silt loam; weak coarse prismatic structure; friable moist; broken thin grey cutans along vertical ped faces; many fine tubular pores; common fine roots; clear smooth boundary; slight effervescence with HCl; pH 6.37 (7.0)
Bw2	35-53	Olive grey (5Y 5/2) moist with many fine distinct yellowish brown and dark brown mottles; silt loam; ; weak coarse prismatic structure; friable moist; many fine tubular pores; few fine roots; clear smooth boundary; slight effervescence with HCl; pH 6.56 (7.0)
C1	53-71	Olive grey (5Y 5/2) moist with few fine faint olive brown mottles; silt loam; massive; very friable moist; few fine tubular pores; abrupt smooth boundary; slight effervescence with HCl; pH6.46 (7.0)
C2	71-105+	Olive grey (5Y 5/2) moist with few fine faint strong brown mottles; coarse iron staining; on soil mass; silt loam; massive; very friable moist; few fine tubular pores; slight effervescence with HCl; pH 6.37 (7.0)

Note: pH figures in bracket recorded in the field using a Hellige- Troug test kit

Fig 24. Landscape and vegetation around Ramgati soil profile site.

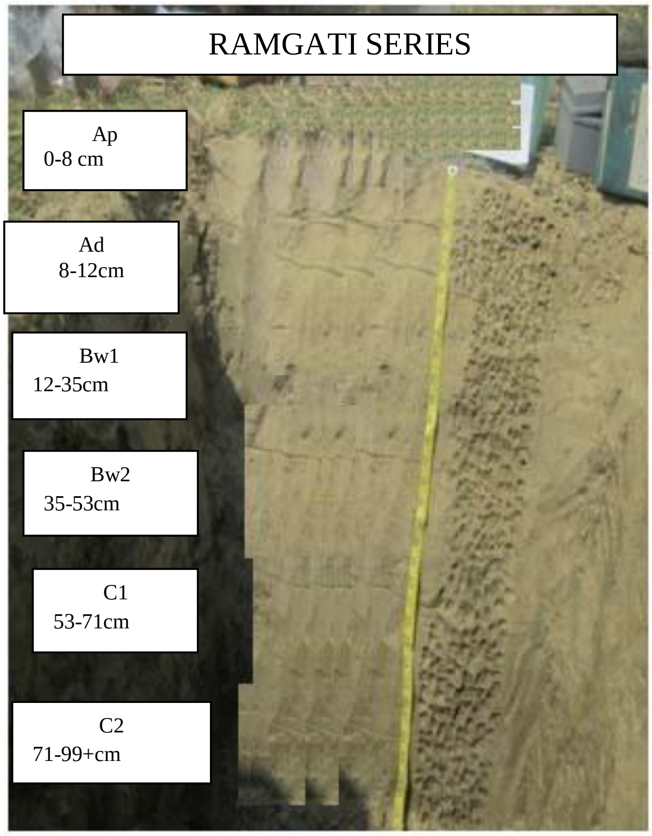


Fig 25. Profile of the Ramgati series

CHAPTER-5

RESULTS AND DISCUSSION

CHAPTER – 5

RESULTS AND DISCUSSION

The results of the investigations carried out in the field as well as in the laboratory are presented and discussed in this section.

5.1 Suspended sediment load

The amounts of suspended sediment carried by the two rivers such as the Bishkhali and the Arial Khan rivers flowing through the coastal zone of Bangladesh ranged from 4.10 to 13.06 kg/ sq. meter/ month (Table 4 and Appendix 1 & 2).

Suspended sediment load of the Bishkhali river water in the coastal zone of Bangladesh was very high (9.4 kg per sq. meter per month) in the dry season as compared to that in the wet season (4.6 kg per sq. meter per month) whereas in the Arial Khan river the suspended sediment load was low in dry season (4.1 kg per sq. meter per month) as compared to that in the wet season (13.06 kg per sq. meter per month) due to variation in water turbulence of the two rivers.

Suspended sediment load was found higher in the dry season than that in the wet season in Bishkhali River (Figs. 26 to 28). Because of extreme flow of water in wet season, sediment load was found lower in wet season than in dry season.

Suspended sediment load was noticed higher in wet season compared to the dry season in Arial Khan river (Figs. 29 to 31). Conducive environment of sedimentation may prevails in the wet season of Arial Khan River; hence sediment discharge was higher in wet season than the dry season. Similar observation has been made by Siddiqi (1989) and Rahman (2009). They noted that the sediment load is very high and the sediment carrying capacity of the rivers is also very high during the wet season.

The sediment load of the Ganges and the Brahmaputra river water in Bangladesh was examined by Rahman *et al*. (2009) and concluded that in dry season the average content of sediment of the river water was 75 mg/l and that in wet season was705 mg/l.

Chakrapani (2005) studied the sediment discharge in some large rivers in the world as well as factors controlling variations in river sediment load and concluded that sediment in the river water is 1200 t/yr in Amazon; 1060 ton/yr in Ganges/ Brahmaputra; 1050 t/yr in Huang He and 210 t/yr in Mississippi river and factors like relief, channel slope, basin size, seasonality of rains, human perturbations, water flow and tectonic activities control sediment loads in river.

The major sources of these sediments are the vast slopes of the Himalayas and the adjoining land. Factors such as relief, channel slope, basin size, deformation of tides, bottom layer sediment concentration, water discharge, flow of water, turbidity of water, weathering of rocks and the erosion of surface materials, seasonality of rains and tectonic activities which may individually or in combination with others control sediment loads in rivers. Meade and Parker (1984) reported that the major source of sediment supplied to the United States Rivers are the sediments occurring in the floodplain.

Table 4. Seasonal pattern of mean sediment load in the Bishkhali and theArial khan river.

Bishkhali river					
Year	Season	Location 1 ($kg/m^2/month$)	Location 2 ($kg/m^2/month$)	Location 3 ($kg/m^2/month$)	Mean ($kg/m^2/month$)
2013-14	Wet	4.0	3.8	4.5	4.0
	Dry	7.8	8.0	8.6	8.2
2014-15	Wet	4.1	4.5	4.6	4.4
	Dry	7.4	7.8	8.1	7.8
2015-16	Wet	5.3	5.3	5.3	5.3
	Dry	12.2	12.9	13.4	12.3
Mean value of Wet season					4.6
Mean value of Dry season					9.4
Arial khan river					
2013-14	Wet	10.3	10.7	10.6	10.6
	Dry	3.7	3.9	4.3	3.9
2014-15	Wet	14.7	14.5	14.5	14.6
	Dry	2.8	3.3	3.7	3.3
2015-16	Wet	13.8	14.0	14.1	14.0
	Dry	5.3	4.9	5.1	5.1
Mean value of Wet season					13.06
Mean value of dry season					4.10

5.2 Physical properties of sediments

5.2.1 Particle density

The results of particle density in the Bishkhali and the Arial Khan river sediments have been presented in Appendix 3 & 4. Particle density of the Bishkhali river sediments ranged from 2.58 to 2.72 g/cm^3 with a mean value of 2.63 g/cm^3. Particle density of Arial Khan river sediment ranged from 2.66 to 2.73 g/cm^3 with a mean value 2.68 g/cm^3. The seasonal variation of sediment content is more or less similar. The higher particle densities in the sediments were probably due to their variation in mineralogical composition.

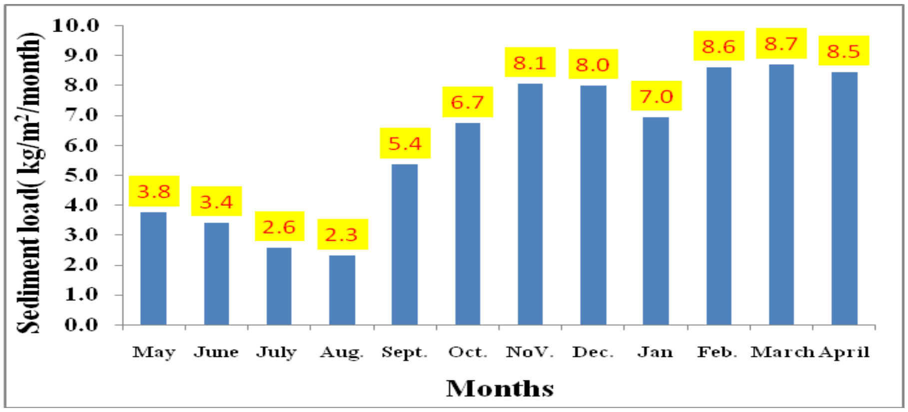


Fig 26. Seasonal pattern of sediment load in the Bishkhali river (May 2013 to April 2014).

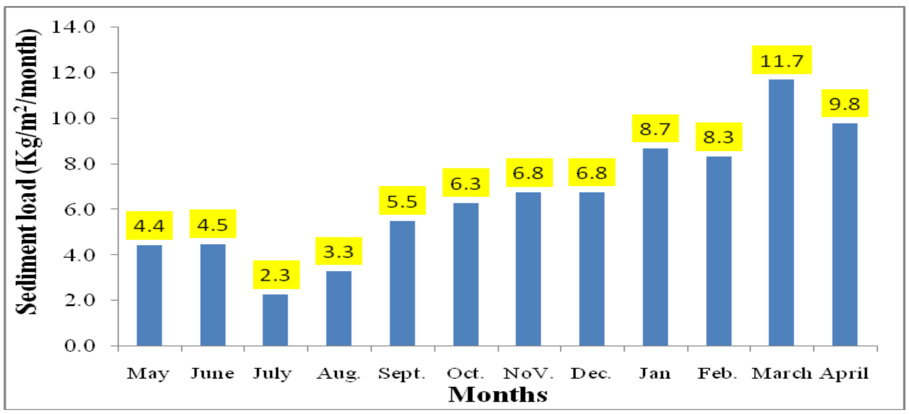


Fig 27. Seasonal pattern of sediment load in the Bishkhali river (May 2014 to April 2015).

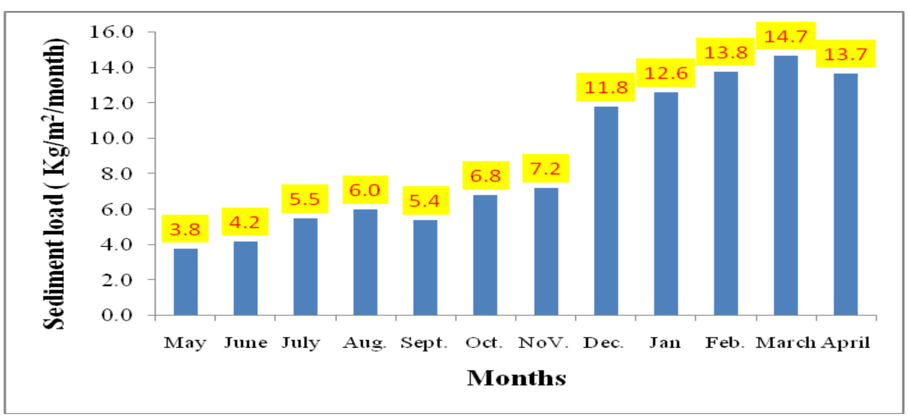


Fig 28. Seasonal pattern of sediment load in the Bishkhali river (May 2015 to April 2016).

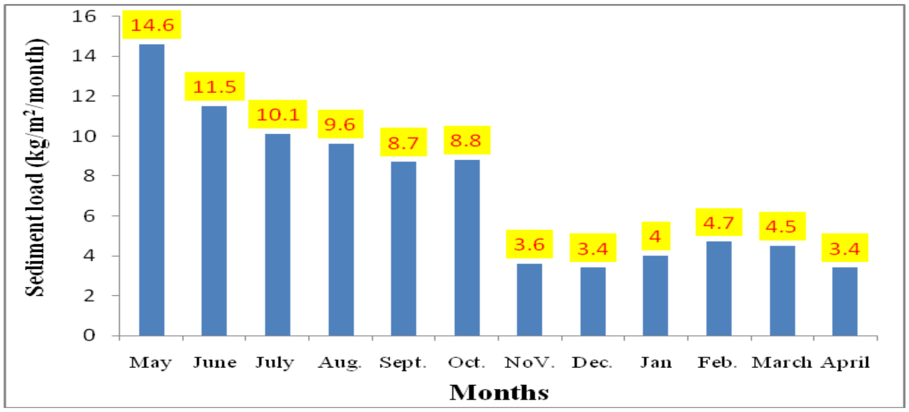


Fig 29. Seasonal pattern of sediment load in the Arial Khan river (May 2013 to April 2014).

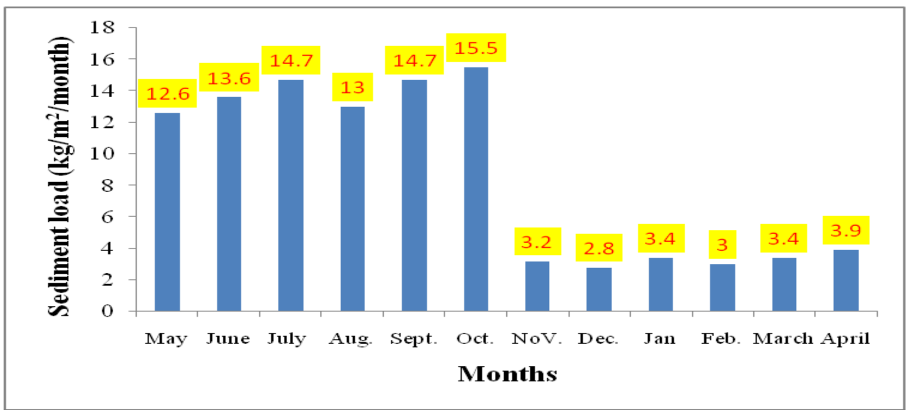


Fig 30. Seasonal pattern of sediment load in the Arial Khan river (May 2014 to April 2015).

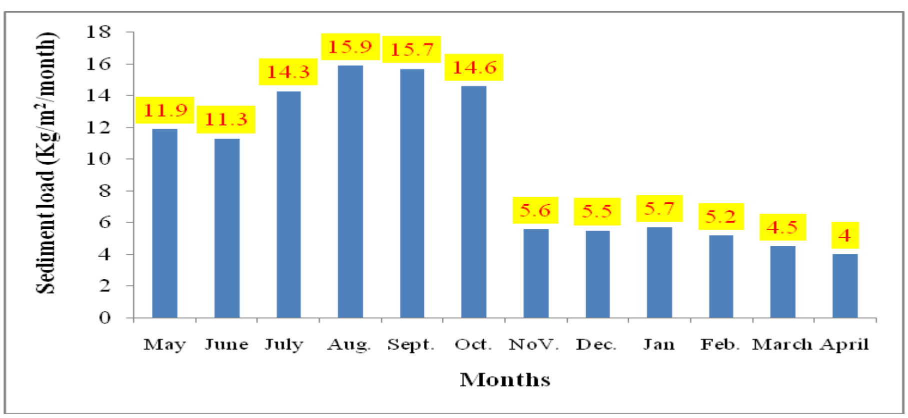


Fig 31. Seasonal pattern of sediment load in the Arial Khan river (May 2015 to April 2016).

5.2.2 Loss on ignition (LOI)

The results of LOI in the Bishkhali and the Arial Khan river sediments have been presented in Appendix 3 & 4. LOI ranged from 5.0 to 6.5 percent with a mean value of 5.8 percent in Bishkhali river sediment and 4.9 to 6.1 percent with an average value of 5.6 percent in Arial Khan river sediment. The loss on ignition is usually dependent on organic matter, lime and relative abundance of the clay minerals (Khan 1954; Quasem 1956, Hussain, 1961, and Rahman, 2009).

5.2.3 Particle size distribution

The results of particle size distribution in the studied sediments have been presented in Table 5 & 6. The particle size analysis of the sediments indicates that sediments of both the rivers consist exclusively of sand, silt and clay. Silt was the dominant size fraction followed by sand and clay. The silt content in the Bishkhali river sediment ranged from 57 to 61 percent with a mean value of 59 percent and in the Arial Khan river it ranged from 57 to 65 percent with a mean value of 61 percent in. This is in agreement with the findings of Hossain (1992). He studied on loose sediments of some coastal river and noted that silt was the dominant size fraction in them (>50%).

The sand content in the suspended sediments ranged from 16 to 24 percent and clay content ranged from 18 to 23 percent. The percentage of sand, silt and clay fraction slightly varied between the wet and dry season. There were no appreciable variations in the contents of sand, silt and clay between the sediments of two rivers. These results are in agreement with the findings of Morghan and Mclntire (1959); (FAO, 1977); Alam *et al*. (1990) and Umitsu (1993). The above authors stated that the floodplain sediments of the Ganges- Brahmaputra- Meghna (GBM) rivers in the Bengal basin were mainly composed of fine sand and silt.

Jalal *et al*. (2009) have studied the physico-chemical characteristics of the coastal water sediments in Pulau Tuba River, Langkawi, Malaysia from four stations and remarked that the silt was the dominant size fraction followed by sand and clay. Their findings are also in accord with us.

The textural classes of both the river suspended sediments were silt loam (Fig 27 & 28). Similar observations have been made by Rahman *et al.* (2009). They noted that the textural classes in the suspended sediments of the Ganges and Brahmaputra rivers from silt loam to loam.

Table 5. Results of particle size distribution of the Bishkhali river sediment.

Location	Season	Month	Sand	Silt	Clay	Textural class*
			2-0.2 mm	**0.02-0.002mm**	**<0.002 mm**	
1	**Wet Season**	May 2013	20	57	25	SiL
		June 2013	21	57	21	SiL
		July 2013	21	59	20	SiL
		Aug 2013	23	57	20	SiL
		Sep 2013	23	59	19	SiL
		Oct 2013	18	56	26	SiL
		Mean	**20**	**58**	**22**	**SiL**
	Dry season	Nov 2013	14	60	26	SiL
		Dec 2013	22	57	22	SiL
		Jan 2014	19	59	22	SiL
		Feb 2014	20	59	20	SiL
		Mar 2014	24	58	18	SiL
		Apri 2014	22	54	24	SiL
		Mean	**20**	**58**	**22**	SiL
2	**Wet Season**	May 2014	23	56	21	SiL
		June 2014	18	58	23	SiL
		July 2014	19	55	26	SiL
		Aug 2014	20	56	24	SiL
		Sep 2014	23	56	22	SiL
		Oct 2014	19	59	22	SiL
		Mean	**22**	**57**	**22**	SiL
	Dry season	Nov 2014	22	56	22	SiL
		Dec 2014	21	57	23	SiL
		Jan 2015	23	56	21	SiL
		Feb 2015	21	57	22	SiL
		Mar 2015	22	57	21	SiL
		April 2015	23	56	21	SiL
		Mean	**19**	**60**	**21**	SiL
3	**Wet Season**	May 2015	22	55	23	SiL
		June 2015	22	57	21	SiL
		July 2015	19	60	21	SiL
		Aug 2015	21	58	21	SiL
		Sep 2015	21	60	19	SiL
		Oct 2015	19	62	19	SiL
		Mean	**21**	**59**	**21**	SiL
	Dry season	Nov 2015	20	59	21	SiL
		Dec 2015	21	58	21	SiL
		Jan 2016	20	61	19	SiL
		Feb 2016	18	63	19	SiL
		Mar 2016	18	62	20	SiL
		April 2016	18	62	20	SiL
		Mean	**19**	**61**	**20**	**SiL**
		Grand mean	**20**	**59**	**21**	**SiL**

SiL= Silt loam

Table 6. Results of particle size distribution of the Arial Khan river sediment.

Location	Season	Month	Sand	Silt	Clay	Textural class*
			2-0.2 mm	**0.02- 0.002mm**	**<0.002 mm**	
	Wet Season	May 2013	18	65	22	SiL
		June 2013	16	65	21	SiL
		July 2013	17	66	20	SiL
		Aug 2013	19	59	22	SiL
		Sep 2013	20	65	18	SiL
		Oct 2013	17	62	22	SiL
1		**Mean**	**16**	**65**	**23**	SiL
	Dry season	Nov 2013	16	66	21	SiL
		Dec 2013	16	62	23	SiL
		Jan 2014	21	53	23	SiL
		Feb 2014	19	55	25	SiL
		Mar 2014	18	59	24	SiL
		Apri 2014	25	49	22	SiL
		Mean	**21**	**60**	**20**	SiL
	Wet Season	May 2014	22	60	19	SiL
		June 2014	19	63	21	SiL
		July 2014	22	58	22	SiL
		Aug 2014	23	58	20	SiL
		Sep 2014	21	60	20	SiL
		Oct 2014	21	58	22	SiL
2		**Mean**	**21**	**59**	**22**	SiL
	Dry season	Nov 2014	22	58	19	SiL
		Dec 2014	22	58	19	SiL
		Jan 2015	23	56	20	SiL
		Feb 2015	24	55	19	SiL
		Mar 2015	23	56	19	SiL
		April 2015	24	59	16	SiL
		Mean	**24**	**57**	**18**	SiL
	Wet Season	May 2015	22	61	17	SiL
		June 2015	20	61	19	SiL
		July 2015	20	62	18	SiL
		Aug 2015	20	60	20	SiL
		Sep 2015	20	63	17	SiL
		Oct 2015	24	62	14	SiL
3		**Mean**	**21**	**62**	**18**	SiL
	Dry season	Nov 2015	20	62	18	SiL
		Dec 2015	18	60	22	SiL
		Jan 2016	17	59	24	SiL
		Feb 2016	17	61	22	SiL
		Mar 2016	19	59	22	SiL
		April 2016	20	61	19	SiL
		Mean	**19**	**60**	**21**	SiL
Grand mean			**20**	**61**	**20**	SiL

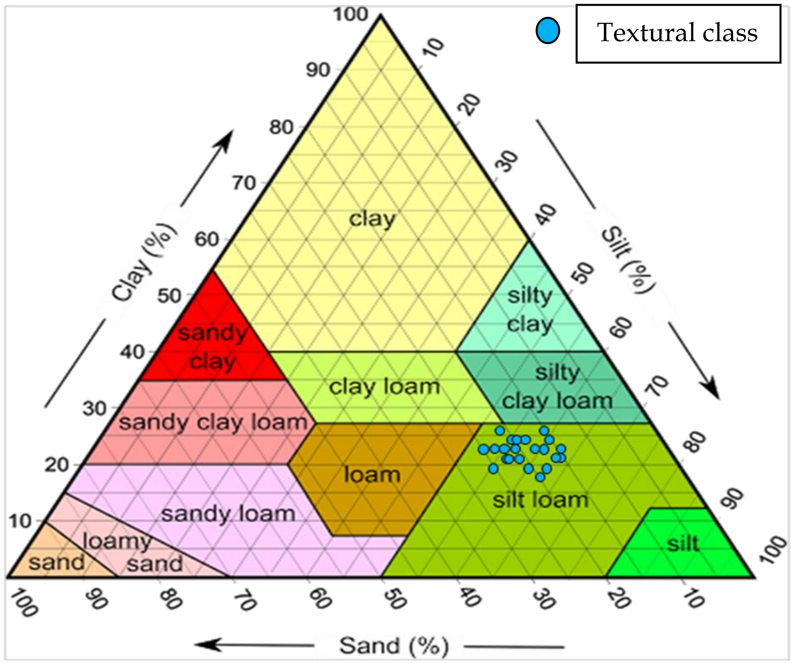


Fig 32. Distribution of the textural classes in the sediments of Bishkhali River.

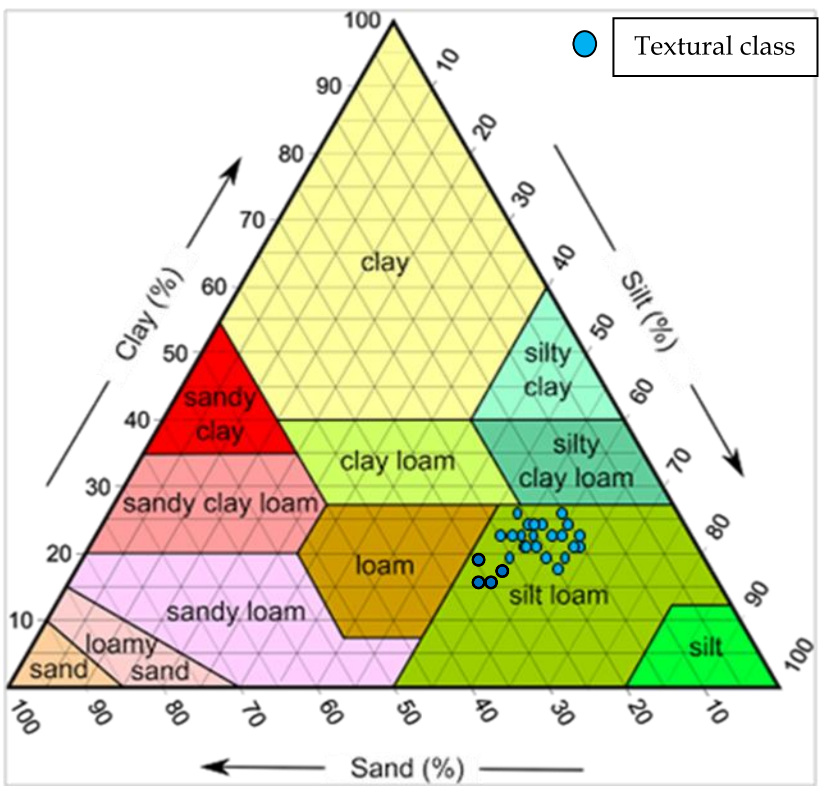


Fig 33. Distribution of the textural classes in the sediments of Arial Khan river.

5.3 Chemical parameters of the sediments

5.3.1 pH

The results of pH (H_2O) of the sediment samples have been presented in Table 7 & Appendix 5 & 6. The pH of the sediments ranged from 7.7 to 8.0 with a mean value of 7.9. The high pH value was found in both the river suspended sediments that indicates slightly alkaline in reaction. The results showed that there were no significant differences in pH value between the sediments of two rivers. When pH was determined with I N KCl solution in place of water, there was a substantial decrease in pH values than that in water. This decrease in pH value has been designated as ΔpH value. The ΔpH values of all the studied sediments were negative and ranged from – 0.1 to – 0.3 which point out low content of reserve acidity.

Hossain (1992) studied the loose sediments of some coastal river of Bangladesh and noted pH values in all the sediments around 8.0. Rahman *et al.* (2009) found the pH of the Ganges and the Brahmaputra sediments ranged from 6.95 to 7.9.

Jalal *et al*. (2009) examined the coastal sediment of Malaysia and found the pH value ranged from 7.72 to 8.20.

5.3.2 Electrical conductivity (EC)

The electrical conductivity of the sediment ranged from 0.248 to 0.167 dS/m (Table 7; Appendix 5 & 6) which was very low. EC value in the sediments indicates that sediments are non-saline. The results showed seasonal variation among the sediments of two rivers and are in accord with the findings of Rahman *(*2009); (BARC, 2012). Rahman studied the Ganges and Brahmaputra river sediment and found the (EC) ranged from 0.20 to 0.32 dS/m .

5.3.3 Free lime of the sediments

The presence of free lime provides information about the nature of sediment. The free lime contents in the studied sediments range from 3.0 to 5.4 percent (Table 7; Appendix 5 & 6). In both the season free lime was found more or less similar in composition in both the river sediments. From these findings it can be assumed that sediments are well mixed of three mighty rivers – Ganges, Brahmaputra and Meghna and slightly calcarious in nature. Lime content in the Ganges sediments was found higher than the Brahmaputra sediment and Ganges sediments reported as calcareous sediment (Rahman *et al.* 2009).

Table 7. Mean values of chemical properties of the Bishkhali and the Arial khan river sediment.

Location	Year	Season	pH (H_2O)	pH (KCl)	ΔpH	EC* (dS/m)	Free lime (%)	Organic carbon %
Bishkhali river sediment								
1	2013-14	Wet	7.8	7.5	-0.3	0.153	5.4	0.55
		Dry	7.9	7.7	-0.3	0.348	5.0	0.63
2	2014-15	Wet	7.8	7.5	-0.3	0.168	4.9	0.59
		Dry	7.7	7.5	-0.2	0.313	4.4	0.77
3	2015-16	Wet	7.7	7.4	-0.2	0.217	4.7	0.57
		Dry	7.7	7.4	-0.2	0.288	3.4	0.64
Grand Mean			**7.8**	**7.5**	**-0.2**	**0.248**	**4.6**	**0.63**
Mean of wet season			**7.8**	**7.5**	**-0.2**	**0.179**	**5.0**	**0.57**
Mean of dry season			**7.8**	**7.6**	**-0.2**	**0.316**	**4.3**	**0.68**
Arial Khan river sediment								
1	2013-14	Wet	7.8	7.5	-0.2	0.139	3.9	0.63
		Dry	7.7	7.5	-0.2	0.215	3.4	0.79
2	2014-15	Wet	8.0	7.8	-0.3	0.137	3.1	0.61
		Dry	7.9	7.7	-0.1	0.185	3.0	0.70
3	2015-16	Wet	8.0	7.8	-0.2	0.131	3.3	0.46
		Dry	8.0	7.8	-0.2	0.195	3.2	0.46
Grand Mean			**7.9**	**7.7**	**-0.2**	**0.167**	**3.3**	**0.61**
Mean of wet season			**7.8**	**7.7**	**-0.2**	**0.136**	**3.4**	**0.57**
Mean of dry season			**7.9**	**7.7**	**-0.2**	**0.198**	**3.2**	**0.65**

*EC= Electrical conductivity at saturation extract

5.3.4 Organic carbon of the sediments

The organic carbon content in the studied sediments was low and ranged from 0.46 to 0.79 percent (Table 7; Appendix 5 & 6). The organic carbon content in the Bishkhali river sediment ranged from 0.55 to 0.77 percent and in the Arial Khan river sediment ranged from 0.46 to 0.79 percent, respectively. The amount of organic carbon slightly varies from season to season. These results are in agreement with the findings of Hossain (1992) and Rahman (2009). Hossain (1992) studied on loose sediments of some coastal river of Bangladesh and concluded that organic matter content is poor in all the sediments. Rahman *et al.* (2009) observations were similar with our findings. They noted the average content of organic matter in the Ganges river sediments is 0.65 percent and Brahmaputra river sediments is 0.62 percent. Kamaruzzaman *et al*. (2006) have conducted an experiment on the sediment of the Pahang coastal area, Malaysia and reported that organic carbon content varies from season to season.

5. 4 Physico- chemical Properties of the sediments

5.4.1 Exchangeable cations (Na^+, K^+, Ca^{++}, Mg^{++})

Results of exchangeable cations have been registered in Table 8 & Appendix 7 & 8. Among the exchangeable cations Mg^{++} is by far the dominant cation in the sediments of Bishkhali and the Arial Khan river.

The exchangeable magnesium contents in the suspended sediments vary from 1.17 to 1.84 cmol kg^{-1} sediment (Table 8). The higher values of exchangeable Mg^{++} in the coastal river sediments is thought to be an indication of old marine deposits and Mg^{++} is maintained at a relatively high level, probably as results of progressive clay disintegration and release of Mg^{++}. Moreover, the higher amount of Mg^{++} content presumably was due to the connection with seawater of high Mg^{++} content.

Exchangeable Ca^{++} in the coastal sediments varies from 0.43-0.76 cmol/kg in Bishkhali and 0.55-0.76 cmol kg^{-1} (Table 8). The exchangeable calcium was found higher in Arial Khan sediment (0.64 cmol kg^{-1}) in compared to Bishkhali sediment (0.49 cmol kg^{-1}).

The mean value of exchangeable K^+ in the Bishkhali sediment ranges from 0.02-0.05 cmol kg^{-1} and 0.14 to 0.16 cmol kg^{-1} in Arial Khan sediment (Table 8). This value is found higher in Arial Khan sediment.

The mean value of exchangeable Na^+ in the Bishkhali sediment was found 2.50 cmol/kg and 2.45 cmol kg^{-1} in Arial Khan sediment. This value is more or less similar in both the river sediment (Table 8).

5.4.2 Cation exchange capacity (CEC)

The CEC is a very important physic-chemical property of sediments for predicting the type of clay minerals. The cation exchange capacity of the sediments under the present investigation ranged from as low as 6.80 to as high as 11.36 cmol kg^{-1} (Table 8). The reason for such low CEC values is due in most cases to their low clay content.

5.4.3 Base saturation percentage (BSP)

The base saturation percentage of the sediments under the present investigation ranges between 44 to 62 percent. The highest mean value was found in Bishkhali sediment (62%) and the lowest in the Arial Khan river sediment (Table 8; Appendix 7 & 8).

Table 8. Mean results of exchangeable bases, CEC, BSP of the Bishkhali and the Arial khan river sediment.

Location	Year	Season	Na^+	K^+	Ca^{++}	Mg^{++}	TEB*	*CEC	BSP
Bishkhali river sediment									
			Cmol kg^{-1}						
1	2013-14	Wet	2.55	0.03	0.71	1.21	4.49	6.82	66
		Dry	2.37	0.05	0.46	1.31	4.19	6.82	61
2	2014-15	Wet	2.45	0.05	0.45	1.39	4.35	7.2	60
		Dry	2.84	0.03	0.45	1.32	4.63	7.40	63
3	2015-16	Wet	2.42	0.02	0.43	1.20	4.08	6.55	62
		Dry	2.39	0.03	0.45	1.17	4.04	6.72	60
Grand Mean of wet season			**2.47**	**0.03**	**0.53**	**1.27**	**4.31**	**6.86**	**63**
Grand Mean of dry season			**2.53**	**0.03**	**0.45**	**1.27**	**4.29**	**6.98**	**61**
Arial Khan river sediment									
1	2013-14	Wet	2.49	0.14	0.76	1.69	5.07	10.06	50
		Dry	2.47	0.14	0.66	1.65	4.91	11.51	43
2	2014-15	Wet	2.63	0.16	0.56	1.71	5.06	11.36	45
		Dry	2.39	0.15	0.75	1.69	4.98	11.87	42
3	2015-16	Wet	2.40	0.14	0.56	1.84	4.93	11.28	44
		Dry	2.33	0.15	0.55	1.69	4.72	11.51	41
Grand Mean of wet season			**2.51**	**0.15**	**0.63**	**1.75**	**5.02**	**10.90**	**46**
Grand Mean of dry season			**2.40**	**0.15**	**0.65**	**1.68**	**4.87**	**11.63**	**42**

5.5 Total analyses of the sediments

The results of total analyses of the suspended sediments are registered in Table 9 & 10; Appendix 9 - 10 & 11 - 12. Highest concentration of silica was found in Bishkhali river sediment (SiO_2 = 60 %,) followed by Al (Al_2O_3 = 17.98%), Fe (Fe_2O_3 = 5.45%), Mg (MgO =4.62 %), Ca (CaO = 2.36 %), K (K_2O = 1.55 %), and Ti ($TiO_{2=}$ 0.51 %).

In the Arial Khan river sediment silica had the highest average concentration (SiO_2 = 61%), followed by Al (Al_2O_3 = 17.84 %) and Fe (Fe_2O_3 = 5.46 %) , Mg (MgO = 4.31 %) , Ca (CaO = 2.39%), K (K_2O = 1.47 %) and Ti (TiO_2 = (1.00 %) .

The total elemental composition in the studied sediments show the following gradation in the decreasing order of abundance: SiO_2> Al_2O_3 > Fe_2O_3 > MgO > CaO > K_2O > TiO_2 > MnO_2. Rahman *et al.* (2009) found the similar trend in the Ganges and Brahamaputra river sediments in their study.

Table 9. Mean results of chemical composition of the Bishkhali and the Arial khan river sediment

Bishkhali river							
Location	Year	Season	SiO_2	Al_2O_3	Fe_2O_3	MgO	SiO_2/R_2O_3 molar ratio
			%				
1	2013-14	Wet	59	18.87	4.60	4.38	5.48
		Dry	61	17.43	5.13	4.72	5.85
2	2014-15	Wet	60	18.15	5.69	4.70	5.34
		Dry	59	18.02	5.50	4.66	5.43
3	2015-16	Wet	60	18.26	5.50	4.55	5.43
		Dry	60	17.18	6.29	4.70	5.54
Grand Mean of wet season			**60**	**18.43**	**5.26**	**4.68**	**5.61**
Grand Mean of dry season			**60**	**14.27**	**5.64**	**4.69**	**5.61**
Arial Khan river							
1	2013-14	Wet	62	18.14	5.06	3.75	5.62
		Dry	62	17.61	5.37	4.44	5.73
2	2014-15	Wet	61	18.23	5.69	4.39	5.39
		Dry	60	18.26	5.83	4.46	5.42
3	2015-16	Wet	61	17.59	5.50	4.48	5.65
		Dry	61	17.21	5.33	4.35	5.81
Grand Mean of wet season			**61**	**17.99**	**5.42**	**4.21**	**5.55**
Grand Mean of dry season			**61**	**17.52**	**5.51**	**4.42**	**5.65**

Table 10. Mean results of CaO, K_2O, and P2O5, TiO2 contents in the Bishkhali and the Arial khan river sediment.

Bishkhali river						
Location	Year	Season	CaO	K_2O	P_2O_5	TiO_2
			%			
1	2013-14	Wet	2.35	1.63	0.18	0.41
		Dry	2.44	1.63	0.21	0.47
2	2014-15	Wet	2.18	1.51	0.24	0.56
		Dry	2.44	1.58	0.21	0.48
3	2015-16	Wet	2.34	1.59	0.26	0.58
		Dry	2.43	1.39	0.25	0.56
Grand Mean of wet season			**2.29**	**1.58**	**0.23**	**0.52**
Grand Mean of dry season			**2.44**	**1.54**	**0.22**	**0.52**
Arial Khan river						
1	2013-14	Wet	2.35	1.44	0.20	0.94
		Dry	2.44	1.11	0.22	1.01
2	2014-15	Wet	2.18	1.44	0.30	1.00
		Dry	2.44	1.61	0.35	1.01
3	2015-16	Wet	2.34	1.72	0.33	1.06
		Dry	2.57	1.49	0.31	1.00
Grand Mean of wet season			**2.29**	**1.53**	**0.28**	**0.98**
Grand Mean of dry season			**2.48**	**1.23**	**0.29**	**1.01**

5.6 Morphological characteristics of the soils

An attempt has been made to look into the morphological characteristics of the coastal floodplain soils of Bangladesh to see whether they reflect the influence of the existing soil forming factors. Detailed morphological description of the soil profiles have been presented in the previous chapter. From that description it is evident that an incipient B horizon has developed in all the soils under study. This development is an outstanding feature in the life history of these soils. This B horizon has been designated as structural B and therefore has been considered as a cambic horizon.

The coded morphological properties of the studied soils have been presented in Table 11. Among the salient morphogenetic properties of the soils colour, mottling, consistence, structure, texture and root distribution have been recorded and discussed in the following sections.

The matrix colour of the present soils is a combination of grey to dark grey and olive grey to light olive grey colours. Under moist condition, the matrix color of surface horizon of all the profiles was found to be grey (5Y 5/1, moist) and dark grey (5Y 4/1 moist). The dominant hue of the soil matrix, when moist is 5Y while two or three horizons were 2.5Y. These hues in these soils have been developed due to prolonged submergence during rainy season and drying condition during the dry months. These hues are related to the loss of free iron in these soils. The soils have low chroma which is < 2 in most of them (Table 11).

All the soils remain flooded during the monsoon season. Oxidation during the dry season and reduction during the wet season are the two usual conditions in these soils. Through this alternate oxidation-reduction condition the soil materials gradually become ripened. The seasonal alternate drying and wetting cycles in the soils resulted in release of iron from iron bearing minerals and create a condition for transformation of Fe^{2+} to Fe^{3+} which in turn was precipitated and fixed in the form of mottles in the sub-surface horizon of the soils. This process has been designated as Ferrolysis by Brinkman (1977).

Table 11. Coded morphological properties of the studied soils of the coastal zone of Bangladesh*.

Soil Series	Horizon	Depth (cm)	Munsell Colour notation		Texture	Structure	Consistence	Boundary	Special feature	Effervescene
			Matrix	Mottles						
Bhola	Ap	0 – 8	5Y5/1 G	C1Dt dyb	SIL	PM*	WSST,WSPL,MFR	AS		N
	Ad	8 – 12	5Y4/1 DG	F1Dt ob	SIL	PM	WSST,WSPL,MFR	AS	Fe-staining	N
	Bw1	12 – 28	5 Y5/2 OG	C1 Dt dyb	SIL	CO1PR	WSST,WSPL,MFR	CS		N
	C1	28 – 40	5 Y5/2 OG	C2Dt yr	SIL	CO2PR	WSST,WSPL,MFR	CS		N
	C2	40– 90+	5Y5/2 OG	F2-3Dt yr	SIL	MA	WSST,WSPL,MVFR	CS		N
Nilkamal	Ap	0 – 13	5Y5/1G	F1Fa yb	SIL	PM	WSST,WSPL,MFI	CS	patchy grey cutans	N
	Ad	13 – 18	5Y 5/1 G	M1Dt ob	SIL	PM	WSST,WSPL,MFI	AS		N
	Bw1	18 – 45	5Y 5/2 OG	C1Dt yb	SICL	VC2PR	WSST,WSPL,MFI	CS		N
	Bw2	45 – 80	5Y5/2 G	C2Dt drb	SIL	MA	WSST, WSPL MFR	GS		MO
	C1	80– 105+	5Y5/1 G	F1-2 dt db	SIL	MA	WSST,WSP, MVFR	GS		MO
Pirojpur	Ap	0 – 10	5Y4/1	C1Dt yb	C	PM	WVST,WVP, MFR	AS	.	N
	Ad	10 – 14	5Y4/1 DG	C1Dt yb	C	PM	WVST,WVP,MVFR	CW	A buried peat layer was present below the sub surface	N
	Bw1	14 – 28	5Y5/2 G	C1Dt yb	C	CV 3PRAB	WVST,WVPL,NVFR	CS		N
	Bw2	28 – 50	5Y5/2 G	F1Dt yb	SIC	C 3 PRAB	WVST,WVPL,MVFR	CS		N
	C1	50—70	5Y4/1 DG	------	SIC	MA	WST WSPL MFR	AS		N
	C2	70 – 120+	5Y4/1 DG	------	SIC	MA	WST, WSPL ,MFR	-		N
Hogla	Ap	0 – 11	5Y5/1G	C1Dt yb	SICL	PM	WST,WPL, MFI	AS	a buried peat layer was present below the sub surface.	N
	Ad	11 – 15	5Y4/2 DG	C1Dt yb	SIC	PM	WST,WPL,MVFI	AS		N
	Bw1	15 – 48	5Y4/2 DG	M1Dt yb	SICLl	C 3 PRAB	WVST, WPL, MFI	CS		N
	Bw2	48 – 60	5Y4/2 DG	C1Dt yb	SICL	C 3PR	WVST,WPL,MFI	CS		N
	C1	60 – 85	5Y4/2 DG	-----	SIC	MA	WST, WPL MVFI	CS		N
	C2	85 – 110+	5Y4/2 DG	------	SIC	MA	WST, WPL, MVFI	CS		N

Continued next page-

Table 11 Coded Morphological Properties of the studied soils of the coastal zone of Bangladesh*.

	Ap	0 – 10	5Y5/1 G	C1Dt dyb+sb	SICL	PM	WST, WPL, MFR	AS	Dark gray	
Muladi	Ad	10 – 17	2.5Y 5/2 OG	C1Dt ob+sb	SICL	PM	WST, WPL, MFR	AS	Stratification found below the surface soil.	SL
	Bw1	17 – 34	5Y 4/2 DG	C1Fa ob	SICL	C 3 PRAB	WST, WPL, MFR	CS		MO
	Bw2	34 – 62	5Y 4/2 DG	M1Dt o	SICL	C 3PR	WST, WPL,MFR	CS		MO
	C1	62 – 94	2.5Y5/2 OB	M1Dt dbm	SL	MA	WSST, WNSL,MFR	AS		MO
	C2	94– 105+	5Y5/2 OG	C2Dt yb	SL	MA	WNSTWNPLMFR	-		MO
Barisal	Ap	0 – 10	5Y5/1 G	C1Dt dyb-yb	SIC	PM	WST,WVPL,MVFI	AS	patchy iron cutans along pores. Width of crack is Fine(<1 cm) and depth is <2 cm .on the surface.	N
	Ad	10– 18	5Y4/2 DG	F1Dt yb +sb	C	PM	WVST, WVPL, MVFI	aAS		N
	Bw1	18 – 50	5Y4/2DG	C1Dt yb	SIC	C 3 PRAB	WVST,WVPL, MVFI	CS		N
	Bw2	50 – 77	5Y4/2 DG	F1Dt yb	SIC	C 3 PRAB	WVST, WVPL MVFI	CS		N
	C1	77 – 110	5Y5/2 G	C2 Dt yb	C	MA	WVST, WVPL, MVFI	CS		N
	C2	110 – 125+	5Y5/1 G	C1Dt dyb	C	MA	WVST, WVPL, MVFI	-		N
Jhalakati	Ap	0 – 10	5Y5/1 G	C1Dt yb	SICL	PM	WST,WSPL, MFI	AS	Artifacts & krotovina found below the surface soil. White salt crust found on the surface.	N
	Ad	10 – 16	5Y5/1 G	C1Dt yb	SIC	PM	WST, WSPL, MVFI	AS		N
	Bw1	16 – 35	5Y5/2 DG	M1Dt yb	SICL	VC 3 PRSB	WST, WSPL, MFI	CS		N
	Bw2	35 – 55	5Y5/2 DG	M1Dt yb	SICL	VC 3 PRAB	WST, WSPL, MFI	CS		N
	C1	55– 80	5Y5/1OG	C2Dt , yb- db	SICL	ME 2 SB	WST, WSPL MFI	CS		N
	C2	80 – 99+	5Y5/2 OG	C2Dt yb- db	SIL	MA	WSST,WSPL,MVFI	-		N
Ramgati	Ap	0 – 8	5Y5/1 G	M1Dt	SIL	PM	WSST, WSPL MFR	AS	Coarse iron staining on soil mass	N
	Ad	8 – 12	5Y5/1 G	M1Dt dyb	SIL	PM	WSST, WSPL, MFR	AS		N
	Bw1	12 – 35	2.5 Y 4/3OB	M1Dt yb	SIL	C 1PR	WSST, WSPL, MFR	CS		N
	Bw2	35 – 53	2.5 Y 4/2OB	M1Dt,yb-db	SIL	C 1PR	WSST, WSPL,MFR	CS		N
	C1	53 – 71	5Y5/2 OG	F1Fa ob	SIL	MA	WSST, WSPL MVFR	AS		N
	C2	71 – 105+	5Y5/2 OG	F1Fa sbr	SIL	MA	WSST, WSPL, MVFR	AS		N

*According to the guidelines for soil description (fourth edition) (FAO, 2006). Explanation of abbreviations of coded morphological properties is given in Appendix 13.

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The variation of soil colors may be related to variation in duration of flooding period, oxidation-reduction and movement of iron from the surface downward as well as the quantity of organic matter (Brammer, 1971; Daniel *et al.* 1971; Diwakar and Singh, 1992; Begum *et al.* 2004). The variation in drainage condition is also responsible for variation in soil colors

Moorman (1978) noted that in seasonally flooded soils the sub-surface horizon usually develop perfect grey colors. It must be remembered that the relict colors i.e. those inherited from the parent materials, may be present in some soils.

Hussain *et al.* (1989) also pointed out the occurrence of similar hues in some soils of coastal belt. It was noted earlier that the studied soils are basically poorly drained. In poorly drained soil, water is removed so slowly that the soil remains wet for longer period of time. The land sometimes remains wet after the monsoon season.

Due to alternate wetting and drying condition abundant quantities of mottles have formed in all the soil profiles (Table 11). The color of mottles was a combination of dark brown to strong brown and light yellowish brown to yellowish brown. These color patterns might have been developed along root channels and pores created by crabs and other soil habitats that facilitate air to enter into the soil mass when the flood water recedes. The size and contrast of mottles showed variation from soil to soil. This is due to the intensity and duration of oxidation-reduction conditions in the soils (Rahman *et al.* 2009; Khan *et al.* 2012; Islam *et al.* 2014b). The presence of mottled in the sub-surface zone is the characteristics of hydromorphic soils (Joffe, 1966).

The formation of variously coloured mottles is generally associated with seasonal fluctuation of ground water table (Mckeague, 1965). Field evidence suggests that the degree of development of mottles differs considerably in soils of apparently similar moisture regime. Such difference in development of mottle at least partly may be ascribed to the nature of the parent materials.

Silt loam to silty clay loam is the dominant texture in the sub-soil horizons of ridge position whereas in the sub-soils horizons of basin soil profile it is silty clay to clay.

The structure of the soils was massive in all the surface horizon of the studied soils. Any stable structure did not develop in the surface horizon as it has been ploughed for many years with puddling as a usual feature. Weak prismatic to angular blocky structure showed in the B horizon of all the studied profiles.

Continuous or nearly continuous thick dark grey to very dark grey cutans along vertical and horizontal ped faces were found in the sub-soils in all the profiles. The coatings on ped faces may possibly be due to mechanical down washing of material from the soil surface through cracks when the soils are flooded and ploughed (Khan *et al.* 2012).

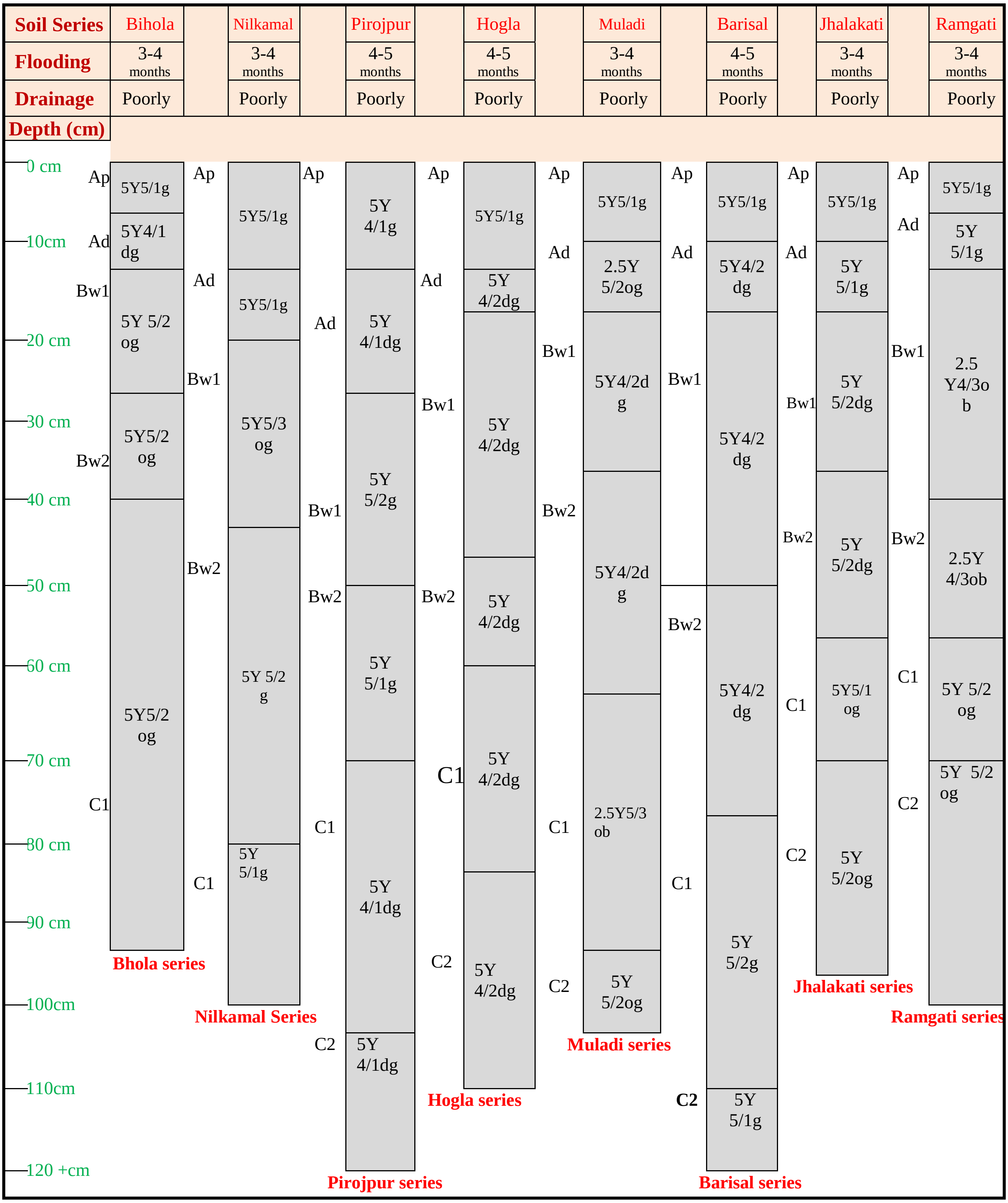

Fig 34. Some morphological properties of the studied pedons.

Horizon boundaries are important morphological properties in soil profiles. Horizon boundaries provide information on the dominant soil- forming processes that have formed the soil. Most soil boundaries are zones of transition rather than sharp line of division. Clear smooth boundary was found in most of the soils. Khan *et al.* (2012) also found the similar boundary in the floodplain soil of Bangladesh.

Another important feature is the effervescence of carbon dioxide gas with 10% HCl to the soil. The effervescence indicates the amount of calcium carbonate present of the soils. Bhola, Nilkamal and Ramgati soil show slightly effervescence (audible effervescence but not visible) while Muladi soil showed moderately effervescence (visible effervescence) with HCl. No effervescence phenomenon found in the rest soil pedon.

Ploughpan occurs at a depth of 5 to 15 cm in all the pedons, depending on the normal depth of ploughing. It is normally formed due to continuous rice cultivation (FAO, 1971). It has been observed that the ploughpan becomes thicker and harder through continuous practice of transplanted *Aman* rice cultivation.

Results of soil consistence are very important for soil management especially during tillage. This assumes importance when the soils are ploughed in wet condition. The consistence of the soils under study have been determined under three moisture conditions- moist and wet (Soil Survey Staff, 1975).

The consistence of the surface soils of studied alluvium soil was found to be hard to very hard when dry. Most of these soils had firm consistence in moist condition. In the lower part of Hogla and Pirojpur series slightly sticky to sticky and plastic consistence was observed in wet condition. The consistence of the soil material of different horizons depends on several characteristics of the soils such as textural class and the type of clay minerals present.

It seems expedient to summarize here the salient morphological features of the soils under the present investigation.

- Grey matrix color is a characteristic feature of these soils. The top soils were generally grey to dark grey in color (moist) with silt loam to silty clay textures except Pirojpur and Barisal soils where it was clayey in the top soil.
- The sub-soils were generally grey to olive grey in color (moist) with silt loam to silty clay textures except in Pirojpur and Barisal soils where it was clayey.
- Flood coatings and variously colored mottles present in the sub-soil zone of all the soil profiles.
- Prismatic to sub-angular blocky structures were developed in the sub-surface horizons of all the profiles whereas massive structure was found in the surface horizons.

- Development of cambic horizon is the most notable morphogenetic feature in these soils.
- All the soil profiles showed abrupt to clear smooth horizon boundaries reflecting rejuvenation in soil development.
- Parent material of the soils is of alluvial origin with regular siltation from flooding water. The attributes of parent material and the associated aquic soil moisture regime dominantly influenced the genesis of these soils.

Thus it seems quite clear that the pedogenic factors such as climate, parent material, drainage conditions and relief position etc. that are pertinent to the soils under the investigation were responsible for the development of some morphological features.

5.7 Physical properties of the soils

Physical properties does not change their pattern easily as chemical properties and hence impart the most useful contribution in soil classification, management and improvement of cultivated soils. Some of these characteristics are recorded in the field and others in the laboratory. The outstanding findings of physical parameters are described below:

5.7.1 Particle density

Particle density of the studied soils ranged from 2.54 to 2.67 g/cm^3 in top soils while it was observed 2.50 to 2.72 g/cm^3 in sub-soils (Table 12). In almost all soils particle density showed higher values in sub soils than top soils due to the presence of higher clay contents. The higher particle densities in the sub-soils are also probably due to their variation in mineralogical composition. Higher values of particle density (2.70-2.72 g/cm^3) in the sub-soils of some Bangladesh soils were reported by Huizing (1970). These findings were in accord with the results reported by BARC (1991), Rahman *et al.* (2005).

5.7.2 Bulk density and porosity

The bulk density of the soils varies from 1.23 to 1.53 g/cm^3 with a mean value of 1.37g/cm^3 (Table12). Higher bulk density was associated with compactness and low pore space in soils. Low bulk density values (generally below 1.3 g/cm^3) indicate a porous soil condition. Most of the floodplain soils were found to have higher bulk density due to compaction resulting from rice cultivation in wet season.

Table 12. Results of particle density, bulk density and porosity of the studied soils.

Soil Series	Horizon	Depth (cm)	Particle density (Dp)g/cm^3	Bulk density (Db)g/cm^3	Total porosity (%)
Bhola	Ap	0-8	2.62	1.31	50
	Ad	8-12	2.63	1.45	45
	Bw1	12-28	2.65	1.39	48
	Bw2	28-40	2.64	1.38	48
	C1	40-90+	2.67	1.41	47
	Mean		**2.64**	**1.39**	**47**
Nilkamal	Ap	0-13	2.59	1.39	46
	Ad	13-18	2.64	1.51	43
	Bw1	18-45	2.67	1.45	46
	Bw2	45-80	2.68	1.43	47
	C1	80-105+	2.67	1.46	45
	Mean		**2.65**	**1.45**	**45**
Pirojpur	Ap	0-10	2.66	1.32	50
	Ad	10-14	2.53	1.4	45
	Bw1	14-28	2.66	1.35	49
	Bw2	28-50	2.65	1.32	50
	C1	50-70	2.67	1.33	50
	C2	70-120+	2.69	1.34	48
	Mean		**2.64**	**1.34**	**49**
Hogla	Ap	0-12	2.54	1.28	50
	Ad	12-15	2.56	1.48	42
	Bw1	15-48	2.68	1.25	53
	Bw2	48-60	2.59	1.29	50
	C1	60-85	2.67	1.31	51
	C2	85-110+	2.72	1.31	50
	Mean		**2.63**	**1.32**	**49**

Continued next page-----------

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Table 12. Results of particle density, bulk density and porosity of the studied soils .

Soil Series	Horizon	Depth (cm)	Particle density (Dp)g/cm^3	Bulk density (Db)g/cm^3	Total porosity (%)
Muladi	Ap	0-10	2.54	1.27	50
	Ad	10-17	2.56	1.46	43
	Bw1	17-34	2.55	1.23	52
	Bw2	34-62	2.55	1.25	51
	C1	62-94	2.59	1.3	50
	C2	94-105+	2.62	1.32	49
	Mean		**2.58**	**1.36**	**47**
Barisal	Ap	0-10	2.54	1.27	50
	Ad	10-18	2.55	1.53	40
	Bw1	18-50	2.5	1.34	46
	Bw2	50-77	2.54	1.3	49
	C1	77-110	2.62	1.3	50
	C2	110-125+	2.7	1.31	50
	Mean		**2.58**	**1.36**	**47**
Jhalakati	Ap	0-10	2.59	1.28	51
	Ad	10-16	2.64	1.38	48
	Bw1	16-35	2.6	1.3	50
	Bw2	35-55	2.63	1.31	50
	C1	55-71	2.67	1.32	49
	C2	71-99+	2.69	1.33	51
	Mean		**2.64**	**1.32**	**49**
Ramgati	Ap	0-8	2.64	1.32	50
	Ad	8-12	2.67	1.51	43
	Bw1	12-35	2.7	1.47	46
	Bw2	35-53	2.68	1.41	47
	C1	53-71	2.65	1.32	50
	C2	71-99+	2.66	1.34	49
Mean			**2.67**	**1.41**	**47**
Grand Mean			**2.63**	**1.37**	47

High bulk density values indicate a poorer environment for root growth, reduced aeration (FAO, 2006). This values are slightly higher than those presented by Kawaguchi and Kyama (1969a and 1969b); Tanaka and Yoshida (1970); and Van Breeman (1976). These values are comparatively higher in the Ad horizons than in the Ap horizons of all the pedons under the investigation. These higher bulk density values are thought to be due to compaction by ploughing and decrease of organic matter content (Landon, 1991).

The porosity of the soils ranges from 43 to 53 percent with a mean value of 47 percent (Table 12). Total porosity values were comparatively lower in the Ad horizons than in the Ap horizon in all the investigated soils. The high bulk density and low porosity in the Ad horizons of these soils is due to formation of a compact plough layer at the shallow depth of the soils. Joshua *et al*. (1983) was in all agreement with this results who reported that higher bulk densities could be attributed to the structural breakdown and compaction of the soils due to ploughing under wet conditions. Similar results were also obtained by Xing and Dudas (1992) in some floodplain soils of China and Rahman *et al.* (1992).

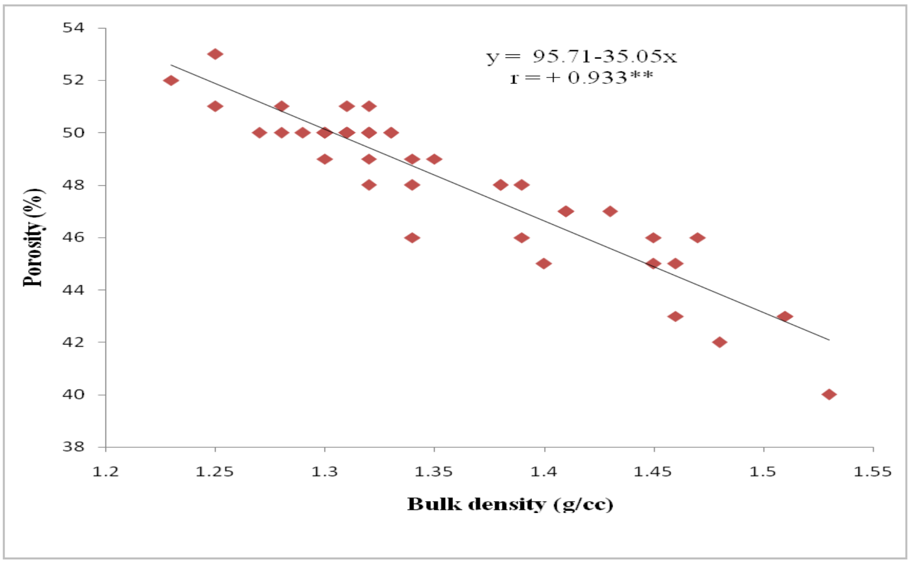

Fig 35. Relationship between bulk density and Percent porosity of the studied soil.

A significant positive correlation (r = +0.933) was found between bulk density and porosity in all the studied soils (Fig 35) which indicates that the higher the porosity the lower is the bulk density and vice versa that may be due to clay and organic matter content of the soils.

5.7.3 Moisture at field condition

The moisture contents at field condition of the studied soils ranged from 17 to 44 percent with a mean value of 26 percent (Table 13). The highest mean moisture of the profiles was observed in the Pirojpur and Barisal soils whereas the lowest mean moisture was observed in the Muladi soil. Moisture in soils at sampling time was found relatively higher in most fine textured soils than the medium textured soils. It was probably due to the relatively low lying position of the fine textured soils in the landscape (Barisal, Pirojpur, Hogla) coupled with greater surface area and better structure in soils (Islam *et al.* 2014b).

Burrows and Kirkham (1958) observed variation in field moisture values with the variation in texture of different soils. They stated that the increase of field moisture of the soils can be attributed to the increase of clay content with depth. During the collection of soil samples the lower horizons were wet due to rise of ground water through capillary pores in soils whereas the upper horizons were relatively dry.

5.7.4 Hygroscopic moisture

Hygroscopic moisture of the investigated soils is rather low and ranges from 1.22 to 4.17 percent with an average of 2.14 percent (Table 13). The highest hygroscopic moisture percent are recorded in the Barisal soil series and the soils of the Muladi series contain the lowest hygroscopic moisture. Such a variation in moisture content retained by air- dry soils is probably due to the difference in their clay and organic matter contents.

A highly significant positive correlation (r =+0.828) was found between percent clay and hygroscopic moisture percent in the present soils (Fig 36). From the figure it is clear that the clay content of the soils shows a positive correlation with the hygroscopic moisture content.

The oven dry/ air dry (OD/AD) ratio of the present soils was found to vary from 0.95 to 0.99 with a mean value of 0.98 (Table 13). The highest same mean value of oven dry/ air dry ratio among the profiles were found in Bhola, Jhalakati and Ramgati soil series and the lowest in Pirojpur and Hogla soil series.

Table 13. Some physical properties of the studied soils.

Soil Series	Horizon	Depth (cm)	Field moisture (%)	Hygroscopic moisture (%)	OD/AD ratio	Loss on ignition (%)
Bhola	Ap	0-8	20	3	0.97	10
	Ad	8-12	19	2	0.98	7
	Bw1	12-28	23	2	0.98	8
	Bw2	28-40	24	2	0.97	8
	C1	40-90+	26	2	0.99	6
	Mean		**22**	**2**	**0.98**	**8**
Nilkamal	Ap	0-13	20	2	0.98	8
	Ad	13-18	19	3	0.97	7
	Bw1	18-45	23	3	0.97	6
	Bw2	45-80	26	2	0.98	6
	C1	80-105+	28	2	0.97	5
	Mean		**23**	**2**	**0.97**	**7**
Pirojpur	Ap	0-10	23	4	0.96	9
	Ad	10-14	21	4	0.96	9
	Bw1	14-28	31	3	0.97	5
	Bw2	28-50	37	4	0.96	9
	C1	50-70	40	4	0.97	8
	C2	70-120+	44	4	0.96	10
	Mean		**33**	**4**	**0.96**	**8**
Hogla	Ap	0-12	27	4	0.95	8
	Ad	12-15	25	4	0.96	8
	Bw1	15-48	29	4	0.97	7
	Bw2	48-60	30	4	0.97	7
	C1	60-85	33	4	0.96	7
	C2	85-110+	35	4	0.96	14
	Mean		**30**	**4**	**0.96**	8

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Table 13. Some physical properties of the studied soils.

Soil Series	Horizon	Depth (cm)	Field moisture (%)	Hygroscopic moisture (%)	OD/AD ratio	Loss on ignition (%)
Muladi	Ap	0-10	19	3	0.97	9
	Ad	10-17'	17	3	0.97	6
	Bw1	17-34	20	3	0.96	5
	Bw2	34-62	20	3	0.95	5
	C1	62-94	21	1	0.99	5
	C2	94-105+	21	1	0.99	5
	Mean		**20**	**3**	**0.97**	**6**
Barisal	Ap	0-10	22	3	0.99	9
	Ad	10-18	24	3	0.97	9
	Bw1	18-50	34	3	0.96	9
	Bw2	50-77	35	3	0.97	8
	C1	77-110	38	4	0.96	8
	C2	110-125+	39	3	0.97	9
	Mean		**32**	**3**	**0.97**	**9**
Jhalakati	Ap	0-10	22	4	0.96	8
	Ad	10-16	20	3	0.97	8
	Bw1	16-35	22	2	0.98	8
	Bw2	35-55	24	2	0.98	7
	C1	55-71	25	2	0.98	6
	C2	71-99+	28	2	0.98	6
	Mean		**24**	**2**	**0.98**	**7**
Ramgati	Ap	0-8	25	2	0.98	6
	Ad	8-12	23	1	0.99	6
	Bw1	12-35	26	2	0.98	6
	Bw2	35-53	28	2	0.98	6
	C1	53-71	28	2	0.98	5
	C2	71-99+	29	3	0.97	5
	Mean		**27**	**2**	**0.98**	**6**
Grand Mean			**26**	**3**	**0.91**	**7**

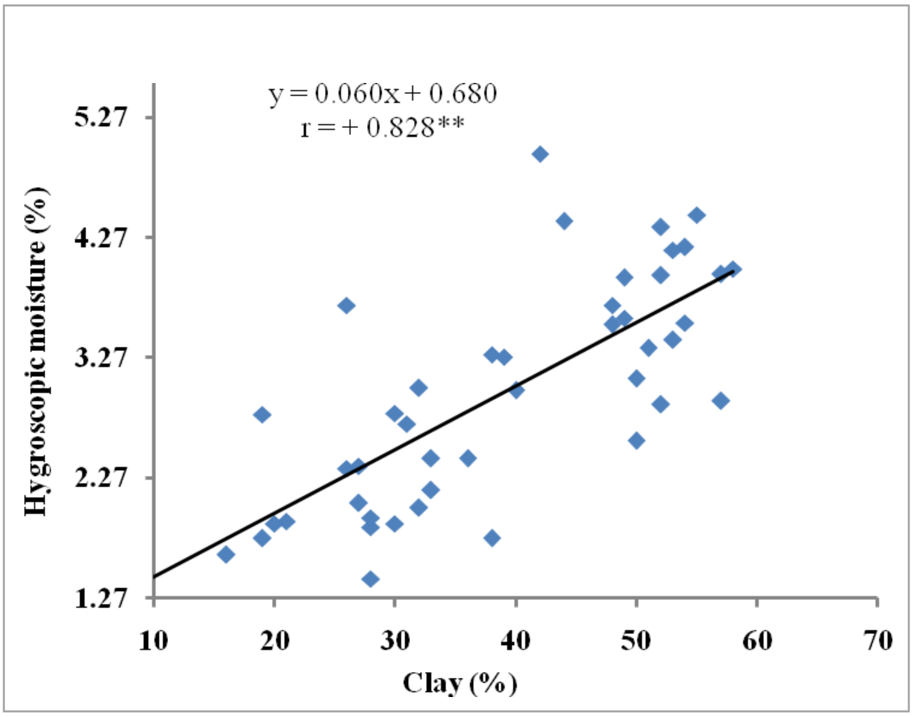

Fig 36. Correlation and regression between hygroscopic moisture and percent clay of the studied soil.

The OD/AD ratio is dependent on the quantity and the type of clay minerals present in the soil. The relationship between the OD/AD ratios of the soils with the percent clay content has been presented in Fig. 37 and showed a positive correlation (r = +0.691).

5.7.5 Loss on ignition (LOI)

The results of loss on ignition of soils have been given in Table 13. It ranges from 4.59 to 13.95 percent with an average value is 5.57%. The highest value of loss on ignition is found in the Barisal soils which also contain higher percentage of clay whereas the Muladi soils have the lowest value which have low contents of clay. A careful examination of loss on ignition of soils show that higher values are encountered in the surface soils where organic carbon too has registered higher values than the sub-surface soils. This is in agreement with the findings of Karim (1954) who stated that LOI of soils may be taken as an approximate measure of organic matter in absence of any combustion data, provided the consideration of data is restricted to soils which do not posses any lime. The mean value of field moisture, hygroscopic moisture and loss on ignition has shown in Fig 38.

A positive correlation (r= +0.609) found between percent organic matter and loss on ignition (Fig 39). The loss on ignition is usually depended on a number of factors such as organic matter, calcium carbonate and the type and relative abundance of the clay minerals (Khan, 1954, Quasem, 1956 and Hussain, 1961). These values have been found to be positively correlated (r= +0.607) with the percent clay content (Fig 40).

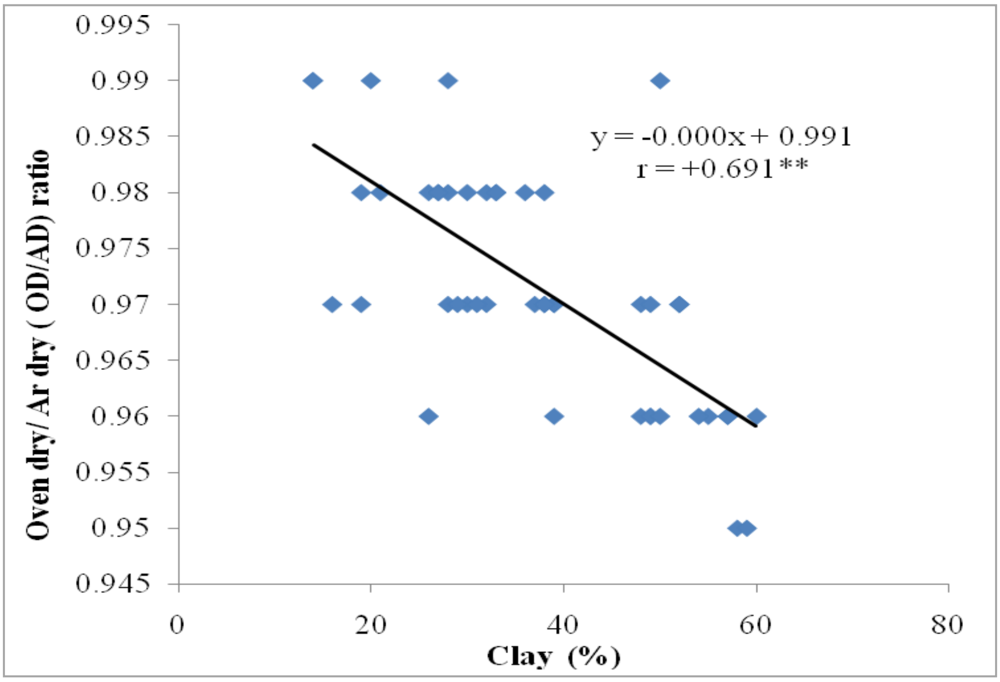

Fig 37. Correlation between percent clay and oven dry/air dry ratio of the studied soils.

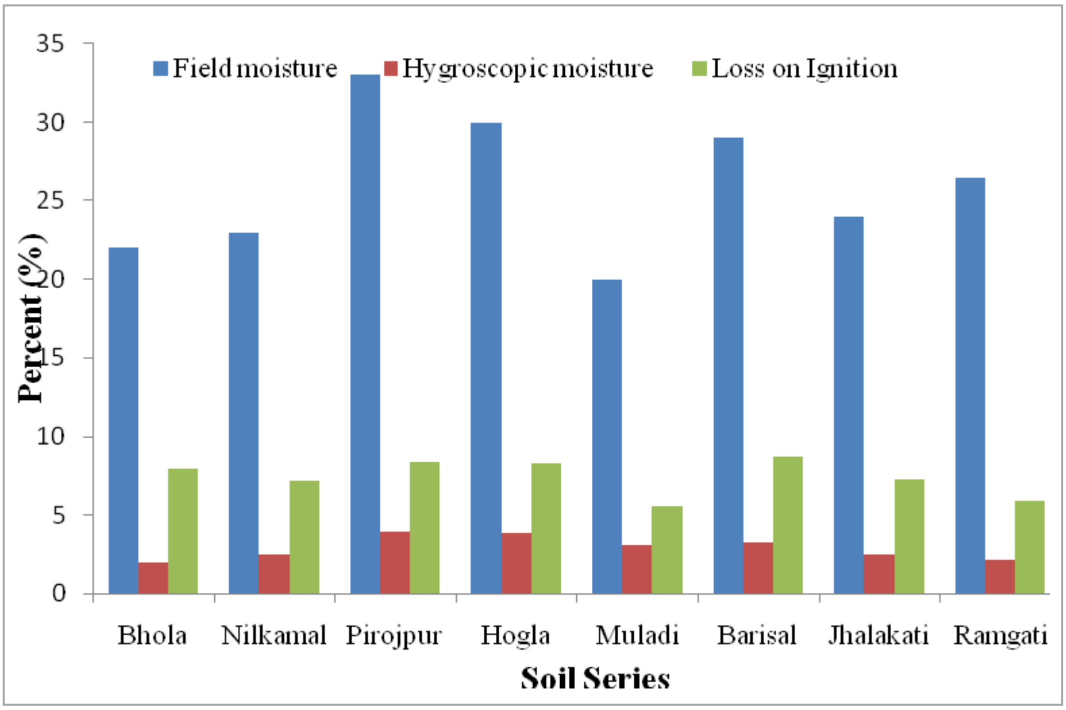

Fig 38. Graph shows the mean value of field moisture, hygroscopic moisture and loss on ignition of the studied pedons.

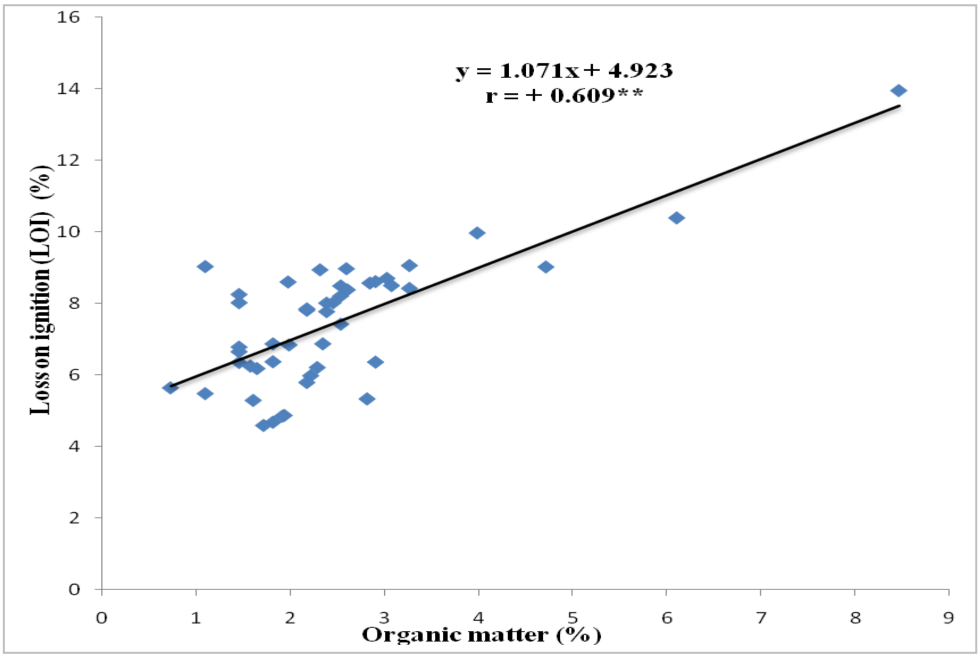

Fig 39. Relationship between organic matter and loss on ignition of the studied pedons.

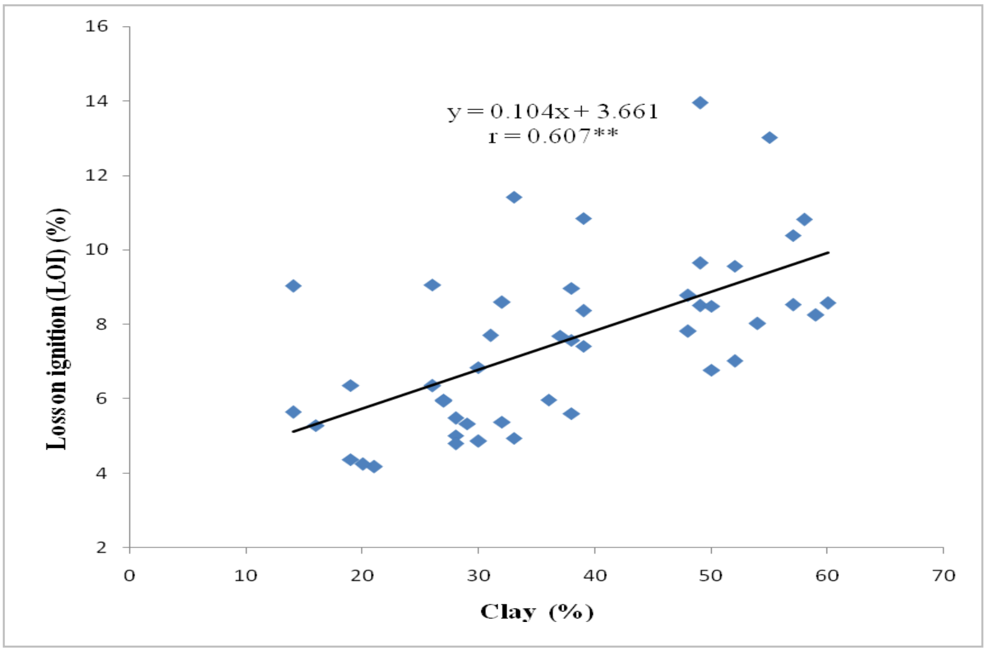

Fig 40. Correlation between percent clay and loss on ignition of the studied soil.

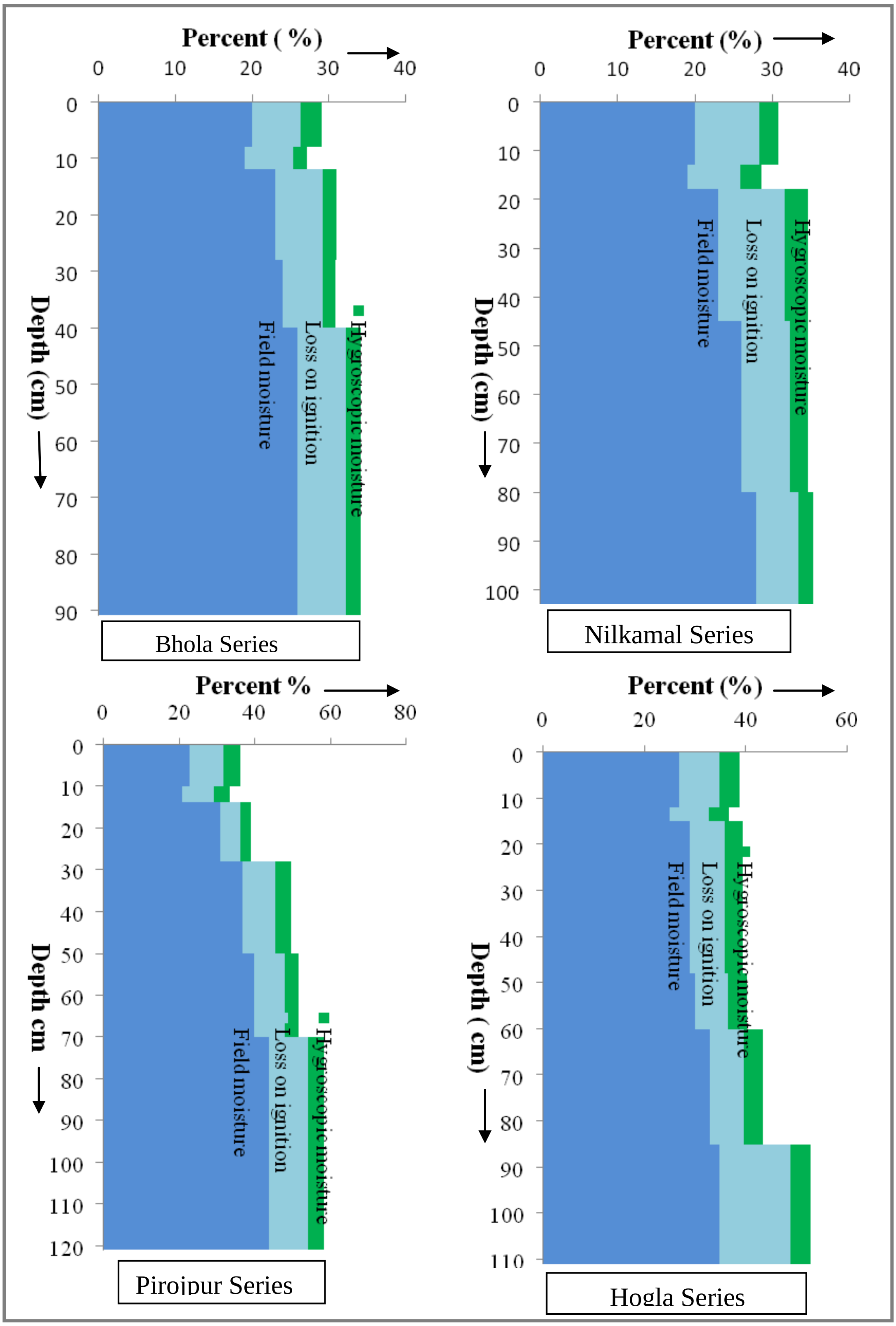

Fig 41. Vertical distribution of field moisture, hygroscopic moisture and loss on ignition of the Bhola, Nilkamal , Pirojpur and Hogla soil series .

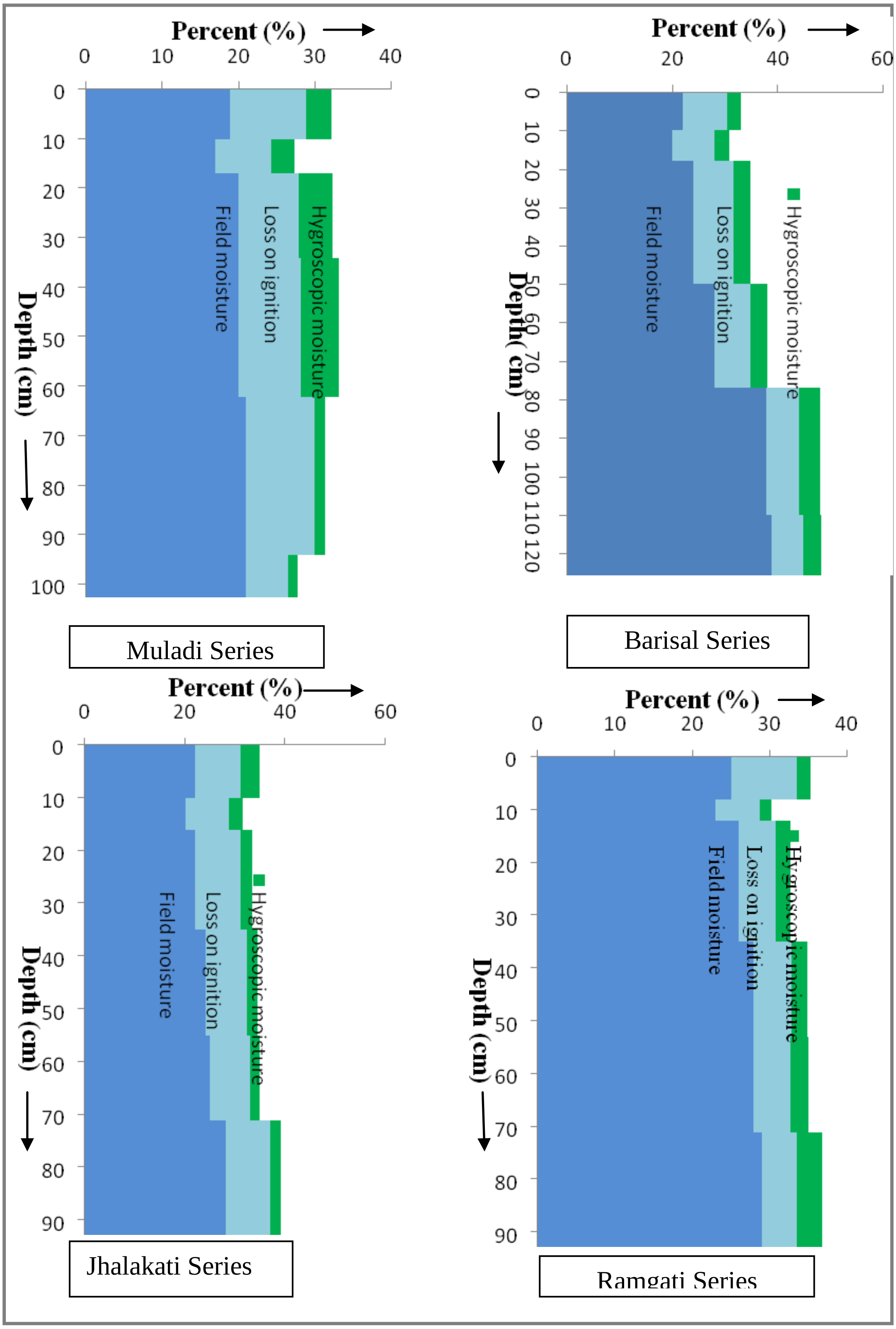

Fig 42. Vertical distribution of field moisture, hygroscopic moisture and loss on ignition of Muladi, Barisal, Jhalakati and Ramgati soil series.

5.7.6 Particle size distribution

The percentage of sand, silt and clay and textural class of soils are very important characteristics of soil profile which reflect the pedogenic and geologic history of a soil. The results of particle size distribution in the studied soils have been presented in Table 14. The mean values of sand, silt and clay of the studied soil profiles are shown in Fig 43.

The **sand** contents in the studied soils vary within very wide limits. Quantity of sand ranges from 3 to 52 percent with the mean of 13 percent. These results are in agreement with the findings o SRDI Staff (1965-86); Brammer (1971); Islam *et al.* 2014b. The highest value of sand was found in Muladi soil while the lowest value in Bhola soil. Based on the sand content the studied pedon shows the following gradation:

Muladi > Barisal > Nilkamal > Jhalakati > Ramgati > Pirojpur > Hogla > Bhola

The vertical distribution patterns of of sand fraction in these pedons shows an irregular trend which is related to their geogenic origin rather than pedogenic (Figs.44 & 45). In Muladi soil sand content of the surface horizon is 12 percent which increases from 45 to 52 percent in the C1 and C2 horizons. In the Barisal profile sand content of the surface horizon is 17 percent which decreases to 11 percent in the C2 horizon. On the basis of the vertical distribution of sand it can be generally concluded that the parent materials of the present soils are heterogeneous and this heterogeneity may be related to their depositional environment.

The **silt** content has assumed a significant status in the soils. The general level of silt content is high ranging from 32 to 77 percent with a mean value of 50 percent (Table 18). The highest mean silt content within the profile is observed in the Bhola soil (76 percent) whereas the lowest in the Barisal soil (36 percent) (Fig. 56). Silt is the dominant fraction in Bhola, Nilkamal, Muladi, Jhalakati and Ramgati soils but in the Pirojpur, Hogla and Barisal soils the clay contents exceed the silt content. Such a high level of silt is due to their geogenic orogin and annual siltation regularly. Based on the per cent silt content, the pedons show the following gradation:

Bhola > Jhalakati > Nilkamal > Ramgati > Muladi > Hogla > Pirojpur > Barisal

The vertical distribution of silt fraction in the pedons shows an irregular trend (Figs. 44 & 45). There is no significant trend in the distribution of silt in the profiles under studied. In addition the sand/ silt ratio of the present soils varies from 0.04 to 1.21 with a mean value of 0.29 (Table 14).

Table 14. Particle size distribution and textural classes of the studied soils

Soil Series	Horizon	Depth (cm)	Particle Size Distribution (%)			Textural Class	Sand / Silt ratio	Silt/Clay ratio
			Sand	Silt	Clay			
Bhola	Ap	0-8	4	77	19	SiL	0.05	4.05
	Ad	8-12	5	76	19	SiL	0.07	4.00
	Bw1	12-28	3	76	21	SiL	0.04	3.62
	Bw2	28-40	5	79	16	SiL	0.06	4.94
	C1	40-90+	8	72	20	SiL	0.11	3.60
	Mean		**5**	**76**	**19**		**0.07**	**4.04**
Nilkamal	Ap	0-13	14	53	33	SiCL	0.26	1.61
	Ad	13-18	12	57	31	SiCL	0.23	1.90
	Bw1	18-45	12	56	32	SiCL	0.21	1.75
	Bw2	45-80	15	59	26	SiL	0.25	2.27
	C1	80-105+	16	56	28	SiL	0.29	2.00
	Mean		**14**	**56**	**30**		**0.25**	**1.91**
Pirojpur	Ap	0-10	8	37	55	C	0.22	0.67
	Ad	10-14	9	37	54	C	0.24	0.69
	Bw1	14-28	9	34	57	C	0.26	0.60
	Bw2	28-50	10	38	52	C	0.26	0.73
	C1	50-70	11	35	54	C	0.31	0.65
	C2	70-120+	13	34	53	C	0.38	0.64
	Mean		**10**	**36**	**54**		**0.28**	**0.66**
Hogla	Ap	0-12	6	36	58	C	0.17	0.62
	Ad	12-15	6	37	57	C	0.16	0.65
	Bw1	15-48	5	47	48	SiC	0.11	0.98
	Bw2	48-60	4	47	49	SiC	0.09	0.96
	C1	60-85	8	44	48	SiC	0.18	0.92
	C2	85-110+	9	42	49	SiC	0.21	0.86
	Mean		**6**	**42**	**52**		**0.15**	**0.83**

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Table 14. Particle size distribution and textural classes of the studied soils

Soil Series	Horizon	Depth (cm)	Particle Size Distribution (%)			Textural Class	Sand / Silt ratio	Silt/Clay ratio
			Sand	Silt	Clay			
Muladi	Ap	0-10	12	49	39	SiCL	0.24	1.26
	Ad	10-17	12	48	40	SiCL	0.25	1.20
	Bw1	17-34	15	41	44	SiC	0.37	0.93
	Bw2	34-62	21	37	42	CL	0.57	0.88
	C1	62-94	45	49	6	SL	0.92	8.17
	C2	94-105+	52	43	5	SL	1.21	8.60
	Mean		**26**	**45**	**29**		**0.59**	**3.51**
Barisal	Ap	0-10	17	33	50	C	0.52	0.66
	Ad	10-18	16	32	52	C	0.50	0.62
	Bw1	18-50	13	37	50	C	0.47	0.68
	Bw2	50-77	15	34	51	C	0.31	1.30
	C1	77-110	14	34	52	C	0.30	1.21
	C2	110-125+	11	46	53	C	0.35	1.21
	Mean		**15**	**36**	**51**		**0.48**	**0.64**
Jhalakati	Ap	0-10	14	60	26	SiL	0.23	2.31
	Ad	10-16	15	54	31	SiL	0.28	1.74
	Bw1	16-35	14	59	27	SiL	0.24	2.19
	Bw2	35-55	12	56	32	SiL	0.21	1.75
	C1	55-71	13	59	28	SiL	0.22	2.11
	C2	71-99+	12	55	33	SiL	0.22	1.67
	Mean		**13**	**57**	**30**		**0.23**	**1.96**
Ramgati	Ap	0-8	14	48	38	SiCL	0.29	1.26
	Ad	8-12	13	59	28	SiL	0.22	2.11
	Bw1	12-35	10	60	30	SiCL	0.17	2.00
	Bw2	35-53	12	61	27	SiL	0.20	2.26
	C1	53-71	13	51	36	SiCL	0.25	1.42
	C2	71-99+	13	49	38	SiCL	0.27	1.29
	Mean		**13**	**55**	**33**		**0.23**	**1.72**
Grand mean			**13**	**50**	**37**		**0.29**	**1.91**

The highest mean sand/ silt ratio was found in the Muladi soils (0.59) whereas the lowest in the Bhola soils (0.07). The vertical distribution pattern of this ratio is like before, irregular and heterogeneous and this lead to conclude that parent materials deposited at different time had variation during the time of deposition.

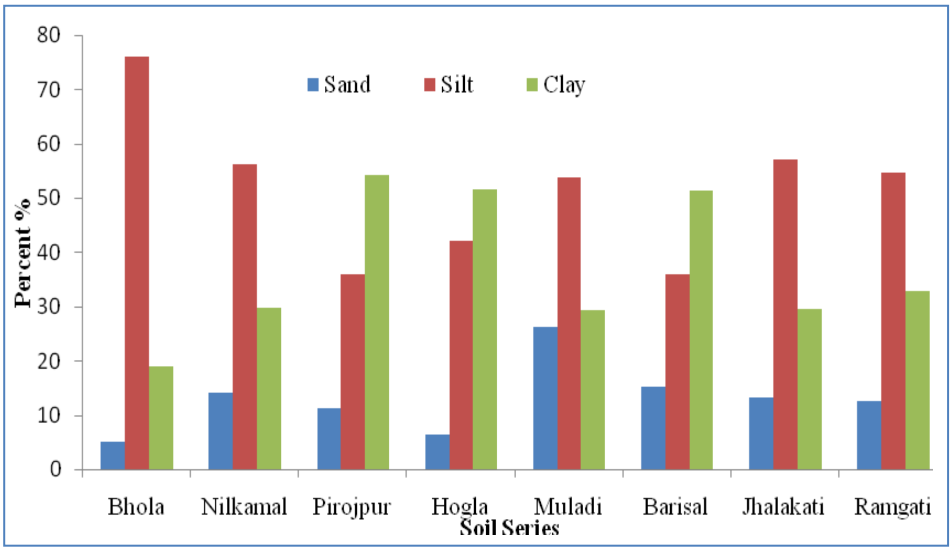

Fig 43. Graph shows the mean value of sand, silt and clay of the studied pedons

The clay content in the studied soils varies from 5 to 58 percent with a mean value of 37 percent (Table 14) which shows that one- third of soil materials are clay. The highest average value is observed in the Pirojpur profile whereas the lowest value is in the Bhola profile. Based on the clay content the pedons show the following gradation:

Pirojpur > Hogla > Barisal > Ramgati > Jhalakati > Nilkamal > Muladi > Bhola

The clay contents in the Pirojpur, Hogla and Barisal soils may be attributed to the higher clay content in their parent materials. These soils have formed in the lower part of the landscape where more clay is accumulated as compared to that in the levees. The vertical distribution of clay content is irregular in all the profiles (Figs.44 & 45). Perhaps, this is the result of restricted movement of the clay downward due to poor drainage condition.This irregularity in the clay distribution in the profiles may be attributed to sedimentation processes rather than the pedological process.

Impoverishment of clay in the upper horizons of the soil profiles is a common feature in some seasonally flooded Bangladesh soils where ferrolysis is a common soil forming process (Brammer, 1964; Brinkman, 1970). According to them the clay fraction in the surface horizons are destroyed by the ferrolysis process. In all the soils, surface impoverishment of clay is quite a noticeable feature. But it is difficult to predict this impoverishment has been caused by the ferrolysis process.

The silt/ clay ratio of the studied soils varies from 0.60 to 8.60 with a mean value of 1.91. The distribution patterns of this ratio down the profiles are not equally uniform in all the soils under the present investigation (Table 14). The silt/ clay ratio thus varies within wide limits. The highest average ratio is observed in the Bhola pedon (4.04) and lowest in Barisal pedon. The irregular silt/ clay ratio in the profiles indicates that the present soils are young and there is little possibility of movement of clay downward and their sub-sequent accumulation in the B horizon. In addition, this is due to the fact that the parent materials of these soils were deposited in different depositional environments such as near the levee or away from the levee. Variation in the above ratio may also be due to the fact that the silt minerals are being destroyed during weathering and clay minerals are being formed.

Textural class was determined on the basis of sand, silt and clay percent are reported in Fig 46. The textural class of the soil under investigation shows a wide variation. It ranges from silt loam to clayey texture (Table 14). This variation in textural classes of soils is a common feature in many of the floodplain areas of Bangladesh.

From Marshall textural triangle it is clear that most of the studied soils are silty clay, silty clay loam, silt loam, sandy loam, and clay texture. Among the 46 studied soils 15 soils are silt loam, 14 soils are clay, 9 soils are silty clay loam, 5 soils are silty clay, 2 soils are sandy loam, and 1 soil is clay loam textural class.

To sum up the results of particle size distribution of soils the following points may be made:

a. The vertical distribution of sand, silt and clay in all the studied soil profiles are more or less irregular which indicates heterogeneous nature of the parent materials.
b. Silt is the dominant size fraction in the soils of coastal zone.
c. The sand content is low in all the soils except Muladi soil.
d. Particle size distribution of the soils appears to be similar to that of the river borne sediments.
e. From the particle size distribution it is clear that the geological deposition is the main factor for their formation. Pedological processes have been very weak and have not brought about any significant translocation of materials of any size within the pedons.

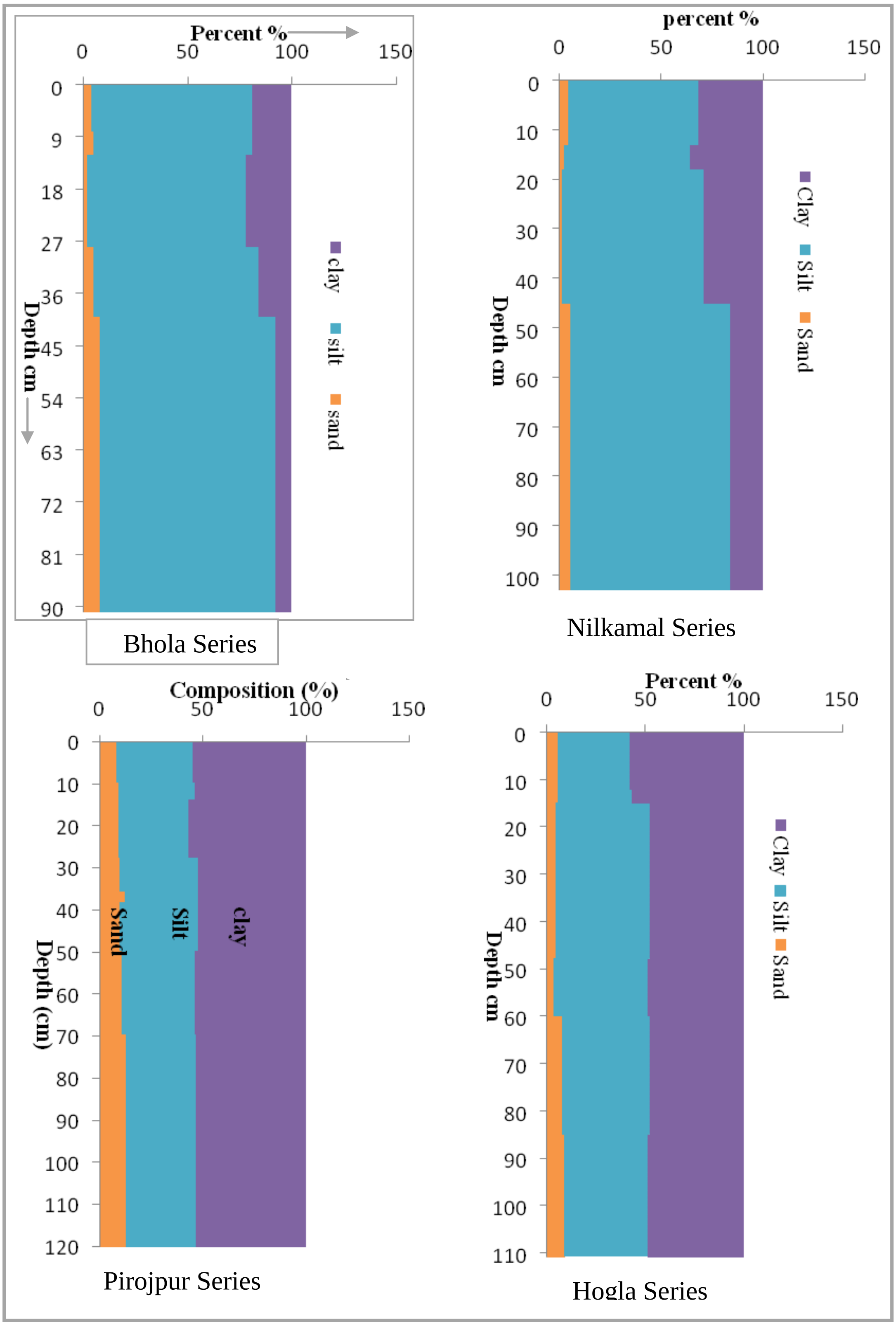

Fig 44.Vertical distribution of sand, silt and clay in Bhola, Nilkamal. Pirojpur and Hogla soil series.

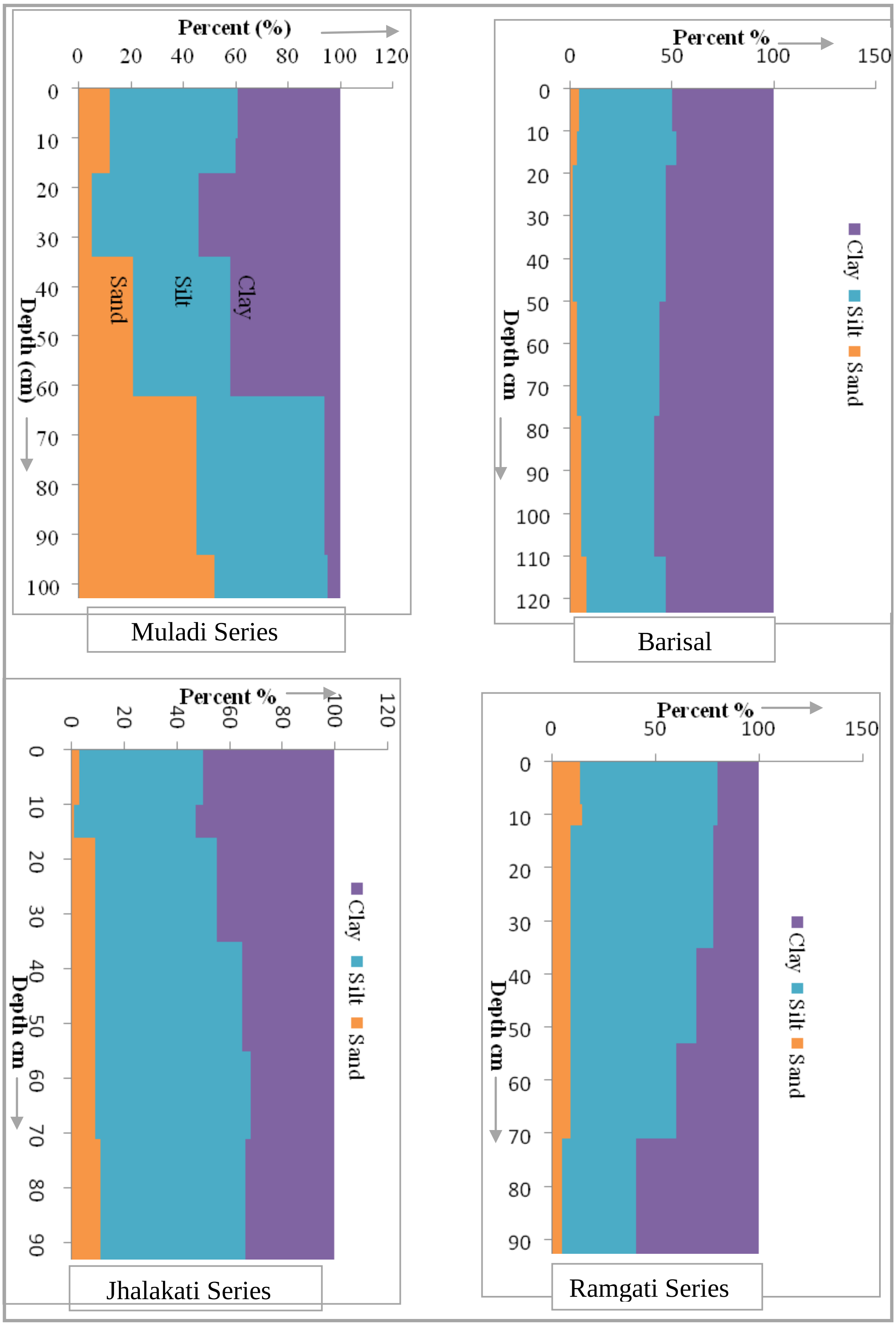

Fig 45.Vertical distribution of sand, silt and clay in Muladi, Barisal. Jhalakati and Ramgati soil series.

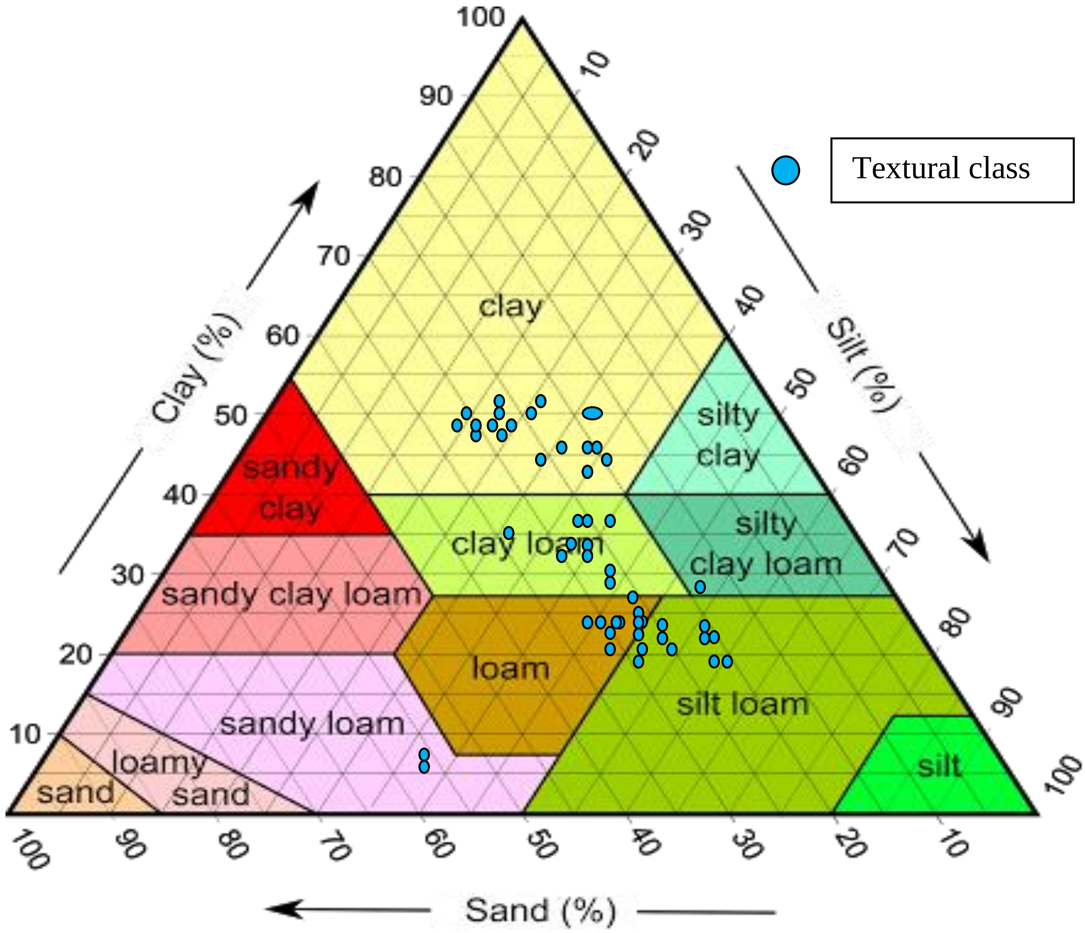

Fig 46. A projection of the textural class of the studied soil

5.8 Chemical Properties of the soils

Chemical properties of soils for all horizons of the profiles were undertaken with a view to characterize the soils. Therefore horizon wise soil samples from each profile were analyzed for pH, electrical conductivity (EC), lime, organic carbon, total nitrogen, C/N ratio, CEC, exchangeable cations, fusionl analyses, citrate extractable free iron and manganese etc.

5.8.1 Soil reaction (pH)

The pH (water) value of the studied soils has been presented in Table 15. The pH of the soils ranges from 5.71 to 7.75 with a mean value of 6.97. All the soils, therefore, are slightly acidic to slightly alkaline in reaction. Among the soils the highest mean value of pH is found in Nilkamal profile whereas the lowest mean is found in Ramgati profile.

Table 15. Results of some chemical properties of the studied soils.

Soil Series	Horizon	pH		Δ pH*	Free lime (%)	EC*(dS/m) at 25ºC
		H_2O	KCl			
Bhola	Ap	6.53	6.04	-0.49	1.34	1.25
	Ad	7.05	6.64	-0.41	0.89	1.22
	Bw1	7.35	6.93	-0.42	0.89	1.22
	Bw2	7.42	6.95	-0.47	0.89	1.11
	C1	7.75	7.16	-0.59	1.34	0.76
	Mean	**7.22**	**6.74**	**-0.48**	**1.07**	**1.11**
Nilkamal	Ap	6.68	5.98	-0.70	0.45	0.46
	Ad	7.37	6.01	-1.36	0.89	0.23
	Bw1	7.52	6.12	-1.40	1.34	0.29
	Bw2	7.63	6.14	-1.49	2.23	0.24
	C1	7.71	6.15	-1.56	2.23	0.28
	Mean	**7.38**	**6.08**	**-1.30**	**1.43**	**0.30**
Pirojpur	Ap	6.34	5.65	-0.69	0.89	0.24
	Ad	6.75	6	-0.75	1.34	0.29
	Bw1	7.07	6.29	-0.78	1.79	0.18
	Bw2	7.13	6.36	-0.77	1.34	0.30
	C1	7.16	6.38	-0.78	1.34	0.15
	C2	7.21	6.42	-0.79	0.89	0.36
	Mean	**6.94**	**6.18**	**-0.76**	**1.26**	**0.25**
Hogla	Ap	6.4	4.99	-1.41	1.34	0.32
	Ad	6.95	5.95	-1.00	0.89	0.17
	Bw1	6.98	6.11	-0.87	1.34	0.15
	Bw2	7.12	6.15	-0.97	1.34	0.13
	C1	7.15	5.95	-1.20	0.89	0.12
	C2	7.26	5.61	-1.65	0.89	0.21
	Mean	**6.98**	**5.79**	**-1.18**	**1.12**	**0.19**

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Table 15. Results of some chemical properties of the studied soils .

Soil Series	Horizon	pH		Δ pH*	Free lime (%)	EC*(dS/m) at 25ºC
		H_2O	KCl			
Muladi	Ap	6.51	5.71	-0.80	1.79	0.22
	Ad	6.82	5.97	-0.85	1.34	0.16
	Bw1	7.23	6.57	-0.66	2.68	0.27
	Bw2	7.34	6.64	-0.70	2.68	0.26
	C1	7.36	6.67	-0.69	2.23	0.16
	C2	7.36	6.69	-0.67	2.23	0.18
	Mean	**7.10**	**6.38**	**-0.73**	**2.23**	**0.21**
Barisal	Ap	5.81	4.14	-0.97	1.34	0.55
	Ad	6.22	4.83	-0.82	0.89	0.24
	Bw1	6.73	5.56	-0.85	1.34	0.18
	Bw2	6.81	5.8	-0.74	0.89	0.26
	C1	6.84	5.83	-0.77	0.45	0.37
	C2	6.91	5.88	-0.8	0.45	0.54
	Mean	**6.55**	**5.34**	**-0.83**	**0.89**	**0.36**
Jhalakati	Ap	6.42	6.38	-0.3	0.45	1.65
	Ad	6.73	7.05	-0.46	0.89	1.45
	Bw1	7.22	7.06	-0.55	0.89	1.09
	Bw2	7.58	7.14	-0.72	0.45	1.05
	C1	7.59	7.21	-0.9	0.45	1.03
	C2	7.61	7.25	-1.45	0.45	0.94
	Mean	**7.19**	**7.02**	**-0.73**	**0.60**	**1.20**
Ramgati	Ap	5.71	4.85	-0.56	0.45	0.99
	Ad	6.32	5.06	-0.86	0.45	0.54
	Bw1	6.45	5.55	-0.9	1.34	0.50
	Bw2	6.51	5.6	-0.94	1.34	0.65
	C1	6.52	5.6	-0.91	0.45	0.75
	C2	6.85	5.89	-0.96	0.45	1.04
	Mean	**6.39**	**5.43**	**-0.86**	**0.74**	**0.74**
Grand Mean		**6.97**	**6.01**	**-0.86**	**1.17**	**0.54**

EC= Electrical conductivity at saturation extract, determined at 1:5 soil- moisture ratio. Δ pH= (pH_{KCl}- pH_{water}).

In every profile there is a trend of increasing pH with depth (Figs. 48 & 49). This is a common feature of the seasonally flooded soils in Bangladesh (Mujib, 1969; Brammer, 1971 and Matin, 1972). This has been attributed to the oxidation- reduction conditions of the soils (Ponnamperuma, 1972). When the groundwater recedes from the surface soil the ferrous iron is oxidized and the pH naturally drops first in the surface horizon or up to the oxidized zone. From the subsoil zone the soluble bases are not removed as the internal drainage is poor. As a consequence the pH of the sub-soils tends to remain at a higher level. The variations observed in soil pH were related to variations in exchangeable calcium, magnesium, iron, aluminum, free iron oxide and organic matter of the soils (Khan *et al.* 2012).

When pH is determined with 1N KCl solution in place of water, there was a substantial decrease in pH values in all the soils that measured in distilled water. This decrease in pH value has been designated as Δ pH. All these Δ pH values are negative and ranges from - 0.41 to – 1.65 with a mean value of -0.86 (Table 15) which may be due to high quantity of reserve acidity. The highest mean Δ pH values within the profiles were found in Nilkamal soils and the lowest in Bhola soils. The distribution pattern of Δ pH values within the soil profile is irregular and the Δ pH value is lower in the surface than in the sub-surface. Begum (1996) studied on some soils of Manpura Island and reported that Δ pH values increasing with depth in soil profile.

When pH (water) values are plotted against pH (KCl) a significant positive correlation (r = +0.879) is found (Fig 47).

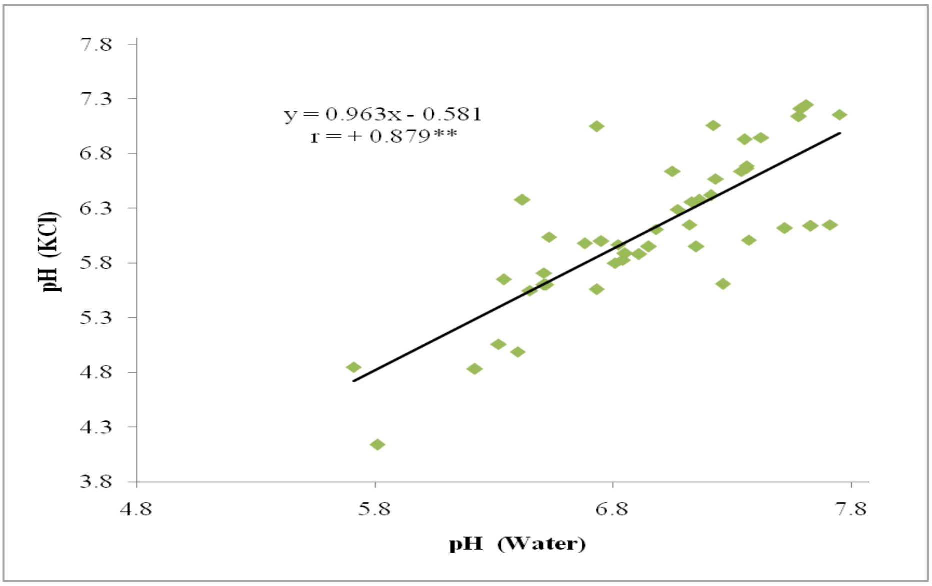

Fig 47. Correlation between pH (H_2O) and pH (KCl) in the soils under investigation.

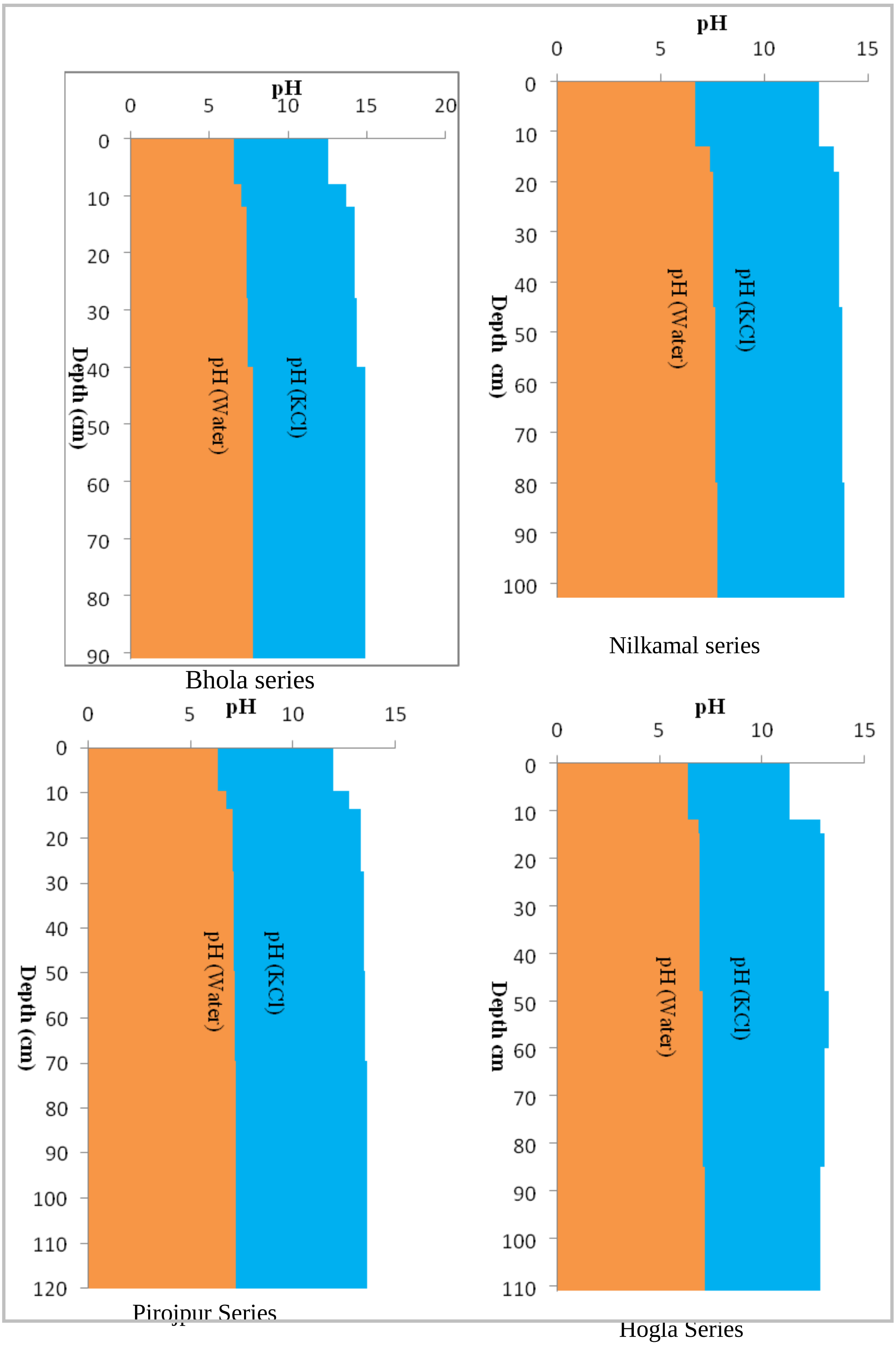

Fig 48. Vertical distribution of pH (H_2O) and pH (KCl) in Bhola, Nilkamal. Pirojpur and Hogla series under study.

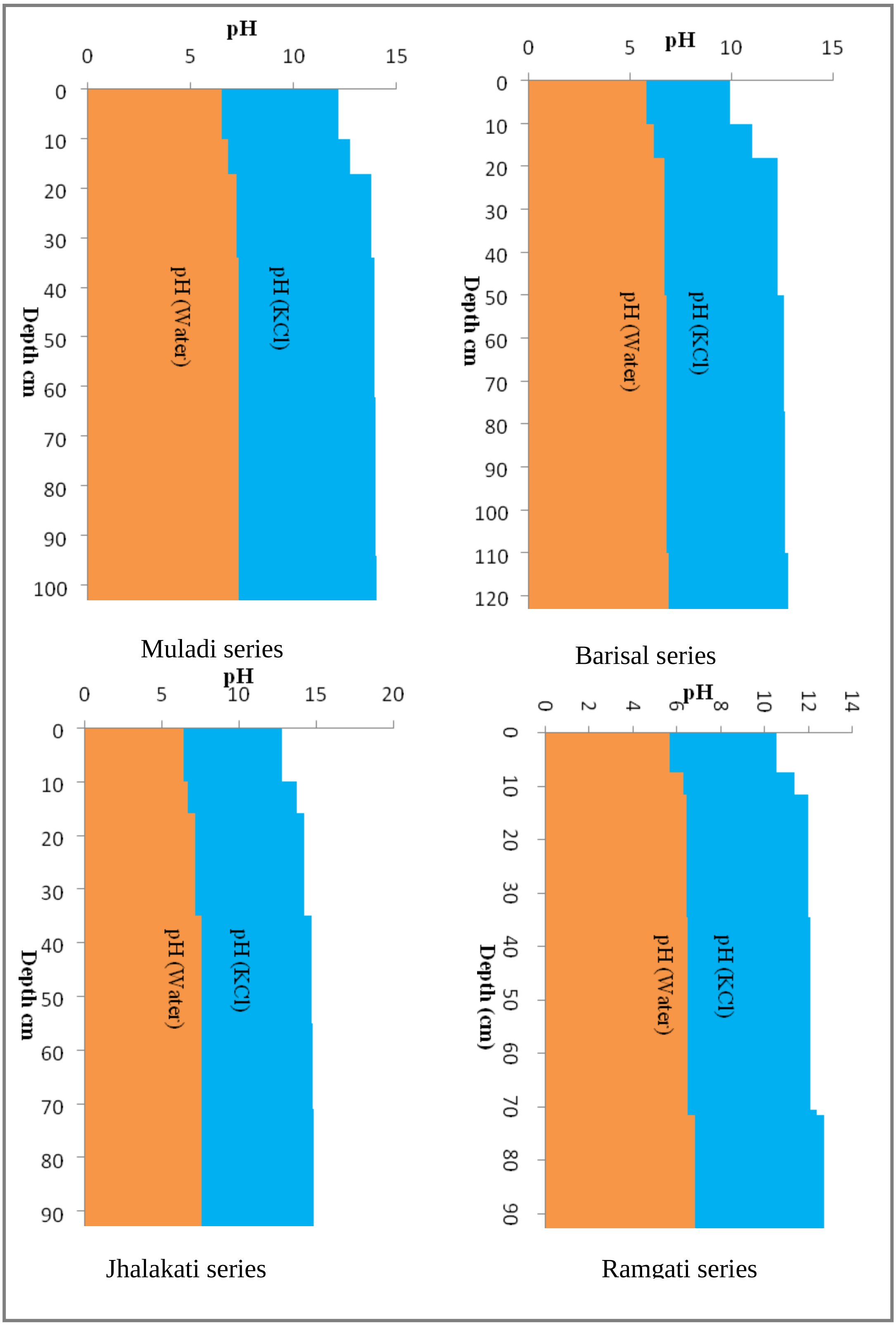

Fig 49. Vertical distribution of pH (H_2O) and pH (KCl) in Muladi, Barisal, Jhalakati and Ramgati series under study.

5.8.2 Free lime

Results of free lime content in the studied soils are presented in Table 15. Free lime content varies from 0.45 to 2.68 percent with a mean value 1.17 percent. Free lime less than 2 percent indicate that the soils are non-calcareous in nature. The highest mean value is observed in Muladi profile (2.23 percent) whereas lowest mean value in Hogla profile (Fig 50). The results indicate that there is no free lime in the studied soils except Muladi soil. Muladi soil is regarded as slightly calcareous but rest of the soils is non-calcareous in nature.

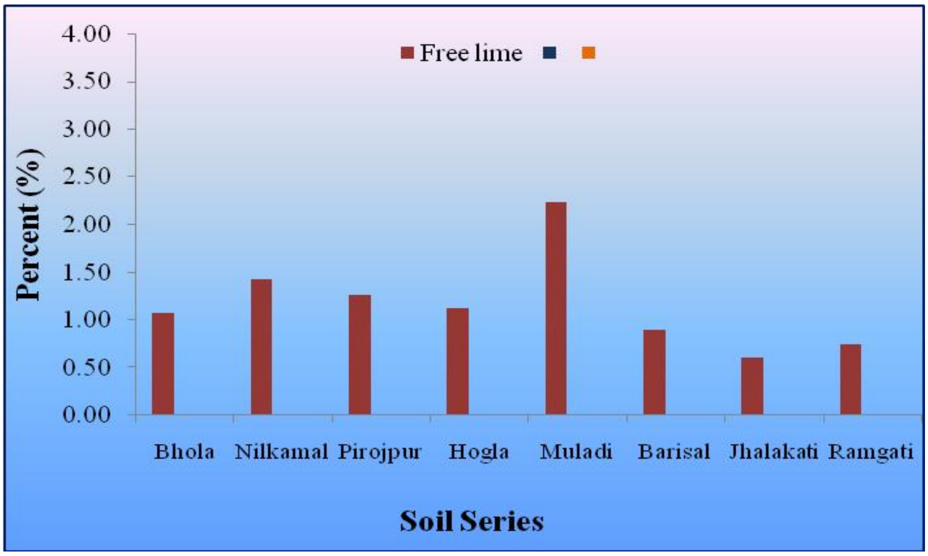

Fig 50. Graph shows the mean value of free lime of the studied soils

5.8.3 Electrical conductivity (EC)

The EC content ranges from 0.12 to 1.65 dS/m with a mean value of 0.54 dS/m at 25°C (Table 15). Highest value is found in Jhalakati soil and lowest in Hogla soils (Fig 51). The surface horizon of Jhalakati soil has EC value of 1.29 dS/m due to higher electrolytic elements. EC value (less than 4 dS/m) suggested all the soils contained at nondetrimental level for agricultural production (BARC, 2012).

The vertical distribution pattern of EC is found irregular. In some profiles, however, there is a trend of decreasing EC value with depth. The low salt content in these soils is due to the fact that all these soils are located within the polders. Due to continuous leaching by rainwater every year during the wet season free salts in these soils have been washed away. As a consequence salt content is low and with respect to salinity these are completely normal soils. However during the dry season in the months of late February and early march white salts appear at the surface of the soils which disappear with falling of first rain.

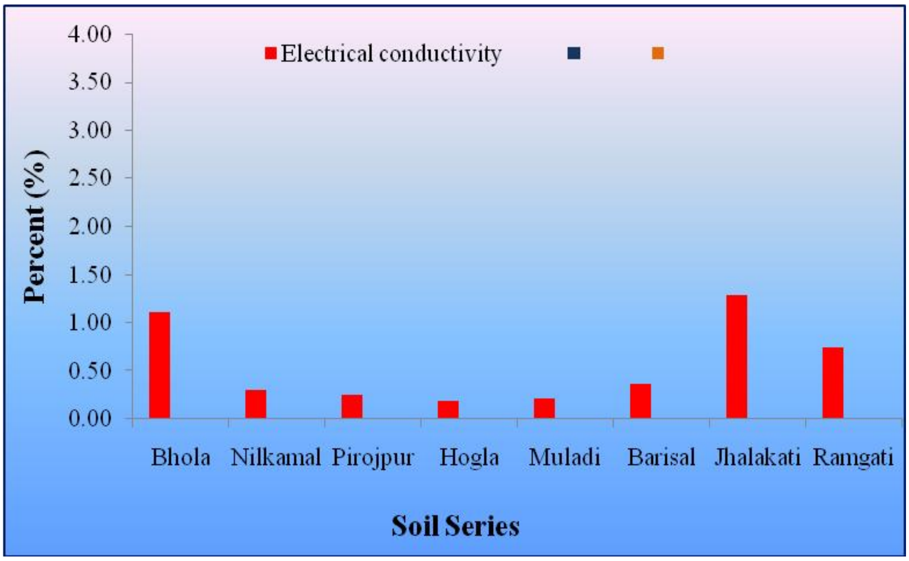

Fig 51. Graph shows the mean value of electrical conductivity of the soils under study.

5.8.4 Organic matter (OM), total nitrogen and C/N ratio of the soils

Organic matter is denoted as the life of the soil and it is regarded as the store house of plant nutrients. Results of organic matter are presented in Table 16. Organic matter content ranges from 0.72 to 8.46 percent with a mean value of 2.43 percent.

Organic matter content in soils reflects the effect of vegetation in soil genesis. From the mean value it may be concluded that the soils contained medium organic matter (Appendix 14). The highest mean value of organic matter occurs in the soils of Pirojpur (3.68 percent) whereas the lowest mean is found in Muladi soil (1.87). The organic matter content in these soils is rather high. The organic matter content in the studied soils show the following gradation in decreasing order:

Pirojpur > Hogla > Barisal > Jhalakati > Ramgati > Nilkamal > Bhola > Muladi.

The organic matter content of surface horizons of the pedons is higher than those in the sub-surface horizon except in Pirojpur and Hogla soils (Figs.52 & 53). There is high content of organic matter in the lower horizon of Pirojpur (6.10 %) and Hogla soils (8.46%). This rise may be attributed to the presence of a buried peat layer within the depth of 70 to 120 cm in the profiles, caused rather by geological processes than the pedological ones.

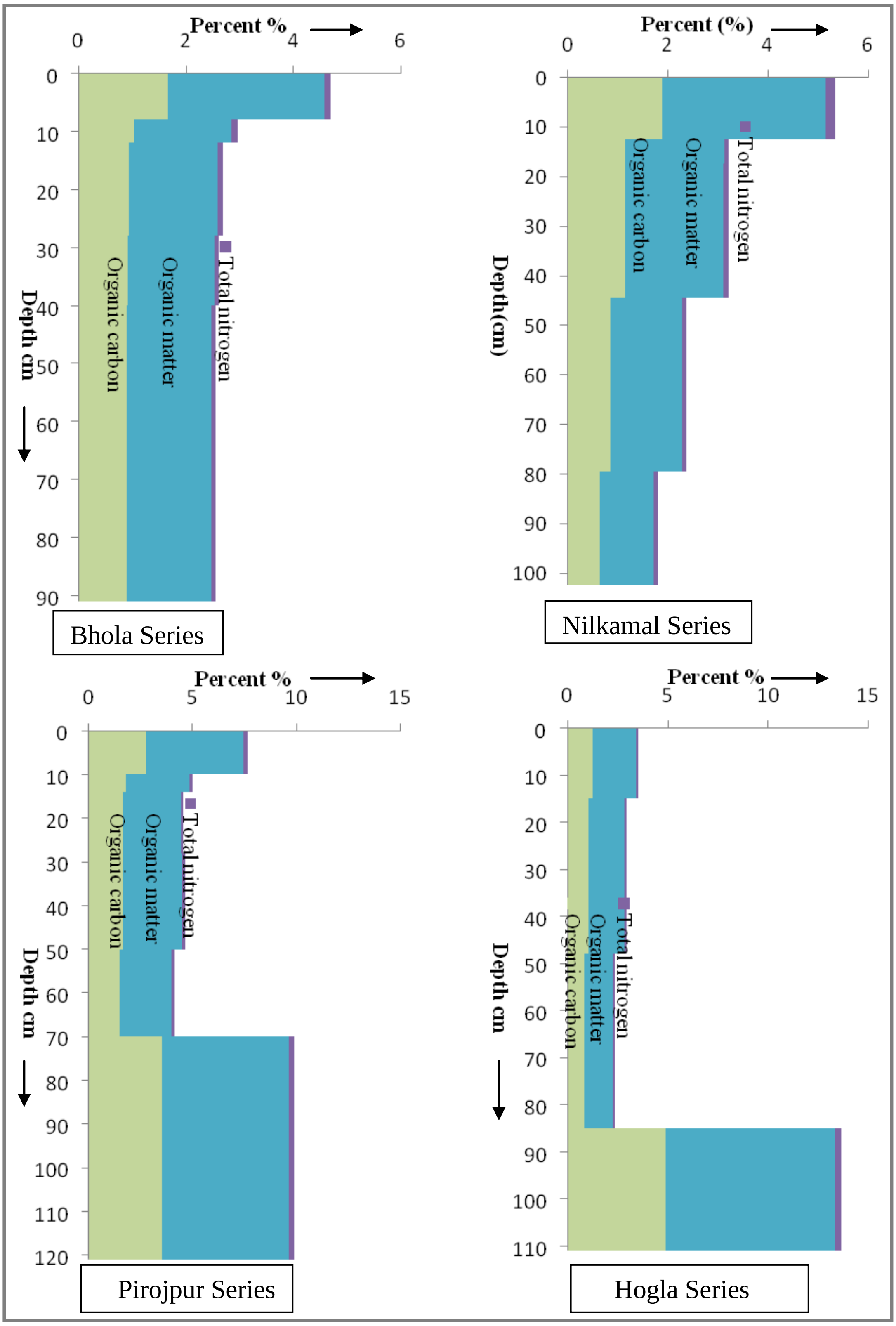

Fig 52. Vertical distribution of organic carbon, organic matter and total N in Bhola, Nilkamal, Pirojpur and Hogla soil series.

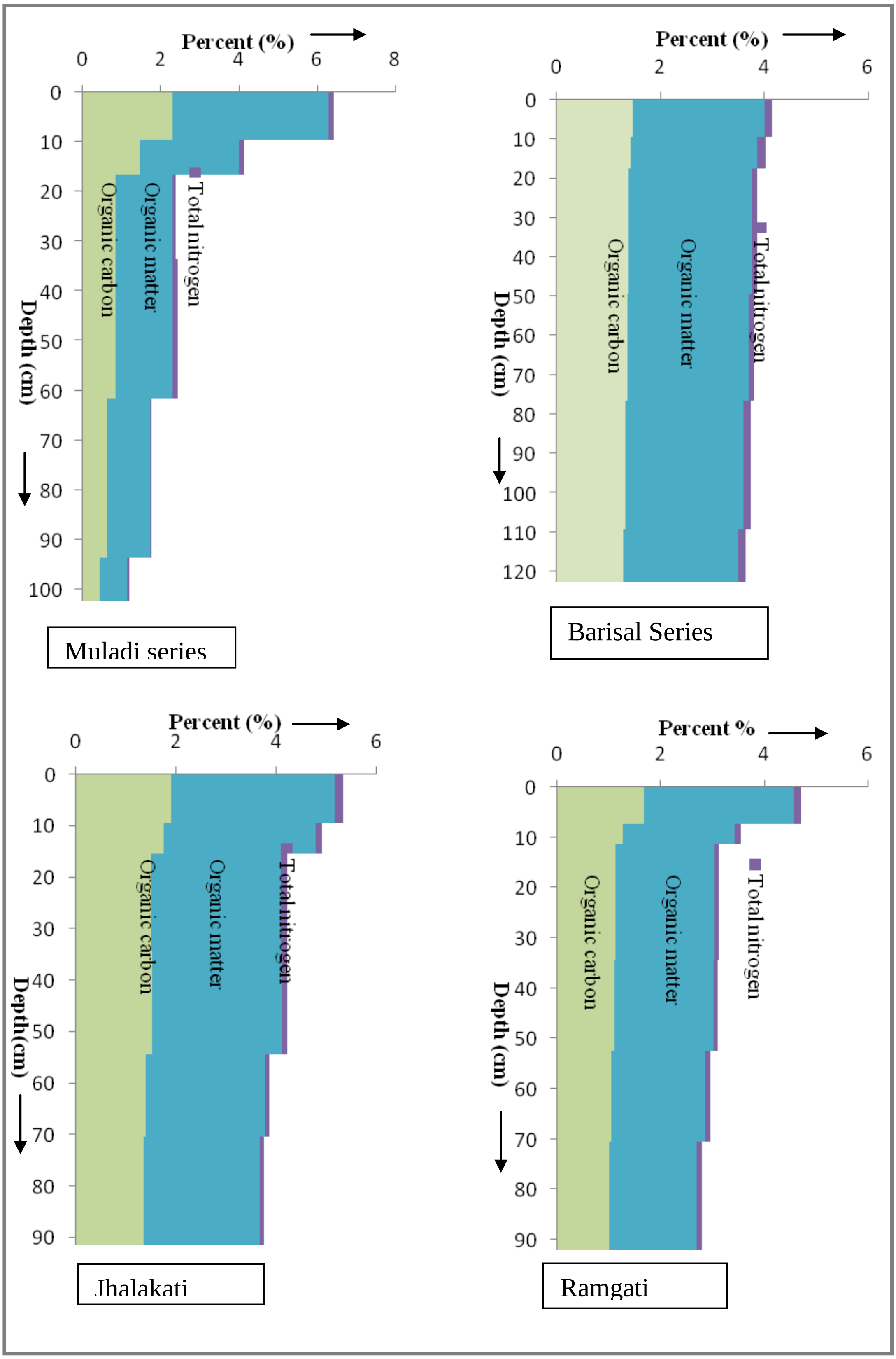

Fig 53. Vertical distribution of organic carbon, organic matter and total N in Muladi, Badrisal, Jhalkati and Ramgati soil series.

Table 16. Results of organic matter, total nitrogen and C/N ratio of the studied soils

Soil Series	Horizon	OC*	OM*	Total N*	C/N ratio
		←	%	→	
Bhola	Ap	1.68	2.9	0.12	14
	Ad	1.05	1.81	0.12	09
	Bw1	0.95	1.64	0.10	10
	Bw2	0.93	1.6	0.09	10
	C1	0.91	1.57	0.07	13
	Mean	**1.10**	**1.90**	**0.10**	**11**
Nilkamal	Ap	1.89	3.26	0.19	10
	Ad	1.15	1.98	0.09	13
	Bw1	1.14	1.97	0.10	11
	Bw2	0.84	1.45	0.08	11
	C1	0.63	1.09	0.08	08
	Mean	**1.13**	**1.95**	**0.11**	**10**
Pirojpur	Ap	2.73	4.71	0.21	13
	Ad	1.78	3.07	0.15	12
	Bw1	1.63	2.81	0.11	15
	Bw2	1.65	2.84	0.14	12
	C1	1.47	2.53	0.14	11
	C2	3.54	6.1	0.28	13
	Mean	**2.13**	**3.68**	**0.17**	**12**
Hogla	Ap	1.26	2.17	0.12	11
	Ad	1.26	2.17	0.13	10
	Bw1	1.05	1.81	0.10	11
	Bw2	0.84	1.45	0.09	09
	C1	0.84	1.45	0.09	09
	C2	4.91	8.46	0.33	15
	Mean	**1.69**	**2.92**	**0.14**	**12**

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Table 16. Results of organic matter, total nitrogen and C/N ratio of the studied soils.

Soil Series	Horizon	OC*	OM*	Total N*	C/N ratio
Muladi	Ap	2.31	3.98	0.14	17
	Ad	1.47	2.53	0.13	11
	Bw1	0.84	1.45	0.09	09
	Bw2	0.84	1.45	0.12	06
	C1	0.63	1.09	0.05	13
	C2	0.42	0.72	0.05	08
	Mean	**1.09**	**1.87**	**0.09**	**11**
Barisal	Ap	1.89	3.26	0.14	11
	Ad	1.75	3.02	0.15	09
	Bw1	1.5	2.59	0.10	14
	Bw2	1.51	2.6	0.10	14
	C1	1.38	2.38	0.14	09
	C2	1.35	2.31	0.15	09
	Mean	**1.56**	**2.69**	**0.13**	**11**
Jhalakati	Ap	1.47	2.53	0.18	11
	Ad	1.42	2.45	0.14	13
	Bw1	1.38	2.38	0.11	14
	Bw2	1.36	2.34	0.11	14
	C1	1.32	2.28	0.10	14
	C2	1.28	2.21	0.09	15
	Mean	**1.37**	**2.36**	**0.12**	**13**
Ramgati	Ap	1.68	2.90	0.13	13
	Ad	1.26	2.17	0.12	11
	Bw1	1.12	1.93	0.08	14
	Bw2	1.11	1.91	0.08	14
	C1	1.05	1.81	0.10	11
	C2	0.99	1.71	0.10	10
	Mean	**1.20**	**2.07**	**0.10**	**12**
Grand mean		**1.33**	**2.43**	**0.12**	**11**

*OC= organic carbon, *OM= Organic matter, *Total N= Total nitrogen, *Total P= Total phosphorus, *Total K= Total potassium

This soil was subsequently buried under new deposits. After burial the high organic carbon content in these horizons was preserved as their decomposition was slowed or almost stopped.

At a distant past, these high organic matter containing layers were at the soil surface but fresh deposition of sediments have buried these surface soil layers converting them into *paleosols* (Saheed and Hussain, 1992). Such surface deposition of fresh sediments on previous soil surfaces was a common feature in many flooded soils of the southwestern part of Bangladesh (Ferdous *et al.* 2005). With respect to the organic matter content, the investigated soils are similar to those of other nearly offshore islands (Hussain *et al.* 1989; Begum, 1996; Islam *et al.* 2014b) in Bangladesh.

There is high content of organic matter in the lower horizon of Pirojpur (6.10 %) and Hogla soils (8.46%). This rise may be attributed to the presence of a buried peat layer within the depth of 70 to 120 cm in the profiles, caused rather by geological processes than the pedological ones. This soil was subsequently buried under new deposits. After burial the high organic carbon content in these horizons was preserved as their decomposition was slowed or almost stopped. At a distant past, these high organic matter containing layers were at the soil surface but fresh deposition of sediments have buried these surface soil layers converting them into *paleosols* (Saheed and Hussain, 1992). Such surface deposition of fresh sediments on previous soil surfaces was a common feature in many flooded soils of the southwestern part of Bangladesh (Ferdous *et al.* 2005).

With respect to the organic matter content, the investigated soils are similar to those of other nearly offshore islands (Hussain *et al.* 1989; Begum, 1996; Islam *et al.* 2014b) in Bangladesh. Pirojpur and Hogla soils contains relatively high amount of organic matter throughout the profile. This rise may be attributed to the presence of a buried peat layer within the depth of 70 to 120 cm in the profiles, caused rather by geological processes than the pedological ones. This soil was subsequently buried under new deposits. After burial the high organic carbon content in these horizons was preserved as their decomposition was slowed or almost stopped. At a distant past, these high organic matter containing layers were at the soil surface but fresh deposition of sediments have buried these surface soil layers converting them into *paleosols*. Such surface deposition of fresh sediments on previous soil surfaces was a common feature in many flooded soils of the southwestern part of Bangladesh (Ferdous *et al.* 2005).

The highest content of organic matter is found in the surface soil of Pirojpur profile (4.71 percent) while the lowest content is found in Hogla profile. The higher organic matter in the surface horizons might be due to maximum root activity of biomass as well as natural and artificial additions of fresh or partly decomposed organic matterial in the form of manure and crop residues (Hussain *et al.* 1989).

Nitrogen plays an important role in soil fertility level as well as in soil pedogenesis. The total nitrogen content in the present soils ranges from 0.07 to 0.33 percent with a mean value of 0.12 percent (Table 16). Like before as with organic matter, the highest mean value of nitrogen content within the profile is found in Pirojpur soil whereas the lowest amount is found in Muladi soil. The total nitrogen content s in the studied soils shows the following gradation in the decreasing order:

Pirojpur > Hogla > Barisal > Jhalakati > Ramgati > Nilkamal > Bhola > Muladi.

The vertical distribution of total nitrogen follows closely the sequence of organic matter (Table 16). Surface soil of the studied pedon contains the higher amount of nitrogen than the underlying horizons except Pirojpur and Hogla soils.

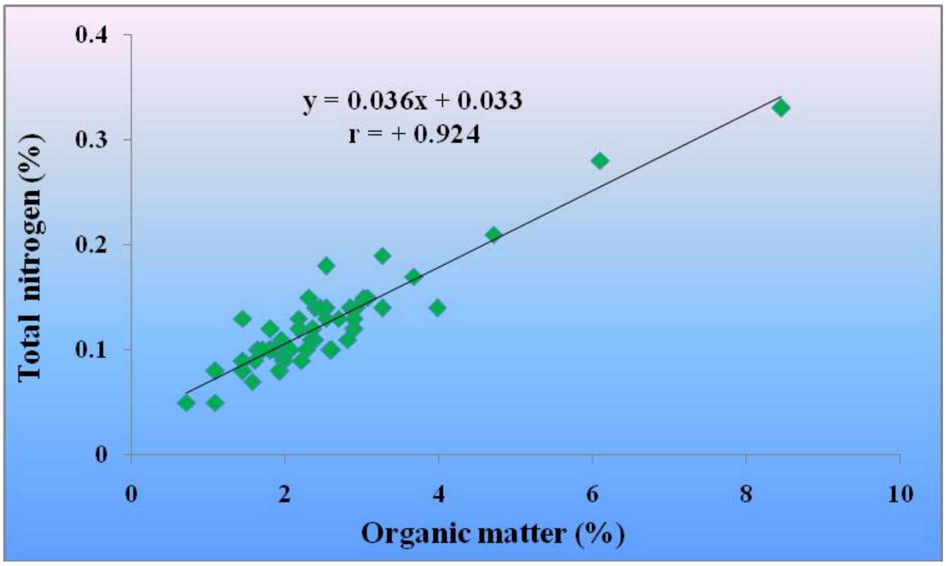

Fig 54. Relationship between percent organic matter and total nitrogen contents in the soils.

A highly significant positive correlation (r = + 0.928) was found between percent organic matter and percent total nitrogen in the studied soils (Fig 54). Similar correlation was found by many authors whose analyzed a large number of soil samples from Bangladesh (Hussain and Mazumder, 1992; Ferdous *et al.* 2005). The values of organic carbon and total nitrogen is in accord weith the findings of Begum *et al.* (2004) who observed similar results in the coastal belt soils.

The C/N ratio of the studied soils ranges from 8 to 17 with a mean value of 11 (Table 16). This indicates that the organic matter fraction in the studied soils is highly oxidized even if these soils remain flooded for more than three months or more in every year. The microbial activity in these soils appears to be quite vigorous.

Distribution pattern of C/N ratio value in the profiles from the surface downward show an irregular pattern with depth in most of the soils (Table 16). The irregular distribution of C/N ratio value in the profiles is due to the different degree of decomposition at various horizons.This short of irregular pattern is quite common in the floodplain soils of Bangladesh (Mazumder, 1996; Hussain *et al.* 1989). Slight fall of C/N ratio with depth in the profile has been reported by SRDI Staff (1965-86) in the soils from the coastal areas of Barisal division.

5.9 Physico- chemical properties of the soils

5.9.1 Cation Exchange Capacity (CEC) of thec soils

The cation exchange capacity of the soils under the present investigation ranges from 14.01 to 23.21 cmol kg^{-1} with a mean value of 17.22 cmol/ kg soil (Table 17). The highest mean value of CEC among the profiles is found in the Hogla soils and the lowest in the Ramgati soil. These results indicate that fine textured soils contain the higher CEC than the medium textured soils due to their higher clay content. The increase in CEC values with increasing clay contents in soils was also observed by many researchers (Gupta and Mishra, 1970; Pathak *et al*.1980; Begum, 2004 Islam *et al.* 2014b).

Nahar (1987) studied some soils of coastal area in Bangladesh and reported that the CEC values ranges from 8.41 to 16.2 cmol kg^{-1}.

The variation of CEC of the studied pedons reflected the important influence of both the clay and organic matter content of these soils. The distribution patterns of CEC with depth in the profiles show an irregular trend like those of clay and organic matter.

The index of weathering (IW = CEC/ clay ratio) of these soils is found to vary from 0.31 to 2.77 with a mean index of 0.58 (Table 17). Such a wide range in the above ratio indicates a wide variation in the type and amount of clay minerals present in the clay fraction of these soils. These results are in accord with the findings of Begum (1996) and Taraqqi (2007) who worked on some soils of coastal zone.

A significant positive correlation (r = +0.71) has been found between CEC and percent clay (Fig 55) and also found a significant positive correlation (r = +0.676) between CEC and percent organic matter in the present studied soils (Fig 56).

Table 17. Results of some physico-chemical properties of the studied soils

Soil Series	Horizon	Exchangeable cation (cmol/kg)						Ca^{++}/Mg^{++} ratio	CEC/Clay ratio
		Na^+	K^+	Mg^{++}	Ca^{++}	TEB*	*CEC		
Bhola	Ap	1.47	0.24	6.48	2.75	10.94	15.01	0.42	0.79
	Ad	1.37	0.29	7.24	2.98	11.88	15.78	0.41	0.83
	Bw1	1.25	0.22	7.21	2.67	11.35	15.51	0.37	0.74
	Bw2	1.25	0.21	6.99	2.58	11.15	15.12	0.37	0.95
	C1	1.18	0.26	6.84	2.72	11.00	15.11	0.40	0.76
	Mean	**1.30**	**0.24**	**6.95**	**2.74**	**11.26**	**15.31**	**0.39**	**0.81**
Nilkamal	Ap	1.52	0.31	6.68	2.98	11.49	16.98	0.45	0.51
	Ad	1.48	0.33	7.31	2.42	11.54	16.68	0.33	0.54
	Bw1	1.45	0.33	8.94	2.25	12.97	16.89	0.25	0.53
	Bw2	1.42	0.32	8.28	2.21	12.23	15.52	0.27	0.60
	C1	1.37	0.32	6.9	2.14	10.73	14.52	0.31	0.52
	Mean	**1.45**	**0.32**	**7.62**	**2.40**	**11.79**	**16.12**	**0.32**	**0.54**
Pirojpur	Ap	1.58	0.64	8.47	2.51	13.2	17.31	0.30	0.31
	Ad	1.56	0.9	8.48	2.45	13.39	17.82	0.29	0.33
	Bw1	1.49	1.08	8.79	2.58	13.94	17.68	0.29	0.31
	Bw2	1.14	0.63	8.42	2.54	12.73	17.77	0.30	0.34
	C1	1.12	0.76	8.21	2.42	12.51	17.87	0.29	0.33
	C2	1.05	0.81	8.11	2.35	12.32	17.95	0.29	0.34
	Mean	**1.32**	**0.80**	**8.41**	**2.48**	**13.02**	**17.73**	**0.29**	**0.33**
Hogla	Ap	1.41	0.29	9.97	4.89	16.56	23.21	0.49	0.40
	Ad	1.12	0.31	9.98	4.85	16.26	23.12	0.49	0.41
	Bw1	1.21	0.33	9.68	3.89	15.11	20.94	0.40	0.44
	Bw2	1.15	0.32	9.65	3.65	14.77	22.31	0.38	0.46
	C1	1.11	0.33	9.69	4.95	16.08	21.99	0.51	0.46
	C2	0.92	0.35	9.62	4.98	15.87	22.14	0.52	0.45
	Mean	**1.15**	**0.32**	**9.77**	**4.54**	**15.78**	**22.29**	**0.46**	**0.43**

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Table 17. Results of some physico-chemical properties of the studied soils.

Soil Series	Horizon	Exchangeable cation (cmol/kg)						Ca^{++}/Mg^{++} ratio	CEC/Clay ratio
		Na^{+}	K^{+}	Mg^{++}	Ca^{++}	TEB*	*CEC		
Muladi	Ap	0.98	0.37	5.61	3.32	10.28	15.57	0.59	0.40
	Ad	0.86	0.25	6.72	2.57	10.4	18.83	0.38	0.47
	Bw1	0.85	0.23	6.27	2.94	10.29	17.67	0.47	0.40
	Bw2	0.71	0.24	6.83	2.58	10.36	17.68	0.38	0.42
	C1	0.86	0.31	5.74	3.01	9.92	14.53	0.52	2.42
	C2	0.75	0.25	5.52	2.52	9.04	13.87	0.46	2.77
	Mean	**0.84**	**0.28**	**6.12**	**2.82**	**10.06**	**16.36**	**0.54**	**1.15**
Barisal	Ap	1.96	0.13	7.68	3.98	13.75	20.35	0.52	0.41
	Ad	1.94	0.26	8.54	3.51	14.25	20.56	0.41	0.40
	Bw1	1.74	0.26	8.74	3.44	14.18	21.64	0.39	0.43
	Bw2	1.72	0.15	7.89	3.56	13.32	21.75	0.45	0.43
	C1	1.71	0.18	7.89	3.45	13.23	20.69	0.44	0.40
	C2	1.54	0.6	8.12	3.74	14	21.68	0.46	0.41
	Mean	**1.77**	**0.26**	**8.14**	**3.61**	**13.79**	**21.11**	**0.45**	**0.41**
Jhalakati	Ap	1.38	0.22	5.89	2.54	10.03	15.64	0.43	0.60
	Ad	1.12	0.17	5.68	2.21	9.18	14.86	0.39	0.48
	Bw1	1.21	0.18	6.12	2.65	10.16	14.62	0.43	0.54
	Bw2	1.17	0.14	5.54	2.54	9.39	14.71	0.46	0.46
	C1	1.15	0.14	5.26	2.51	9.06	13.54	0.48	0.48
	C2	1.08	0.22	5.12	2.69	9.11	14.01	0.53	0.42
	Mean	**1.19**	**0.18**	**5.60**	**2.52**	**9.49**	**14.56**	**0.45**	**0.50**
Ramgati	Ap	1.48	0.26	5.78	3.21	10.73	14.9	0.56	0.39
	Ad	1.42	0.29	5.25	2.29	9.25	13.8	0.44	0.49
	Bw1	1.39	0.3	5.52	2.31	9.52	13.5	0.42	0.45
	Bw2	1.33	0.15	5.21	2.54	9.23	14.8	0.49	0.55
	C1	1.25	0.16	5.12	3.33	9.86	14.5	0.65	0.40
	C2	1.28	0.16	4.87	3.33	9.64	14.3	0.68	0.38
	Mean	**1.36**	**0.22**	**5.29**	**2.84**	**9.71**	**14.30**	**0.54**	**0.44**
Grand mean		**1.30**	**0.33**	**9.65**	**2.82**	**11.86**	**17.22**	**0.57**	**0.58**

*TEB= total exchangeable bases. *CEC= Cation exchange capacity

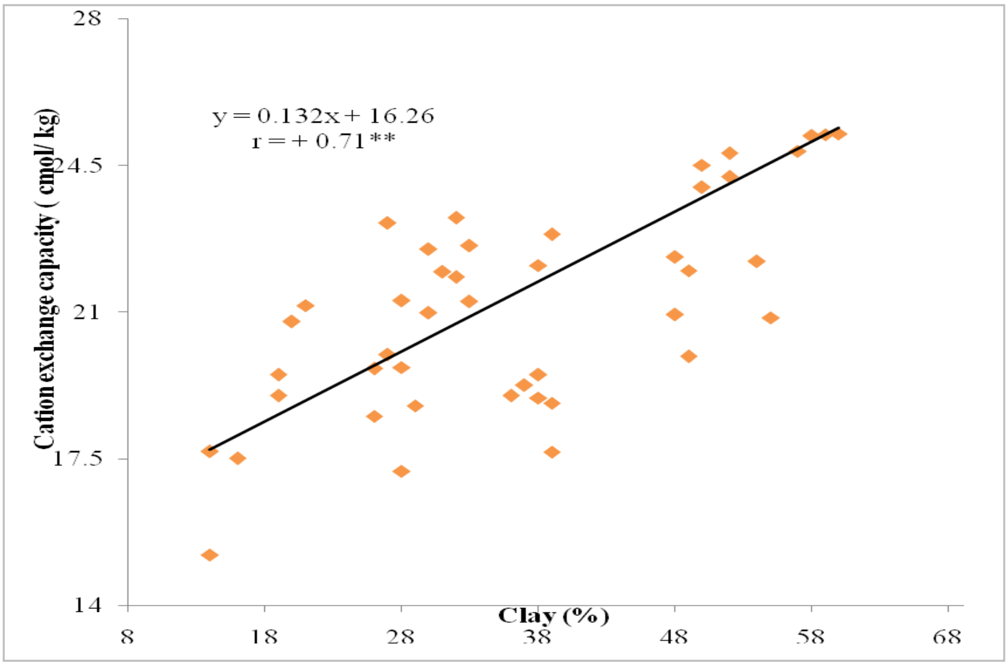

Fig 55. Relationship between percent clay and cation exchange capacity in the soils under investigation.

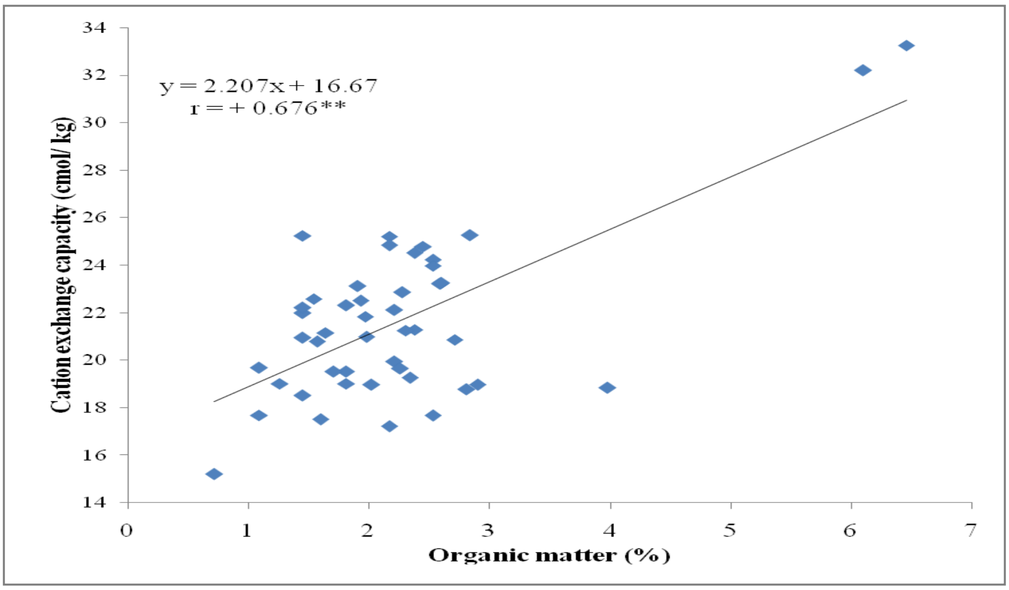

Fig 56. Relationship between percent organic matter and cation exchange capacity in the soils under investigation.

However, the degree of correlation coefficient between CEC and clay is appreciably higher than that between CEC and organic matter. The above results corroborate with the findings of Lavti *et al*. (1969) and Landon (1991), who pointed out that the CEC was significantly correlated with both clay and organic matter, but clay was the biggest contributor in mineral soils.

The soils under the present study have relatively lower CEC as compared to the CEC of soils developed under similar climatic condition (Dudal and Bramo, 1965). The CEC of mineral soils may range, in accordance with the clay content, from a few tro 50 to 60 meq per 100 g, whereas the CEC of organic soils may exceed 200 cmol per kg (Wiklander, 1965). Karim and Islam (1956) reported that the average CEC of clay and silt fractions of the soils and sediments of Bangladesh was 27 and 12 cmol per kg, respectively. This indicates that the silt fraction of Bangladesh soils have cation exchange capacity. This is possibly due to the occurrence of considerable quantity of mica in different stages of weathering (Jackson, 1965).

5.9.2 Exchangeable bases (Na^+, K^+, Ca^{++} and Mg^{++})

Results of exchangeable bases (Na^+, K^+, Ca^{++} and Mg^{++})and their percentage composition have been presented in Table 17 and Table 18. Among the bases in the exchange positions, Mg^{++} is the dominant cation followed by Ca^{++} in all the soil profiles. The exchangeable Mg^{++} in the soils varies from 4.87 to 9.98 cmol kg^{-1} with a mean value of 9.65 cmol kg^{-1} (Table 17). The highest mean exchangeable Mg^{++} was found in Hogla soil while the lowest value is found in Ramgati soil (Fig 57).

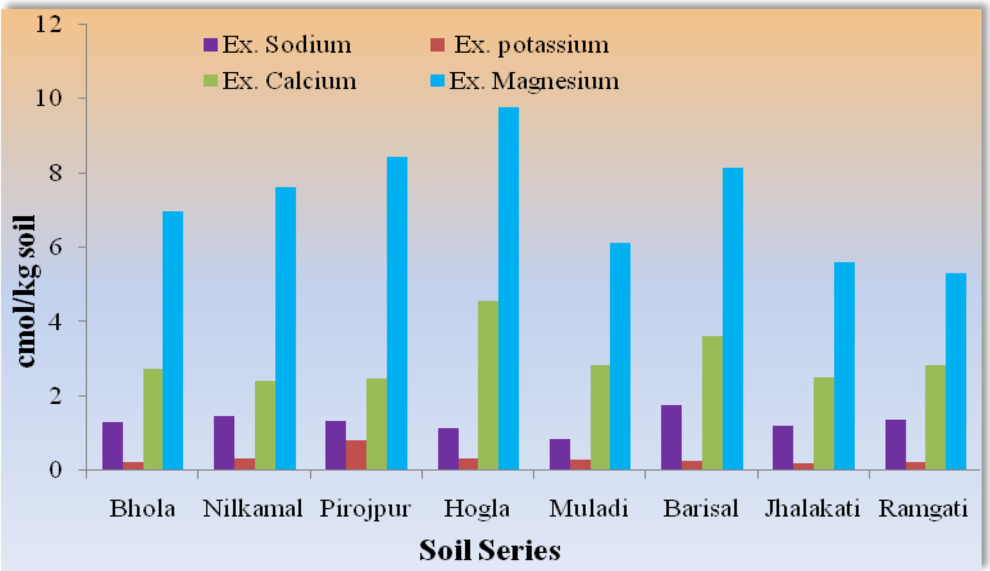

Fig 57. Graph shows mean value of the exchangeable Na^+, K^+, Ca^{++}, Mg^{++} of the studied soils.

It was observed that maximum amounts of Mg^{++} was found in the B or C horizons in most of the profiles due to leaching loss from the overlying horizons which was subsequently illuviated in the underlying horizon. Magnesium occupies around 58 percent of the total exchange sites among the bases (Table 18). The amount of exchangeable Mg^{++} in the soils was very high in relation to Ca^{++}, which is an indication of old marine deposits where the Ca^{++} is largely leached and Mg is maintained at a relatively high level, probably as results of progressive clay disintegration and release of Mg. Moreover, the higher amount of Mg^{++} content presumably was due to the connection with seawater of high Mg content. Predominance of Mg^{++} in the exchangeable phases in the coastal soils was also reported by many authors (Panaullah, 1984; SRDI Staff, 1967; Rahman, 1990; Hussain, 1992). The vertical distribution of Mg^{++} in the soil profiles shows an irregular pattern with depth.

On the quantitative basis, exchangeable Ca^{++} comes after exchangeable Mg^{++}. The amount of exchangeable Ca^{++} varies from 2.14 to 4.89 cmol kg^{-1} with a mean of 2.82 coml. kg^{-1}. The highest mean exchangeable Ca^{++} was found in the soils of the Hogla series while the lowest value is found in Nilkamal series. Exchangeable calcium occupies around 29 percent of the total exchange sites among the bases (Table 18). The vertical distribution of Ca^{++} in the soil profiles also shows an irregular pattern.

These results are in agreement with the findings of Taraqqi (2007) who worked on some soils of coastal zone. The author stated that the exchangeable Ca^{++} was also the dominant exchangeable cation like Mg^{++} in the exchange complex. The predominance of Ca^{++} was reported by George (1958) in some humic gley soils of Ohio, USA. Similar observation was also made by Bloomfield (1959). Predominance of exchangeable Ca^{++} was reported by many other authors in the soils formed on Gangetic alluvium (Hussain *et al.* 1981 and Mazumder, 1976). The vertical distribution of exchangeable Ca^{++} in the profiles shows an irregular pattern. Similar results were obtained by Khan (1995) and Mazumder (1996) for some other floodplain soils of Bangladesh.

The soils have a low Ca^{+2}/ Mg^{+2} ratios. The exchangeable Ca^{++}/ Mg^{++} ratio of the studied soils varies from 0.25 to 0.59 with a mean ratio of 0.57 (Table 17). Similar results were also reported by Panaullah (1984). The highest mean ratio among the profiles is found in the Muladi soils and the lowest in the Pirojpur soils. Buol *et al.* (1973) noted that the Ca^{+2}/ Mg^{+2} ratio in soils decreases with increasing maturity of the soils and is occasionally lower than 2.0.

Table 18. Results of percent composition of exchangeable bases and base saturation percentage (BSP) of the studied soils.

Soil Series	Horizon	Depth (cm)	%Composition				%BSP*
			Na^+	K^+	Mg^{++}	Ca^{++}	
Bhola	Ap	0-8	13	2	59	25	73
	Ad	8-12	12	2	61	25	75
	Bw1	12-28	11	2	64	24	73
	Bw2	28-40	11	2	63	23	74
	C1	40-90+	11	2	62	25	73
	Mean		**12**	**2**	**62**	**24**	**74**
Nilkamal	Ap	0-13	13	3	58	26	68
	Ad	13-18	13	3	63	21	69
	Bw1	18-45	11	3	69	17	77
	Bw2	45-80	12	3	68	18	79
	C1	80-105+	13	3	64	20	74
	Mean		**12**	**3**	**65**	**20**	**73**
Pirojpur	Ap	0-10	12	5	64	19	76
	Ad	10-14	12	7	63	18	75
	Bw1	14-28	11	8	63	19	79
	Bw2	28-50	9	5	66	20	72
	C1	50-70	9	6	66	19	70
	C2	**70-120+**	9	7	66	19	69
	Mean		**10**	**6**	**65**	**19**	**73**
Hogla	Ap	0-12	9	2	60	30	71
	Ad	12-15	7	2	61	30	70
	Bw1	15-48	8	2	64	26	72
	Bw2	48-60	8	2	65	25	66
	C1	60-85	7	2	60	31	73
	C2	85-110+	6	2	61	31	72
	Mean		**7**	**2**	**62**	**29**	**71**

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Table 18. Results of percent composition of exchangeable bases and base saturation percentage (BSP) of the studied soils.

Soil series	Horizon	Depth (cm)	% Composition				% BSP*
			Na+	K+	Mg++	Ca++	
Muladi	Ap	0-10	10	4	55	32	66
	Ad	10-17	8	2	65	25	55
	Bw1	17-34	8	2	61	29	58
	Bw2	34-62	7	2	66	25	59
	C1	62-94	9	3	58	30	68
	C2	94-105+	8	3	61	28	65
	Mean		**8**	**3**	**61**	**28**	**62**
Barisal	Ap	0-10	14	1	56	29	68
	Ad	10-18	14	2	60	25	69
	Bw1	18-50	12	2	62	24	66
	Bw2	50-77	13	1	59	27	61
	C1	77-110	13	1	60	26	64
	C2	110-125+	11	4	58	27	65
	Mean		**13**	**2**	**59**	**26**	**65**
Jhalakati	Ap	0-10	14	2	59	25	64
	Ad	10-16	12	2	62	24	62
	Bw1	16-35	12	2	60	26	69
	Bw2	35-55	12	1	59	27	64
	C1	55-71	13	2	58	28	67
	C2	71-99+	12	2	56	30	65
	Mean		**12**	**2**	**59**	**27**	**65**
Ramgati	Ap	0-8	14	2	54	30	72
	Ad	8-12	14	3	57	25	67
	Bw1	12-35	14	3	58	24	71
	Bw2	35-53	14	2	56	28	62
	C1	53-71	13	2	52	34	68
	C2	71-99+	13	2	51	35	67
	Mean		**14**	**2**	**55**	**29**	**68**
Grand Mean			**11**	**3**	**58**	**29**	**69**

Hussain *et al*. (1992) studied some coastal soils of Bangladesh and found the Ca^{+2}/ Mg^{+2} ratios range from 0.23 to 0.50 with a mean ratio of 0.35.

Hearly (1959) also reported that in the gley soils of Newzeland, the exchangeable Ca^{+2}/ Mg^{+2} ratios are low. Edelman and Vander (1963) emphasized that the exchangeable Ca^{+2}/ Mg^{+2} ratio influences the development of structure and agricultural use of the soils. As the exchangeable Ca^{+2}/ Mg^{+2} ratios of the soils decreases, the structure becomes poorer. The high Ca^{+2}/ Mg^{+2} ratios in the Muladi soils indicate that the structure is quite strong and in course of time will be well developed.

Buol *et al.* (1973) noted that the ratio of exchangeable Ca^{++}/ Mg^{++} ratio are an indicator of relative weathering and degree of development of soils. In humid and sub-humid regions, exchangeable Mg^{++} increases with respect to increasing exchangeable Ca^{++}.

The vertical distribution pattern of exchangeable Ca^{++}/ Mg^{++} ratio in the profiles showed an irregular decrease with depth in all the profiles. The vertical distribution pattern of exchangeable Na^{+} in the studied profiles is more or less irregular (Table 17). It can be suggested that due to very high rainfall in the studied area, there is washing out of sodium from the exchange positions.

Exchangeable sodium is the third most abundant metal ion in the exchange complex of all the profiles. The amount of exchangeable Na^{+} varies from 0.71 to 1.96 cmol/kg with a mean value 1.30 cmol/kg (Table 21). Similar results were also reported by SRDI Staff (1965-86) and Ali (1994) on a profile from Brahamaputra floodplain. The highest mean exchangeable Na^{+} ion within the profile is found in Barisal soil series whereas the lowest is found in the Muladi soil series. The percentage composition of exchangeable sodium varies from 6 to 14 with a mean value of 11. It is clear that exchangeable sodium percentage of the studied soils is less than 15 percent. It can be safely concluded, therefore, that the present soils are non-sodic and non-saline (Bower and Hatcher, 1962) in nature.

Hussain and Rahman (1983) noted that the salt affected soils along the coastal belt of Bangladesh are non-sodic as the exchangeable sodium percentage (ESP) was less than 15. They further indicated that the residual sodium carbonate of the soil solution was low as well. The vertical distribution of ESP in the studied pedons was found to be irregular.

Exchangeable K^{+} content in the soils is very low and ranges from 0.13 to 1.08 cmol/kg with a mean value of 0.33 cmol/kg (Table 17). Similar results were also reported for these soils by the SRDI Staff (1965-86) and Islam *et al.* (2014b). The highest mean

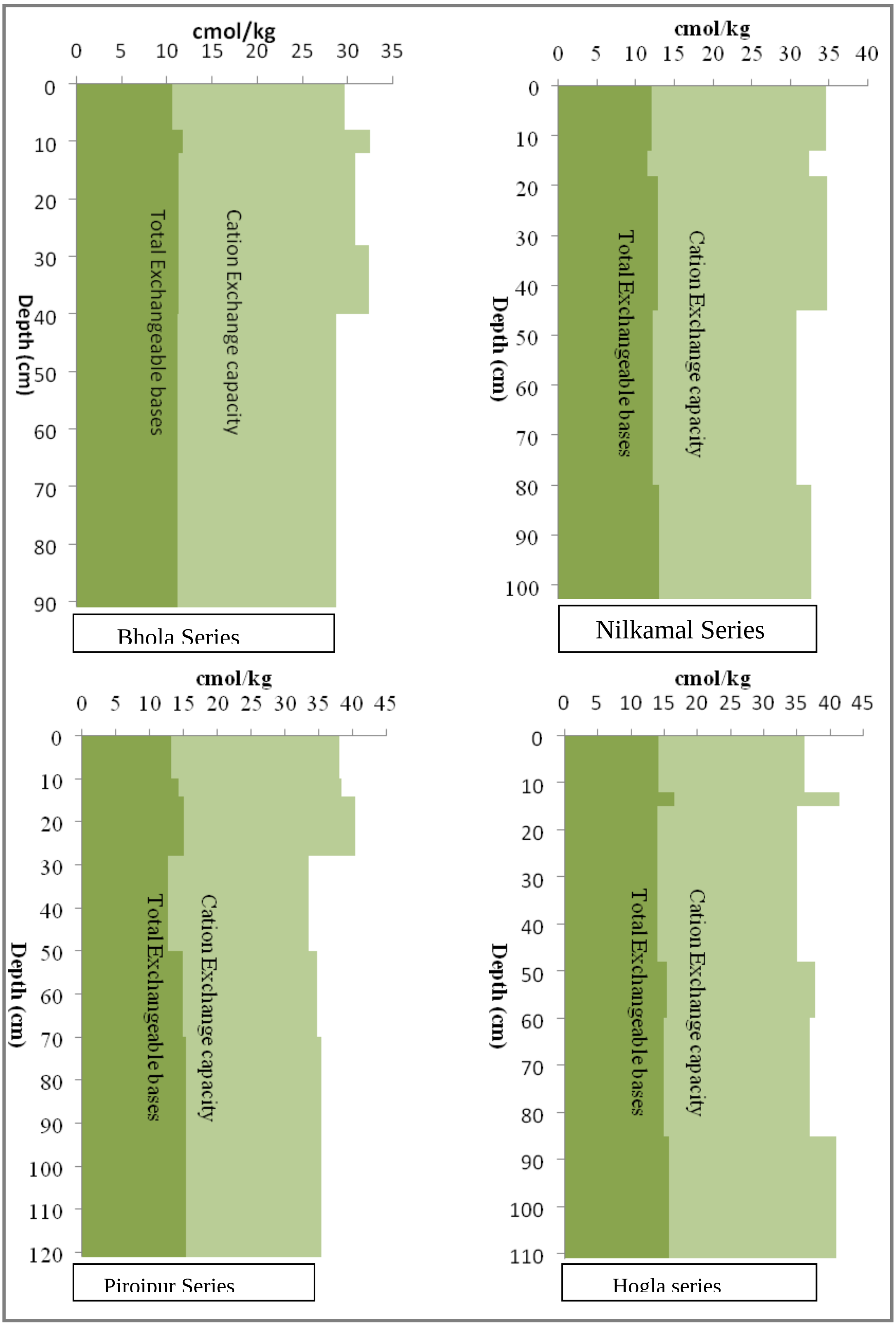

Fig 58. Vertical distribution of cation exchange capacity and total ex. bases in Bhola, Nilkamal.Pirojpur and Hogla soil under study.

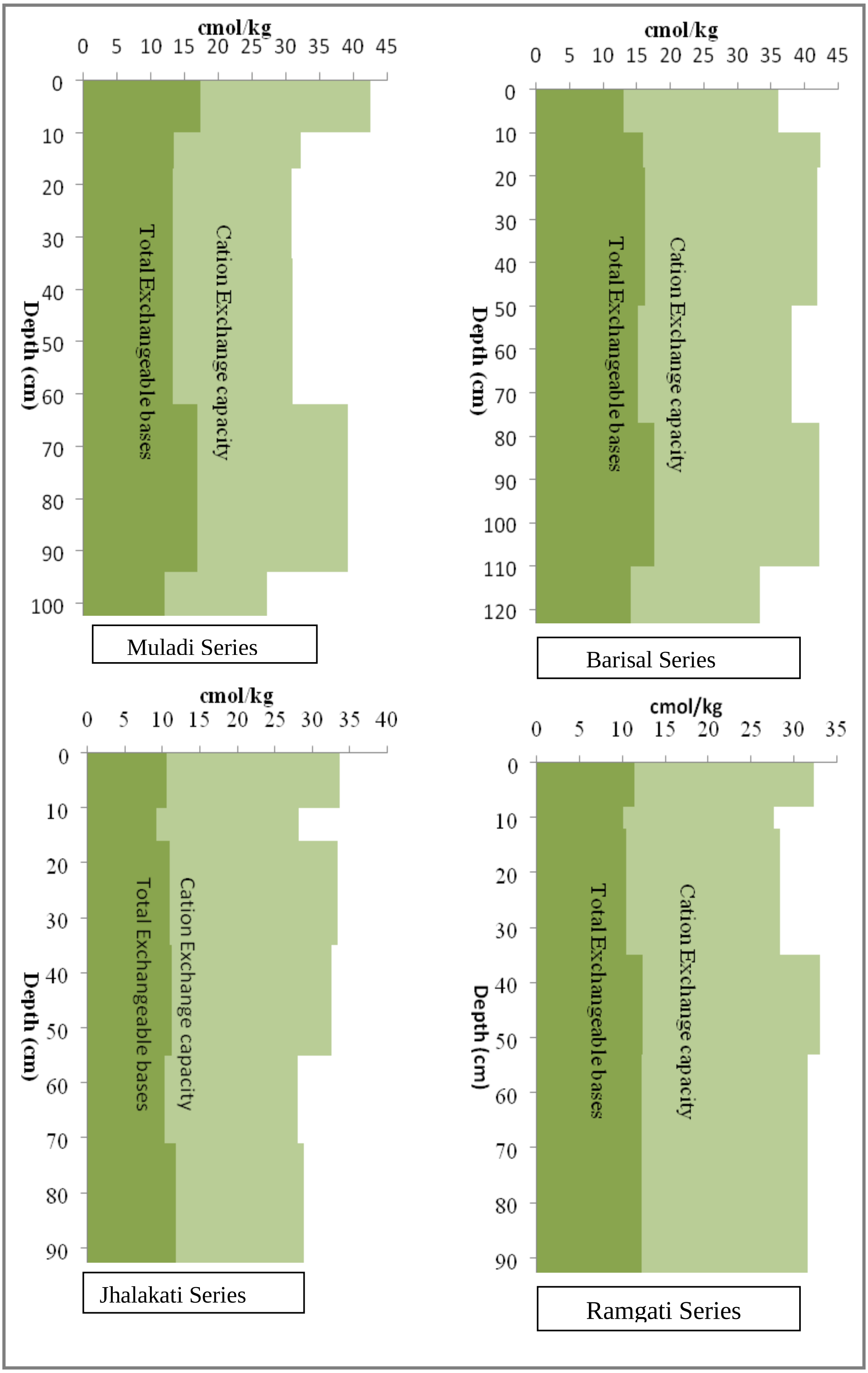

Fig 59. Vertical distribution of cation exchange capacity and total ex. bases in Muladi, Barisal, Lhalakati and Ramgati soil under study

exchangeable K^+ among the profiles is found in the Pirojpur soil and lowest in the Jhalakati soil (Table 17). Exchangeable K^+ contents in the soils under study revealed that these soils are rich in Potassium and little application of potassic fertilizer will be needed for better growth of crops.

It shows an irregular distribution pattern with depth. The exchangeable potassium percentage (EPP) in the soils is low and ranges from 1 to 8 with an average of 3 percent. It may be pointed out here that the EPP in Bangladesh soils is low. Even in the mica rich soils developed in the Gangetic alluvium the EPP is low reported by many authors (Hussain *et al*. 1980; Hussain and Majumder, 1992). This indicates that the K- bearing mica minerals are not replenishing potassium in the exchange sites as it is being taken up by the plants.

Brooks *et al.* (1956) studied the effect of various exchangeable cations upon the physical condition of the soil. It was suggested that both sodium and magnesium ion in the soil solutions affect the physical structure of the soils. Bower and Hatcher (1962) noted that Mg^{++} ion has similar effect as that of Ca^{++} on the physical structure of the soils. The physical implications of the cationic composition in the soluble and exchangeable phases of Bangladesh soils have not been studied well as yet. The soils in the south central coastal areas do not demonstrate any bad physical condition due to the predominance of sodium and magnesium in the soluble and exchangeable phases. On the basis the soils under the present study may be considered as very close to the ideal.

5.9.3 Total exchangeable bases (TEB)

The total exchangeable bases (Ca^{++}, Mg^{++}, K^+, Na^+) ranges from 9.06 to 16.56 cmol/kg soil with a mean value of 11.86 cmol/kg soil in the soil profiles (Table 17). The vertical distribution of total exchangeable bases and CEC with depth is irregular in all the soil profiles (Figs.58 & 59). The total mean exchangeable bases are noticed higher in the Hogla soils while the lowest in the Ramgati soils (Fig 60).

5.9.4 Base saturation percentage (BSP)

The BSP of soils are very important for predicting the genetic processes in soil as well as their stages of development. The BSP have also been used in soils for their classification (Soil Survey Staff, 1975). It is also frequently used as an indicator of soil nutrient status (Landon, 1991). It is also frequently used as an indicator of soil nutrient status (Landon, 1991).

The base saturation percentage of the soils under the present investigation ranges from 55 to 79 with an average value of 69 (Table 18). This high base saturation may be attributed due to rapid replenishment of bases from the weathering minerals.

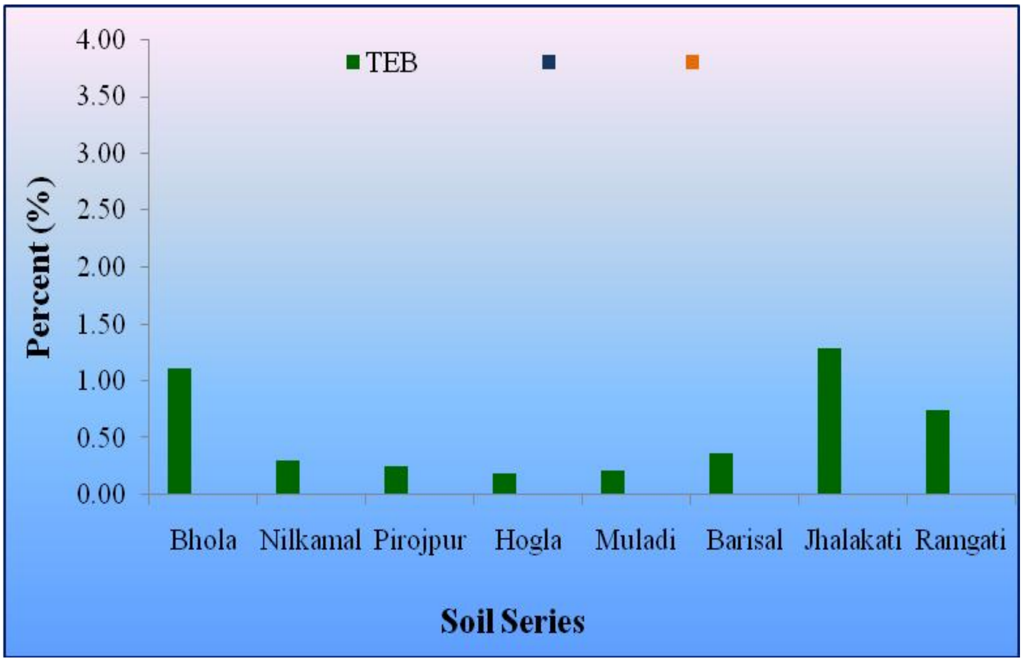

Fig 60. Graph shows the mean value of exchangeable bases of the studied soils.

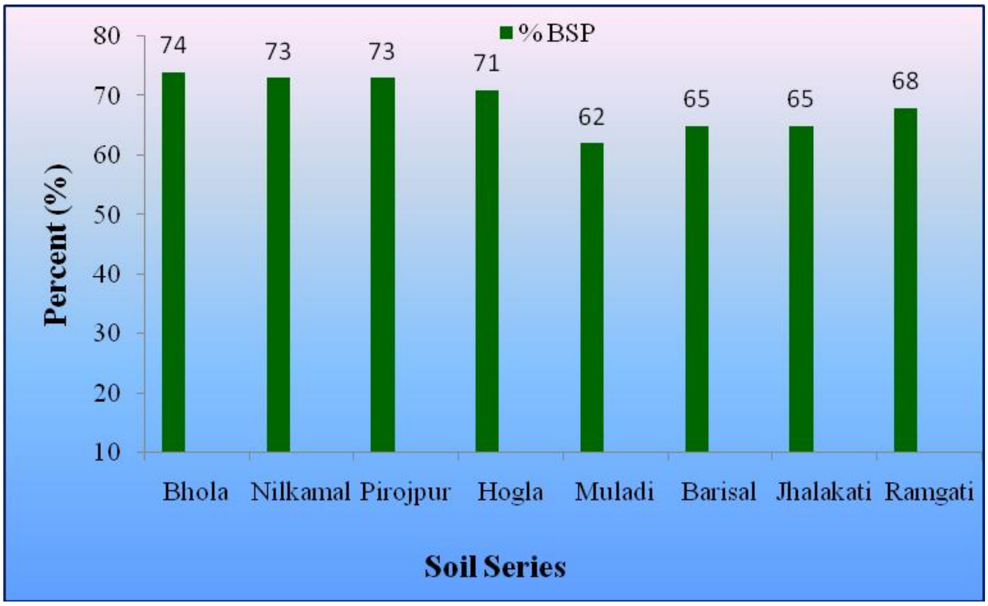

Fig 61. Graph shows the mean value of percent base saturation of the studied soils.

The highest mean value of base saturation percentage is found in the Bhola soil and the lowest in the Muladi soils among the profile (Fig 61).

The vertical distribution pattern of BSP showed an irregular trend with depth (Table 18). In some of the pedons the percent base saturation shows a slight rise with depth. The increase of base saturation with depth was reported by George *et al.* (1958) in some humic gley soils of Ohio. In some cracking clay soils from basin areas Hussain and Chowdhury (1980) reported percent base saturation ranging from 40 to 78. From the above discussion it is clear that percent base saturation in Bangladesh soils is dependent on parent materials over which they have been formed. Since these soils are leached mainly by rain and river water which have high pH, the high base saturation in these soils tends to persist. Some workers have found the similar results in some floodplain soils of Bangladesh (Mazumder, 1976; Islam *et al.* 2014b).

5.10 Free oxides in soils

The soils under the present study remain flooded for 3 to 5 months or so far. The C/N ratio of these soils indicates that this seasonal flooding does not inhibit their oxidation and the organic matters in the studied soils are well oxidized.

The amount of free oxides and their fixation in soils is very important in evaluating mineral weathering and pedogenic changes in soils (Mc.keague and Day, 1966; Blume and Schwertman, 1969; Santos *et al* .1986; Mirabella and Carnicelli, 1992).

5.10.1 Dithionate extractable free iron oxide (Fe_2O_3)

Free Fe_2O_3 contents in the studied soils vary from 0.60 to 1.62 percentwith a mean of 1.12 percent (Table 19). The highest mean value of free iron oxide among the studied profiles is found in Barisal soil and the lowest in Ramgati soil (Fig 63). This low content of free Fe_2O_3 is due to the loss of iron from the soils during the flooding season when they undergo reduction (Bouma, 1983). The free iron contents varied from 0.4 to 1.3 percent in the Gangetic alluvium soils of Bangladesh (Ali, 1994).

Karim (1984) noted that goethite content in Bangladesh soils ranged from 0.48 to 1.20 percent. He also reported substantial substitution of iron by aluminium in the crystals of goethite mineral.

Perhaps, it should be noted that the studied soils remain flooded for varying periods during the wet season. Moreover, all these soils are used for cultivation of transplanted *Aman* paddy when the soils remain submerged under water. During the wet season, some of the reduced dissolved iron move down along with ground water and are deposited in the B horizon of the soils in the form of mottles. Mottles, therefore, are prominent in the middle

Table 19. Results of dithionate extractable iron and manganese oxides of the studied soils.

Soil Series	Horizons	Free Fe_2O_3	Free MnO_2	Total Fe_2O_3	Free Fe_2O_3/ Free MnO_2 ratio	Total Fe_2O_3/ Free Fe_2O_3 ratio
		→	%	→		
Bhola	Ap	1.41	0.032	4.70	44	3
	Ad	1.25	0.035	4.59	36	4
	Bw1	1.07	0.033	5.93	32	6
	Bw2	1.21	0.035	4.69	35	4
	C1	1.04	0.043	5.09	24	5
	Mean	**1.20**	**0.035**	**5.00**	**34**	**4**
Nilkamal	Ap	1.04	0.019	6.43	55	6
	Ad	1.44	0.032	5.16	45	4
	Bw1	1.80	0.030	7.58	60	4
	Bw2	1.14	0.052	6.51	22	6
	C1	1.08	0.055	4.63	20	4
	Mean	**1.30**	**0.038**	**6.06**	**40**	**5**
Pirojpur	Ap	1.16	0.046	6.71	25	6
	Ad	1.42	0.043	7.92	33	6
	Bw1	1.61	0.054	7.64	30	5
	Bw2	1.27	0.049	6.94	26	5
	C1	1.22	0.049	5.39	25	4
	C2	1.29	0.055	6.63	23	5
	Mean	**1.33**	**0.049**	**6.87**	**27**	**5**
Hogla	Ap	1.17	0.028	6.87	42	6
	Ad	1.12	0.022	7.90	51	7
	Bw1	1.37	0.032	7.90	43	6
	Bw2	1.48	0.035	6.89	42	5
	C1	1.36	0.036	5.87	38	4
	C2	0.73	0.014	6.68	52	9
	Mean	**1.21**	**0.028**	**7.02**	**45**	**6**

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Table 19. Results of dithionate extractable iron and manganese oxides of the studied soils.

Soil Series	Horizons	Free Fe_2O_3	Free MnO_2	Total Fe_2O_3	Free Fe_2O_3/ Free MnO_2 ratio	Total Fe_2O_3/ Free Fe_2O_3 ratio
		→	%	→		
Muladi	Ap	1.12	0.021	2.63	53	2
	Ad	1.06	0.022	2.54	48	2
	Bw1	1.20	0.076	4.35	16	4
	Bw2	1.47	0.095	4.65	15	3
	C1	1.32	0.025	4.11	53	3
	C2	1.41	0.035	4.86	40	3
	Mean	**1.26**	**0.046**	**3.86**	**38**	**3**
Barisal	Ap	0.96	0.046	2.12	21	2
	Ad	1.52	0.043	2.69	35	2
	Bw1	1.53	0.044	2.78	35	2
	Bw2	1.52	0.040	2.68	38	2
	C1	1.48	0.027	2.89	55	2
	C2	1.28	0.025	2.99	51	2
	Mean	**1.38**	**0.037**	**2.69**	**39**	**2**
Jhalakati	Ap	0.79	0.051	2.17	15	3
	Ad	1.13	0.040	1.98	28	2
	Bw1	1.43	0.044	1.94	33	1
	Bw2	1.09	0.040	2.12	27	2
	C1	1.00	0.033	1.98	30	2
	C2	0.93	0.043	2.21	22	2
	Mean	**1.06**	**0.042**	**2.07**	**26**	**2.0**
Ramgati	Ap	1.16	0.022	2.25	53	2
	Ad	0.93	0.021	2.31	44	2
	Bw1	0.60	0.049	2.45	12	4
	Bw2	1.01	0.046	2.55	22	3
	C1	0.64	0.024	2.56	27	4
	C2	1.62	0.025	2.52	65	2
	Mean	**0.99**	**0.031**	**2.44**	**37**	**3**
Grand mean		**1.12**	**0.038**	**4.50**	**36**	**4**

zone of the soil profiles, where oxidation and reduction condition alternate with season (Saheed and Hussain, 1992).

The vertical distribution pattern of free Fe_2O_3 with depth in the profiles is almost irregular (Figs. 65 & 66). Similar results were also obtained by Deturck and Somasiri (1992) in the rice soils of Srilanka with Anthraquic features and also by Fanning *et al.* (1992) in their study of micro- macromorphology of some wet soils.

Brinkman (1977) also reported that in the surface water gley soils free Fe_2O_3 is accumulated in the middle zone of the pedon.

Joffe (1966) stated that the surface enrichment of free iron oxide is possibly due to the fact that with the receding of ground water table, ferrous iron is oxidized easily to form free iron oxide in the surface soil, while in the sub- surface soil the ferrous iron does not change.

Habibullah *et al*. (1971) identified amorphous iron and silicon oxides in the clay fraction of some ferrolysed soils formed on seasonally flooded surfaces.

A significant positive correlation (r= + 0.469**) is found between total and free iron contents of the soils (Fig 62). This indicates that where the free iron oxide contents are high the total iron oxide contents are also high (Jha *et al*. 1984).

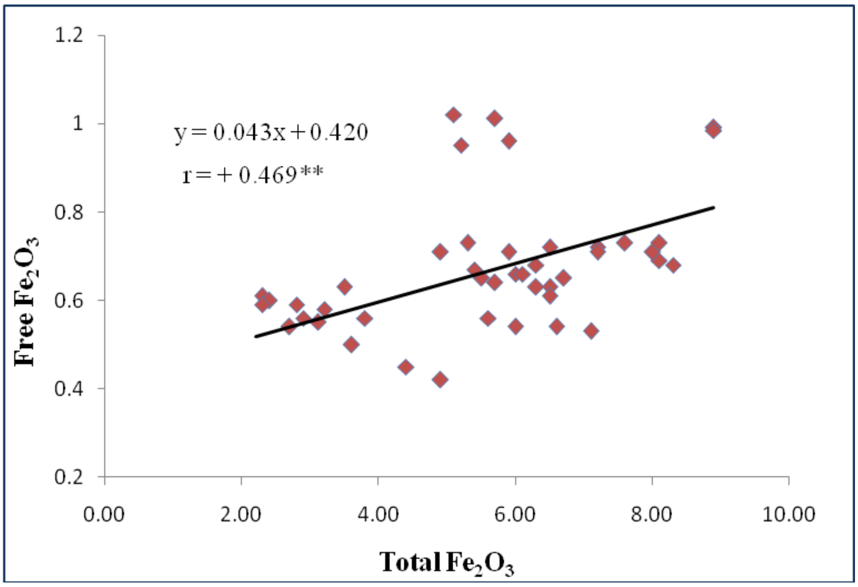

Fig 62. Relationship between percent total Fe_2O_3 and percent free Fe_2O_3 in the soils under investigation

5.10.2 Dithionate extractable free manganese oxide (MnO_2)

The movement of manganese oxide and its fixation in the soil profiles are significant criteria in a pedogenic study as it behaves to some extent like iron (Joffe, 1968).

The free manganese oxides contents in the studied soils vary from 0.019 to 0.055 percent with a mean value of 0.038 percent (Table 19). The highest mean value of free iron oxide among the studied profiles is found in Pirojpur soil and the lowest in Hogla soil (Fig 63). This low free MnO_2 content is probably due to intense reduction of manganese caused by flooding during the monsoon period and their subsequent removal by ground water. Daniel *et al*. (1962) noted that poor drainage condition is probably the most important factor that caused the decrease in free MnO_2 content of the soils.

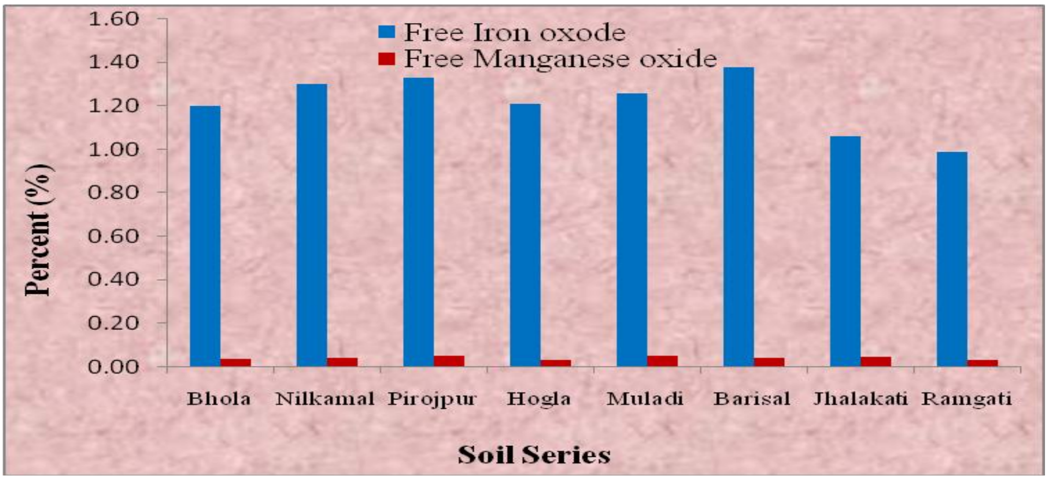

Fig 63. Graph shows the mean value of the free iron oxide and free manganese oxide in the studied soils.

A significant positive correlation (r = +0.467**) is found between free Fe_2O_3 and free MnO_2 contents in the studied soil profiles (Fig 64). The vertical distribution pattern of free MnO_2 in the studied soil profiles showed an irregular trend (Figs. 65 & 66).

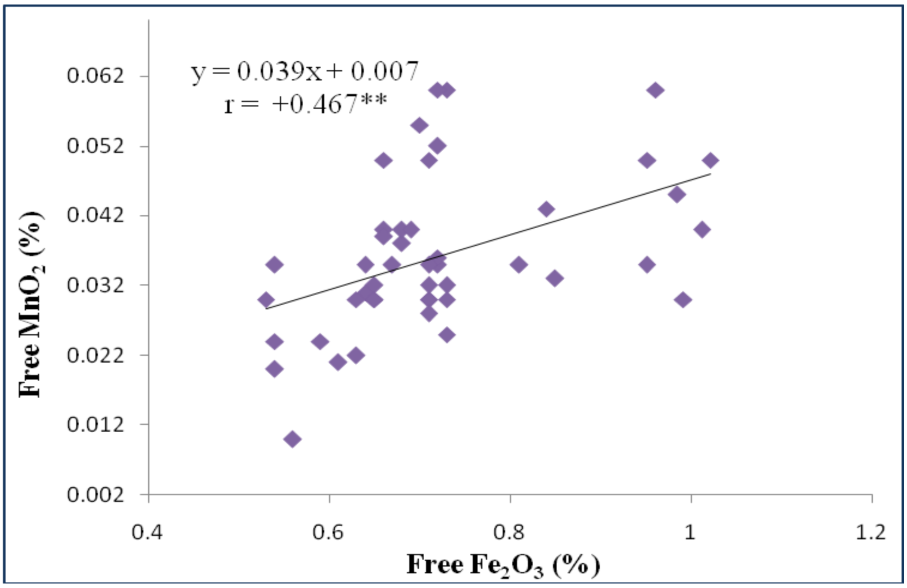

Fig 64. Relationship between percent free Fe_2O_3 and percent free MnO_2 in the studied soils .

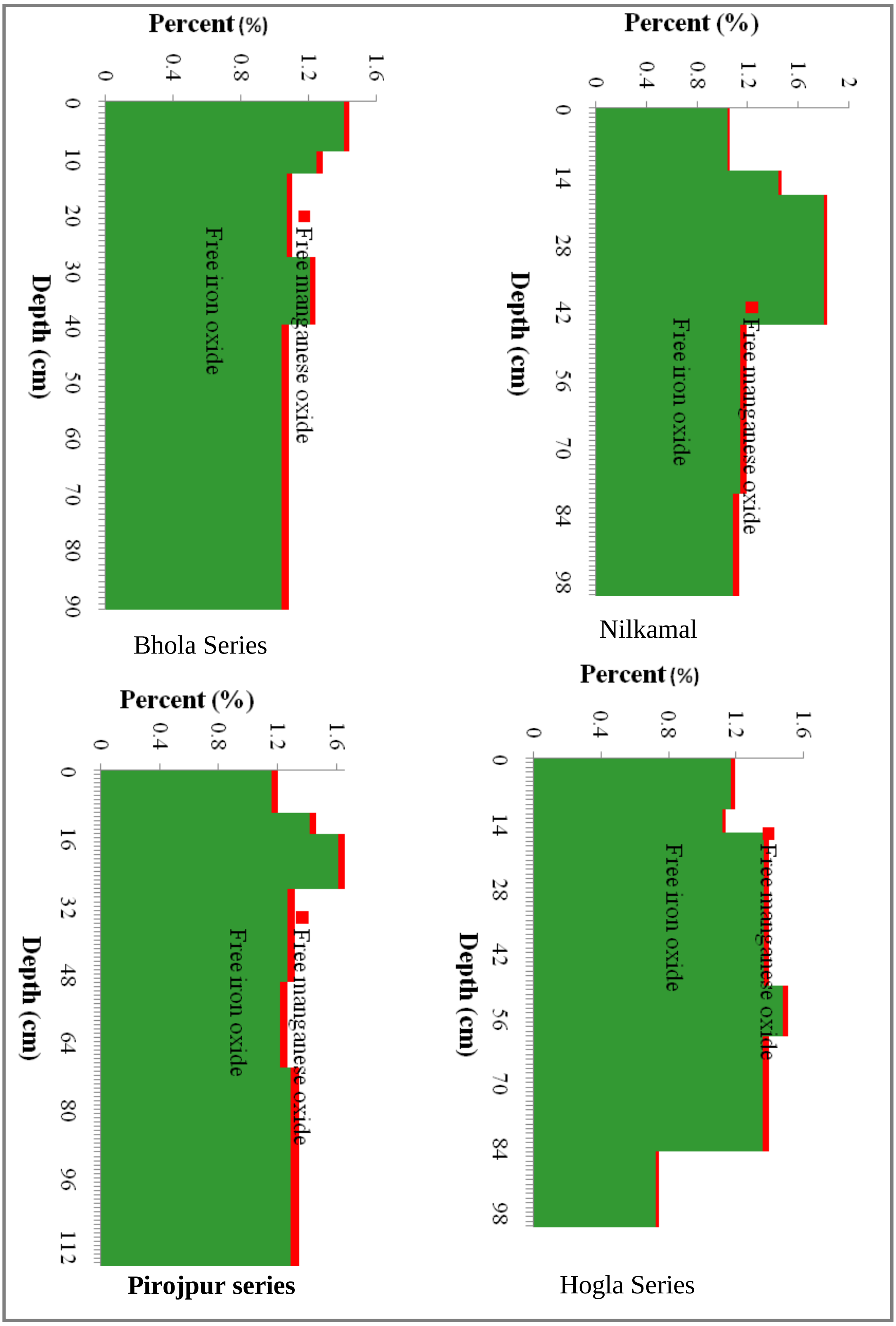

Fig 65. Graph shows the vertical distribution of free iron and manganese oxide in Bhola, Nilkamll, Barisal and Jhalakati series.

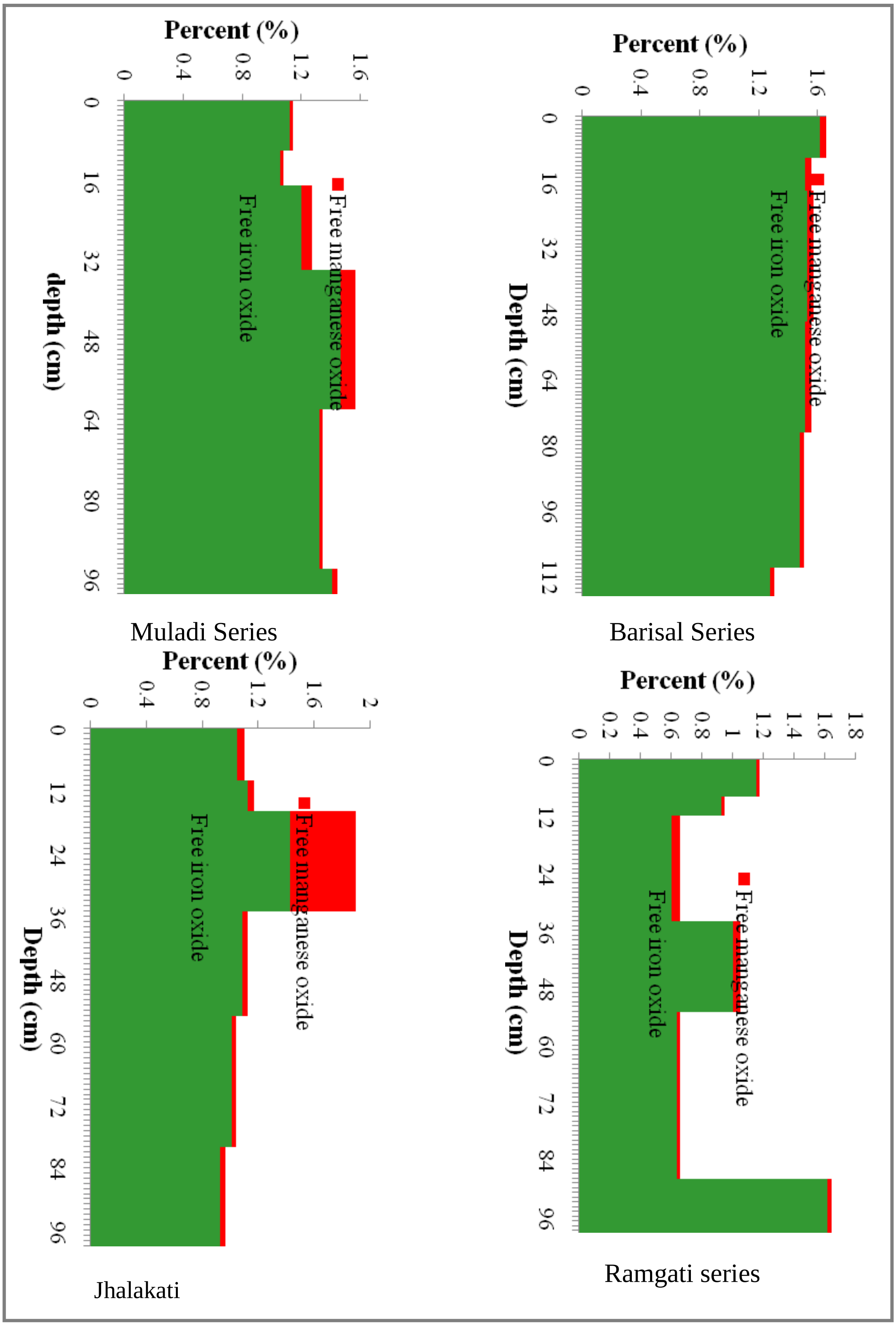

Fig 66. Graph shows the vertical distribution of free iron and manganese oxide in Muladi, Barisal, Jhalakati and Ramgati series.

The free Fe_2O_3/ MnO_2 ratio ranges from 12 to 65 with a mean value of 36 (Table 19). The highest mean ratio value was found in Hogla soils while the lowest in Pirojpur soil. On the other hand total Fe_2O_3 and free Fe_2O_3 ratio ranges from 1 to 9 with a mean value of 4 and the highest mean value was found in Hogla soil whereas the lowest mean value was found in Jhalakati soil (Fig 67). This indicates that manganese from the soils has been washed away.

5.10.3 Free iron oxides as indicator of soil development

The distribution of iron oxide in the profile elucidated the most important and sometimes even the only indicator of what is going on the soil development. The breakdown of iron-bearing minerals by chemical weathering leads to accumulation of free iron oxide in the form of amorphous iron oxides, cryptocrystalline oxides and organic bound iron and with time the rate of accumulation of free iron increases in the B horizon under leaching environment. Keeping this point in view, Arduino *et al*. (1984, 1986) used the ratio of dithionate- citrate- bicarbonate extractable iron (Fe_d) to total iron (Fe_t) for the soils of different river terraces in Italy and found that the ratio did reflect the relative ages of the terraces. This method has been applied in the present study to examine the amount of chemical weathering that has taken place in the soils. The Fe_d/Fe_t ratio has been calculated and presented in Table 20. It is observed that the Barisal series contain greater amount of free iron in the profile suggesting a higher degree of weathering than other soils. The Muladi soils contain lesser amount of free iron and indicate a relatively lower degree of weathering (Fig 68).

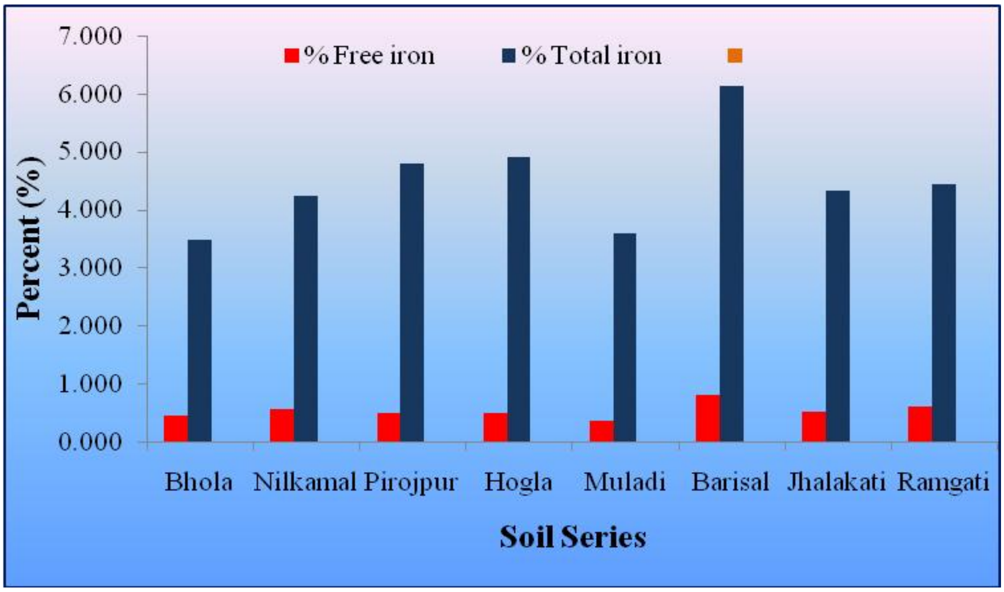

Fig 67. Graph shows the mean value of the total iron (Fe_t) and free iron (Fe_d) of the studied soils.

Table 20. Results of total and extractable iron and manganese in the studied soils**.**

Soil Series	Horizon	Free % Fe(*Fe_d)	Total % Fe(*Fe_t)	Free Mn(%)(*Mn_d)	Fe_d/Mn_d ratio	$(Fe_d/Fe_t)\times100$
Bhola	Ap	0.45	3.29	0.020	23	14
	Ad	0.46	3.21	0.022	21	14
	Bw1	0.51	4.15	0.021	24	12
	Bw2	0.44	3.28	0.022	20	13
	C1	0.48	3.56	0.027	18	13
	Mean	**0.47**	**3.50**	**0.022**	**21**	**13**
Nilkamal	Ap	0.56	4.50	0.012	47	12
	Ad	0.57	3.61	0.02	29	16
	Bw1	0.58	5.30	0.019	31	11
	Bw2	0.57	4.55	0.033	17	13
	C1	0.55	3.24	0.035	16	17
	Mean	**0.57**	**4.24**	**0.024**	**28**	**14**
Pirojpur	Ap	0.57	4.69	0.01	57	12
	Ad	0.59	5.54	0.012	49	11
	Bw1	0.45	5.34	0.014	32	8
	Bw2	0.48	4.85	0.013	37	10
	C1	0.49	3.77	0.015	33	13
	C2	0.54	4.64	0.015	36	12
	Mean	**0.52**	4.80	**0.013**	**41**	**11**
Hogla	Ap	0.52	4.80	0.018	29	11
	Ad	0.56	5.53	0.014	40	10
	Bw1	0.51	5.53	0.02	26	9
	Bw2	0.49	4.82	0.022	22	10
	C1	0.47	4.11	0.023	20	11
	C2	0.44	4.67	0.009	49	9
	Mean	**0.50**	4.91	**0.018**	**31**	**10**

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Table 20. Results of total and extractable iron and manganese in the studied soils.

Soil Series	Horizon	Free % Fe(*Fe_d)	Total % Fe(*Fe_t)	Free Mn(%)(*Mn_d)	Fe_d/Mn_d ratio	$(Fe_d/Fe_t)\times100$
Muladi	Ap	0.32	4.91	0.013	25	7
	Ad	0.31	4.22	0.014	22	7
	Bw1	0.47	4.38	0.048	10	11
	Bw2	0.53	4.18	0.06	9	13
	C1	0.31	5.08	0.016	19	6
	C2	0.32	4.40	0.022	15	7
	Mean	**0.38**	**3.59**	**0.03**	**17**	**8**
Barisal	Ap	0.75	4.31	0.01	75	17
	Ad	0.79	5.74	0.015	53	14
	Bw1	0.81	4.87	0.017	48	17
	Bw2	0.82	4.91	0.018	46	17
	C1	0.88	6.05	0.017	52	15
	C2	0.89	5.37	0.016	56	17
	Mean	**0.82**	**6.14**	**0.02**	**55**	**16**
Jhalakati	Ap	0.52	5.51	0.009	6	9
	Ad	0.58	6.07	0.008	73	10
	Bw1	0.59	5.67	0.015	39	10
	Bw2	0.51	5.89	0.016	32	9
	C1	0.48	5.19	0.011	44	9
	C2	0.52	4.60	0.059	9	11
	Mean	**0.53**	**4.33**	**0.03**	**34**	**10**
Ramgati	Ap	0.64	5.29	0.014	46	12
	Ad	0.65	3.93	0.013	50	17
	Bw1	0.69	4.22	0.031	22	16
	Bw2	0.62	4.41	0.029	21	14
	C1	0.60	4.44	0.015	40	14
	C2	0.59	4.17	0.016	37	14
	Mean	**0.63**	4.24	**0.02**	**36**	**14**
Grand mean		**0.49**	**3.87**	**0.02**	**27.60**	**11**

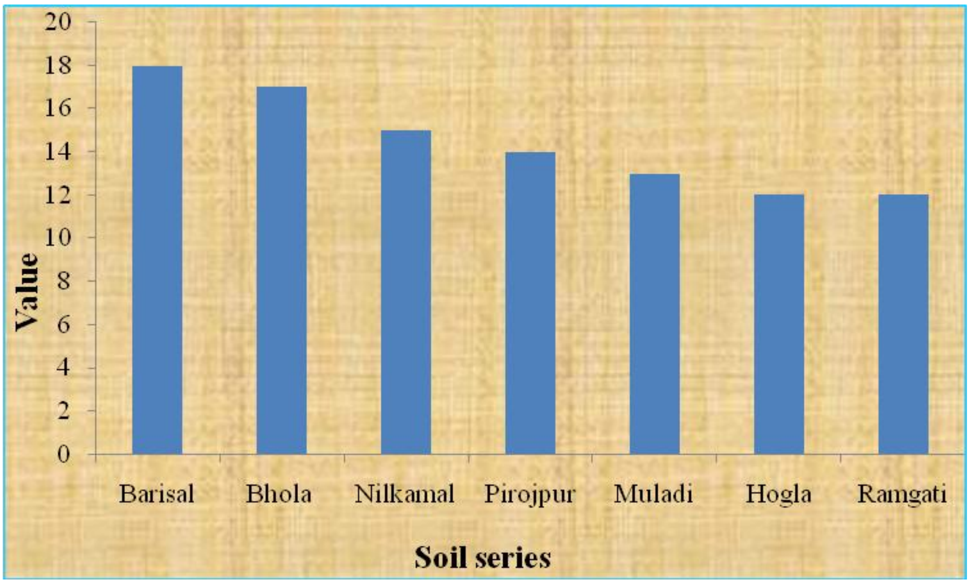

Fig 68. Graph shows the (Free Fe/ Total Fe)*100 ratio as indicators of soil development..

Based on the concepts of Arduino *et al.* (1984, 1986) the pedons under the present study can be arranged on the basis of their development as follows:

Barisal > Ramgat i > Nilkamal > Bhola > Pirojpur > Hogla > Jhalakati > Muladi**.**

5.11 Total analysis

5.11.1 Fusion analysis of the soils

The results of the fusion analysis of fine earth fractions have been presented in Table 21 & 22. The results show that:

- The SiO_2 content varies from 54.1 to 70.3 percent with a mean value of 61.6 %.
- The Al_2O_3 content varies from 13.6 to 26.1 percent with a mean value of 18.3 %.
- The Fe_2O_3 content varies from 4.9 to 7.9 percent with a mean value of 4.5 %.
- The SiO_2/R_2O_3 molar ratio varies from 3.0 to 6.0 with a mean value of 4.9.
- The SiO_2/ Al_2O_3 molar ratio varies from 4.8 to 7.6 with a mean value of 6.1.
- The Al_2O_3/ Fe_2O_3 molar ratio varies from 3.4 to 4.9 % with a mean value of 4.1.

Table 21. Results of chemical composition of the whole soils from fusion analysis.

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2
		%						
Bhola	Ap	70.3	16.0	4.7	3.4	2.2	1.9	1.2
	Ad	65.9	19.1	4.6	4.1	3.1	1.8	1.7
	Bw1	65.4	16.7	5.9	4.5	2.5	1.6	1.7
	Bw2	68.3	17.1	4.7	3.4	2.3	1.5	1.6
	C1	67.2	15.9	5.1	4.3	2.5	1.5	1.3
	Mean	**67.4**	**16.9**	**5.0**	**3.9**	**2.5**	**1.7**	**1.5**
Nilkamal	Ap	61.1	20.6	6.4	4.6	2.5	1.9	1.5
	Ad	63.2	20.9	5.2	3.5	2.7	1.6	1.6
	Bw1	56.3	22.5	7.6	5.2	3.6	1.8	1.4
	Bw2	58.0	22.0	6.5	5.0	3.7	1.9	1.4
	C1	65.4	19.0	4.6	3.9	2.7	2.0	1.4
	Mean	**60.8**	**21.0**	**6.1**	**4.4**	**3.0**	**1.8**	**1.5**
Pirojpur	Ap	62.5	19.1	6.7	4.7	2.4	1.6	1.1
	Ad	58.4	20.9	7.9	4.5	2.9	1.7	1.2
	Bw1	64.5	17.2	7.6	4.9	2.5	1.9	1.2
	Bw2	58.9	21.7	6.9	4.8	2.6	1.2	1.2
	C1	59.2	23.2	5.4	4.6	2.6	1.3	1.1
	C2	58.4	23.7	6.6	3.8	2.4	1.3	1.2
	Mean	**60.3**	**21.0**	**6.9**	**4.5**	**2.6**	**1.5**	**1.2**
Hogla	Ap	58.1	23.8	6.9	5.7	2.7	1.9	1.1
	Ad	54.7	24.9	7.9	6.0	3.5	2.1	1.3
	Bw1	54.1	26.1	7.9	5.7	3.0	2.2	1.2
	Bw2	59.0	23.8	6.9	3.5	2.8	2.4	1.3
	C1	59.5	24.7	5.9	3.6	2.7	2.3	1.5
	C2	58.4	24.5	6.7	4.0	2.7	2.1	1.1
	Mean	**57.3**	**24.6**	**7.0**	**4.7**	**2.9**	**2.2**	**1.2**

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Table 21. Results of chemical composition of the whole studied soils from fusion analysis

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2
					%			
Muladi	Ap	62.2	18.2	2.6	3.6	2.3	4.0	1.0
	Ad	61.4	18.5	2.5	3.3	2.4	1.4	1.3
	Bw1	58.6	18.0	4.4	4.5	3.5	3.5	1.2
	Bw2	57.6	18.3	4.7	4.3	3.0	3.3	1.1
	C1	59.4	18.7	4.1	4.1	3.1	3.4	1.2
	C2	64.3	15.4	4.9	4.5	2.7	3.2	1.1
	Mean	**60.6**	**17.9**	**3.9**	**4.0**	**2.8**	**3.1**	**1.2**
Barisal	Ap	60.6	15.0	2.1	3.2	2.8	2.5	0.6
	Ad	61.3	16.1	2.7	3.1	2.6	2.1	0.8
	Bw1	59.7	15.3	2.8	4.8	3.2	3.2	0.6
	Bw2	64.5	14.8	2.7	3.1	2.2	2.9	0.6
	C1	64.0	15.3	2.9	3.2	2.2	2.9	0.7
	C2	59.1	17.1	3.0	3.4	2.7	**2.7**	0.6
	Mean	**61.5**	**15.6**	**2.7**	**3.5**	**2.6**	**2.7**	**0.6**
Jhalakati	Ap	57.5	16.9	2.2	4.1	2.8	3.3	0.9
	Ad	60.1	16.1	2.0	3.9	2.4	2.6	1.0
	Bw1	62.7	14.7	1.9	3.3	2.2	3.2	0.8
	Bw2	63.4	15.1	2.1	3.7	2.4	3.1	0.8
	C1	61.9	16.0	2.0	3.5	2.5	2.3	0.7
	C2	64.8	14.5	2.2	3.4	2.4	**2.9**	0.6
	Mean	**61.7**	**15.5**	**2.1**	**3.7**	**2.5**	**2.2**	**0.8**
Ramgati	Ap	66.4	13.8	2.3	3.5	2.4	2.1	0.8
	Ad	65.2	13.7	2.3	4.0	2.1	2.8	0.9
	Bw1	64.2	13.4	2.5	3.5	2.4	2.4	0.7
	Bw2	64.8	14.5	2.6	3.8	2.4	2.3	0.8
	C1	59.3	15.6	2.6	4.7	3.5	2.2	0.8
	C2	58.8	13.5	2.5	4.6	3.1	2.1	0.8
	Mean	**63.1**	**14.1**	**2.4**	**4.0**	**2.7**	**2.6**	**0.8**
Grand mean		**61.6**	**18.3**	**4.5**	**4.1**	**2.7**	**2.2**	**1.1**

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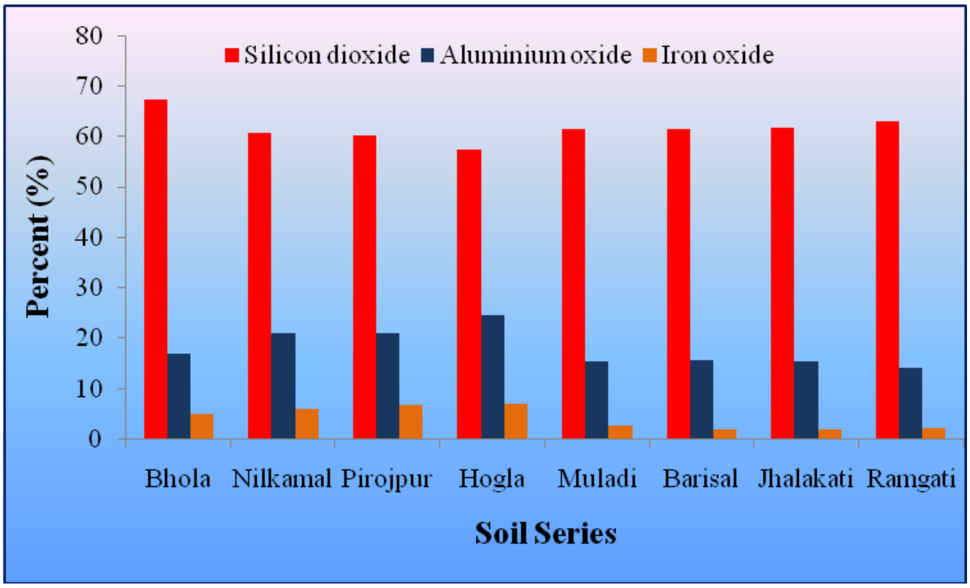

Fig 69. Graph shows mean value of total silica, alumina and iron oxide of the soils under study.

It may be pointed out that the silicon comprises more than two - third of the total mineral matter in these soils. The abundance of silica in the soil is due to the high content of sand and silt fraction in the soils. The highest mean value of silica content has been found in the Bhola soils whereas the lowest in the Hogla soils (Fig 69).

The vertical distribution patterns of silica content in the soil profiles are, in general, irregular in nature (Figs.70 & 71). This irregular distribution pattern within the profile is thought to be due to stratification of the parent materials.

Next to silica the most abundant element is aluminium. But the content of Al_2O_3 relatively low which may be due to their low aluminosilicates and high quartz contents. The highest Al_2O_3 in the profile has been found in the Hogla profile whereas lowest in the Ramgati soil profile (Fig. 69).

The vertical distribution of Al_2O_3 contents in the soil profile is also irregular in nature (Figs.70 & 71). This irregular distribution pattern of Al_2O_3 within the profiles is probably due to the variation in clay content as well as to alluvial nature of the soil materials. Gotoh and Patrick (1974) also reported that the pattern of the distribution of the total alumina with depth closely resembled that of the distribution of clay.

The next abundant element after aluminium is iron. The highest Fe_2O_3 has been found in the Hogla soil whereas lowest in the Jhalakati soils. The variations of the highest and the lowest mean value is wide (Fig 69).

The vertical distribution of total Fe_2O_3 content in the soil profiles is irregular in nature but in some cases a slight enrichment of Fe_2O_3 was noticed in the subsoils of the profiles (Figs. 70 & 71).

Chatterjee and Dalal (1976) observed higher Fe_2O_3 content in the surface horizon of some alluvial soils in India. Higher Fe_2O_3 content in the sub-soils was noticed by Mazumder (1996) in some Brahamaputra floodplain soils of Bangladesh.

The SiO_2/R_2O_3 molar ratio of the studied soils range from 3.0 to 6.0 with a mean value of 4.9 (Table 22). This ratio in the studied soil profile is thought to be due to their medium texture. Higher SiO_2/R_2O_3 ratio in the studied pedons is observed in the Bhola soil whereas the lowest value is found in the Hogla soils.

The vertical distribution pattern of SiO_2/R_2O_3 ratio from the surface downward follows an irregular pattern in all the soil profiles (Table 22). The irregular distribution of SiO_2/R_2O_3 ratio throughout the profile suggested parent materials were heterogenity of mixed origin.

The mean SiO_2/R_2O_3 ratio in the studied soils is high. Such a high ratio also indicates that the little weathered primary silicates are the dominant mineral fraction in these soils. The SiO_2/R_2O_3 ratios of the soils are more or less identical to that of the SiO_2/R_2O_3 ratio of the suspended sediments of the coastal rivers.

The SiO_2/ Al_2O_3 molar ratio in the studied soils varies from 4.8 to 7.6 with a mean value of 6.1 (Table 22). Such type of ratio confirms the heterogeneous nature of the soil materials. The highest mean of SiO_2/ Al_2O_3 ratio in the studied soils is observed in Bhola soils while the lowest value is found in Hogla soil.

The vertical distribution of SiO_2/ Al_2O_3 ratio from the surface downward follows an irregular pattern in all the studied pedons . This may indicate the existence of stratification.

Similar results were observed by Nahar (1987) in some coastal plain soils in Bangladesh.

Table 22. Results of molar ratios of SiO_2, Al_2O_3, Fe_2O_3 in the studied soils.

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/R_2O_3	SiO_2/Al_2O_3	Al_2O_3/Fe_2O_3
		←	%	→	←	Molar ratio	→
Bhola	Ap	70.3	16.0	4.7	6.3	7.5	5.3
	Ad	65.9	19.1	4.6	5.1	5.9	6.5
	Bw1	65.4	16.7	5.9	5.4	6.6	4.4
	Bw2	68.3	17.1	4.7	5.8	6.8	5.7
	C1	67.2	15.9	5.1	6.0	7.2	4.9
	Mean	**67.4**	**16.9**	**5.0**	**5.7**	**6.8**	**5.3**
Nilkamal	Ap	61.1	20.6	6.4	4.2	5.0	5.0
	Ad	63.2	20.9	5.2	4.4	5.1	6.3
	Bw1	56.3	22.5	7.6	3.5	4.2	4.7
	Bw2	58.0	22.0	6.5	3.8	4.5	5.3
	C1	65.4	19.0	4.6	5.0	5.8	6.4
	Mean	**60.8**	**21.0**	**6.1**	**4.2**	**4.9**	**5.4**
Pirojpur	Ap	62.5	19.1	6.7	4.5	5.6	4.5
	Ad	58.4	20.9	7.9	3.8	4.7	4.1
	Bw1	64.5	17.2	7.6	5.0	6.4	3.5
	Bw2	58.9	21.7	6.9	3.8	4.6	4.9
	C1	59.2	23.2	5.4	3.8	4.3	6.7
	C2	58.4	23.7	6.6	3.6	4.2	5.6
	Mean	**60.3**	**21.0**	**6.9**	**4.0**	**4.9**	**4.8**
Hogla	Ap	58.1	23.8	6.9	3.5	4.2	5.4
	Ad	54.7	24.9	7.9	3.1	3.7	4.9
	Bw1	54.1	26.1	7.9	3.0	3.5	5.2
	Bw2	59.0	23.8	6.9	3.6	4.2	5.4
	C1	59.5	24.7	5.9	3.6	4.1	6.6
	C2	58.4	24.5	6.7	3.5	4.1	5.7
	Mean	**57.3**	**24.6**	**7.0**	**3.3**	**4.0**	**5.5**

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Table 22. Results of molar ratios of total SiO_2, Al_2O_3, Fe_2O_3 in the studied soils

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/R_2O_3	SiO_2/Al_2O_3	Al_2O_3/Fe_2O_3
		← % →			← Molar ratio →		
Muladi	Ap	62.2	18.2	2.6	3.9	4.6	6.0
	Ad	61.4	18.5	2.5	3.8	4.4	5.9
	Bw1	58.6	18.0	4.4	3.6	4.1	6.3
	Bw2	57.6	18.3	4.7	3.3	3.9	5.5
	C1	59.4	18.7	4.1	3.5	4.1	6.2
	C2	64.3	15.4	4.9	4.6	5.4	6.2
	Mean	**60.6**	**17.9**	**3.9**	**3.7**	**4.4**	**6.0**
Barisal	Ap	60.6	15.0	2.1	3.6	4.5	4.4
	Ad	61.3	16.1	2.7	3.8	4.5	5.2
	Bw1	59.7	15.3	2.8	3.7	4.4	5.2
	Bw2	64.5	14.8	2.7	4.5	5.8	3.4
	C1	64.0	15.3	2.9	4.3	5.4	4.1
	C2	59.1	17.1	3.0	3.4	4.2	4.3
	Mean	**61.5**	**15.6**	**2.7**	**3.85**	**4.73**	**4.4**
Jhalakati	Ap	57.5	16.9	2.2	3.3	4.1	4.3
	Ad	60.1	16.1	2.0	3.6	4.4	4.5
	Bw1	62.7	14.7	1.9	4.1	5.2	3.9
	Bw2	63.4	15.1	2.1	4.3	5.4	4.2
	C1	61.9	16.0	2.0	3.9	4.6	5.5
	C2	64.8	14.5	2.2	4.5	5.4	5.2
	Mean	**61.7**	**15.5**	**2.1**	**3.9**	**4.8**	**4.5**
Ramgati	Ap	66.4	13.8	2.3	5.0	6.0	5.2
	Ad	65.2	13.7	2.3	4.9	5.9	4.9
	Bw1	64.2	13.4	2.5	4.5	5.3	5.1
	Bw2	64.8	14.5	2.6	4.7	5.6	4.8
	C1	59.3	15.6	2.6	4.3	5.1	5.4
	C2	58.8	13.5	2.5	5.2	6.4	4.5
	Mean	**63.1**	**14.1**	**2.4**	**4.8**	**5.7**	**5.0**
Grand Mean		**61.6**	**18.3**	**4.5**	**4.5**	**5.0**	**5.1**

The Al_2O_3/ Fe_2O_3 ratio in the studied soils varies from 3.4 to 4.9 with a mean value of 4.1 (Table 22). The vertical distribution of Al_2O_3/ Fe_2O_3 ratio from the surface downward follows an irregular pattern in all the soil profiles. The highest mean value of Al_2O_3/ Fe_2O_3 ratio is found in the Muladi soils and the lowest in the Barisal soils (Table 22). From the vertical distribution pattern of the above ratios, it may be inferred that the parent materials of the soils are not homogenous in nature. This finding is in conformity with the previous works carried out by many authors on Bangladesh soils (Khan, 1995; Mazumder, 1996; Rahman, 2001). From the above result it seems that the parent materials of these soils are of mixed origin and of non-uniform chemical composition. The molar ratios of the soils are very much close to that of the suspended sediments of the rivers in the coastal zone of Bangladesh.

The total CaO contents in the soils range from 3.05 to 5.99 percent with a mean value of 4.10 percent (Table 23). The highest value of CaO content found in the soil of Hogla and the lowest in the Barisal series (Fig. 94). The total CaO contents in these soils are rather high. The vertical distribution pattern of CaO content from the surface downward follows an irregular trend.

The total MgO content ranges from 3.1 to 6.0 percent with a mean value of 2.7 percent (Table 23). The highest mean value of MgO content found in the soil of Hogla series whereas the lowest in the Barisal series. The total MgO contents in these soils are rather low. These results are in accord with the findings of Ali (1994).

The vertical distribution pattern of CaO content from the surface downward follows an irregular trend in the studied soils (Table 23). These findings are in accord with the results of many authors worked on floodplain soils (Mazumder, 1996; Khan *et al*. 1997). Higher CaO content in the surface horizon was observed by Chatterjee and Dalal (1976) in some alluviated soils of Bihar and west Bengal.

The irregular distribution pattern of calcium and magnesium oxides in all the soil profiles may be considered as an indication of the fact that the pedochemical weathering processes have not brought any change in the distribution pattern of the minerals containing these elements. In other words, the ferromagnesium minerals have had no time allowance for weathering and remained as they were when deposited by geological processes. Consequently, the soils may be regarded as in the youthful stage.The total MnO_2 content in the soils under study ranges from 0.01 to 0.14 percent with a mean value of 0.04 percent (Table 23).

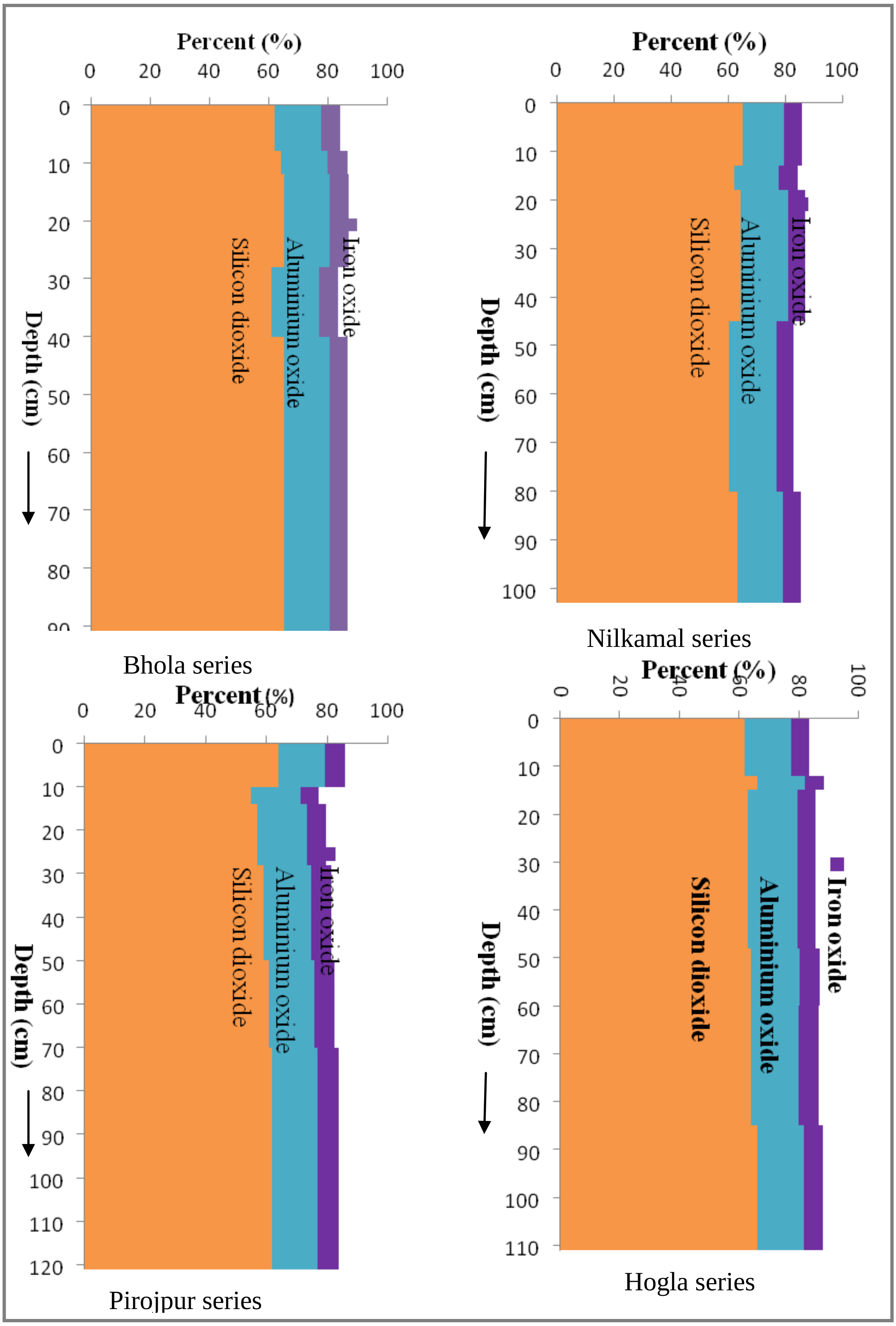

Fig 70. Graph shows the vertical distribution of silica, alumina and iron oxide in the soil of Bhola, Nilkamal, Pirojpur and Hogla soil.

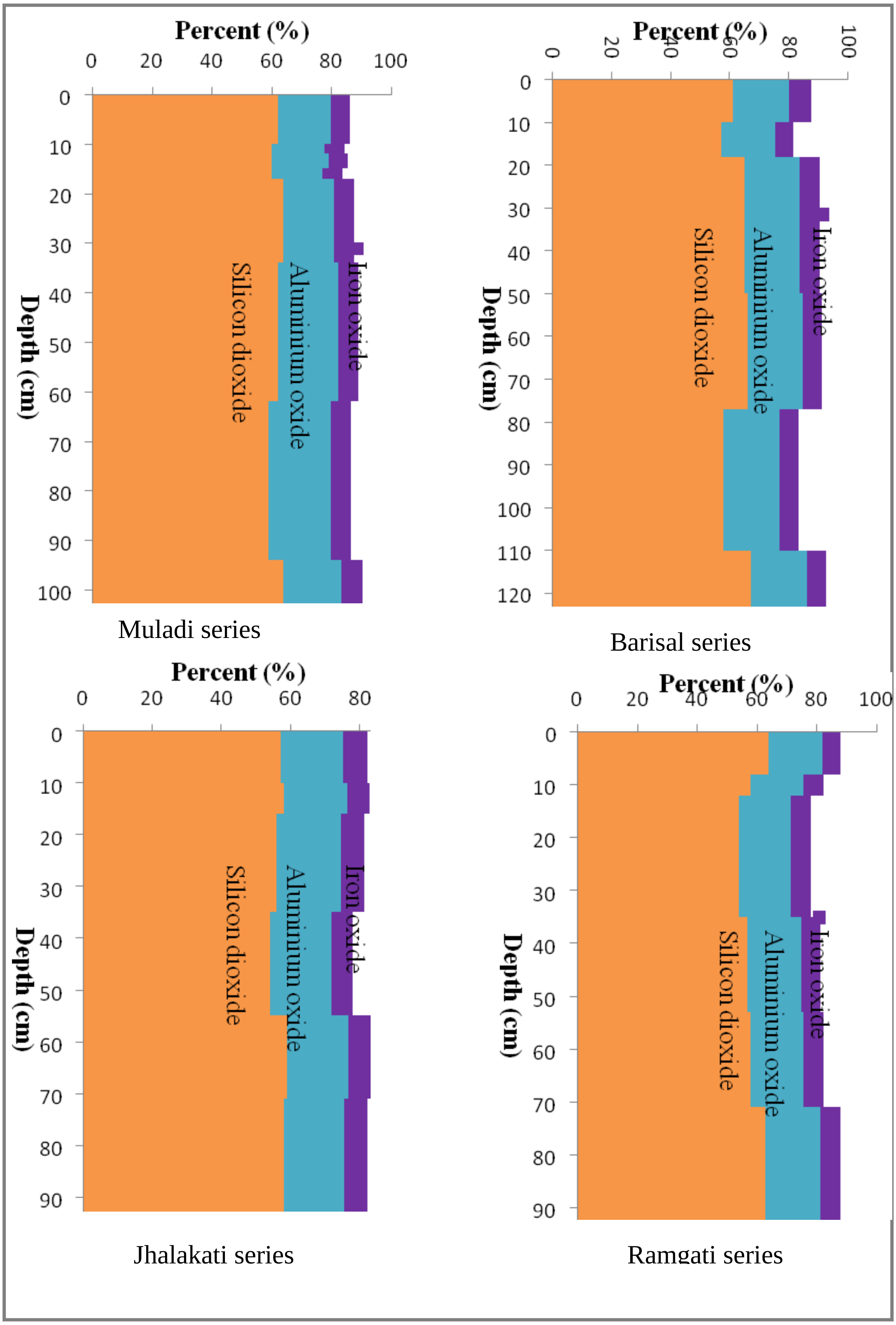

Fig 71. Graph shows the vertical distribution of silica, alumina and iron oxide in the whole soil of Muladi, Barisal, Jhalakati and Ramgati soil.

Table 23. Results of total CaO, MgO, P_2O_5, and MnO_2 content in the whole soils.

Soils	**Horizon**	**CaO**	**MgO**	**(CaO+MgO)**	**P_2O_5**	**MnO_2**
		→	%	←		
Bhola	Ap	3.4	2.2	5.6	0.14	0.03
	Ad	4.1	3.1	7.3	0.24	0.03
	Bw1	4.5	2.5	7.0	0.16	0.03
	Bw2	3.4	2.3	5.7	0.19	0.03
	C1	4.3	2.5	6.8	0.21	0.04
	Mean	**3.9**	**2.5**	**6.5**	**0.19**	**0.03**
Nilkamal	Ap	4.6	2.5	7.1	0.13	0.02
	Ad	3.5	2.7	6.2	0.12	0.03
	Bw1	5.2	3.6	8.8	0.22	0.03
	Bw2	5.0	3.7	8.6	0.18	0.05
	C1	3.9	2.7	6.6	0.22	0.06
	Mean	**4.4**	**3.0**	**7.5**	**0.17**	**0.04**
Pirojpur	Ap	4.7	2.4	7.1	0.10	0.02
	Ad	4.5	2.9	7.5	0.27	0.02
	Bw1	4.9	2.5	7.5	0.17	0.02
	Bw2	4.8	2.6	7.3	0.14	0.02
	C1	4.6	2.6	7.2	0.15	0.02
	C2	3.8	2.4	6.2	0.15	0.02
	Mean	**4.5**	**2.6**	**7.1**	**0.16**	**0.02**
Hogla	Ap	5.7	2.7	8.4	0.14	0.03
	Ad	6.0	3.5	9.4	0.18	0.02
	Bw1	5.7	3.0	8.7	0.28	0.03
	Bw2	3.5	2.8	6.3	0.16	0.03
	C1	3.6	2.7	6.3	0.18	0.04
	C2	4.0	2.7	6.7	0.17	0.01
	Mean	**4.7**	**2.9**	**7.6**	**0.19**	**0.03**

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Table 23. Results of total CaO, MgO, P_2O_5, and MnO_2 content in the whole soils.

Soils	Horizon	MgO	CaO	(CaO+MgO)	P_2O_5	MnO_2
		→		%		←
Muladi	Ap	3.6	2.3	5.9	0.16	0.02
	Ad	3.3	2.4	5.6	0.26	0.02
	Bw1	4.5	3.5	8.0	0.25	0.08
	Bw2	4.3	3.0	7.3	0.22	0.09
	C1	4.1	3.1	7.2	0.25	0.03
	C2	4.5	2.7	7.2	0.28	0.03
	Mean	**4.0**	**2.8**	**6.9**	**0.24**	**0.05**
Barisal	Ap	3.2	2.8	6.0	0.15	0.02
	Ad	3.1	2.6	5.7	0.26	0.02
	Bw1	4.8	3.2	8.0	0.25	0.03
	Bw2	3.1	2.2	5.3	0.29	0.03
	C1	3.2	2.2	5.4	0.17	0.03
	C2	3.4	2.7	6.1	0.26	0.03
	Mean	**3.5**	**2.6**	**6.1**	**0.23**	**0.03**
Jhalakati	Ap	4.1	2.8	6.9	0.15	0.14
	Ad	3.9	2.4	6.3	0.24	0.01
	Bw1	3.3	2.2	5.6	0.22	0.02
	Bw2	3.7	2.4	6.1	0.16	0.03
	C1	3.5	2.5	6.0	0.16	0.02
	C2	3.4	2.4	5.8	0.20	0.09
	Mean	**3.7**	**2.5**	**6.1**	**0.19**	**0.05**
Ramgati	Ap	3.5	2.4	5.9	0.15	0.02
	Ad	4.0	2.1	6.2	0.23	0.02
	Bw1	3.5	2.4	5.9	0.21	0.05
	Bw2	3.8	2.4	6.2	0.17	0.05
	C1	4.7	3.5	8.2	0.15	0.02
	C2	4.6	3.1	7.7	0.21	0.03
	Mean	**4.0**	**2.7**	**6.7**	**0.19**	**0.03**
Grand Mean		**4.1**	**2.7**	**6.8**	**0.19**	**0.04**

The vertical distribution pattern of MnO_2 contents in the soil profiles is irregular .The total P_2O_5 contents in the studied soils vary from 0.10 to 0.29 percent with a mean value of 0.19 (Table 23). The highest mean value is found in Muladi soil whereas thelowest mean value is found in Bhola soils.

The low content of P_2O_5 at the surface is probably due to the uptake of phosphorus by plants or due to the mobilization of them. But they show no tendency of accumulation in any depth zone of profiles. The lower content of P_2O_5 in the surface horizon has also been reported by Hussain *et al*. (1982).

From the above results it seems that the parent materials of these soils are of mixed origin and of non-uniform chemical composition. Nevertheless, the silica indicates that the parent materials of the soils were derived from acid to intermediate type of sedimentary rocks. The content of alumina may be taken as the reflection of aluminosilicates. The Fe_2O_3 together with CaO and MgO content of these soils constitute about 11% of the total composition in soil which may be due to high content of ferromagnesium minerals in these soils.

5.11.2 Fusion analysis of the clay fraction (< 2µm)

The clay fraction was separated from the other fractions of the soil by the sedimentation-decantation process and lastly analysed by fusion method. The results of the total analysis of the clay fraction are presented in Table 28 & 30. The results are as follows:

- The SiO_2 content varies from 54.1 to 67.4 percent with a mean value of 61.7 %.
- The Al_2O_3 content varies from 14.5 to 20.8 percent with a mean value of 17.1 %.
- The Fe_2O_3 content varies from 6.0 to 7.7 with a mean value of 6.6 %.
- The SiO2/R_2O_3 molar ratio varies from 4. 2 to 5.7 with a mean value of 4.9.
- The SiO_2/ Al_2O_3 molar ratio varies from 4.8 to 7.6 with a mean value of 6.1.
- The Al_2O_3/ Fe_2O_3 molar ratio varies from 3.5 to 4.7 with a mean value of 4.1.

The silica content in the clay fraction of the soils varies from 54.1 to 67.4 percent with a mean value of 61.7 percent (Table 24). The highest mean value of silica is found in the Hogla soils and the lowest in the Jhalakati soil (Fig 72).

The Al_2O_3 content in the clay fraction of the soils ranges from 14.5 to 20.8 percent with a mean value of 17.1 percent (Table 24). The highest mean value of Al_2O_3 is found in the Muladi soils and the lowest in the Bhola and Pirojpur soils (Fig 72).

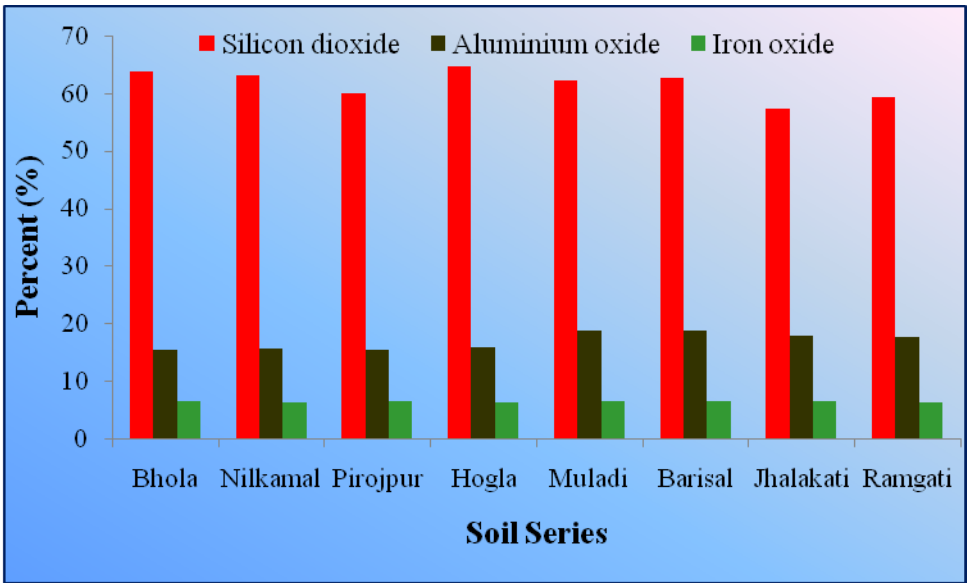

Fig 72. Graph shows the mean value of total silica, alumina and iron oxide of the clay fraction of the studied soils.

The total Fe_2O_3 contents in the clay fraction ranges from 6.0 to 7.7 percent with a mean value of 6.6 percent (Table 24). The highest mean value of total Fe_2O_3 contents is found in Muladi soils and the lowest in the Hogla soil.The variation between the highest and the lowest value is also found small in these soils. The vertical distribution pattern of Fe_2O_3 content in the clay fraction within the pedons studied is more or less identical.

The silica sesquioxide (SiO_2/ R_2O_3) molar ratio of the clay fraction ranges from 4.2 to 5.7 with a mean ratio of 4.9 (Table 25). This ratio may indicate the presence of considerable amount of 2:1 lattice type of clay minerals which might be a mixture of variable amount of mica, montmorrilonite and vermiculite minerals followed by small amount of kaolinite. The vertical distribution of SiO_2/ R_2O_3 ratio from the surface downward follows an irregular pattern in all the profiles.

Mazumder (1996) on a pedogenic study of some soils from the Brahmaputra floodplain soils of Bangladesh reported 2.9 to 3.9 SiO_2/ R_2O_3 molar ratio of clay fraction which probably due to considerable amount of 2:1 lattice type clay minerals. Khan (1995) obtained SiO_2/ R_2O_3 molar ratio in clay fraction from 2.73 to 4.75 with a mean of 3.77 in some Benchmark soils of Bangladesh.

Table 24. Results of chemical composition in the clay fraction of the studied soils.

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2
		→			%	←		
Bhola	Ap	62.1	15.5	6.7	0.01	2.3	2.1	1.9
	Ad	64.2	15.8	6.8	0.02	2.5	2.6	2.1
	Bw1	65.3	15.4	6.6	0.06	1.9	2.4	1.8
	Bw2	61.4	15.9	6.6	0.01	3.2	2.0	1.8
	C1	65.7	15.5	6.1	0.07	1.8	2.0	1.9
	Mean	**63.7**	**15.6**	**6.6**	**0.03**	**2.4**	**2.9**	**1.8**
Nilkamal	Ap	65.3	14.5	6.2	0.02	3.2	3.1	1.6
	Ad	62.4	15.4	6.9	0.03	3.1	2.5	1.6
	Bw1	64.5	16.8	6.1	0.02	3.0	2.4	1.6
	Bw2	60.2	16.6	6.2	0.01	2.7	2.6	1.7
	C1	63.3	15.9	6.5	0.02	2.1	2.3	1.3
	Mean	**63.1**	**15.8**	**6.4**	**0.02**	**2.8**	**2.9**	**1.6**
Pirojpur	Ap	64.7	15.2	6.9	0.02	4.7	2.6	2.0
	Ad	56.2	16.2	6.2	0.02	4.0	2.7	2.0
	Bw1	57.1	16.4	6.4	0.01	3.9	2.2	1.9
	Bw2	59.1	15.9	6.7	0.02	3.7	2.7	1.9
	C1	61.4	14.9	6.6	0.03	3.5	2.9	1.8
	C2	62.2	15.1	6.9	0.05	2.2	2.0	1.8
	Mean	**60.1**	**15.6**	**6.6**	**0.03**	**3.7**	**2.5**	**1.9**
Hogla	Ap	62.8	15.4	6.1	0.02	3.0	3.3	1.9
	Ad	66.4	16.2	6.5	0.01	3.2	3.5	1.9
	Bw1	63.5	16.6	6.0	0.02	3.5	3.9	1.9
	Bw2	64.1	16.4	6.7	0.01	3.7	3.4	1.9
	C1	64.5	15.9	6.9	0.05	3.8	3.1	1.8
	C2	66.8	15.8	6.2	0.02	3.6	2.8	1.7
	Mean	**64.7**	**16.1**	**6.4**	**0.02**	**3.5**	**3.3**	**1.9**

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Table 24. Results of chemical composition in the clay fraction of the studied soils.

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2
		→			%		←	
Muladi	Ap	62.3	17.7	6.6	0.02	3.5	4.5	1.4
	Ad	60.8	19.1	6.5	0.01	4.0	4.3	1.5
	Bw1	64.2	16.9	6.8	0.03	3.7	4.6	1.6
	Bw2	62.5	20.2	6.8	0.02	3.6	4.1	1.6
	C1	59.4	20.8	6.6	0.01	3.2	3.4	1.6
	C2	64.5	19.4	6.9	0.02	2.9	4.2	1.2
	Mean	**62.3**	**19.0**	**6.7**	**0.02**	**3.5**	**4.1**	**1.5**
Barisal	Ap	61.4	18.9	7.7	0.05	3.4	4.3	1.1
	Ad	57.2	18.4	6.1	0.04	3.5	4.1	1.0
	Bw1	65.5	18.5	6.9	0.03	3.2	3.9	1.1
	Bw2	66.3	18.8	6.4	0.02	3.8	3.8	1.1
	C1	58.4	18.9	6.5	0.02	3.9	2.6	1.0
	C2	67.4	19.1	6.5	0.03	3.1	3.7	0.9
	Mean	**62.7**	**18.8**	**6.7**	**0.03**	**3.5**	**4.3**	**1.0**
Jhalakati	Ap	57.2	18.2	6.9	0.03	3.1	4.2	1.0
	Ad	58.3	18.3	6.5	0.02	3.3	4.0	1.0
	Bw1	56.7	18.5	6.9	0.02	3.5	3.9	0.9
	Bw2	54.1	17.9	6.1	0.03	3.5	3.4	1.1
	C1	59.3	17.6	6.9	0.03	3.7	2.6	1.2
	C2	58.6	17.5	6.8	0.02	3.0	3.6	1.3
	Mean	**57.4**	**18.0**	**6.7**	**0.03**	**3.4**	**4.2**	**1.1**
Ramgati	Ap	64.2	17.9	6.1	0.02	2.8	3.7	1.3
	Ad	58.3	17.6	6.8	0.03	2.9	3.4	1.0
	Bw1	54.1	17.5	6.4	0.01	3.5	3.1	1.1
	Bw2	57.3	17.8	6.5	0.04	3.2	3.7	1.3
	C1	58.4	17.6	6.8	0.01	3.0	3.7	1.4
	C2	63.5	18.1	6.7	0.01	3.0	3.7	1.3
	Mean	**59.3**	**17.8**	**6.6**	**0.02**	**3.1**	**3.5**	**1.2**
Grand Mean		**61.7**	**17.1**	**6.6**	**0.02**	**3.2**	**3.1**	**1.5**

Table 25. Results of molar ratios of SiO_2/R_2O_3 , SiO_2/Al_2O_3 and Al_2O_3/Fe_2O_3 in clay fraction of the soils.

Soils	Horizon	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/R_2O_3	SiO_2/Al_2O_3	Al_2O_3/Fe_2O_3
		←	%	→	←	Molar ratio	→
Bhola	Ap	62.1	15.5	6.7	5.3	6.8	3.6
	Ad	64.2	15.8	6.8	5.4	6.9	3.6
	Bw1	65.3	15.4	6.6	5.6	7.2	3.7
	Bw2	61.4	15.9	6.6	5.2	6.5	3.8
	C1	65.7	15.5	6.1	5.7	7.1	4.0
	Mean	**63.7**	**15.6**	**6.6**	**5.4**	**6.9**	**3.7**
Nilkamal	Ap	65.3	14.5	6.2	6.0	7.6	3.7
	Ad	62.4	15.4	6.9	5.3	6.8	3.5
	Bw1	64.5	16.8	6.1	5.3	6.5	4.3
	Bw2	60.2	16.6	6.2	5.0	6.1	4.2
	C1	63.3	15.9	6.5	5.3	6.7	3.8
	Mean	**63.1**	**15.8**	**6.4**	**5.4**	**6.8**	**3.9**
Pirojpur	Ap	64.7	15.2	6.9	5.5	7.2	3.5
	Ad	56.2	16.2	6.2	4.6	5.8	4.1
	Bw1	57.1	16.4	6.4	4.7	5.9	4.0
	Bw2	59.1	15.9	6.7	5.0	6.3	3.7
	C1	61.4	14.9	6.6	5.4	7.0	3.5
	C2	62.2	15.1	6.9	5.4	7.0	3.4
	Mean	**60.1**	**15.6**	**6.6**	**5.1**	**6.5**	**3.7**
Hogla	Ap	62.8	15.4	6.1	5.5	6.8	4.0
	Ad	66.4	16.2	6.5	5.5	6.9	3.9
	Bw1	63.5	16.6	6.0	5.2	6.4	4.3
	Bw2	64.1	16.4	6.7	5.3	6.6	3.8
	C1	64.5	15.9	6.9	5.4	6.8	3.6
	C2	66.8	15.8	6.2	5.7	7.1	4.0
	Mean	**64.7**	**16.1**	**6.4**	**5.4**	**6.8**	**3.9**

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Table 25. Results of molar ratios of SiO_2/R_2O_3 , SiO_2/Al_2O_3 and Al_2O_3/ Fe_2O_3 in clay fraction of the soils.

Soils	Horizon	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/R_2O_3	SiO_2/Al_2O_3	Al_2O_3/ Fe_2O_3
		←	%	→	←	Molar ratio	→
Muladi	Ap	62.3	17.7	6.6	4.8	5.9	4.2
	Ad	60.8	19.1	6.5	4.4	5.3	4.6
	Bw1	64.2	16.9	6.8	5.1	6.4	3.9
	Bw2	62.5	20.2	6.8	4.3	5.2	4.7
	C1	59.4	20.8	6.6	4.0	4.8	4.9
	C2	64.5	19.4	6.9	4.6	5.6	4.4
	Mean	**62.3**	**19.0**	**6.7**	**4.5**	**5.6**	**4.4**
Barisal	Ap	61.4	18.9	7.7	4.4	5.5	3.8
	Ad	57.2	18.4	6.1	4.3	5.3	4.7
	Bw1	65.5	18.5	6.9	4.8	6.0	4.2
	Bw2	66.3	18.8	6.4	4.9	6.0	4.6
	C1	58.4	18.9	6.5	4.3	5.2	4.6
	C2	67.4	19.1	6.5	4.9	6.0	4.6
	Mean	**62.7**	**18.8**	**6.7**	**4.6**	**5.6**	**4.4**
Jhalakati	Ap	57.2	18.2	6.9	4.3	5.3	4.1
	Ad	58.3	18.3	6.5	4.4	5.4	4.4
	Bw1	56.7	18.5	6.9	4.2	5.1	4.2
	Bw2	54.1	17.9	6.1	4.2	5.1	4.6
	C1	59.3	17.6	6.9	4.6	5.7	4.0
	C2	58.6	17.5	6.8	4.5	5.6	4.0
	Mean	**57.4**	**18.0**	**6.7**	**4.4**	**5.4**	**4.2**
Ramgati	Ap	64.2	17.9	6.1	5.0	6.1	4.6
	Ad	58.3	17.6	6.8	4.5	5.6	4.1
	Bw1	54.1	17.5	6.4	4.3	5.2	4.3
	Bw2	57.3	17.8	6.5	4.4	5.4	4.3
	C1	58.4	17.6	6.8	4.5	5.6	4.1
	C2	63.5	18.1	6.7	4.8	5.9	4.2
	Mean	**59.3**	**17.8**	**6.6**	**4.6**	**5.6**	**4.3**
Grand Mean		**61.7**	**17.1**	**6.6**	**4.9**	**6.1**	**4.1**

The SiO_2/ Al_2O_3 molar ratio in the clay fraction varies from 4.8 to 7.6 with a mean value of 6.1 (Table 25). The highest mean value is found in the Bhola soil and the lowest in the Jhalakati soil. The Al_2O_3/ Fe_2O_3 ratio varies from 3.5 to 4.7 percent with a mean value of 4.1 (Table 25). The highest mean ratio is found in Barisal soil whereas the lowest in Bhola soil. The vertical distribution of the ratio within the profiles shows an irregular trend.

The CaO content of the clay fraction is very low ranges from 0.01 to 0.07 percent with a mean value of 0.02 percent (Table 26).

The MgO content in the clay fraction ranges from 1.8 to 4.7 with a mean of 3.2 percent (Table 26). These results indicate that the clay minerals are rich in magnesium. The highest mean ratio is found in Pirojpur soil whereas the lowest value is found in Bhola soils. The MnO_2 content in the clays varies from 0.07 to 0.36 percent with an average value of 0.14 percent (Table 26). The P_2O_5 content in the clays varies from 0.07 to 0.21 percent with an average value of 0.13 percent (Table 26).The vertical distribution of P_2O_5 and MnO_2 content in the clay fraction of the pedons show irregular pattern.

The loss on ignition of the clay fraction ranges from 10 to 21 percent with a mean of 13 percent (Table 26). The loss on ignition of the clay fraction was found to be highest in Barisal soil whereas the lowest value is found in Muladi and Hogla soils. The variation of LOI is mainly due to variation of the type and amount of clay minerals present in the clay fraction of these soils.

5.11.3 Total potassium (K_2O) contents in soils and clays

Potassium in the soils

The K_2O content in mineral soils usually ranges from 0.05 to 3.5 percent (Jackson, 1975). The distribution of K_2O in soils on a worldwide basis follows a definite geomorphologic pattern and is related more to the conditions of weathering of the potash feldspars and mica than to the composition of the parent rock themselves (Jackson, 1964).

The total K_2O content of the soils under the present study have been presented in Table 27. The K_2O contents in the whole soils vary from 1.31 to 3.99 percent and the mean value is 2.30 percent. Similar results were also observed in Bangladesh soils by Mazumder, 1976; Chowdhury *et al*. 1992; Khan, 1995 and Rahman, 2001.

The total potassium content in these soils is quite high, which may be due to the presence of abundant quantity of potassium bearing minerals such as micas and feldspars. In fact, mica flakes in some soil samples could be seen even with unaided eye in the field.

Table 26. Results of CaO, MgO, P_2O_5, MnO_2 and LOI in the clay fraction of the studied soils.

Soils	Horizon	CaO	MgO	(CaO+MgO)	P_2O_5	MnO_2	LOI*
		→		%	←		
Bhola	Ap	0.01	2.34	2.35	0.17	0.11	14
	Ad	0.02	2.5	2.52	0.15	0.12	12
	Bw1	0.06	1.91	1.97	0.14	0.1	18
	Bw2	0.01	3.2	3.21	0.15	0.13	14
	C1	0.07	1.84	1.91	0.16	0.12	15
	Mean	**0.03**	**2.36**	**2.39**	**0.15**	**0.12**	**14.6**
Nilkamal	Ap	0.02	3.23	3.25	0.14	0.11	19
	Ad	0.03	3.1	3.13	0.12	0.12	17
	Bw1	0.02	3	3.02	0.12	0.12	18
	Bw2	0.01	2.7	2.71	0.1	0.13	16
	C1	0.02	2.14	2.16	0.13	0.13	17
	Mean	**0.02**	**2.83**	**2.85**	**0.12**	**0.12**	**17.4**
Pirojpur	Ap	0.02	4.71	4.73	0.1	0.11	15
	Ad	0.02	4.01	4.03	0.08	0.1	16
	Bw1	0.01	3.94	3.95	0.12	0.12	17
	Bw2	0.02	3.71	3.73	0.14	0.12	19
	C1	0.03	3.5	3.53	0.13	0.11	15
	C2	0.05	2.23	2.28	0.12	0.09	19
	Mean	**0.03**	**3.68**	**4.00**	**0.12**	**0.11**	**16.8**
Hogla	Ap	0.02	3.02	3.04	0.08	0.35	20
	Ad	0.01	3.21	3.22	0.09	0.21	10
	Bw1	0.02	3.5	3.52	0.1	0.2	14
	Bw2	0.01	3.7	3.71	0.08	0.16	12
	C1	0.05	3.8	3.85	0.07	0.15	12
	C2	0.02	3.6	3.62	0.12	0.18	13
	Mean	**0.02**	**3.47**	**3.49**	**0.09**	**0.21**	**13.5**

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Table 26. Results of CaO, MgO, P_2O_5, MnO_2 and LOI in the clay fraction of the studied soils.

Soils	Horizon	CaO	MgO	(CaO+MgO)	P_2O_5	MnO_2	LOI*
		→		%		←	
Muladi	Ap	0.02	3.52	3.54	0.18	0.13	13
	Ad	0.01	3.98	3.99	0.15	0.23	12
	Bw1	0.03	3.67	3.7	0.15	0.22	13
	Bw2	0.02	3.58	3.6	0.16	0.21	14
	C1	0.01	3.24	3.25	0.13	0.23	14
	C2	0.02	2.9	2.92	0.11	0.36	15
	Mean	**0.02**	**3.48**	**3.50**	**0.15**	**0.23**	**13.5**
Barisal	Ap	0.05	3.36	3.41	0.18	0.1	21
	Ad	0.04	3.5	3.54	0.17	0.08	18
	Bw1	0.03	3.2	3.23	0.15	0.12	18
	Bw2	0.02	3.8	3.82	0.14	0.14	16
	C1	0.02	3.9	3.92	0.16	0.13	17
	C2	0.03	3.1	3.13	0.15	0.12	18
	Mean	**0.03**	**3.48**	**3.51**	**0.16**	**0.12**	**18.0**
Jhalakati	Ap	0.03	3.14	3.17	0.1	0.14	12
	Ad	0.02	3.26	3.28	0.08	0.12	13
	Bw1	0.02	3.45	3.47	0.09	0.15	19
	Bw2	0.03	3.54	3.57	0.11	0.13	20
	C1	0.03	3.69	3.72	0.15	0.14	15
	C2	0.02	2.99	3.01	0.14	0.07	15
	Mean	**0.03**	**3.35**	**3.37**	**0.11**	**0.13**	**15.7**
Ramgati	Ap	0.02	2.8	2.82	0.17	0.09	19
	Ad	0.03	2.9	2.93	0.15	0.1	17
	Bw1	0.01	3.5	3.51	0.17	0.17	15
	Bw2	0.04	3.2	3.24	0.16	0.18	18
	C1	0.01	3.01	3.02	0.15	0.12	15
	C2	0.01	3	3.01	0.21	0.13	10
	Mean	**0.02**	**3.07**	**3.09**	**0.17**	**0.13**	**15.7**
Grand mean		**0.02**	**3.21**	**3.24**	**0.13**	**0.14**	**13**

Table 27. Total potassium (K_2O) contents in the soils and their clay fractions.

Soils	Horizon	K_2O (%)		%Mica in clay fraction	
		Soils	Clays	(Jackson,1975)*	(Karim,1954)**
Bhola	Ap	1.91	2.07	21	26
	Ad	1.82	2.57	26	32
	Bw1	1.63	2.38	24	30
	Bw2	1.52	2.03	20	25
	C1	1.56	2.01	20	25
	Mean	**1.69**	**2.21**	**22**	**28**
Nilkamal	Ap	1.85	3.11	31	39
	Ad	1.64	2.52	25	31
	Bw1	1.82	2.43	24	30
	Bw2	1.86	2.61	26	33
	C1	1.98	2.33	23	29
	Mean	**1.83**	**2.60**	**26**	**33**
Pirojpur	Ap	1.68	2.58	26	32
	Ad	1.70	2.69	27	34
	Bw1	1.87	2.18	22	27
	Bw2	1.53	2.69	27	34
	C1	1.35	2.89	29	36
	C2	1.31	2.03	20	25
	Mean	**1.57**	**2.51**	**25**	**31**
Hogla	Ap	1.92	3.31	33	41
	Ad	2.15	3.45	35	43
	Bw1	2.24	3.94	39	49
	Bw2	2.43	3.36	34	42
	C1	2.31	3.14	31	39
	C2	2.11	2.78	28	35
	Mean	**2.19**	**3.33**	**33**	**42**

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Table 27. Total potassium (K_2O) contents in the soils and their clay fractions.

Soils	Horizon	K_2O (%)		%Mica in clay fraction	
		Soils	**Clays**	**(Jackson,1975)****	**(Karim,1954)****
Muladi	Ap	3.99	4.51	45	56
	Ad	3.43	4.32	43	54
	Bw1	3.54	4.63	46	58
	Bw2	3.25	4.11	41	51
	C1	2.42	3.42	34	43
	C2	3.18	4.17	42	52
	Mean	**3.30**	**4.19**	**42**	**52**
Barisal	Ap	2.52	4.31	43	54
	Ad	2.12	4.12	41	51
	Bw1	3.24	3.91	39	49
	Bw2	2.88	3.82	38	48
	C1	2.93	2.62	26	33
	C2	2.74	3.71	37	46
	Mean	**2.74**	**3.75**	**37**	**47**
Jhalakati	Ap	3.33	4.21	42	53
	Ad	2.55	4.01	40	50
	Bw1	3.16	3.92	39	49
	Bw2	3.12	3.43	34	43
	C1	2.34	2.62	26	33
	C2	2.90	3.61	36	45
	Mean	**2.90**	**3.63**	**36**	**45**
Ramgati	Ap	2.11	3.71	37	46
	Ad	2.82	3.37	34	42
	Bw1	2.43	3.09	31	39
	Bw2	2.31	3.71	37	46
	C1	2.26	3.66	37	46
	C2	2.13	3.72	37	47
	Mean	**2.34**	**3.54**	**35**	**44**
Grand mean		**2.30**	**3.22**	**32**	**40**

*% mica in clay= % K_2O in clay x 100/10 ** % mica in clay= % K_2O in clay x 100/8

Presence of mica flakes in the soil under study also indicates that these soils are relatively young. The highest amount of K_2O in the whole soil is found in Muladi soil while the lowest amount is found in Pirojpur soil (Fig 73). This variation in K_2O content in these soils is due probably to the variation in the K-bearing minerals in their parent material (Laves, 1978; Mengel and Kirkby, 1982; Mazumder *et al.* 2010).

The vertical distribution of K_2O content in the soil profiles is in general irregular in nature (Figs. 73 & 74). Although the distribution pattern within the soil profile is irregular, there is a little accumulation of K_2O content in the B-horizon of all the soils. The impoverishment of K_2O from the surface horizons of the studied pedons indicates that the mica present in these horizons are being weathered and K is being lost from their inter lattice space forming iliite / hydrated mica. This may be caused by the seasonal flooding and fluctuating ground water table. The K is known to be highly sensitive to leaching during weathering and soil formation (Jenny, 1941). The differential leaching of potassium in the soils studied may be due to variation in their drainage condition. The above results are in agreement with the findings of Diwakar and Singh (1992) in some floodplain soils of India.

Potassium in the clay fraction

The amount of K_2O in the clay fraction varies from 2.01 to 4.63 percent with a mean value is 3.22 percent (Table 27). The highest amount of K_2O in the clay fraction was found in Muladi soil while the lowest amount was found in Bhola soil. This variation of potassium content in the clay fraction is due to the variations in the K-bearing minerals mainly mica in the clay fraction.The vertical distribution pattern of K_2O content in the clay fraction within the profile is irregular (Figs. 77 & 78).

A rough estimation of mica minerals in the clay fraction has been made from their K_2O contents using Karim's (1954) and Jackson's (1975) method. The former author used 8 percent K_2O and the latter author used 10 percent K_2O for calculating percent mica in the clay fraction.

In the clay fraction potassium is usually present in mica minerals. The amount of mica mineral can be approximately estimated when it is assumed that there is no potassium bearing minerals except mica. It is clear that there is abundant mica minerals present in the clay fraction. The amount varies from 26 to 58 percent with a mean value of 40 percent (Karim, 1954) (Table 27). The highest mica content is present in Muladi soil while the lowest in Bholal soil.

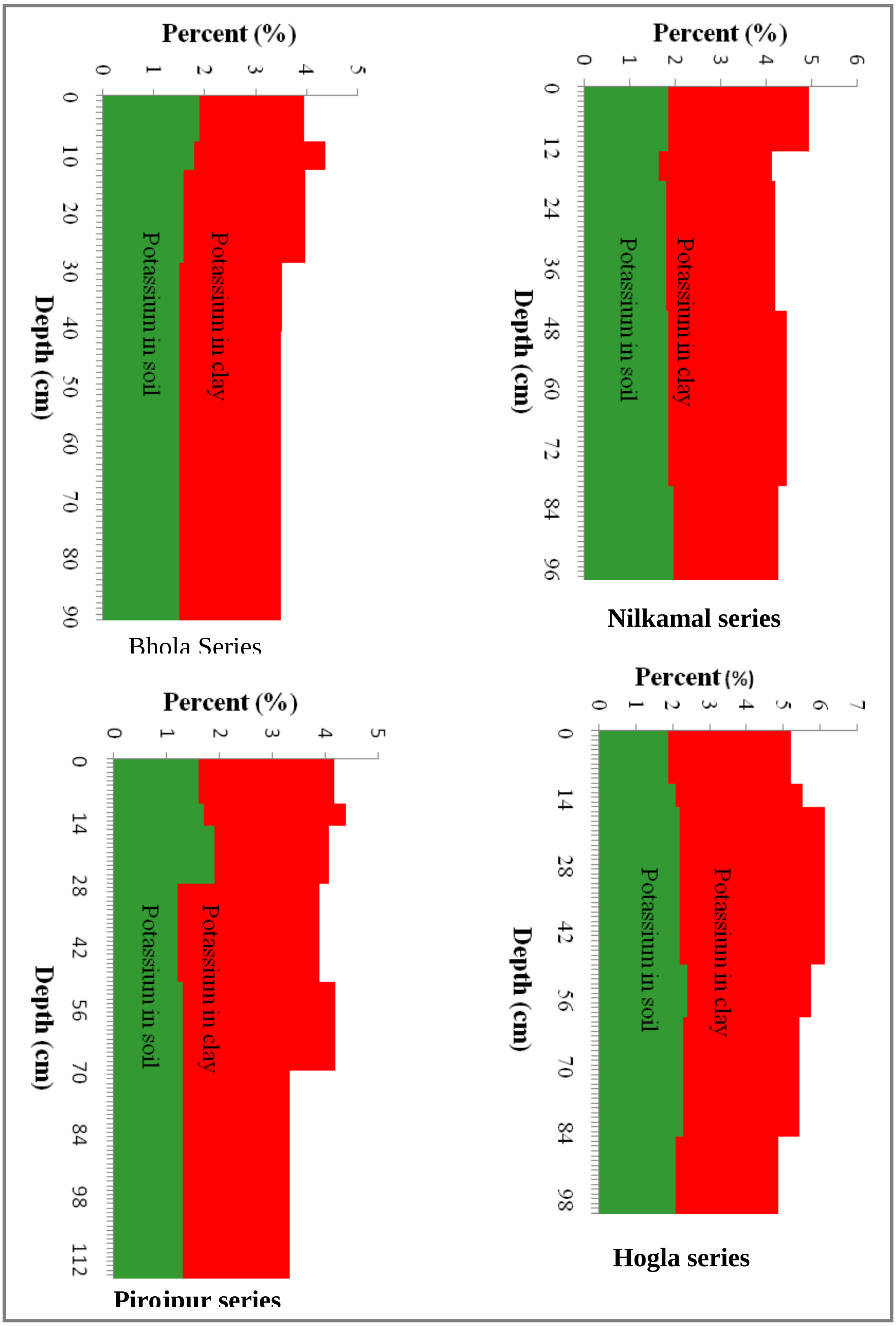

Fig 73. Vertical distribution of total potassium oxide (K_2O) in soils and clay fraction of soil of Bhola, Nilkamal. Pirojpur and Hogla Series.

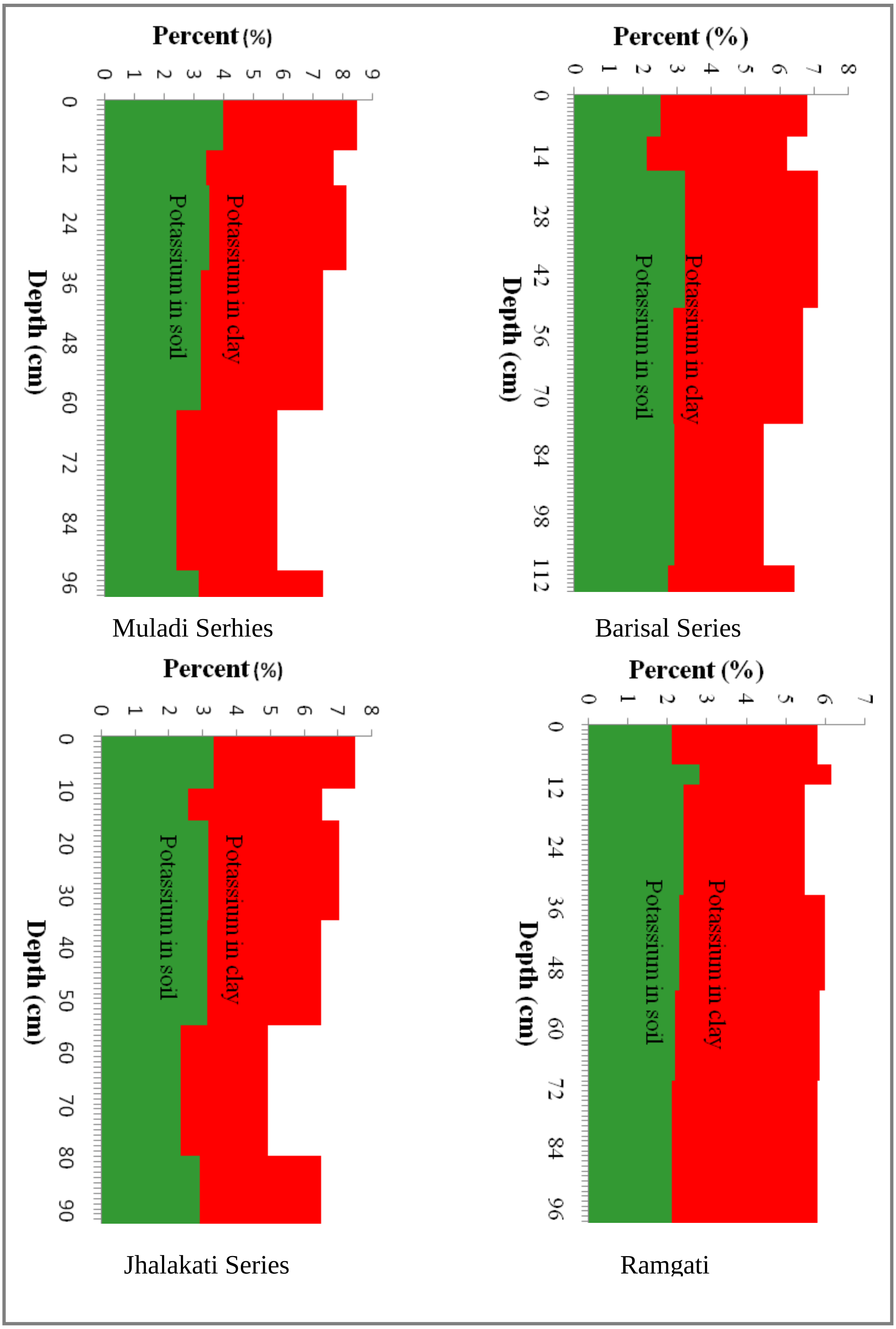

Fig 74. Vertical distribution of total potassium oxide (K_2O) in soils and clay fraction of soil of Muladi, Barisal, Jhalakati and Ramgati Series.

The mean mica content in the clay fraction of the soils was in 32 percent according to Jackson's method (1975) and according to Karim's method the mean mica content in the clay fraction was 40 percent.Such a high quantity of mica is present in the soils under the present investigation which suggests that the supply of potassium for consumption by plants will be adequate and there will be little need for application of potassium containing fertilizer for optimum crop production.

5.11.4 Titanium (TiO_2) content in soils and clays

Titanium bearing minerals are often used as index minerals for pedogenetic studies. The mean value of TiO_2 content in whole soils and clay shown in Fig 75.

The results of TiO_2 contents in the studied soils vary from 0.56 to 1.74 percent with a mean value of 1.05 percent. The highest mean value within the profile was found in Bhola soil whereas the lowest TiO_2 content was found in Barisal soil (Table 28). Similar results were obtained in rice soils in Combodia, Indonesia, Malaysia, Phillipines and Tropical Asia (Kyuma, 1978) and in some coastal floodplain soils in Bangladesh (Begum, 2004). Source of this titanium is mostly titanium bearing primary minerals such as rutile, anatase, and ilmenite in the parent materials.

The vertical distribution of TiO_2 in soils from the surface downward follows an irregular pattern (Figs. 76 and 77) in all the soil profiles. Slight depletion of TiO_2 from the surface horizons may also be noticed in some studied soils

Titanium in the clay fraction

The TiO_2 content in clay fraction of the soils ranges from 0.88 to 2.11 percent with a mean value of 1.47 percent (Table 28). TiO_2 contents in the clay fraction are more than that in the whole soil. This is because most of the TiO_2 minerals occur in the clay fraction of the soils. This is in accord with the findings of Robinson and Holmes (1924) ; Khan *et al.* 2010).

The highest mean value of titanium in clay fraction among the profiles is observed in Pirojpur soils and the lowest mean value in Barisal soil. It may be mentioned here that TiO_2 in clay fractions may occur in two distinct forms- firstly in discrete oxide forms which usually occur as clay sized and discrete titanium oxide minerals and secondly, titanium may occur in the octahedral layers of clay minerals (Jackson and Sherman, 1953; Brain, 1976 and Hutton, 1977) because titanium can isomorphously replace aluminium in the octahedral layer of clay lattice.

Table 28. Total TiO_2 contents in the soils and their clay fractions.

Soils	**Horizon**	**TiO_2 (%)**	
		Soils	**Clays**
Bhola	Ap	1.15	1.87
	Ad	1.74	2.11
	Bw1	1.65	1.78
	Bw2	1.61	1.79
	C1	1.25	1.88
	Mean	**1.48**	**1.82**
Nilkamal	Ap	1.52	1.58
	Ad	1.56	1.64
	Bw1	1.43	1.64
	Bw2	1.39	1.66
	C1	1.41	1.31
	Mean	**1.46**	**1.57**
Pirojpur	Ap	1.12	1.98
	Ad	1.24	1.95
	Bw1	1.15	1.89
	Bw2	1.21	1.87
	C1	1.12	1.76
	C2	1.18	1.83
	Mean	**1.17**	**1.88**
Hogla	Ap	1.05	1.87
	Ad	1.25	1.89
	Bw1	1.21	1.88
	Bw2	1.25	1.87
	C1	1.47	1.83
	C2	1.08	1.74
	Mean	**1.22**	**1.85**

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Table 28. Total TiO_2 contents in the soils and their clay fractions.

Soils	Horizon	TiO_2 (%)	
		Soils	**Clays**
Muladi	Ap	0.99	1.35
	Ad	1.27	1.48
	Bw1	1.21	1.58
	Bw2	1.13	1.59
	C1	1.22	1.64
	C2	1.13	1.24
	Mean	**1.16**	**1.48**
Barisal	Ap	0.58	1.09
	Ad	0.78	0.98
	Bw1	0.56	1.08
	Bw2	0.58	1.1
	C1	0.65	0.99
	C2	0.63	0.89
	Mean	**0.63**	**1.02**
Jhalakati	Ap	0.91	0.99
	Ad	0.95	0.95
	Bw1	0.84	0.88
	Bw2	0.81	1.1
	C1	0.67	1.2
	C2	0.57	1.3
	Mean	**0.79**	**1.07**
Ramgati	Ap	0.75	1.29
	Ad	0.89	0.98
	Bw1	0.72	1.1
	Bw2	0.84	1.26
	C1	0.81	1.35
	C2	0.75	1.29
	Mean	**0.79**	**1.21**
Grand mean		**1.05**	**1.47**

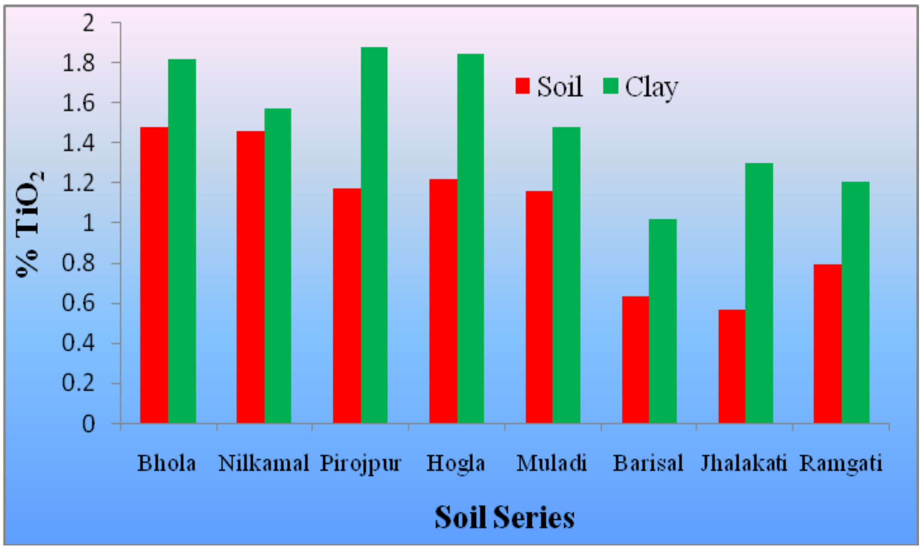

Fig 75. Graph shows the mean value of TiO_2 in whole soil and clay fraction of the soil under study.

The irregular distribution of titanium oxide in the clay fraction indicates that the parent material is the possible source of this element in the soils. The variation in titanium content suggests heterogeneity and stratification of parent material in these soils (Smith and Wilding, 1972; Sharma and Dev, 1985).

5.12 Mineralogical composition of clay fraction (2μm)

5.12.1 X-ray diffraction (XRD) analysis of clay fraction

The X-ray diffractograms (XRD) of clay fractions of the studied soils are presented in Figures 78- 85. The quantity of clay minerals in the clay fraction was determined semi - quantitatively based on peak heights and peak areas of the X-ray diffraction peaks (Johnson *et al.* 1963, Egasira and Yasmin, 1990). Results of X-ray diffraction analysis are presented in Table 33. Peaks are generally sharp, broad that indicating good crystallnity or large crystal size of the minerals. Illite was the dominant mineral in the clay fraction of Muladi, Barisal, Jhalakati and Ramgati soils whereas the other soils had mixed mineralogical compositions consisting of mica, smectite, chlorite, kaolinite and trace amount of vermiculite. A significant proportion of smctite was found in the clay fraction of Pirojpur soil.

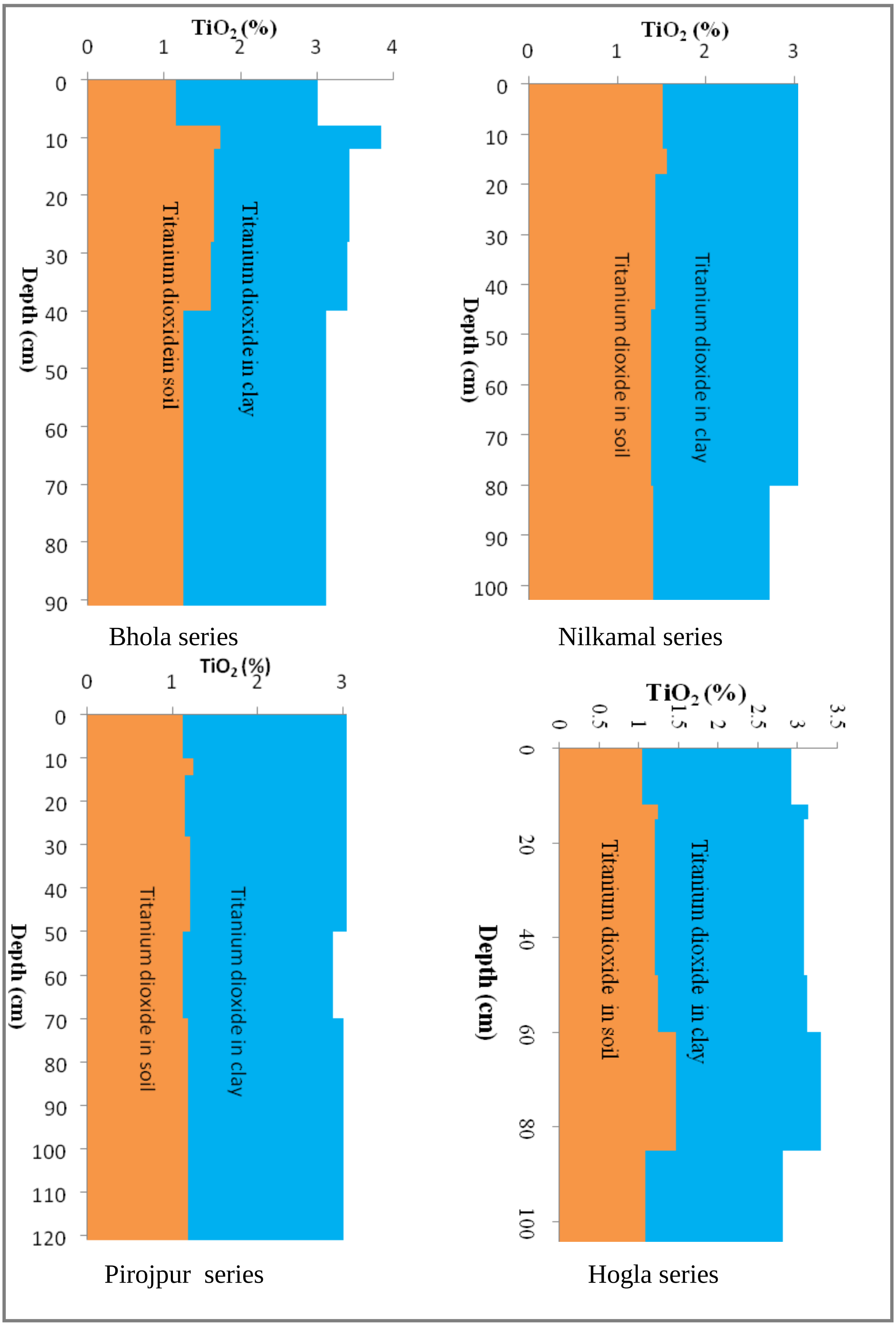

Fig 76. Graph shows the vertical distribution of TiO_2 in soil and clay in Bhola, Nilkamal. Pirojpur and Hogla series.

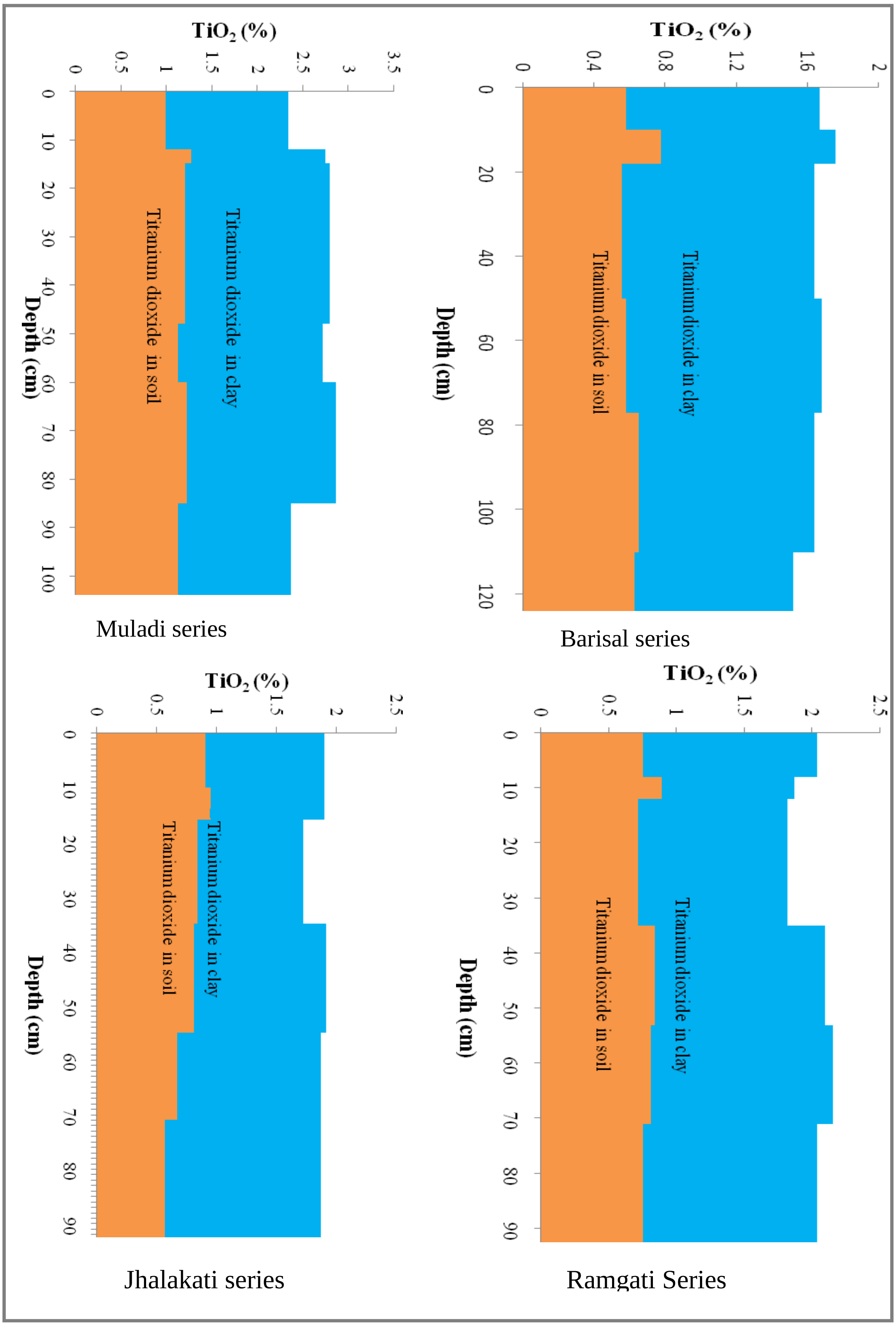

Fig 77. Graph shows the vertical distribution of TiO_2 in soil and clay in Muladi, Barisal, Jhalakati and Ramgati series.

This results are in accord with the findings of White (1985), Hassan and Razzaq (1981), Hussain *et al.* (1989); Egashira and Yasmin, 1990; Alam *et al.* 1993; Moslehuddin and Egashira, 1996)

Begum (1996) studied on some soils from the coastal area of Bangladesh (Bhola district) and reported that presence of considerable quantity of smectite mineral in the clay fraction of the soils there. Quartz was found in relatively smaller amounts but vermiculite was not detected in these soils.

Moslehuddin *et al.* (1998a) studied the mineralogy of two soils of Meghna Estuarine Floodplain soil and found that mica, smectite and chlorite present in good proportion with small amounts of kaolinite and vermiculite minerals. They supposed that the soils of Young Meghna Estuarine Floodplain were originated from the Ganges sediment mainly, with admixture of the Brahamaputra (Jamuna) and Meghna sediments and assumed that these regions have mica- smectite suite. They also opined that due to decalcification of Ganges sediments and/ or admixture of the Brahamaputra and Meghna sediments, smectite may not always be a dominant mineral and chlorite may be present in high proportions. Mica-smectite suite and vermiculite were not found in the studied soils. Presence of high chlorite along with less dominance of smectite indicates contribution of Meghna/ Old Brahamaputra sediments over the Ganges sediments in these soils. Akter *et al*. (2015) found the similar results and stated that variation in the mineralogical composition was supposed to be attributed from the difference in the proportion of parent sediments from the major Rivers of Bangladesh.

The presence of mica and vermiculite in the studied soils indicates that the transformation of mica to vermiculite has taken place in some soil and some soils are not due to the congenial atmosphere of weathering. Ali (1994) also indicated that this type of transformation of minerals in the alluvial soils is differing likely. The transformation of mica to vermiculite during pedogenesis has also been described by Jackson (1965) and many investigators.

According to Eaqub (1985) the transformation of micas to expandable 2:1 minerals may be represented by the following equation.

Mica ⟶ Hydrous mica ⟶ Illite ⟶ Transitional minerals (Smectite, Vermiculite)

⟶ K content decreases ⟶ (11.0 % K_2O)

(5.5% K_2O) 0.02 %(K_2O)

Fanning and Keramidas (1977) pointed out that mica in most soils originate mainly from soil parent materials and tend to weather to other minerals with time. They generally are more prevalent in the clay mineralogy of younger and less weathered soils (Entisols, Inceptisols, and Alfisols). Also, Micas tend to occur more as discrete mica particles in the less weathered soils, if such particles are present in the soil parent material, whereas in more weathered materials the mica is more commonly interstratified with expansible 2:1 minerals that may also be partially chloritized (Jackson *et al.* 1952 ; Jackson, 1964).

The clay minerals present in the studied soils appeared to be mainly inherited from their parent materials, although some in situ transformations might possibly have taken place (Ali, 1994; Saheed and Hussain, 1996). The above facts also indicate that the clay minerals in the studied soil profiles under their existing pedochemical environment are quite persistent and stable. The relatively high pH and high percent base saturation of the soils under the present investigation appear to be congenial for thepr existence.

Saheed and Hussain (1992) reported that clay minerals in the floodplain soils of Bangladesh have been derived exclusively from their parent materials. They commented that neosynthesis of smectites is believed to be possible in the calcarious Gangetic alluvium because the chemical environment is suitable for their formation.

Moslehuddin *et al.* (1996) also studied mineralogical composition of some paddy soils of Bangladesh and noted that the clay fraction in the floodplain soils contained relatively higher quantity of mica as compared to that of the terrace soils.

An admixture of mica, vermiculite, smectite, chlorite and kaolinite in the clay fraction of the studied soils may be considered as a boon as the soils with such mixed clay mineralogy will not show any extreme physical property. With such a combination of clay mineralogical composition the soils are expected to demonstrate the physical properties quite ideal for agricultural management.

Table 29. Semi-quantative estimation of minerals in the clay fraction (<2µm) of the surface soils under study.

Soil Series	**Horizon**	**Depth (cm)**	**% Mineral content***												**USDA Mineralogy class**
			Mc	**Sm**	**Vt**	**Ch**	**Kt**	**Vt-Ch**	**Mc/Vt/St**	**Mc/Ch**	**Qr**	**Gt**	**Lp**	**Fd**	
Bhola	Surface	0 – 8	40	5	0	19	16	12	-	1	7	-	-	-	Mixed
Nilkamal	Surface	0 – 12	45	3	0	26	21	-	-	1	4	-	-	-	Mixed
Pirojpur	Surface	0 – 10	48	22	0	16	13	-	-	1	-	-	-	-	Mixed
Hogla	Surface	0 – 12	34	3	18	23	15	3	-	1	-	3	-	-	Mixed
Muladi	Surface	0 – 10	50	16	0	14	13	6	-	1	-	-	-	-	Illitic
Barisal	Surface	0 – 10	60	5	2	12	12	3	-	1	5	-	-	-	Illitic
Jhalakati	Surface	0 – 10	54	5	1	20	20	-	-	-	-	-	-	-	Illitic
Ramgati	Surface	0 – 8	53	4	0	17	14	-	-	1	10	-	1	-	Illitic

***According to the method of Moslehuddin and Egashira (1996) and Islam and Lotse (1986**).
Mc = Mica, Sm = Smectite, Vt = Vermiculite, Ch = Chlorite, Kt = Kaolinite, Vt-Ch = Vermiculite-Chlorite, Mc/Vt/St = Mica-Vermiculite-Smectite, Mc/Ch = Mica-Chlirite, Qr = Quartz, Gt = Goethite, Lp = Lepodocrocite, Fd = Feldsper,

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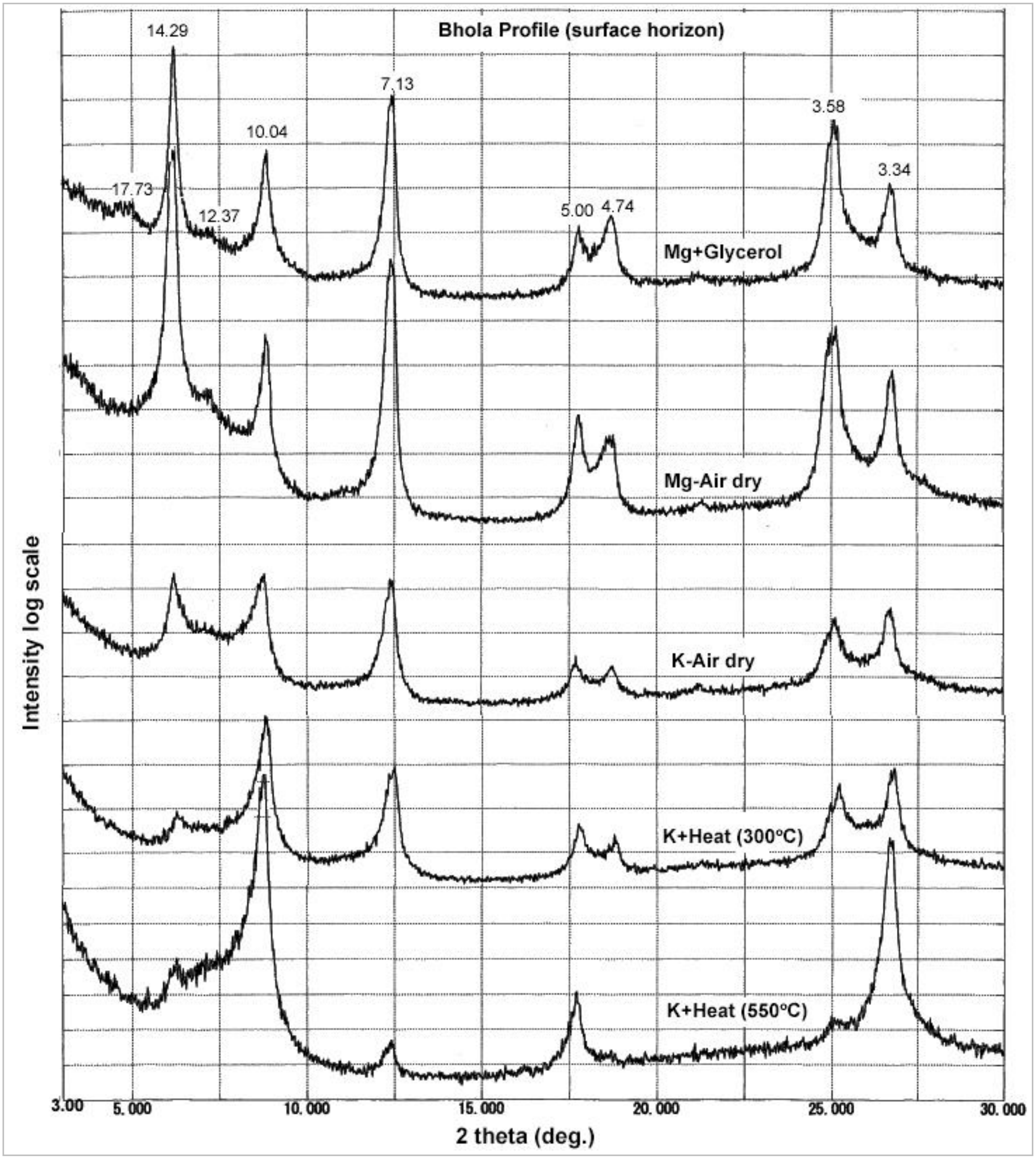

Fig 78. X-ray diffractogram of clay samples from Ap horizon of Bhola series

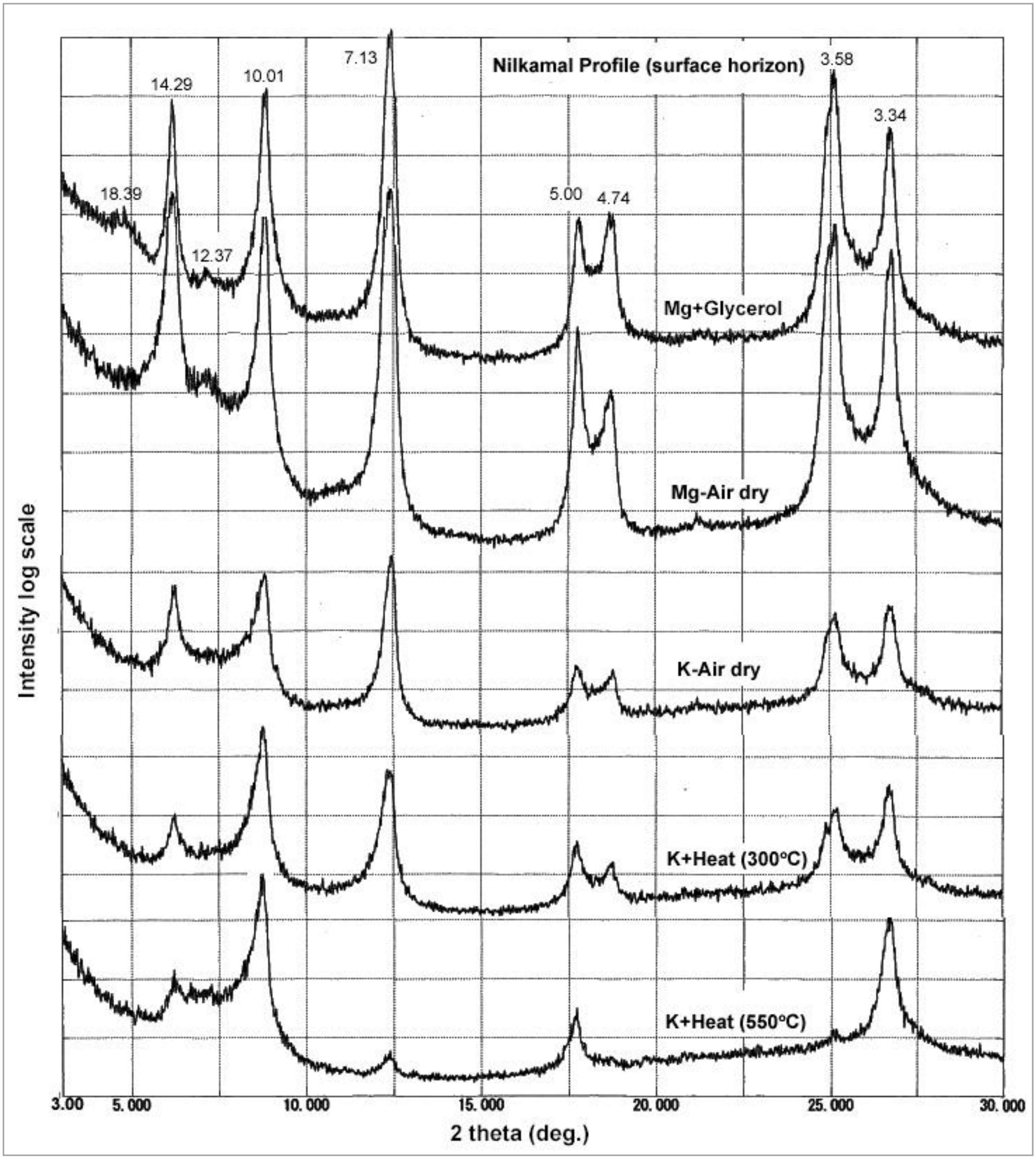

Fig 79. X-ray diffractogram of clay samples from Ap horizon of Nilkamal series

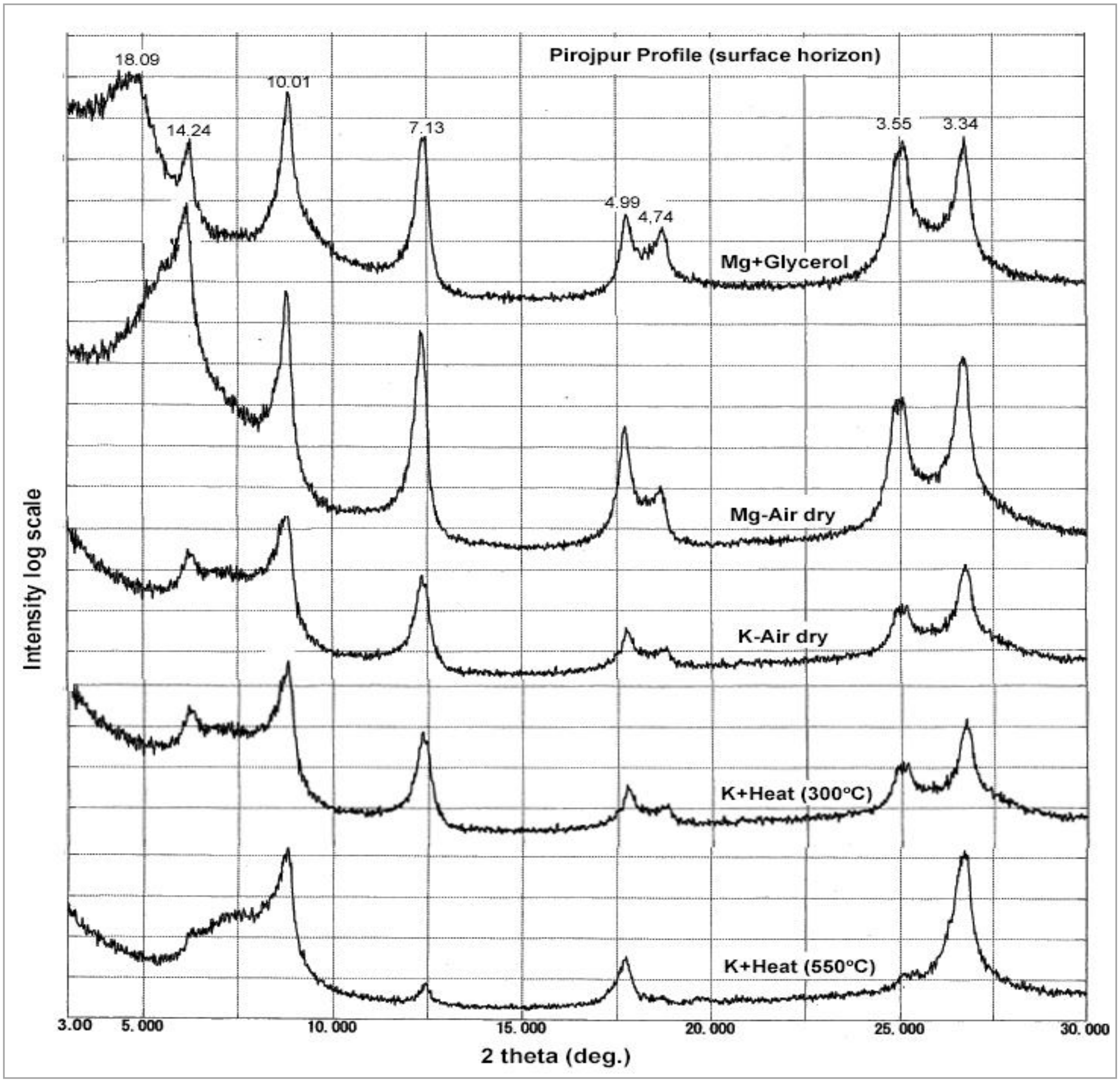

Fig 80. X-ray diffractogram of clay samples from Ap horizon of Pirojpur series

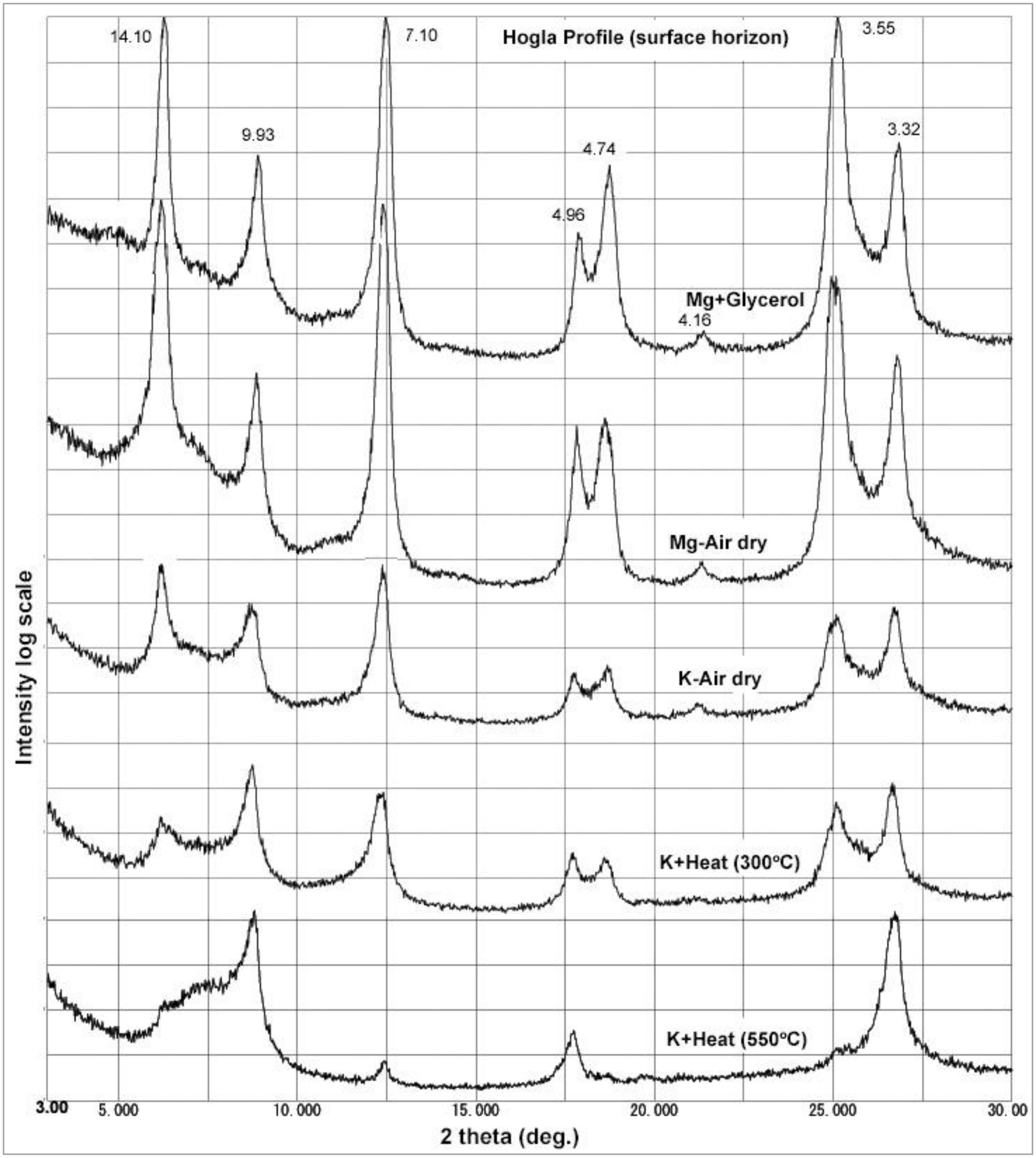

Fig 81. X-ray diffractogram of clay samples from Ap horizon of Hogla series.

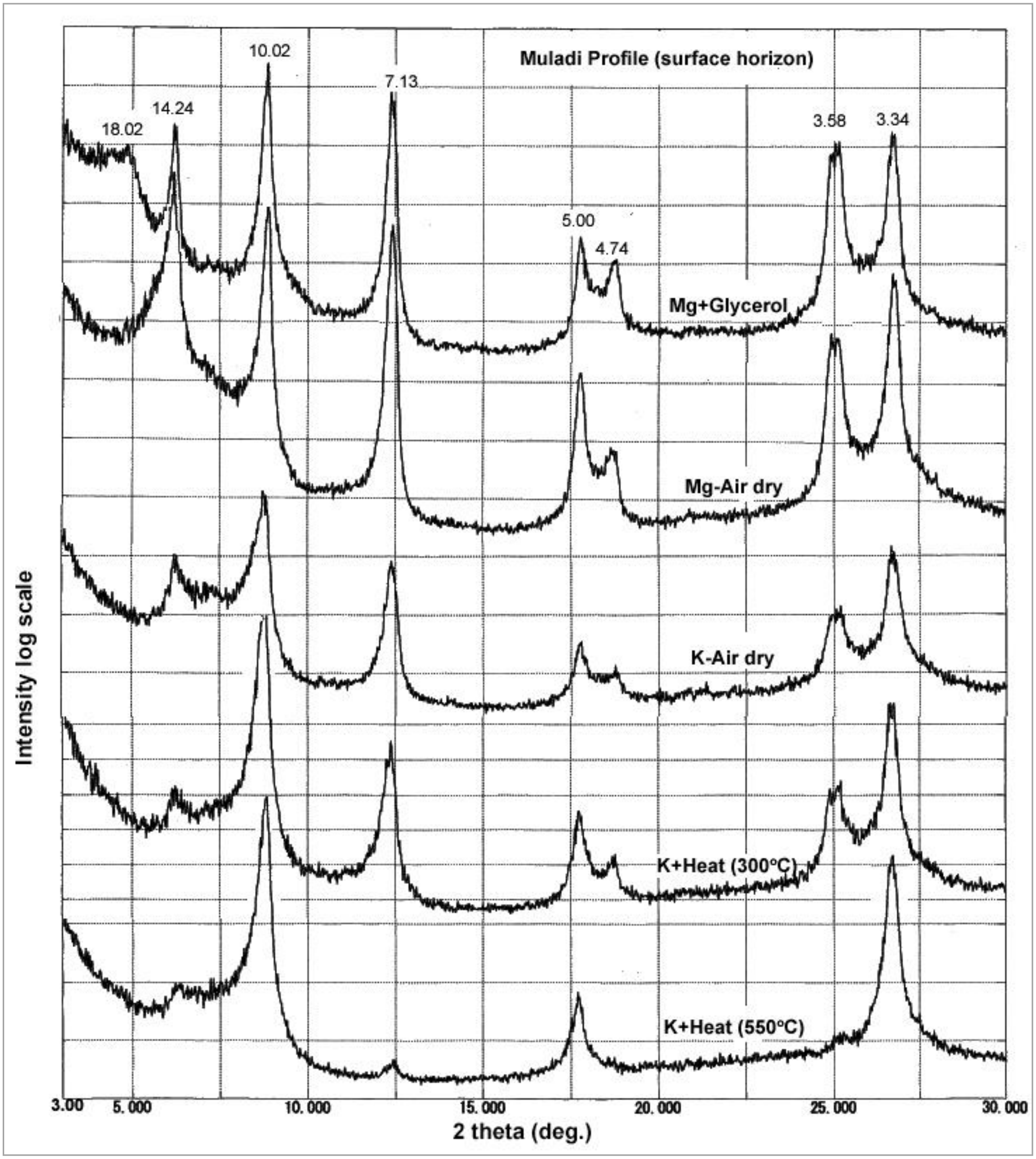

Fig 82. X-ray diffractogram of clay samples from Ap horizon of Muladi series.

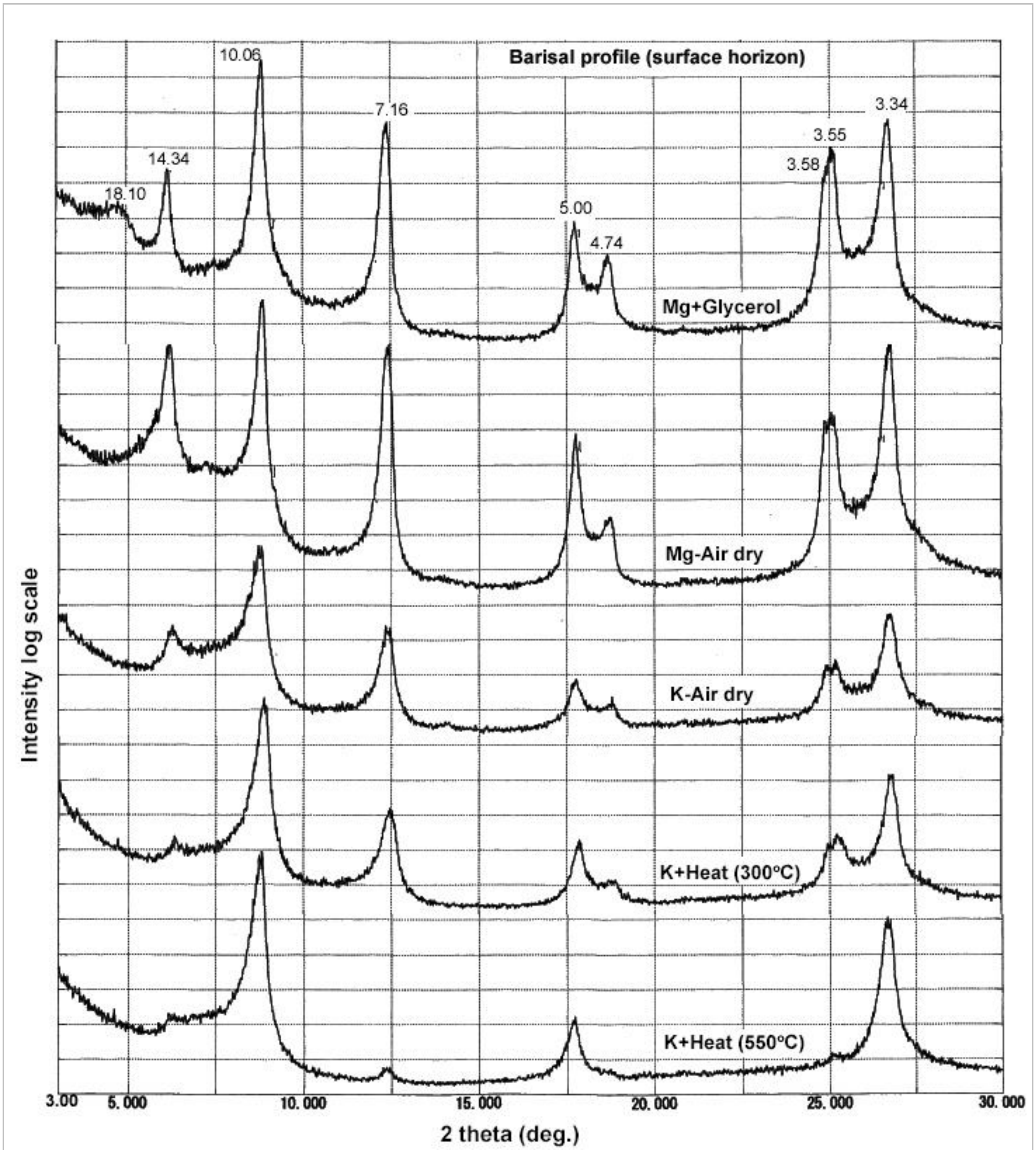

Fig 83. X-ray diffractogram of clay samples from Ap horizon of Barisal series.

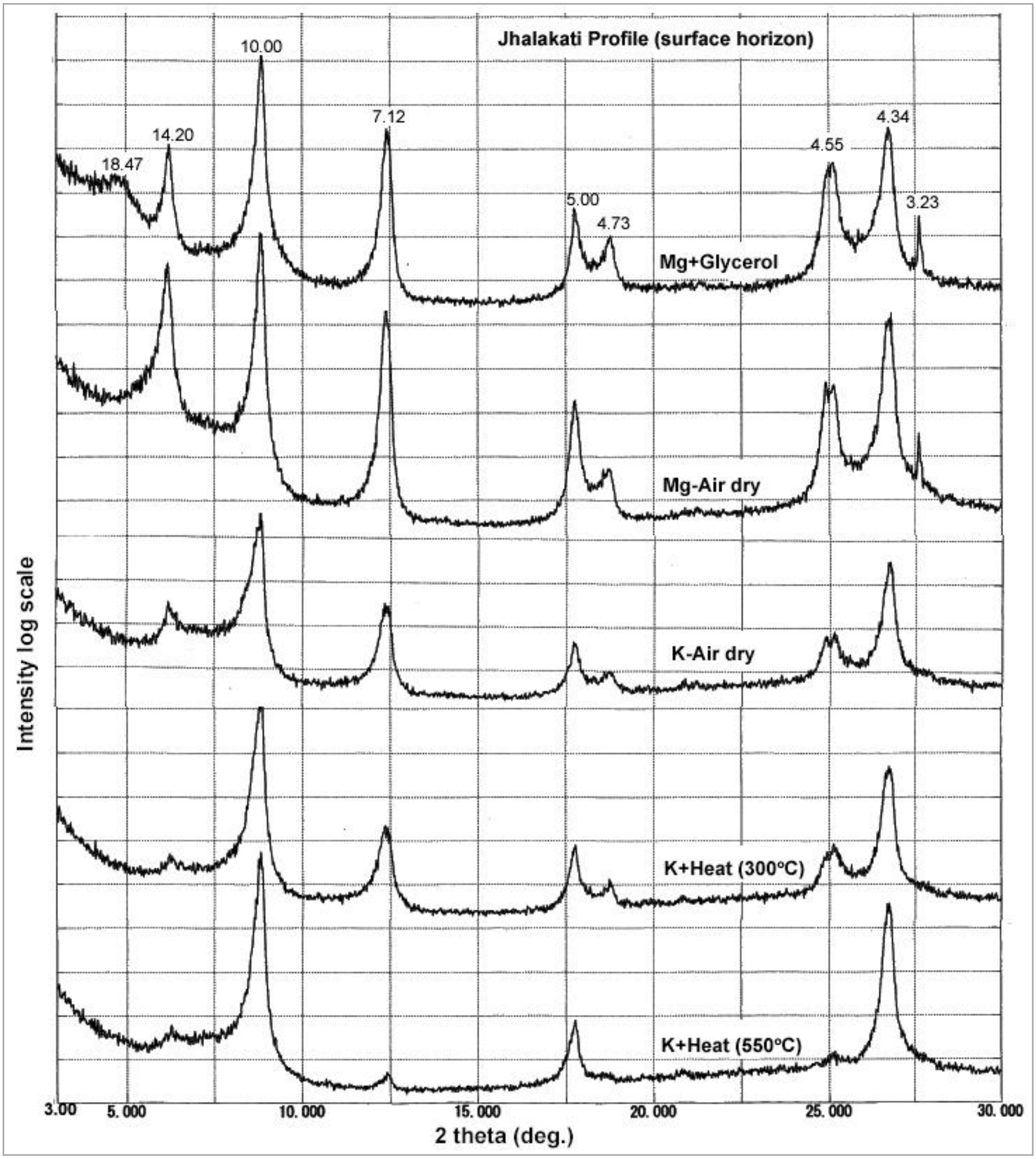

Fig 84. X-ray diffractogram of clay samples from Ap horizon of Jhalakati series

Fig 85. X-ray diffractogram of clay samples from Ap horizon of Ramgati series

CHAPTER-6

GENESIS OF THE SOILS UNDER INVESTIGATION

CHAPTER – 6

GENESIS AND CLASSIFICATION OF THE SOILS

6.1 Genesis of the soils

On the basis of information obtained from the field and laboratory studies, an attempt has been made to look into the pedogenic processes that are operating in these soils and also into their classification according to the USDA Soil Taxonomy and the other system (WRB, 2015) of soil classification.

In consideration of the geological history, the area wherefrom the soils have originated, may be considered to be of recent age. The environmental, morphological, physical, chemical and mineralogical properties of these soils indicate clearly that the parent material of the studied soils were alluvial deposits of mixed origin. Profile characteristics of these soils indicate that their development did not proceed far. All the soils under investigation appear to be weakly developed. This may be due to the short duration and the annual siltation that take place during flooding period. The soils may, therefore, be reasonably considered to be in tits incipient stage of development.

The parent materials and the prevailing environmental conditions like the poor drainage and aquic moisture regime due to submergence during the rainy season are probably the factors affecting the development of the soils and are responsible for the formation of the morphological properties of the soils. Since the soils are at their youthful stage presumably, the parent materials will play a dominant role in exhibiting the properties of the soils. Since the soils are located in the basin and basin - margin and ridge sites and are poorly drained, create a situation not conducive for normal soil development. The direct consequence of poor internal drainage is the retardation of leaching and little alteration of soil materials. Moreover, the soils have been under cultivation for a long time and thus disturbed the normal pedological processes and helped in the mechanical translocation of finer fractions downward forming the plough pan and the flood coatings. The finer fraction blocked the pore space and restricted the movement of the products of weathering.

Seasonal submergence and drying set the condition of alternate oxidation – reduction in the soils. The elements susceptible to oxidation- reduction conditions would respond readily and eventually would impart certain characteristics like mottles to the soil. The soil reactions (pH) closely follow the course of oxidation- reduction conditions as because the soils contain considerable amount of Fe and Mn which are subject to change. The grey tinges of the soils are probably due to the above said conditions. Another interesting feature of these soils are the presence of mottling of yellow or brown colours usually along the old root channels and pores. The horizons containing the variously coloured mottling may be considered as evidence of weak type of gleization process.

In most of the soils, alternate wet and dry conditions produce vertical cracks leading to big prism. With the passage of time, the horizontal cracks and combined effect of flocculation, root penetration, organic matter addition and the biotic activity produces blocky structure. Translocation of finer materials from the top through the cracks along with the first flood water made the structural aggregate more conspicuous.

The development of coating along the ped faces, fissures and pores in the sub-soil are the typical characteristics of these soils. These coatings are not equivalent to true clay skins but are flood coatings as called by Brammer, 1971. They appear to have developed rapidly from the materials that were taken down from the surface under flooded condition.

Plough pan is a soil layer compacted by tillage and occurs below 5 to 15 cm from the surface of the soil depending on the normal depth of ploughing . It is mainly formed due to continuous wetland rice cultivation (FAO, 1971; Brammer, 1979). It becomes thicker and harder through continuous practice of transplanted rice cultivation. Plough pan was found to develop 3 to 7 cm thick in the studied soils. The ploughpan prevent vertical water percolation, restricts aeration as well as root penetration (Brammer, 1971).

The vertical distribution of sand, silt and clay of these soils support the assumption that the parent materials of the soils were of mixed origin. The annual deposition of silts by flooding affects the existing pedogenic processes by cumulization effect. The soil profiles with weak to moderate prismatic to angular blocky structure suggest the formation of altered B horizon (Cambic) in all the soils. However all the soils in the surface horizons have massive structure.

In each soil profile, there is a trend of increasing pH with depth. Nevertheless, in all the soils the surface horizons have acidic reaction. The surface soil acidification is due to the alternate oxidation reduction cycles in the floodplain areas (Brammer, 1971).

The colloidal complex of the soils is also well supplied with exchangeable metal ions. The base saturation increases gradually with depth and calcium and magnesium dominant the exchange complex. Exchangeable Ca^{++}/Mg^{++} ratio is less than 1. It may be noted here that under hydromorphic conditions this ratio tends to be low (Joffe, 1968). X-ray diffraction analysis indicates the dominance of non-expanding types of minerals in the clay fraction. Cracking, as a result, is usually weak.

The silica-sesquioxide ratio in the clay fraction indicates the presence of a considerable amount of 2:1 lattice type clay minerals which might be an admixture of a variable amount of mica and illitic mica. Alteration of mica to illitic mica may be a common pedochemical weathering processes in the soils under investigation. It is of interest to note that a low to medium quantity of smetite has been detected in all the pedons.

Vertical distribution of clay in all the soil profiles indicates an impoverishment of clay in the surface horizons. This low clay near the soil surface may be for two reasons. It may be because of stratification or there may be destruction of clay near the surface because of the ferolysis process. Quantity of chlorite is high in the surface horizon of this pedon.

From the characteristics discussed in the preceding paragraphs it appears that the soils under investigation are likely to be generally designated as hydromorphic in nature. However the absence of well developed gley horizons in these soils may lead to doubt about the true hydromophic nature of these soils. Nevertheless, it may be worthwhile to mention that the very weak gley horizons represented by the occurrence of mottles, low exchangeable Ca^{++}/ Mg^{++} ratio, massive structure in the top soil and structurelessness in the lowermost horizon of these soils also support this fact. Weak type of gleization seems to be a process of soil formation in all these soils.

Hossain *et al.* (2011) suggests that gleization seems to be the dominant pedogenic processes in the floodplain soils of Bangladesh.

Albretch (1941) reported that gleization occurs in the zone of soils, where the three factors, such as high base saturation with ample calcium and magnesium, organic matter infiltration and poor drainage operate jointly for anaerobiosis. This was later on supported by many other authors (Bloomfield 1959; Nizamuddin *et al*. (2009b); Khan *et al.* (2012).

In conclusion it may be said that the soils developed under study show the necessary marks of gleying in their body. Several rivers are passing through the coastal zone. These rivers carry huge amount of sediments and water. Part of these sediments continuously hampers the pedogenic processes of these soils. The groundwater fluctuates considerably with the season in all the profiles. As groundwater influences strongly in the studied soils, the groundwater gley soils are developed and gleization, therefore, is thought to be a process of soil formation in them. Parent materials of mixed origin which are at their incipient stage played a dominant role in the evolution of genetic processes that have taken place in the studied soils.

6.2 Classification of the soils

An endeavor has been made in this section to classify the soils on the basis of the available information. Relevant properties of these soils were matched with the criteria set out in the USDA Soil Taxonomy (Soil Survey Staff 1975 and 2014). In the present investigation, one of the important objectives was to classify the studied soils in the US Soil Taxonomy. As evident from the results of morphological, physical, chemical and mineralogical properties of the studied soil profiles as presented in chapter 4 and 5 revealed that there was a variation in surface and sub-surface colors, texture, structure, pH, calcium carbonate, exchangeable bases, base saturation percentage, effervescence, total analysis results of whole soil and clay and clay mineralogical composition. The variation of the above properties in the profiles was considered very important in differentiating the soils into the various orders, suborders, great groups, subgroups, and families' level of US Soil Taxonomy. The studied soil series from the Ganges River Floodplain (Muladi), Young Meghna Estuarine Floodplain (Bhola, Nilkamal) and Ganges River Tidal floodplain (Pirojpur, Hogla, Barisal, Jhalakati, Ramgati) have been characterized on the basis of the results presented in Table 30.

Results presented in the above table show that structures (prismatic to angular blocky) have developed in the sub-soils of all the studied profiles which indicates the destruction of alluvial stratification and their alteration. It has already been pointed out in the former chapters that these soils are not bestowed with well formed structures in the top soil. Burried horizons were found in the Pirojpur and Hogla soil. This indicates the two sequence nature of the soil. Occurrence of variously colored mottles along root channels is another persisting feature in all the soils. The leaching loss of $CaCO_3$, exchangeable bases and sesquioxides from the surface to the underlying horizons and the gradual decrease of organic carbon from the upper layers to the lower layers proved alteration in these soil profiles. Hence it was assumed that cambic B horizon has developed in all the studied profiles. Hence, all the soils under study may be placed in the Inceptisols order (Soil Survey Staff, 1975 and 1994).

Soils belonging to the Inceptisol order are subdivided into suborders on the basis of soil moisture regime, and some other extreme physical and chemical properties. Since these soils have developed under seasonally flooded conditions therefore the **aquic** soil moisture regime occurs in these soils. At the suborder level all the soils are designated as **Aquepts** .

Considering the moisture regime as the basis, the soils belonging to Aquepts suborder may be placed into the **Endoaquepts** great group because of endo saturation

At the sub group level the soils of Bhola, Nilkamal, Muladi, Barisal, Jhalakhati and Ramgati series may be suit into the **Typic Endoaquepts** as they have 50% or more matrix colour chroma ≤ 2 within 75 cm depth and have no extreme properties or irregular trend of organic matter. The soils of Pirojpur and Hogla series may be designated as **Fluventic Endoaquepts** due to their irregular trend of organic matter from top to bottom in the soil profiles. Climatologically all the studied soils have **"Hyperthermic"** temperature regime (Table 30).

On the basis of the soil reaction, most of the studied soils can be placed under the **nonacid class** except Nilkamal and Muladi soil. Nilkamal and Muladi soils are calcareous and alkaline in reaction.

Clay mineralogical study indicates that Muladi, Barisal, Jhalakati and Ramgati soils have illitic mineralogy class as mica is the dominant clay minerals constituting more than 50 percent. On the other hand Bhola, Nilkamal, Pirojpur and Hogla soils have mixed mineralogy class as they do not have more than 50 percent of any particular type of clay mineral.

On the basis of particle size distribution in the profile the Pirojpur, Hogla and Barisal series are classed as clayey while the Bhola, Nilkamal, Muladi, Jhalakati and Ramgati series are classed as loamy.

Therefore, on the basis of texture, soil reaction, temperature regimes and clay mineralogical composition the soils have been classed into six soil families of US Soil Taxonomy (Table 31).

Soils of coastal zone of Bangladesh have not been classified earlier at the family level of Soil Taxonomy because of lack of mineralogical data (SRDI Staff, 1965- 86). Zijsvelt (1980) characterized the 476 soil series of Bangladesh into Taxonomic soil family on the basis of assumptions as soils formed on the alluvia deposited by the rivers except the Ganges having a mixed mineralogy while Gangetic alluvium assumed to have montmorillonitic mineralogy. Soils formed on Tertiary hills and Pleistocene terraces assumed to have kaolinitic type.

Lastly an attempt has been made to correlate the studied soils with the World Reference Base (WRB) system of soil classification. The World Reference Base (WRB) (WRB) is the international standard classification system endorsed by the International Union of Soil Sciences (IUSS). According to WRB system, 2015 it may be stated that all the studied soils may be classed into **Gleysols Groups** because these soils having gleyic properties within 50 cm from the soil surface.

Table 30 Derived values for soil classification

Soils	Surface soil color (Moist)	Subsoil color (Moist)	Subsoil texture	Subsoil structure	Organic carbon	BSP up to 75 cm depth	pH range upto 50 cm depth	Organic matter	Mineralogy class	EC(mS/m)	$CaCO_3$(%)	ESP
Bhola	Grey(5 Y 5/1)	Olive grey(5 Y 5/2)	SIL	CO1PR	0.91-1.68	56-64	6.53-7.75	1.90	Mixed	1.448	1.07	11
Nilkamal	Grey (5 Y 5/1)	Olive Grey (5Y 5/2)	SICL	VC2PR	0.63-1.89	53-66	6.68-7.63	1.95	Mixed	0.298	1.43	12
Pirojpur	Dark grey (5 Y 4/1)	Grey (5Y 5/1)	C	CV 3PRAB	1.47-3.54	52-71	6.34-7.13	3.68	Mixed	0.252	1.26	9
Hogla	Grey (5 Y 5/1)	Dark Grey (5Y 4/1)	SIC	C 3 PRAB	0.84-4.91	65-69	6.4-7.12	2.92	Mixed	0.185	1.12	8
Muladi	Grey (5 Y 5/1)	Dark Grey (5Y 4/2)	L	C 3 PRAB	0.42-2.31	69-75	6.43-7.61	1.87	Illitic	0.207	2.23	6
Barisal	Grey (5 Y 5/1)	Dark grey 2.5Y 4/1	C	C 3 PRAB	1.35-1.89	56-66	5.11-6.41	2.69	Illitic	0.358	0.89	11
Jhalakati	Grey (5 Y 5/1)	Olive Grey (5Y 5/2)	SIL	VC 3 PRSB	1.28-1.47	50 - 57	6.68-7.58	2.36	Illitic	1.293	0.60	12
Ramgati	Grey (5 Y 5/1)	Olive brown(2.5 Y 4/4)	SIL	C 1PR	0.99-1.68	55-63	5.41-6.51	2.07	Illitic	0.874	1.17	12

**Temperature regime- Hyperthermic * Moisture regime- Aquic*

Table 31. Classification of the studied soils.

USDA Soil Taxonomy*					Soil Series	World Reference Base(WRB)**
Order	**Suborder**	**Great group**	**Subgroups**	**Family**		
Inceptisols	Aquepts	Endoaquepts	Typic Endoaquepts	Loamy, mixed, nonacid, hyperthermic, Typic Endoaquepts	Bhola	Gleysols
			Typic Endoaquepts	Loamy, mixed, calcareous, hyperthermic, Typic Endoaquepts	Nilkamal	Gleysols
			Fluventic Endoaquepts	Clayey, mixed, nonacid, hyperthermic, Fluventic Endoaquepts	Pirojpur	Gleysols
			Fluventic Endoaquepts		Hogla	Gleysols
			Typic Endoaquepts	Loamy, Illitic, calcareous, hyperthermic, Typic Endoaquepts	Muladi	Gleysols
			Typic Endoaquepts	Clayey, Illitic, nonacid, hyperthermic, Typic Endoaquepts	Barisal	Gleysols
			Typic Endoaquepts	Loamy, Illitic, nonacid, hyperthermic, Typic Endoaquepts	Jhalakati	Gleysols
			Typic Endoaquepts		Ramgati	Gleysols

* (Soil Survey Staff, 1999 and 2014) ** (IUSS Working Group, 2015)

CHAPTER-7

SUMMARY AND CONCLUSION

CHAPTER – 7

SUMMARY AND CONCLUSION

Siltation pattern and pedogenesis in the coastal zone of Bangladesh were studied. Suspended sediment load carried by the two rivers such as the Bishkhali and the Arial Khan were measured.

Eight typical soil profile occurring in the coastal floodplain of Bangladesh, each representing an extensive and established soil series: Bhola, Nilkamal, Pirojpur, Hogla Muladi, Barisal, Jhalakati ,Ramgati along a transect from north to south were selected for pedogenitic study. Pedogenic information about soils is a prerequisite for sound and sustainable land management. Environmental settings and morphogenetic properties of the soils were studied in the field. A total of 46 soil samples from typical genetic horizons of eight soil profiles were collected for physical, chemical and mineralogical analyses.

A. Findings of coastal sediments may be summarized as follows:

- The amounts of suspended sediment ranged from 4.10 to 13.06 kg/sq.m/month.
- Sediment load is relatively higher in the wet season and lowerr in the dry season in the Arial Khan river
- Sediment load is higher in the dry season and lower in the wet season in the Bishkhali river.
- Siltation pattern varies with the season.
- Silt is the dominant size fraction in the sediments of both the rivers.
- Silt loam was the dominant textural class in the sediments of both the rivers.
- pH of the sediments ranges from 7.7 to 8.03 and are slightly calcareous in nature.
- Exchangeable Mg^{++} content was found higher among the exchangeable bases.
- The SiO_2 content in the suspended sediments of the rivers ranged from 60 to 61 percent.
- The SiO_2/R_2O_3 molar ratio in the suspended sediments indicates the presence of 2:1 type clay minerals.

B. The prominent morphological features of the soils may be summarized as follows:

- Grey matrix color is a characteristic feature of these soils. The top soils were generally grey to dark grey in color (moist) with silt loam to silty clay textures except Pirojpur and Barisal soils where it was clayey in the top soil.

- ❖ The sub-soils were generally grey to olive grey in color (moist) with silt loam to silty clay textures except in Pirojpur and Barisal soils where it was clayey.
- ❖ Flood coatings and variously colored mottles present in the sub-soil zone of all the soil profiles.
- ❖ Prismatic to sub-angular blocky structures were developed in the sub-surface horizons of all the profiles whereas massive structure was found in the surface horizons.
- ❖ Development of cambic horizon is the most notable morphogenetic feature in these soils.
- ❖ All the soil profiles showed abrupt to clear smooth horizon boundaries reflecting rejuvenation in soil development.
- ❖ Parent material of the soils is of alluvial origin with regular siltation from flooding water of the coastal rivers. The attributes of parent material and the associated aquic soil moisture regime dominantly influenced the genesis of these soils.

C. Some salient physical properties of the soils have been studied and the results obtained therefore may be summarized as follows:

- ❖ The sand contents in the studied soils ranged from 3 to 52 percent with the mean of 13 percent.
- ❖ The silt contents in the studied soils ranged from 32 to 77 percent with the mean of 50 percent.
- ❖ The clay contents in the studied soils ranged from 5 to 58 percent with the mean of 37 percent.
- ❖ The irregular distribution pattern of sand, silt and clay as well as sand / silt ratio in all the soil profiles reflected the heterogeneous nature of the parent materials from which these soils havedeveloped.
- ❖ Textural classes of the soils showed wide variation. The soils in ridge position are concentrated silt loam to silty clay loam textural classes of textural triangle while the basin soils are mostly silty clay to clay class of textural triangle.
- ❖ Most of the soils showed higher bulk density in the Ad horizons due to compaction resulting from ploughing for rice cultivation.

D. Results of chemical analysis of the soils under investigation may be summarized as follows:

- ❖ The pH (water) value of the studied soils ranged from 5.71 to 7.75 with a mean value of 6.97 indicating slightly acid to slightly alkaline in reaction. All ΔpH values were negative which ranged from -0.48 to -1.30 pH unit. The pH values in H_2O and KCl showed a significant positive correlation.

- ❖ The electrical conductivity (EC) of all the studied soils ranged from 0.12 to 1.65 dS/m with a mean value of 0.54 dS/m at 25°C in the 1:5 soil- water extract indicating non-saline nature of the soils.
- ❖ Organic matter content ranges from 0.72 to 8.46 percent with a mean value of 2.43 percent were detected in all the studied soils indicating moderate content and showed a gradual decrease with depth except in Pirojpur and Hogla soils. The C/N ratio of the soils varies from 8 to 17 with a mean value of 11. The vertical distribution pattern of C/N ratio in the pedons is found irregular.
- ❖ The total nitrogen content in the present soils ranges from 0.07 to 0.33 percent with a mean value of 0.12 percent and showed a gradual decrease with depth except in the C2 horizon of Pirojpur and Hogla soils.
- ❖ The cation exchange capacity of the soils under the present investigation ranges from 14.01 to 23.21 cmol kg^{-1} with a mean value of 17.22 cmol/ kg soil. A significant positive correlation was found between CEC and percent clay content. Amount of exchangeable Mg^{++} is around two times higher than the exchangeable Ca^{++} in all the soils. Magnesium occupies around 58 percent of the total exchange sites among the bases. The base saturation percent was also high (> 50%) in almost all the soils and showed a tendency to increase with depth in the profiles.
- ❖ Dithionate extractable free iron and manganese oxides were found low in all the studied soils. Free Fe_2O_3 content had a significant positive correlation with the free MnO_2 content.
- ❖ Results of fusion analysis of soils have been presented. SiO_2 was the most abundant element in these soils. The other dominant elements were in decreasing order of abundance: $Al_2O_3 > Fe_2O_3 > MgO > CaO > K_2O > TiO_2 > P_2O_5 > MnO_2$.
- ❖ SiO_2/R_2O_3 molar ratios throughout the profiles were non-uniform which indicates that the soil parent materials were heterogeneous and were of mixed origin.

E. Mineralogical composition of the clay fraction of soils may be summarized as follows:

Illite was the dominant mineral in the clay fraction of Muladi, Barisal, Jhalakati and Ramgati soils whereas the other soils had mixed mineralogical compositions consisting of mica, smectite, chlorite, kaolinite and trace amount of vermiculite. A significant proportion of smectite was found in the clay fraction of Pirojpur soil.

F. The pedogenesis of the soils may be summarized as follows:

Morphological and chemical properties of the soils indicate that gleization is the dominant pedogenic process. Gleization is caused by seasonal reducing condition during the monsoon season when the soils remain flooded for several months. During the dry season oxidation condition prevails when iron and manganese are precipitated. Alternation of oxidation and reduction conditions is a characteristic feature of these coastal floodplain soils. The movement and fixation of oxidized iron and manganese in the profiles has caused the formation of cambic B hoizon in the middle zone of the profiles. Some weakly formed structural aggregates have also developed in these cambic B horizons of the soils under the present investigation.

On the basis of the studied of coastal sediments and the coastal soils of Bangladesh the following conclusions could be drawn:

- Gleization seems to be the major pedogenic process of soil formation.
- The soils are rejuvenated every year by the newly deposition of sediment carried by the rivers of the coastal region, on their landscape during flooding in the monsoon season. The elemental composition of the suspended sediments of both the rivers (the Bishkhali and The Arial Khan) was more or less identical to that of the soil parent materials. These sediment loads have had significant role in the genesis of these soils.
- All the studied soils were found to be fit in the Inceptisols order of US Soil Taxonomy.
- The soils have been characterized at the family category level according to the US Soil Taxonomic system as follows:

Soil Series	Family name*
Bhola	Loamy, mixed, nonacid, hyperthermic, Typic Endoaquepts
Nilkamal	Loamy, mixed, calcarious, hyperthermic, Typic Endoaquepts
Pirojpur	Clayey, mixed, nonacid, hyperthermic, Fluvaaquentic Endoaquepts
Hogla	Clayey, mixed, nonacid, hyperthermic, Fluvaaquentic Endoaquepts
Muladi	Loamy, Illitic, calcarious, hyperthermic, Typic Endoaquepts
Barisal	Clayey, Illitic, nonacid, hyperthermic, Typic Endoaquepts
Jhalakati	Loamy, Illitic, nonacid, hyperthermic, Typic Endoaquepts
Ramgati	Loamy, Illitic, nonacid, hyperthermic, Typic Endoaquepts

*According to Key to Soil Taxonomy (Soil Survey Staff, 2014)

This family level soil classification will be useful to soil scientists, agronomists, farm research scientists and the agriculture extension workers involved in agricultural development as well as agro-technology transfer programs for increasing agricultural production in the coastal regions of Bangladesh. This will ultimately help the farmers in assessing the extent of deterioration in the fertility of the soils and adaptation of proper soil and crop management practices in the coastal region of Bangladesh.

CHAPTER-8

REFERENCES

CHAPTER – 8

REFERENCES

Abbas, N. and Subramaniam. 1984. Erosion and sediment transport in the Ganges River Basins (India). J. Hydrol. 69: 173-182.

Akter, K. F., Z. H. Khan, M. S. Hussain, A. R. Mazumder and M. A. Muzib. 2004. Morphological and clay mineralogical characteristics of some seasonally flooded soils of Bangladesh. J. Asiatic. Soc. Bangladesh, Sci. 30(2): 11-22.

Akter, K. F., Z. H. Khan, M. S. Hussain, A. R. Mazumder. 2011. Physico-chemical characteristics of the seasonally flooded soils of Bangladesh and Their management implications. Dhaka Univ. J. Bio. Sci. 20(2): 173-182.

Akter, F., **Abu Zofar Mohammad Moslehuddin, Mohammad Abdul Kader, Md. Mosharaf Hossain Sarker and Yuki Mori. 2015**. Mineralogy of soils from different Agro-ecological regions of Bangladesh: Region 18- Young Meghna Estuarine Floodplain. J.Fac. Agr. Kyushu Univ., 60 (2) pp 457-462.

Alam, M.K., A.K.M.S. Hassan, M.R. Khan and J.W. Whitney. 1990. Geological map of Bangladesh. Dhaka: Geol Survey of Bangladesh.

Alam, M.L., N.Miyauchi and S. Shinagawa. 1993. Study on clay mineralogical characteristics of hill and terrace soils of Bangladesh.. Clay sci., 9: 109-121.

Albretch, N.M.A. 1941. Calcium saturation and anaerobic bacteria as possible factors in gleization. Soil Sci., 61: 213.

Ali A.1989. Storm surges in the Bay of Bengal and some related problems.PhD Dissertation, University of Reading, Reading. USA.

Ali, M. F. 1994. Effects of alternate wetting and drying cycles on pedogenic processes of some representative Bangladesh soils. Ph.D. dissertation, University of Dhaka, Dhaka, Bangladesh.

Amin, M; M.A. Rahman; S.M. Zaman; M.z. Hossain and M.S. Islam. 2008. Cropping system in Coastal and Barind area. Paper presented in National workshop of Multiple Cropping, held at BARc, Farmgate, Dhaka, on 23-24 April, 2008.

ASCE. 1990. Amrican Society of Civil Engineers. Agricultural salinity assessment and management. ASCE Manuals and Reports on Engineering Practice no 71, New York, N.Y. 10017, USA.

Anwar, J. 1989. Geology of Coastal area of Bangladesh and Recommendation for Resource Development and Management. Publication of CARDMA, Dhaka, p 36-66.

Arduino, E., E. Barberis, F. Carraro, and M. G. Forao. 1984. Estimating relative ages from iron-oxide/total iron ratios of soils in the western PO Valley, Italy. Geoderma. 33: 39-52.

Arduino, E., E. Barberis, F. A. Marsan and M. Franchini. 1986. Iron oxides and clay minerals within profiles as indicators of soil age in northern Italy. Geoderma. 37: 45-55.

Aramaki, K. 1996. Mineralogical composition of Main Bangladesh Soils. Graduation Thesis, Faculty of agriculture, Kyushu University. 38 pp. (in Japanese).

Bangladesh Mateorological Department (BMD). 2012. A statistical year book of Bangladesh. Ministry of Defence, Dhaka, Bangladesh.

BARC. 1991. Evaluation of physical parameters of various land development units in Bangladesh for land use planning. Report of the Evaluation Committee on the BARC Coordinated Research Project. pp27.

BARC, 1996. Workshop Proceedings on Climate Change and Global Agricultural Potential held on 28, October, 1996. Soils Publication No. 42. Bangladesh Agricultural Research Council. Dhaka, Bangladesh.

BARc, 1998. Land degradation situation in Bangladesh, December, 1998, BARC, Farmgate, Dhaka, Bangladesh.

BARC. 2012. Fertilizer Recommendation Guide. Bangladesh Agricultural Research Council. Farmgate, Dhaka.

Barua, D.K. 1991.The Coastline of Bangladesh- An Overview of Process and Forms. Proceedings of 7th Symposium on Coastal and Ocean Management, ASCE, Long Beach, CA, USA, 8-12 July 1991, pp 2285-2301.

Begum, A. 1996. A pedogenic study of some soils from the Monpura Island in Bangladesh. Master's thesis. University of Dhaka, Bangladesh.

Begum, A., M.S. Hussain, S.M. Ullah, and F. Ottner, 2004. Morphological and mineralogical features of some soils from the Manpura Island in Bangladesh. J. Asiat. Soc. Bangladesh, Sci. 30(1): 17-28

Black, C.A. 1965. Methods of Soil Analysis. Part 1 and 2. Am. Soc. Agron., Madison, Wisconsin.

Bloomfield. C. 1959. Discussion on Gleying. Newzealand Soil News. p. 39.

Blume, H. P., and U. Schwertmann. 1969. Genetic evaluation of the profile distribution of aluminium, iron and manganese oxides. Soil Sci Soc. Am. Proc. 33: 438-444.

Bonner, F. T. and C. W. Relston. 1968. Oxidation-reduction potential of saturated forest soils. Soil Sci. Soc. Amer. Proc. 32: 111-112.

Borchardt, G. A., F. D. Hole, and M. L. Jackson. 1968. Genesis of layer silicates in representative soils in a glacial landscape of south eastern Wisconsin. Soil Sci. Soc. Am. Proc. 32: 399-403.

Bouma, J. 1983. Hydrology and genesis of soils with aquic moisture regime. In: Pedogenesis and Soil Taxonomy (Wilding. L. P., Smeck, N. E. and all. G. F. eds). Elsevier, Amsterdam, p. 253-281.

Bower, C.A. and J.T. Hatcher. 1962. Characterization of salt affected soils with respect to sodium. Soil Sci. Vol. 93: 275-280.

Brady, N. C. 1994. The Nature and Properties of soils, 10th Edition. MacMillan Publishers, London.

Brammer, H. 1964. An outline of the Geology and Geomorphology of Bangladesh in relation to soil development. Bangladesh J. Soil Sci. 1: 1-23.

Brammer, H. 1971. Bangladesh: Soil resources. Technical Report 3. FAO, Rome. 211 p

Brammer, H. and R. Brinkman. 1977. Surface-water gley soils in Bangladesh: Environment, landforms and soil morphology. Geoderma. 17: 91-109.

Brammer, H. **1979.** Ploughpans and tillage problems in Bangladesh Soils. Technical note. Bangladesh Agri. Res. Council, Farmgate, Dhaka. 6p.

Brammer, H. 1996. The geography of the soils of Bangladesh. The University Press Limited. Dhaka. p. 241-260.

Brammer, H. 2012. The physical geography of Bangladesh. The University Press Limited. Dhaka. p. 3-195.

Brian, D. C. 1976. Titanium-rich soil clay. J. Soil Sci. 27: 68-70.

Brinkman, R. 1970. Ferrolysis : A hydromorphic soil forming process. Geoderma. 3: 199-206.

Brinkman, R. 1977. Surface-water gley soils in Bangladesh: Genesis. Geoderma. 17: 111-144.

Brooks, R.H., C.A. Bower and R.C. Reeve. 1956. The effect of various exchangeable cations upon the physical condition of soils. Soil Sci. Soc. Am. Prac. 20 : 325-327.

Buol, S. W., F. D. Hole and R.J. Cracker. 1973. Soil Genesis and classification. Iowa State University Press, Ames.

Buol, S. W., F. D. Hole and R. J. McCracken and R.J. Southard. 2001. Soil Genesis and classification.5th ed. Iowa State University Press, Ames, Iowa. pp. 527.

Burrows, W.C. and D. Kirkham. **1958.** Measurement of field capacity with neutron meter. Soil Sci. Soc. Amer. Proc.., 22.

Chapman, H.D. and P.E. Pratt. 1965. Methods of analysis for soils, plants and waters. Univ. of Calif., Div. of Agric. Sci. p. 309.

Chakrapani. **J. G. 2005**. Factors controlling variations in river sediment loads. Current Science, vol. 88, No. 4: 569-575.

Chatterjee. R. K. and R. C. Dalal. 1976. Mineralogy of Clay fraction of some profiles from Bihar and West Bengal. J. Indian Soc. Soil. Sci. 24: 153-262.

Chowdhury, S. A., A. Islam, R. Mandal, S. Hoque, and S. Rahman. 1992 (June). Forms of potassium in some soils of Bangladesh. Bangladesh J. Sci. Res. 10(1): 1-8.

Coleman, J.M. 1969. The Sediment Field of Major Rivers of the World. Water Resources Research, Vol. 4 No. 4, 1968, pp26-59.

CZPo, 2005. Coastal Zone Policy, Ministry of Water Resources, Government of the People's Republic of Bangladesh, Dhaka.

Daniel, R. B., J. F. Brasfield and F. F. Riecken. 1962. Distribution of sodium hydro sulfite extractable manganese in Iowa soil profiles. Soil Sci. Soc. Am. Proc. 26: 75-80.

Daniel, R. B., E. E. Gamble and L. A. Nelson 1971. Relations between soil morphology and water table levels on a dissected North Carolina coastal plain surface. Proc. Soil Sci. Soc. Amer. 35 : 781-784.

Daniels. R. B., E. E. Gamble, and S. W. Buol. 1973. Oxygen content in the ground water of some North Carolina Aquults and Udults. Field soil water regime. (Eds R. R. Bruce *et al*.) Soil Sci. Soc. Am. Special Publications series No. 5. Soil Sci. Soc. Am., Madison. Wisconsin. pp. 153-166.

Das, D. K., B. Das and G. C. Naskar. 1974. Water retention and storage characteristics of alluvial soils. J. Indian Soc. Soil Sci. 22: 379-382.

Datta, D.K. and V. Subramaniam. 1996. Texture and Mineralogy of Sediments from the Ganges- Brahamaputra-Meghna river system in the Bengal Basin, Bangladeshand their Environmental Implications. Environmental Geology, Vol. 30, No. 3, 1996, pp. 181-188.

Day, P. R. 1965. Particle formation and particle size analysis. In: Methods of soil analysis (eds. C.A. Black et. al.) American Society of Agronomy, Madison, Wisconsin, p. 545-567.

Deturck, P. and S. Somasiri. 1992. Rice soils of Sri Lanka with anthraquic features. Proceedings of the Eighth International Soil Correlation Meeting (VIII ISCOM): Characterization, Classification, and Utilization of Wet Soils.

Dewis, J and F. Fretas. 1970. Physical and chemical methods of soil and water analysis. Appendix 8. F.A.O. of the United Nations, Rome.

Diwarker, D. P. S and R. N. Singh. 1992. Tal land soils of Bihar.I: Characterization and Classification. J. Indian Soc. Soil Sci. 40: 496-504.

Diwakar, D. P. S. and R. N. Singh. 1992. Tal land soils of Bihar. III: Aggregation and water retention characteristics. J. Indian Soc. Soil Sci., 40: 667-673.

Dolut A. K., I. Chandran and A. K. Nayak. 1987. Comparative studies on different forms of aluminium using various extractions in relation to pedogenic processes in soil profile. J. Indian. Soc. Soil Sci. 35: 103-108.

Dudal, R. 1965. The problem on the genesis and classification of rice (Paddy) soils. Pages 187-192 in V. A. Kovda and E. V. Lobova, ed. Geography and classification of Asian soils. Nauka, Moscow.

Dudal, R., and F. R. Moormann. 1964. Major Soils of Southeast Asia. J. Trop. Geog.18: 54-80.

Dudal, R and D.L. Bramao. 1965. Dark clay soils of tropical and sub-tropical regions. FAO Agricultural development paper No. 83.

Eaqub, M. 1985. Recent findings of potassium effects on Sonatala silt loam soils of Bangladesh. Potassium in agricultural soils. Soil Science Society of Bangladesh and Bangladesh Agriculture Research Council (Proceeding of the Internatioal Symposium of soil). 223-235.

Edelman, C.H. and P.K.J. Vander Voorde. 1963. Important characteristics of alluvial soils in the tropics. Soil Sci. Soc. Am. 95: 258-263.

EGIS, 1998. Environmental and Social Impact Assesment of Khulna – Jessore Drainage Rehabiitation Project, Dhaka. Environment and GIS Project for Water Sector Planning.

Egashira, k. and M. Yasmin, 1990. Clay mineralogical composition of floodplain soils of Bangladesh in relation to physiographic units. Bull. Inst.Trop. Agr. 10: 106-126.

Egashira, k., M. Tyoryo and T. Watanabe. 1994. Clay mineralogical composition of paddy soils of Fukuoka prefecture: Chikugo- Sankan and Chikugo- heiya regions. Sci. Bull, Faculty of Agr. Kyushu Univ.m, 49(1-2): 23-39.. Bull. Inst.Trop. Agr. 10: 106-126.

Elahi, K.M. 1991. Riverbank Erosion, Flood Hazard and Population Displacement in Bangladesh: an Overview, in Elahi, K.M. Ahamed, K.S. and Mafizuddin, M (eds), *Riverbank Erosion, Flood Hazard and Population Displacement in Bangladesh*, Dhaka: Riverbank Erosion impact Study, Jahagirnagar University.

Evans, C. V. and D. P. Franzmeier. 1986. Saturation, aeration and colour patterns in a toposequence of soils in north-central Indiana. Soil Sci. Soc. Am. J. 50: 975-580.

Fanning, D.S. and V.Z. Keramidas. 1977. Micas. In : Dixon and S. B. Weed (Editors). Minerals in Soil Environments. P. 195-258. Soil Sci. Soc. Amer., Madison, Wisconsin.

Fanning, D.S., M.C. Rabenhorst, and M. L. Thompson. 1992. Micro-morphology of wet soils in relation to classification. Proceeding of the 8th Intl. Soil Correlation Meeting (VIII ISCOM): Ed. J. M. Kimble. USDA Soil Conservation Service, National Soil Survey Centre, Lincoin, NE. 106-122 pp.

FAO (Brammer, H). 1971. Soil Survey Project, Bangladesh Soil Resources. AGL: SF/ PAK 6, Tech. Rep. 3. FAO, Rome. 211 p.

FAO. 1977. Soil map of the world, Vol. vii (South Asia). Paris: UNESCO, 117pp.

FAO, 2006. Guidelines for soil description. Food and Agricultural Organization of the United Nations, Rome.50 p.

FAO-UNDP.1988. Land Resources Appraisal of Bangladesh for Agricultural Development. Report 2 and 3. Agroecological regions of Bangladesh. FAO, Rome.

Ferdous, S., M.S. Hussain and M.J. Uddin. 2005. Characterization of some hydromorphic soils from the Ganges delta in Bangladesh. J. Asiat. Soc. Bangladesh, Sci. 31(2): 37-48.

Firoze, A. 2003. The Southwest Coastal Region: problems and potentials. The Daily Star. Friday, July 25, 2003.

Gartels, R. M. and C. L. Christ. 1965. Solutions, minerals and equilibria. Harper and Row, New York.

George, M. Schafer and N. Holoway Chuk. 1958. Characteristics of medium and fine textured humic gley soils of Ohio.Soil. Sci. Soc. Amer. Proc. 22: 262.

Ghabru, S. K., R. J. S.Arnaud and A. R. Mermut. 1990. Association of DCB-Extractable iron with minerals in coarse soil clays. J. Soil Sci.49: 113-120.

Ghimire, G.P.S. and B.K. Uprety. 1990. Causes and Effects of Siltation on the Environment of Nepal. Environmentalist Spring , 1990, Vol. 10, Issue 1, pp 55-65.

Gotoh, S. and W. H. Patrick. 1974. Transformation of iron in waterlogged soils as influenced by redox potential and pH. Soil Sci. Soc. Amer. Proc. 38: 66-71.

Graham, E.R.1953. Soil mineralogy as an index to the trace element status of some Australian soils. Soil Sci. 75: 333-343.

Gupta, G. P. and V. K. Misra. 1970. A comparative study of the methods of estimation of CEC in soils of Gwalior district. Indian J. Agric. Chem. 3: 97-100.

Habibullah, A. K. M., D. J. Gt.eenland and H. Brammer. 1971. Clay mineralogy of some seasonally flooded soils of East Pakistan. J. Soil.Sci. 22: 179-190.

Hannan, M.A. 1995. Structure and related physical properties of some soils of Bangladesh. Unpublished M.Sc. Thesis, Dipt. of Soil Sci., Univ. of Dhaka, Bangladesh. 138-152 p.

Hassan, M. M and M. A. Razzak. 1981. A preliminary evaluation of the clay mineralogy of the Sundarban soils. Bano Bignan Patrika. 10: 1-6.

Hassan, M. K., A. S. M. Mohiuddin and M. J. Uddin. 2012. Characterization of some representative soils from the Ganges floodplain of Bangladesh. Dhaka Univ. J. Biol. Sci. 21(2): 201-205.

Hearly, W.B. 1959. Gley processes. Newzeland Soil News. P. 48.

Hossain, M.M. 1992. Total sediment load in the lower Ganges and Jamuna. J. Inst. Eng, Bangladesh. 20: 1-8.

Hossain, M.M., Z.H. Khan and M.S. Hussain. 2011. Characterization and classification of some intensively cultivated soils from the Ganges river floodplain of Bangladesh. Dhaka Univ. J. Biol. Sci. 20(1): 71-80.

Huizing, H.G.J. 1970. Exploratory Survey of Soil Miosture Relations in East Pakistan (Bangladesh) Soils. Soil Survey Project of Pakistan

Huizing, H. G. J. 1971. A reconnaissance study of the mineralogy of some seasonally flooded soils of East Pakistan. Geoderma. 6: 110-133.

Hussain, M.S. 1961. A pedogenic study of the soils of a portion of north Sylhet, East , Pakistan. M. Sc. Thesis, Dept. of Soil Science, Dhaka University. Dhaka.

Hussain, M. S. and L. D. Swindale. 1974. Physical and chemical properties of the Gray Hydromorphic soils of the Hawaiian islands. Soil Sci. Soc. Amer. Proc. 38: 935-941.

Hussain, M. S. and A. K. M. E. Islam. 1979. Titanium content in the soils and clays rom Bangladesh. Bangladesh. J. Soil Sci. 15: 173-182.

Hussain, M. S. and A. M. Chowdhury. 1980. Studies on some cracking clay soils from Bangladesh: *In.* Physical and physico-chemical properties. Bangladesh Jour. Soil Sci. 16: 1-13.

Hussain, M. S. and A. M. Chowdhury. 1981. Studies on the cracking clay soils from Bangladesh. *In*. Pedochemistry and genesis. Bangladesh Jour. Soil Sci. 17: 1-12.

Hussain, M.S., S. Rahman and M.A Mujib. 1982. Properties and genesis of some pedons from the Tippera surface. The Dhaka Univ. Stud. B. 30: 57-67.

Hussain, M. S. and S. Rahman. 1983. Physico-chemical characteristics of some coastal saline soils of Bangladesh. Bangladesh J. Soil Sci. 19: 21-30.

Hussain, M. S., K. Nahar., A. K. M. E. Islam and S. F. Elahi. 1989. A morphological and clay mineralogical study of some soils from Bhola district in Bangladesh. Dhaka Univ. Stud. (Part-E) 4: 93-104.

Hussain, M. S., S. Rahman, S. A. Ahad. A. S. M. Mohiuddin and A. R. Mazumder. 1992. Physical and chemical properties of four pedons from Bhola. Dhaka, Univ. J. Biol. Sci. 1(1): 95-102.

Hussain, M. S., A.S.M. Mahiuddin and A.R. Mazumder. 1992. Ion composition of exchangeable and soluble phases in some soils from the coastal areas of Bangladesh. J. Asiat. Soc. Bangladesh, Sci. 18 (1) : 1-9. 200p.

Hussain, M. S. 1992. Soil classification with special reference to the soils of Bangladesh. University of Dhaka. 200p.

Hussain, M. S., M. J. Uddin amd S. Ferdous. 2006. Morphology and mineralogy of some hydromorphic soils from the Ganges delta in Bangladesh. J. Asia. Soc. Bangladesh, Sci., 32(2): 257-268

Hussain, M.S., S. Rahman and M.A. Mujib. **2011.** Properties and genesis of some pedons from the Tippera surface. The Dhaka Univ.Stud.B. 30: 57-67.

Hussain, M.S. , M.J. Uddin and A.S.M. Mohiuddin. 2013. Assesment of soil quality in Bangladesh with organic carbon as the indicator property. Dhaka Univ. J. Biol. Sci. 22(2): pp. 163-174.

Hussain, M.S. , Z.H. Khan and M. Ibrahim.2014. Mineralogical composition of soils from Urir Char- a tiny offshore island of Bangladesh. J. Asiat. Soc. Bangladesh, Sci: 39 (1) pp 95-104.

Hussain, M.S. , Z.H. Khan and M.M. Hasan. 2014. Potassium depletion in agricultural soils of Bangladesh and its possible impacts on mineral alteration: some empirical considerations. J. Asiat. Soc. Bangladesh, Sci: 40 (1) pp 157-161.

Hutton. J. T. 1977. Titanium and zirconium minerals, pp. 673-688. In: Dixon *et al*. (ed.) Minerals in Soil Environments. Soil Sci. Soc. Amer. Madison. Wisconsin.

Iftekhar, U Ahmed, S. Akhter and Mainul Ahsan. 2004. Mineralogical characterization of clay fraction of some Ganges floodplain soils. Bangladesh J. Soil Sci. 30(1-2): 71-78.

Islam, A. K. M. E. and E. G. Lotse. 1986. Quantitative mineralogical analysis of some Bangladesh soils with X-ray, ion exchange and selective dissolution techniques. Clay Minerals. 21: 31-42.

Islam,M.R. (ed), 2004. Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh, The University Press Limited, Dhaka

Islam, A.B.M.S., M.J. Uddin, M.S. Hussain and A.S.M. Mohiuddin. 2008. Agricultural sustainability of some low land rice soils of the Chalan Beel area under lower Atrai basin of Bangladesh. J. Agrofor. Environ. 2(2):61-66.

Islam, A.B.M.S., Z.H. Khan, and A.R Mazumder. 2014b. Pedogenesis and Characterization of some soils from the Chalan beel of Bangladesh. J. Asiat. Soc. Bangladesh Sci., 40(2): 271-281.

Jackson, M. L., Y. Hseung, R.B. Corey, E. J. Evans and R. C. Vander Heuvel. 1952. Weathering of clay size minerals in soils and sediments. II. Chemical weathering of layer silicates. Soil Sci. Soc. Am. Proc. 16: 3-6.

Jackson, M. L. and G. D. Sherman. 1953. Chemical weathering of minerals in soils. adv. agron. 5: 221-318.

Jackson, M. L. 1964. Aluminum bonding in soils: A unifying principle in soil science. Soil Sci. Soc. Amer. Proc. 27: 1-10.

Jackson, M. L. 1964. Chemical composition of soils. pp. 71-141. In. F. E. Bear (ed). Chemistry of the Soil. Reinhold Publishing Corp., New York.

Jackson, M. L. 1965. Clay transformation in soil genesis during the Quaternary. Soil Sci. 99: 15-22.

Jackson, M. L. 1967. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd. New Delhi.

Jackson, M.L. 1975. Soil Chemical Analysis- Advanced course. Published by the author. Deptt. of Soils. University of Wisconsin, Madison. 991 p.

Jalal, A.C.K., H.N. Noor Faizul, B.Y. Kamaruzzaman, S Shahbuddin, M.Z. Alam, and Jaswir Irwandi. 2009. Studies on Physico- chemical characteristics and sediment environment along the coastal waters in Pulau Tuba, Langkawi, Malaysia. J. Aquatic Ecosystem Health & Management, 12(4): 350-357, 2009.

Jenny, H. 1941. Factors of Soil Formation, Mc Graw- Hill, New York.

Jenny, H. 1980. The soil resource. Springer-Verlag, New York.

Jha, S. N., L. K. Mishra, N.K. Jha, and S.N. Choudhary. 1984. Distribution of some micronutrients in calcareous soil as influenced by physiography and soil characteristics. J. Indian Soc. Soil. Sci. 32: 375-77.

Joffe, J.S. 1966. Pedology. Pedology Publications, New Branswick, New Jercy, 662p

Joffe, J. S. 1968. Pedology. Pedology publications, New Brunswick, New Jersey. pp. 662.

Johnson, L.T., P.R. Matelski and C. F. Engle. 1963. Clay mineral characterization of modalsoil profiles in several Pennsylvania countries. Am. Proc. 27: 568-572.

Joshua, W. D. and M. Rahman. 1983. Physical properties of soils in the Ganges River floodplain of Bangladesh. Strengthening of Soil Resource Development Institute. FAO/UNDP Project. BGD/81/023. Department of Soil Survey, Dhaka.

Kader, A.M., Abu Zofar Mohammad Moslehuddin, Ahmed Mostafa Kamal and Yuki Mori. 2015. Mineralogical composition of some selected paddy soils of Bangladesh. J. Fac. Agr. Kyushu Univ., Vol 60 (2) pp 463-470.

Kamaruzzaman, B.Y., M.S. Noor Azhar., H. Norhizam and K.Y.S.Willison. 2006. The temporal varation of organic carbon during the Pre-monson and Post-monsoon season in Pahang Coastal water, Malaysia. Sainas Malaysia 6(1), 53-61.

Kanno, I. 1962. A new classification system of rice soils in Japan. Page 617-624. Joint Mtg. Comm. IV. and V. Int. Soc. Soil Sci., New Zealand.

Karim, A. 1954. A mineralogical study of the colloidal fractions of some great soil groups with particular reference to illites. J. Soil Sci. 5 : 1-5.

Karim, A. and A. Islam. 1956. A study of ion -exchange properties of silt. Soil Sci. 82: 433-436.

Karim, A. and M. Hussain. 1963. Distribution of titania in some East Pakistan soils. J. Soil Sci. 6: 125-129.

Karim,Z., S.M. Saheed, A.B.M. Salauddin, M.K. Alam and A. Huq. 1982. Coastal saline soils and their management in Bangladesh. Soils Publication No. 8, BARC. Pp: 33.

Karim. Z. 1984. Formation of aluminium substituted goethite in seasonally waterlogged rice soils. Soil Sci. Soc. Amer. Jour. 48: 410-413

Karim,Z., Hussain, S.G and Ahmed, M. 1990. Salinity Problems and crop intensification in the coastal regions of Bangladesh. Soils Publication no. 8, BARC, p 33.

Karmanov, I. I. 1968. Soils of Burma, Part-1, Hydrophysical properties; Part-2. Peculiarities of cultivated soils. In: V. Kovda and E. V. Loboval (Editors), Geography and classification of the soils of Asia. Israel Program for Sci. Translation, Jerusalem, p. 213-236.

Kawaguchi, K and K Kyuma. **1969 a.** Lowland rice soils in Malaysia. Ntl. Sci. Ser. N- 5. Centre for south-east Asian Studies. Kyoto University. 154 p.

Kawaguchi, K and K Kyuma. 1969 b. Lowland rice soils in Thailand. Ntl. Sci. Ser. N-4. Centre for south-east Asian Studies. Kyoto University. 270 p.

Kawaguchi, K. and K. Kyuma. 1977. Paddy soils in tropical Asia. Monograph 10, Center for Southeast Asian studies, University of Hawaii Press, Hawaii. 258 p.

Khan, D. H. 1954. A pedogenic study of the soils of a high land arc escarping the Brahmaputra valley, East Pakistan (Bangladesh). M. Sc Thesis, Dept. of Soil Sci. Univ. of Dhaka, Dhaka, Bangladesh.

Khan, H.R., S. Rahaman, M.S. Hussain and T. Adachi. 1993. Morphology and characterization of an acid sulphate soils from mangrove floodplain area of Bangladesh. Soil Phys. Cond. Plant Growth, Jpn. 68: 25-36.

Khan, Z. H. 1995. A genetic study of some Benchmark soils of Bangladesh. M.Sc. Thesis, Dhaka University, Dhaka, Bangladesh.

Khan, Z. H., A. R. Mazumder, M. S. Hussain and S. M. Saheed. 1997. Chemical and mineralogical properties of some Benchmark soils in the floodplains of Bangladesh. Journal of the Indian Society of Soil Science 45 (2): 485-489.

Khan, Z. H. and F. Ottner. 2010. mineralogical composition of three soil series from the Meghna floodplain soils of Bangladesh and the soil management implications. Bangladesh J. Sci. Res. 23 (2): 1415-128.

Khan, Z. H., M. S. Hussain and F. Ottner. 2011. Bulk and clay mineralogical composition of some benchmark soils of Bangladesh and their implications in classification and management. Jour. Asiatic. Soc. Bangladesh, sci. 37: 23-34.

Khan, Z. H., M. S. Hussain and F. Ottner. 2012. Morphogenesis of three surface-water gley soils from the Meghna floodplain of Bangladesh. Dhaka Univ. J. Biol. Sci. 21(2): 17-27.

Khan, Z. H., M. S. Hussain and M.M. Hassan. 2013. Potassium availability in relation to mineralogy in some floodplain soils of Bangladesh. Dhaka Univ. J. Biol. Sci. 22(1): 79-83.

Kyuma, K. 1978. Soils and Rice. Mineral composition of Rice soils. The International Rice Research Institute, Los Banos, Leguna, Philippines. p 219-235

Kyuma, K. and K. Kawaguchi. 1966. Major soils of Southeast Asia and the classification of soils under rice cultivation. Southeast Asia Stud. 4 : 290-312.

Kyuma, K., M. Mitsuchi and F. R. Moorman. 1988. Man-induced soil wetness: The "anthraquic" soil moisture regime p. 138-146. Proceeding of the 9th International Soil Classification Workshop. Properties, Classification and Utilization of Andosols and Paddy Soils. Japan.

Landon, J. R. 1991. Booker Tropical Manual. Longman Scientific and Technical, Longman Group. U.K. Ltd.

Lavti, D. L., A. P. Gandhi, and K. V. Paliwal. 1969. Contribution of clay and organic matter in the cation exchange capacity of Rajsthan Soils. J. Indian Soc. Soil Sci. 17: 71-74.

Laves, D. 1978. Potassium transformation in soil. Arch. Acker-u. Pflanzenbau u. Bodenk. 22(8): 521-528.

Mackintosh, E. E. and J. Van Der Hust. 1978. Soil drainage classes and water table relations in medium and coarse textured soils in Southern Ontario. Can. J. Soil Sci. 58: 287-301.

Mall, J. and B. B. Mishra. 1994. Mineralogy of fine sand fractions of some non-calcareous soils of north Bihar. J. Ind. Soc. Soil Sci. 42: 640-644.

Manalo, E. B. 1975. Agroclimatic Survey of Bangladesh. Vol-1. International Rice Research Institute. Los Bons, Philippines. 361 p.

Mandal, L. N. 1960. Transformation of iron and manganese in water logged rice soils. Soil Sci. 91: 121-126.

Martineli, A.L., J.E. Richey and A.H. Devol. 1992. Chemical and Mineralogical composition of Amazon River floodplain sediments, Brazil. Applied Geochemistry, Vol. 8. pp 391-402.

Matin, M. A. **1972.** Genesis and pedochemical properties of some Vertisols in Bangladesh. M.Sc. Thesis. Dept. of Soil Science. Univ. of Dhaka, Dhaka. p.5.

Mazumder, A. R. **1976**. A study on some deep water rice soils of Bangladesh. M.Sc. thesis. Dept. of Soil Science, University of Dhaka, Dhaka.

Mazumder, A. R. 1996. A pedogenic study of soils from the Brahmaputra floodplain. Ph. D. Dissertation, University of Dhaka, Dhaka. 262 p.

Mazumder, A. R., Z. H. Khan and M. S. Hussain. 2010. Morphogenesis and characterization of some representative soil profiles from the old Brahmaputra floodplain in Bangladesh in relation to their agricultural use potential. Bangladesh J. Sci. Res. **23 (1)**: 27-38.

Mc. Keague, J. A. 1965. A laboratory study of gleying. Can. Jour. Soil Sci. 45: 199-202.

Mc. keague, J. A. and J. H. Day. 1966. Dithionite and Oxalate extractable Fe and Al as aids in differentiating various classes of soils. Can. J. Soil Sci. 46: 13-22.

Meade, R.H. and R.S. Parker. 1984. Sediment in rivers of the United States. In national Water Summary, US Geol Surv. Water Suppl. Pap., Vol. 2275, pp. 49-60.

Mehra, O.P. and M.L.Jackson. 1960. Iron oxide removal from soils and clays by dithionate –citrate system buffered with sodium bicarbonate. Proc. 7th Natl. Conf. on Clays and Clay Minerals. Permangon press. New York. p. 317-327.

Mengel, K. and E. A. Kirkby. 1982. Principles of Plant Nutrition. International Potash Institute. Bern, Switzerland. 655 p.

Milliman, J.D. and R.H. Meade. 1983. World-wide Delivery of River sediment to the Oceans. J. of Geol., 91, pp 1-21

Mirabrlla, A and S. Carnicelli. 1992. Iron oxide mineralogy in red and brown soils developed on calcarious rocks in central Italy. Geoderma, 55: 95-109.

Mitsuchi, M. 1974. Pedogenic charactelistics of paddy soils and ther significance in soil classification (Japanese, English Summary). Bull. Natl. Inst. Agric. Sci. B 29: 29-115.

Morghan, J.P. and W.G. McIntire. 1959. Quaternary geology of the Bengal basin, east Pakistan and India. Geol. Soc. Am. Bull. 70: 319-342.

Mokma, D.L.and D.L. Cremens. 1991. Relationships of saturation and B horizon color patterns in sols of three hydrosequences in South-Central Mishigan, USA. Soil use and management. Vol. 7, No. 1.

Moslehuddin, M.Z.A and Kazuhiko Egashira. **1996.** Mineralogical Composition of some Important Paddy Soils of Bangladesh. Bull. Inst. Trop. Agri. Kyushu Univ, Vol. 19 pp 33-54.

Moslehuddin, M.Z.A and Kazuhiko Egashira. **1997.** Characterization of Smectites found in Ganges Floodplain soil of Bangladesh. Clay Science, Vol. 10, pp 151-162.

Moslehuddin, M.Z.A., S.M. Saheed, and Kazuhiko Egashira. **1998a.** Disappearing Trend of Smectite in Ganges Floodplain soil of Bangladesh. Clay Science, Vol. 10, pp 349-362

Moslehuddin, M.Z.A., S.M. Saheed, and Kazuhiko Egashira.**1998b.** Mineralogical Approach to Alternation of Different River Sediments in Meghna Floodplain Soils of Bangladesh. Clay Science, 10 pp 375-384.

Moslehuddin, M.Z.A., M. Sultan Hossain, S.M. Saheed, and Kazuhiko Egashira. **1999.** Clay Mineral Distribution in Correspondence with Agro-ecological Region of Bangladesh. Clay Science, 11 pp 83-94.

Mohr. E. G. J., F. A. van Baren, and J. van Schuylenborgh. 1972. Tropical soils. A comprehensive study of their genesis. 3rd revised and enlarged ed. Mouto ichtiar Baru-van Hoeve, The Hague-Paris-Djakarta. 481 p.

Moorman, F. R. and N. van Breeman. 1978. Rice: soil, water, and land. International Rice Research Institute, Los Banos, Philippines. 185 p.

Moorman, F.R. 1978. Morphology and Classification of soils on which rice is grown. IRRI. Los Banos, Laguna, Philipines. p 255-272.

Moorman, F. R. 1980. The classification of "Paddy soils" as related to Soil Taxonomy. In: Proc. of symp. on paddy Soil. Ed. by Institute of Soil Science, Academia Sinica, Nanjing, The People's Republic of China.

Moslehuddin, A. Z. M. and K. Egashira.1996. Mineralogical composition of some important paddy soils of Bangladesh. Commun. Soil Sci. and Plant Anal., 30(3-4): 329-344.

MoWR, 2006. Coastal Development Strategy, Dhaka, Ministry of Water Resources, Government of the People’s republic of Bangladesh.

Murthy, R. S., B. S. Mathur, and Raychaudhury. 1962. Genesis and classification of some alluvial soils in the Ganges river plain of central Uttar Pradesh. Proc. Natl. Inst. Sci. India, pt. A 28: 549-67.

Muzib, M. A.; M. S. Hussain and S. Rahman. 1969. Distribution of free iron and manganese oxides in the soils of the Tippera surface, East Pakistan. Pak. J. Soil. Sci. Vol. 5, No. 2.

NAP, 2006. National Action Programme (NAP) for combating desertification. DFepertment of Environment, Ministry of Environment and Forest, Govt. of the People’s Republic of Bangladesh. August, 2015.

Nahar, k. 1987. A study of some soils from the coastal belt of Bangladesh. M.Sc. thesis, Dept. of Soil Science, University of Dhaka, Bangladesh.

Nishat,A.1989. Riview of present activities and state of art of the coastal area of Bangladesh. In National workshop on coastal area resource development and management(Part-II).p. 23-35.

Nizam Uddin, A. S. M., M. S. Hussain, M. J. Uddin, A. S. M. Mohiuddin and A. R. Mazumder, 2009a. Characterization of some wetland soils of the Surman-Kushiyara floodplain of Bangladesh. Dhaka Univ. J. Biol. Sci. 18(2): 99-110.

Nizam Uddin, A. S. M., M. S. Hussain, M. J. Uddin, A.S.M. Mohiuddin and A. R. Mazumder, 2009b**.** Morphology and clay mineralogy of soils of the Surman-Kushiyara floodplain of Bangladesh. Dhaka Univ. J. Biol. Sci. 18(1): 47-57

Okusami, T. A. and R. H. Rust. 1992. Occurrence, characteristics, and classification of some hydromorphic soils from south Nigeria. In: J.M. Kimble (1992). Proceedings of the 8th intl. Soil correlation meeting (VIII ISCOM); characterization, classification and utilization of wet soils, USDA Soil conservation service,-National Soil Survey Center, Lincoln, NE; p. 185-198.

Orlov, D. S. 1992. Manganese and iron in soil. In: Soil Chemistry. Oxford and IBM Publishing Co. Pvt. Ltd. New Delhi.

Otowa, M. 1973. Morphological changes of soils by paddy rice cultivation. Pages 381-383 in E. Schlichting and U. Schwertman. Ed. Oseudo- gly and gley. Verlog Chemic Gmb, Weinheim.

Page, A.L.1982. Methods of Soil Analysis. Part 2. 2nd. ed. American Society of Agronomy.Inc. Soil Science Society of America, Madison, Wisconsin, USA.

Panaullah, G.M. 1984. Characteristics of six coastal saline soils of the Philipines in relation to the growth and mineral nutrition of rice. Ph.D. Thesis, Los Banos. University of Philippines.

Paramananthan, S. 1978. Rice soils of Malaysia. Soils and Rice. pp. 87-98. International Rice Research Institute. Los Banos, Leguna, Philippines.

Pathak, S. R. and N. K. Pata1. 1980. Study of some physico-chemical characteristics of salt affected soils of Kaiza district, Gujrat State. J. Indian Soc. Soil. Sci. 28: 31-37.

Pickering, E. W. and P. L. M. Veneman. 1984. Moisture regimes and morphological characteristics in a hydro sequence in central Massachusetts. Soil Sci. Soc. Am. J. 48: 113-118.

Piper, C.S. 1966. Soil and Plant Analysis. The University of Adelide press. Adelide, Australia.

Ponnamperuma, F. N. **1972.** The chemistry of submerged soils. Adv. Agron. 24: 29-96.

Ponnamperuma, F.N. 1985. Chemical kinetics of wetland rice soil relative to soil fertility. In: wetland soils: characterization, classification and utilization. International Rice Research Institute, Los Banos, Laguna, Philippines. p. 71-89.

Quasem, A. 1956. A study of the soils of the Briand tract. East Pakistan. M.Sc. Thesis, Department of Soil Science, Univ. of Dhaka.

Rahman, A.A. 1989. Bangladesh coastal environment and management. Paper presented at the National weorkshop on Bangladeshcoastal area Resource Development and Management Organized by CARDMA, Dhaka, Vol. 11. 139-153 pp.

Rahman, S. 1990. Study on the genesis and reclamation of some acid sulphate soils of Bangladesh. Ph.D. Thesis, University of Dhaka, Dhaka.

Rahman, M. H., T. H. Khan and S. Hoque. 1992. Structural attributes of soils under rice based cropping pattern in the Ganges Kobadak Project area of Bangladesh. J Bangladesh J. Soil Sci. 23: 79-91.

Rahman, M.S. 2001. Chemical and mineralogical composition of major river sediments of Bangladesh and their impact on genesis and nutrient status of soils. Ph. D. Dissertation, University of Dhaka, Dhaka. 211 p.

Rahman, H.M., Abu Zofar Md. Moslehuddin, Dilip Kumar Saha, Iftekhar Uddin Ahmed and Kazuhiko Egashira. **2005**. Mineralogy of Soils from Different Agro-ecological Regions of Bangladesh: Region 12- Low Ganges River floodplain. Clay Science, 11 pp 321 - 326.

Rahman, S.M., M.S. Hussain, S.M.A. Faiz and M.J. Uddin. 2009. Nature and Properties of Water and Sediments of the Ganges and the Brahmaputra Rivers in Bangladesh. J. Asiat. Soc. Bangladesh. Sci., 35(2): 113-122.

Reza , S.M., **Abu Zofar Mohammad Moslehuddin, Md. Rafiqul Islam, Shaila sultana Alam and Yuki Mori. 2013**. Mineralogical Approach to Parent Material Characterization of Soils from Agro-ecological Region 6, Lower Purnabhaba Floodplain, in Bangladesh. J.Fac. Agr. Kyushu Univ., 58 (2) pp 433-437.

Robinson, W.O. and R.S. Holmes. 1924. The inorganic composition of some important American soils. U.S. Dept. Agr. Bull. 1311.

Saheed, S. M. and M. S. Hussain. 1992. Wetland soils of Bangladesh. (J.M. Kimble ed.); ; Characterization, Classification and Utilization of Wet soils. USDA, Soil conservation service, USA. National soil survey centre. Lincoln, NE. p. 220-229.

Saheed, S. M. and M. S. Hussain. 1996. Pedology of the rice soils of Bangladesh In M. rahman et al (Ed.). Biological Nitrogen Fixation Associated with Rice Production. Kluwer Academic Publishers. London p. 71-79.

Salauddin, M and M. Ashikuzzaman. 2012. Nature and extent of population displacement due to climate change triggered disasters in south-western coastal region of Bangladesh. International J. of Climaic Change Strategic and Management, Vol. 4 No. 1, 2012, pp. 54-65.

Santos. M. C. D., R. J. Arnaud and D. W. Anderson. 1986. Quantitative evaluation of pedogenic changes in Boralfs (Gray Luvisols) of east central Saskatchewan: Soil Sci. Soc. Am. J. 50: 1013-1019.

Sarwar, M.G.M. 2005. Impacts of sea level rise on coastal zone of Bangladesh. Master's thesis of Environmental programme. Lunde University, Sweden.

Schulze, D.G. 1989. An introduction on soil mineralogy. *In*: Minerals in soil Environments. J.B. Dixon and S.B. weed (Eds.). Soil Sci. Soc. Amer., Madison, Wisconsin. pp. 1-34

Schwertmann, U. and R. M. Taylor. 1977. Iron oxides. In: J. B. Dixon (ed). Minerals in soil environment. Soil Sci. Soc. Am., Madison, Wis., pp. 145-180.

Sharma, P. K and G. Dev. 1985. Physiography-soil relationship in a transect in north-east Punjab. J. Indian Soc. Soil Sci. 33: 604-612.

Siddiqui, M.U.H. 1989. Land Erosion and Accretion in the Coastal Area. Proceedings of the national Workshop on Bangladesh Coastal Area Resource Development and Management (Part II). Dhaka, 3-4 October, 1989. P. 139-150.

Sidhu, P.S., Raykuman and B.D. Sharma. 1994. Characteristics and classification of Entisols in different soil moisture regimes of the Panjab. J. Ind. Soc. Soil. Sci., 42: 633-640.

Singh, V. N. and B. B. Mishra. 1994. Sodiumization of some Alfisols in toposequence occuring in Indo-Gangetic plain of Bihar. J. Ind. Soc. Soil Sci. 42(4): 629-633.

Sinha, S. D., P. P. Tha and M. P. Singh. 1965. Studies on heavy textured soils of south Bihar developed on alluvial sediments. J. Indian Soc. Soil. Sci. 13: 85-94.

Smith, H and L. D. Wilding. 1972. Some article. Soil Sci. Soc. Am. Proc. 36: 808

Soil Survey Staff. 1975. Soil Taxonomy : A basic system of soil classification for making and interpreting soil surveys. US Department of Agriculture Handbook No. 436, US Government Printing Office, Washington, D. C.

Soil Survey Staff. 1994. Keys to Soil Taxonomy. 6th edi. Soil Conservation Service, USDA. Washington , D. C.

Soil Survey Staff. **1998**. Soil Survey Manual. USDA Handbook No.18. US Govt. Printing Office. Washington, D.C

Soil Survey Staff. **2003**. Keys to Soil Taxonomy. 9th Edi, United States Department of agriculture, Washington, D.C.

Soil Survey Staff. **2014**. Keys to Soil Taxonomy.12th Edi, Natural Resource Conservation Service, United States Department of agriculture, Washington, D.C.360 p.

Somani, L.L. 1991. Crop production with saline water. Agro Botanical Puublishers, Vyas Nagar, India.

SRDI Staff. (**1965-1986).** Reconnaissance Soil Survey Report of different Districts of Bangladesh. Soil Resource Development Institute (SRDI), Dhaka.

SRDI Staff. 1967. Reconnaissance soil survey of Barisal district of Bangladesh. Soil Resource Development Institute (SRDI), Farmgate, Dhaka.

SRDI Staff. 2001. Soils Resources in Bangladesh: Assessment and Utilization. Soil Resource Development Institute (SRDI), Ministry of Agriculture, Farmgate, Dhaka, Bangladesh, p 105.

SRDI Staff. 2010. Saline Soils of Bangladesh. Soil Resource Development Institute (SRDI), Ministry of Agriculture, Farmgate, Dhaka, Bangladesh.

Stoops, G and H. Eswaran, 1985. Morphological characteristics of wet soils: *In*: Wetland Soils Characterization, Classification and Utilization. International Rice Research Institute (IRRI), Los Banos, Philipines. Pp. 177-189.

Strickling, E. 1956. Relationship of porosity to water stability. Soil Sci. 80: 331-335.

Szogi, A. A. and W. H. Hudnall. 1992. Classification of soils in Lausiana according to “Endoaquic" and "epiaquic" concepts. Proc. 8th Intl. Soil Coffel. Meeting. Baton Rouge. p. 271-278.

Tanaka, A. and S.Yoshida. **1970**. Nutritional disorders of Rice plant in Asia. Int. Rice Res. Inst. Tech. Bull. 10 : 51.

Taraqqi, A.K. and M.S. Hussain. 2007. Char Kukri Mukri: A pedological-edaphological study. Nuclear. Sci. Application. 18: 60-67.

Thawale, P. R, D. B. Matte, K. K. Thakare, V. S. Bhoyar and D. R. Kene. 1991. Morphological feature and physico-chemical properties of soils of agricultural school farm, Sawangi District, Nagpur. J. Soils and Crops. 1(2): 102-106.

Thorp. J. and G. D. Smith. 1949. Higher categories of soil classification-order, Suborder and Great Soil Groups. Soil Sci. 67: 117.

Torrent, J. and W. D. Nettleton. 1979. A simple textural index for assessing chemical weathering in soils. Soil Sci. Soc. Am. J. 43: 373-377.

Uhera, G., M.S. Nishina and G.y. Tsuji. 1979. The composition of Mckong River silt and its possible role as a source of plant nutrient in Delta. The department of Agronomy and Soil Science. College of tropical agriculture, University of Hawai, Honlulu, USA.

Umitsy, M.1993. Late Quaternary sedimentary environments and landforms in the Ganges delta. Sediment Geol. 83: 177-186.

UN-ESCAP. 1988. Coastal environment management plan of Bangladesh. ESCAP office, Dhaka.

USDA. 1951. Soil Survey Manual, Hand book, 18. 503 p.

USDA. 1975. Soil Taxonomy. Soil Survey Staff. Soil Conservation Service. Agricultural Handbook No. 436.

USSL Staff, 1954. Diagnosis and Improvement of saline and alkali soils. USDA Handbook no. 60, pp. 147.

Van Breemen, N. **1976.** Genesis and Solution Chemistry of acid sulphate soils in Thailand. Centre for agricultural publishing and documentation, Wageningen. The Netharlands.

Van Mensvoort, M. E., R. S. Lantin, R. Brinkman and N. Van Breemen. 1985. Toxicities of wetland soils. In : Wetland Soils. Characterization, Classification and Utilization. International Rice Research Institute. Los Banos, Leguna, Philippines.

Velayutham, M. and D. Raj. 1977. Available water capacity and its relationship with some soil factors. J. Indian Soc. Soil Sci. 25: 439-441.

Walia, C. S. and G. S. Chamuah. 1992. Flood affected soils of Brahmaputra valley and their suitability for land use planning. J. Indian Soc. Soil Sci. 40: 335-340.

Walkley ,A and I.A. Black. 1934. An examination of the Degtijareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37 : 29-38.

White, J. L. 1985. Clay mineralogy of some soils of Bangladesh. Consultant's Report. BARC, Dhaka, Bangladesh. 211p

Wiklander, l. 1965. Cation and anion exchange phenomena. In: F.E. Bear (ed). Chemistry of the Soil. Reinold Publishing Corporation, New York. P. 163-205.

Wilding, L.P., N. E. Smeck and L.R. Drees. 1977. Silica in soils. : Quartz, Cristobalite, Tridymite and opal. In. J.B. Dixon and S.B. Weed (Editors). Minerals in Soil Environments. Soil Sci. Soc. Am. Madison, Wisconsin, USA. P. 471-552.

World Bank. 2001. Bangladesh: Climate Change and Sustainable Development, South Asia Rural Development Team, World Bank Office, Dhaka.

World Reference Base (WRB). 2015. World Reference Base for Soil Resources. Food and Agriculture Organization of the United Nations. Viale delle Terme di Caracalla, 00100 Rome, Italy.

Xing, B. and M.J. Dudas. 1992. Pedogenic properties of white clay soils of the three river plain, Heilongjiang Province, People's Republic of China. Geoderma. 54 : 187-221.

Zobeck, T. M. **and A. Ritchie. 1984.** Analysis of long-term water table depth records from a hydrosequence of soils in central Ohio. Soil Sci. Soc. Am. J. 48: 119-135.

Zijevelt, N.F.W. 1980. Soil correlation tables for Bangladesh, FAO- UNDP Soil Survey Interpretation Project, Soil Resource Development Institute, Dhaka, 64 p.

CHAPTER-9

APPENDICES

APPENDIX – 1

Sediment load in Bishkhali river

Bishkhali river					
Season	**Month**	**Location 1** (Kg/m^2/month)	**Location 2** (Kg/m^2/month)	**Location 3** (Kg/m^2/month)	**Mean** (Kg/m^2/month)
Wet Season	May,2013	3.5	3.8	4.0	**3.8**
	June,2013	3.9	3.7	3.1	**3.4**
	July,2013	2.4	2.6	2.8	**2.6**
	Aug,2013	3.0	0.5	3.5	**2.3**
	Sep,2013	5.3	5.1	5.7	**5.4**
	Oct,2013	5.8	6.8	7.7	**6.7**
Mean		**4.0**	**3.8**	**4.5**	**4.0**
Dry	Nov,2013	7.3	7.8	9.2	**8.1**
	Dec,2013	7.1	8.2	8.8	**8.0**
	Jan,2014	6.9	6.7	7.3	**7.0**
	Feb,2014	8.3	8.1	9.5	**8.6**
	Mar,2014	8.5	8.6	8.0	**8.7**
	April,2014	8.5	8.4	8.6	**8.5**
Mean		**7.8**	**8.0**	**8.6**	**8.2**
Wet Season	May,2014	4.2	4.5	4.7	**4.4**
	June,2014	4.2	4.9	4.3	**4.5**
	July,2014	2.4	2.4	2.0	**2.3**
	Aug,2014	2.7	3.5	3.7	**3.3**
	Sep,2014	5.0	5.5	6.1	**5.5**
	Oct,2014	6.2	5.9	6.9	**6.3**
Mean		**4.1**	**4.5**	**4.6**	**4.4**
Dry season	Nov,2014	6.9	6.8	6.5	**6.8**
	Dec,2014	6.3	7.1	6.9	**6.8**
	Jan,2015	8.9	8.7	8.4	**8.7**
	Feb,2015	8.2	7.5	9.2	**8.3**
	Mar,2015	9.7	12.3	13.1	**11.7**
	April,2015	4.2	4.5	4.7	**4.4**
Mean		**7.4**	**7.8**	**8.1**	**7.8**
Wet Season	May-2015	3.9	4.2	3.4	**3.8**
	June,2015	4.6	3.9	4.2	**4.2**
	July,2015	5.9	5.5	5.2	**5.5**
	Aug,2015	5.7	5.5	6.7	**6.0**
	Sep,2015	5.0	5.8	5.5	**5.4**
	Oct,2015	6.5	7.1	6.9	**6.8**
Mean		**5.3**	**5.3**	**5.3**	**5.3**
Dry season	Nov,2015	9.6	9.8	11.7	**7.2**
	Dec,2015	10.5	12.1	12.7	**11.8**
	Jan,2016	12.3	12.9	12.6	**12.6**
	Feb,2016	13.5	13.8	14.2	**13.8**
	Mar,2016	14.3	15.4	14.5	**14.7**
	Apr, 2016	12.9	13.5	14.7	**13.7**
Mean		**12.2**	**12.9**	**13.4**	**12.3**

APPENDIX – 2

Sediment load in Arial Khan River

Arial khan river					
Season	**Month**	**Location 1** (Kg/m^2/month)	**Location 2** (Kg/m^2/month)	**Location3** (Kg/m^2/month)	**Mean** (Kg/m^2/month)
Wet Season	May,2013	14.3	14.6	14.8	**14.6**
	June,2013	10.1	12.5	11.8	**11.5**
	July-2013	9.8	9.9	10.7	**10.1**
	Aug,2013	9.2	9.9	9.7	**9.6**
	Sep,2013	8.6	8.8	8.6	**8.7**
	Oct,2013	9.7	8.7	8.1	**8.8**
Mean		**10.3**	**10.7**	**10.6**	**10.6**
Dry season	Nov,2013	3.4	3.9	3.5	**3.6**
	Dec,2013	3	3.5	3.8	**3.4**
	Jan,2014	3.6	3.9	4.5	**4.0**
	Feb,2014	4.6	4.5	4.9	**4.7**
	Mar,2014	4.1	4.2	5.1	**4.5**
	April,2014	3.2	3.4	3.7	**3.4**
Mean		**3.7**	**3.9**	**4.3**	**3.9**
Wet Season	May,2014	11.5	12.5	13.8	**12.6**
	June,2014	14.5	12.8	13.4	**13.6**
	July,2014	14.9	15.4	13.8	**14.7**
	Aug,2014	17.2	15.8	16.2	**16.4**
	Sep,2014	14.7	14.6	14.8	**14.7**
	Oct,2014	15.5	15.8	15.1	**15.5**
Mean		**14.7**	**14.5**	**14.5**	**14.6**
Dry season	Nov,2014	2.9	3.1	3.7	**3.2**
	Dec,2014	2.2	2.9	3.3	**2.8**
	Jan,2015	2.8	3.5	3.8	**3.4**
	Feb,2015	2.5	2.9	3.5	**3.0**
	Mar,2015	3	3.6	3.6	**3.4**
	April,2015	3.5	4	4.3	**3.9**
Mean		**2.8**	**3.3**	**3.7**	**3.3**
Wet Season	May-15	10.9	12.1	12.8	**11.9**
	June,2015	10.4	10.8	12.7	**11.3**
	July,2015	14.9	14.6	13.5	**14.3**
	Aug,2015	16.4	15.9	15.4	**15.9**
	Sep,2015	15.6	15.9	15.7	**15.7**
	Oct,2015	14.4	14.8	14.6	**14.6**
Mean		**13.8**	**14.0**	**14.1**	**14.0**
Dry season	Nov,2015	5.5	5.4	5.8	**5.6**
	Dec,2015	5.7	5.5	5.4	**5.5**
	Jan,2016	5.8	5.3	5.9	**5.7**
	Feb,2016	5.4	5.2	4.9	**5.2**
	March,2016	4.9	4.4	4.1	**4.5**
	April,2016	4.2	3.3	4.6	**4.0**
Mean		**5.3**	**4.9**	**5.1**	**5.1**

APPENDIX – 3

Results of physical properties of Bishkhali river sediment

Location	Season	Month	Loss on ignition (%)	Color (air dry)	Particle density (g/cm^3)
1	**Wet Season**	May,2013	5.7	5 Y 5/2	2.57
		June,2013	5.8	5 Y 5/1	2.62
		July-2013	4.6	5 Y 5/2	2.61
		Aug,2013	3.3	5 Y 5/1	2.63
		Sep,2013	5.6	5 Y 5/1	2.62
		Oct,2013	5.2	5 Y 5/1	2.61
		Mean	**5.0**		**2.61**
	Dry season	Nov,2013	5.5	5Y 5/1	2.64
		Dec,2013	5.4	5 Y 5/1	2.64
		Jan,2014	4.9	5 Y 5/1	2.62
		Feb,2014	4.9	5 Y 5/1	2.64
		Mar,2014	5.0	5 Y 5/1	2.58
		April,2014	4.6	5 Y 5/2	2.61
		Mean	**5.1**		**2.58**
2	**Wet Season**	May,2014	6.4	5Y 5/1	2.62
		June,2014	6.5	5 Y 5/1	2.63
		July,2014	6.1	5 Y 5/1	2.65
		Aug,2014	5.5	5 Y 5/1	2.65
		Sep,2014	5.4	5 Y 5/1	2.66
		Oct,2014	5.6	5 Y 5/2	2.56
		Mean	**6.0**		**2.63**
	Dry season	Nov,2014	5.8	5Y 5/1	2.61
		Dec,2014	5.7	5 Y 5/1	2.64
		Jan,2015	5.5	5 Y 5/1	2.63
		Feb,2015	6.1	5 Y 5/1	2.65
		Mar,2015	6.3	5 Y 5/1	2.64
		April,2015	6.4	5 Y 5/2	2.62
		Mean	**6.0**		**2.63**
3	**Wet Season**	May-15	6.8	5Y 5/1	2.63
		June,2015	6.7	5 Y 5/1	2.65
		July,2015	5.9	5 Y 5/1	2.61
		Aug,2015	5.7	5 Y 5/1	2.59
		Sep,2015	6.1	5 Y 5/1	2.6
		Oct,2015	7.1	5 Y 5/2	2.62
		Mean	**6.4**		**2.62**
	Dry season	Nov,2015	6.9	5Y 5/1	2.66
		Dec,2015	5.8	5 Y 5/1	2.65
		Jan,2016	6.5	5 Y 5/1	2.64
		Feb,2016	6.2	5 Y 5/1	2.79
		Mar,2016	6.7	5 Y 5/1	2.82
		April,2016	6.8	5 Y 5/2	2.74
		Mean	**6.5**		**2.72**
	Grand mean		**5.8**		**2.63**

APPENDIX – 4

Results of physical properties of Arial Khan river sediment

Location	Season	Month	Loss on ignition (%)	Color (air dry)	Particle density (g/cm^3)
1	**Wet Season**	May,2013	3.8	5Y 5/1	2.74
		June,2013	7.1	5 Y 5/1	2.75
		Jul-13	4.6	5 Y 5/1	2.75
		Aug,2013	4.5	5 Y 5/1	2.76
		Sep,2013	4.4	5 Y 5/1	2.73
		Oct,2013	5.2	5 Y 5/2	2.65
		Mean	**4.9**		**2.73**
	Dry season	Nov,2013	5.1	5Y 5/1	2.69
		Dec,2013	6.3	5 Y 5/1	2.68
		Jan,2014	5.1	5 Y 5/1	2.66
		Feb,2014	4.2	5 Y 5/1	2.65
		Mar,2014	5.5	5 Y 5/1	2.67
		April,2014	5.9	5 Y 5/2	2.62
		Mean	**5.4**		**2.66**
2	**Wet Season**	May,2014	5.6	5Y 5/1	2.65
		June,2014	5.4	5 Y 5/1	2.63
		July,2014	5.7	5 Y 5/1	2.64
		Aug,2014	5.1	5 Y 5/1	2.68
		Sep,2014	5.6	5 Y 5/1	2.74
		Oct,2014	7	5 Y 5/2	2.72
		Mean	**5.7**		**2.68**
	Dry season	Nov,2014	4.9	5Y 5/1	2.69
		Dec,2014	5.2	5 Y 5/1	2.68
		Jan,2015	5.8	5 Y 5/1	2.64
		Feb,2015	4.6	5 Y 5/1	2.65
		Mar,2015	6.7	5 Y 5/1	2.66
		April,2015	7.5	5 Y 5/2	2.63
		Mean	**5.8**		**2.66**
3	**Wet Season**	May-15	6.8	5Y 5/1	2.65
		June,2015	6.7	5 Y 5/1	2.66
		July,2015	5.8	5 Y 5/1	2.64
		Aug,2015	5.9	5 Y 5/1	2.68
		Sep,2015	6.4	5 Y 5/1	2.69
		Oct,2015	5.1	5 Y 5/2	2.68
		Mean	**6.1**		**2.67**
	Dry season	Nov,2015	5.4	5Y 5/1	2.64
		Dec,2015	5.8	5 Y 5/1	2.65
		Jan,2016	5.7	5 Y 5/1	2.66
		Feb,2016	5.6	5 Y 5/1	2.68
		Mar,2016	6.5	5 Y 5/1	2.68
		April,2016	6.7	5 Y 5/2	2.66
		Mean	**6.0**		**2.66**
	Grand Mean		**5.6**		**2.68**

APPENDIX – 5

Results of chemical properties of Bishkhali river sediment

Location	Season	Month	pH (H_2O)	pH (KCl)	∆pH	EC* (dS/m)	Free lime (%)	Organic carbon %	Total P
1	Wet Season	May,2013	7.7	7.4	-0.3	0.127	5.4	0.56	0.08
		June,2013	7.7	7.5	-0.2	0.154	5.8	0.55	0.08
		Jul-13	7.9	7.5	-0.4	0.169	5.2	0.51	0.08
		Aug,2013	7.8	7.7	-0.1	0.155	4.9	0.54	0.08
		Sep,2013	7.8	7.7	-0.1	0.135	5.2	0.55	0.06
		Oct,2013	7.9	7.5	-0.4	0.177	5.8	0.57	0.08
		Mean	**7.8**	**7.5**	**-0.3**	**0.153**	**5.4**	**0.55**	**0.08**
	Dry season	Nov,2013	7.9	7.7	-0.3	0.344	4.9	0.26	0.07
		Dec,2013	7.8	7.7	-0.2	0.358	4.9	0.27	0.08
		Jan,2014	7.8	7.6	-0.2	0.355	4.9	0.90	0.10
		Feb,2014	7.9	7.8	-0.2	0.356	5.1	0.24	0.09
		Mar,2014	8.0	7.7	-0.4	0.350	4.9	0.85	0.10
		April,2014	8.0	7.6	-0.4	0.325	5.1	0.89	0.10
		Mean	**7.9**	**7.7**	**-0.3**	**0.348**	**5.0**	**0.63**	**0.09**
2	Wet Season	May,2014	7.7	7.4	-0.3	0.137	4.9	0.68	0.10
		June,2014	7.8	7.5	-0.3	0.154	5.4	0.62	0.11
		July,2014	7.8	7.6	-0.2	0.173	4.6	0.56	0.12
		Aug,2014	7.8	7.6	-0.2	0.182	4.5	0.44	0.09
		Sep,2014	7.8	7.5	-0.3	0.166	4.9	0.60	0.10
		Oct,2014	7.6	7.4	-0.2	0.199	5.1	0.66	0.11
		Mean	**7.8**	**7.5**	**-0.3**	**0.168**	**4.9**	**0.59**	**0.11**
	Dry season	Nov,2014	7.5	7.3	-0.2	0.298	5.2	0.77	0.09
		Dec,2014	7.6	7.5	-0.2	0.284	4.8	0.87	0.09
		Jan,2015	7.7	7.5	-0.1	0.255	3.9	0.92	0.08
		Feb,2015	7.8	7.5	-0.2	0.356	4.0	0.66	0.10
		Mar,2015	7.8	7.6	-0.2	0.340	4.2	0.72	0.08
		April,2015	7.8	7.3	-0.4	0.345	4.5	0.69	0.10
		Mean	**7.7**	**7.5**	**-0.2**	**0.313**	**4.4**	**0.77**	**0.09**
3	Wet Season	May-15	7.5	7.3	-0.3	0.211	4.5	0.55	0.09
		June,2015	7.6	7.3	-0.3	0.221	4.2	0.55	0.10
		July,2015	7.7	7.4	-0.3	0.215	4.6	0.51	0.11
		Aug,2015	7.7	7.5	-0.2	0.214	4.2	0.59	0.12
		Sep,2015	7.6	7.6	0.0	0.224	4.3	0.63	0.12
		Oct,2015	7.7	7.5	-0.2	0.215	4.5	0.62	0.13
		Mean	**7.7**	**7.4**	**-0.2**	**0.217**	**4.7**	**0.57**	**0.11**
	Dry season	Nov,2015	7.6	7.3	-0.1	0.288	3.0	0.91	0.10
		Dec,2015	7.8	7.3	-0.2	0.284	3.8	0.53	0.11
		Jan,2016	7.7	7.4	-0.2	0.255	3.3	0.61	0.11
		Feb,2016	7.7	7.5	-0.1	0.321	3.4	0.63	0.11
		Mar,2016	7.7	7.6	-0.2	0.286	3.2	0.62	0.10
		April,2016	7.9	7.5	-0.2	0.295	3.8	0.51	0.10
		Mean	**7.7**	**7.4**	**-0.2**	**0.288**	**3.4**	**0.64**	**0.11**
		Grand Mean	**7.8**	**7.5**	**-0.2**	**0.248**	**4.6**	**0.63**	**0.10**

*EC= Electrical conductivity, determined by 1:5 sediment- moisture ratio.

APPENDIX – 6

Results of chemical properties of Arial Khan river sediment

Location	Season	Month	pH (H_2O)	pH (KCl)	ΔpH	EC* (dS/m)	Free lime (%)	Organic carbon %	Total P
1	**Wet Season**	May,2013	7.9	7.4	-0.4	0.152	3.8	0.63	0.11
		June,2013	7.8	7.5	-0.4	0.153	4.1	0.66	0.09
		Jul-13	7.8	7.6	-0.3	0.133	4.2	0.67	0.07
		Aug,2013	7.7	7.6	-0.2	0.146	4.1	0.69	0.08
		Sep,2013	7.7	7.6	-0.1	0.123	4.1	0.69	0.09
		Oct,2013	7.7	7.6	-0.1	0.129	3.1	0.45	0.09
		Mean	**7.8**	**7.5**	**-0.2**	**0.139**	**3.9**	**0.63**	**0.09**
	Dry season	Nov,2013	7.5	7.3	-0.1	0.208	3.1	0.50	0.08
		Dec,2013	7.6	7.3	-0.3	0.213	3.7	0.44	0.08
		Jan,2014	7.6	7.3	-0.3	0.234	3.3	1.09	0.09
		Feb,2014	7.8	7.7	-0.2	0.174	3.4	0.99	0.10
		Mar,2014	7.9	7.7	-0.2	0.232	3.4	0.80	0.10
		April,2014	7.9	7.7	-0.3	0.231	3.6	0.91	0.11
		Mean	**7.7**	**7.5**	**-0.2**	**0.215**	**3.4**	**0.79**	**0.09**
2	**Wet Season**	May,2014	8.0	7.7	-0.4	0.142	2.9	0.73	0.15
		June,2014	8.1	7.8	-0.3	0.142	3.7	0.63	0.14
		July,2014	8.1	7.7	-0.4	0.141	3.4	0.61	0.14
		Aug,2014	8.0	7.7	-0.3	0.139	2.9	0.65	0.13
		Sep,2014	7.9	7.8	-0.1	0.128	3.1	0.58	0.12
		Oct,2014	8.0	7.9	-0.2	0.128	2.7	0.45	0.12
		Mean	**8.0**	**7.8**	**-0.3**	**0.137**	**3.1**	**0.61**	**0.13**
	Dry season	Nov,2014	7.9	7.8	-0.1	0.163	3.3	0.89	0.17
		Dec,2014	7.8	7.6	-0.1	0.168	3.5	0.84	0.18
		Jan,2015	7.9	7.8	-0.2	0.182	3.1	0.70	0.15
		Feb,2015	7.9	7.7	-0.2	0.197	2.5	0.73	0.16
		Mar,2015	7.8	7.6	-0.2	0.201	3.1	0.49	0.14
		April,2015	7.9	7.7	-0.2	0.199	2.7	0.57	0.11
		Mean	**7.9**	**7.7**	**-0.1**	**0.185**	**3.0**	**0.70**	**0.15**
3	**Wet Season**	May-15	8.1	7.9	-0.2	0.129	3.2	0.50	0.14
		June,2015	8.0	7.8	-0.2	0.134	3.5	0.45	0.14
		July,2015	8.0	7.8	-0.2	0.136	3.5	0.47	0.16
		Aug,2015	8.0	7.8	-0.2	0.131	3.0	0.44	0.14
		Sep,2015	8.1	7.9	-0.2	0.124	3.2	0.49	0.15
		Oct,2015	8.1	7.9	-0.2	0.125	3.4	0.42	0.14
		Mean	**8.0**	**7.8**	**-0.2**	**0.131**	**3.3**	**0.46**	**0.14**
	Dry season	Nov,2015	8.0	7.8	-0.2	0.199	3.1	0.50	0.12
		Dec,2015	7.9	7.6	-0.3	0.201	3.0	0.45	0.13
		Jan,2016	8.0	7.7	-0.3	0.197	3.4	0.47	0.13
		Feb,2016	8.0	7.8	-0.2	0.182	2.8	0.44	0.14
		Mar,2016	8.0	7.8	-0.2	0.195	3.7	0.49	0.14
		April,2016	8.0	7.8	-0.2	0.198	3.3	0.42	0.15
		Mean	**8.0**	**7.8**	**-0.2**	**0.195**	**3.2**	**0.46**	**0.13**
		Grand Mean	**7.9**	**7.7**	**-0.2**	**0.167**	**3.3**	**0.61**	**0.12**

**EC= Electrical conductivity, determined by 1:5 sediment- moisture ratio.*

APPENDIX – 7

Results of exchangeable cations in Bishkhali river sediment

Location	Season	Month	Exchangeable cations (cmol/kg)						BSP*
			Na^+	K^+	Ca^{++}	Mg^{++}	TEB*	*CEC	
1	**Wet**	May,2013	2.56	0.02	0.53	1.12	4.23	6.56	64
		June,2013	2.76	0.011	0.93	1.13	4.83	7.56	64
		July,20113	2.7	0.005	0.59	1.35	4.65	7.23	64
		Aug,2013	2.17	0.008	0.54	1.1	3.82	6.98	55
		Sep,2013	2.36	0.057	1.15	1.24	4.81	7.15	67
		Oct,2013	2.76	0.066	0.49	1.32	4.64	6.7	69
		Mean	**2.55**	**0.03**	**0.71**	**1.21**	**4.49**	**6.82**	**66**
	Dry	Nov,2013	2.21	0.05	0.45	1.101	3.81	6.16	62
		Dec,2013	2.26	0.043	0.6	1.21	4.11	6.78	61
		Jan,2014	2.1	0.043	0.39	1.65	4.18	7.37	57
		Feb,2014	2.1	0.05	0.43	1.23	3.81	7.18	53
		Mar,2014	2.56	0.057	0.45	1.52	4.59	7.37	62
		April,2014	2.98	0.043	0.45	1.15	4.62	7.35	63
		Mean	**2.37**	**0.05**	**0.46**	**1.31**	**4.19**	**6.82**	**61**
2	**Wet**	May,2014	2.76	0.066	0.44	1.42	4.69	7.2	65
		June,2014	2.17	0.057	0.45	1.26	3.94	7.19	55
		July,2014	2.66	0.05	0.49	1.35	4.55	7.47	61
		Aug,2014	2.26	0.057	0.45	1.35	4.12	6.37	65
		Sep,2014	2.34	0.043	0.43	1.45	4.26	6.38	67
		Oct,2014	2.51	0.05	0.44	1.52	4.52	6.82	66
		Mean	**2.45**	**0.05**	**0.45**	**1.39**	**4.35**	**7.2**	**60**
	Dry	Nov,2014	2.83	0.03	0.44	1.52	4.82	7.19	67
		Dec,2014	2.75	0.025	0.46	1.24	4.48	7.47	60
		Jan,2015	2.42	0.036	0.44	1.36	4.26	6.37	67
		Feb,2015	2.67	0.02	0.45	1.21	4.35	6.89	63
		Mar,2015	3	0.043	0.45	1.32	4.81	8.12	59
		April,2015	3.34	0.02	0.44	1.24	5.04	8.17	62
		Mean	**2.84**	**0.03**	**0.45**	**1.32**	**4.63**	**7.40**	**63**
3	**Wet**	May,2015	2.75	0.043	0.45	1.21	4.45	7.15	62
		June,2015	2.83	0.02	0.44	1.21	4.50	7.20	63
		July, 2015	2.34	0.015	0.44	1.26	4.06	6.94	58
		Aug,2015	2.08	0.03	0.39	1.28	3.78	6.95	54
		Sep2015	2.17	0.011	0.43	1.15	3.76	6.84	55
		Oct 2015	2.34	0.011	0.45	1.11	3.91	6.66	59
		Mean	**2.42**	**0.02**	**0.43**	**1.20**	**4.08**	**6.55**	**62**
	Dry	Nov, 2015	2.26	0.015	0.44	1.12	3.84	**6.89**	56
		Dec, 2015	2.67	0.036	0.45	1.21	4.37	6.84	64
		Jan.,2016	2.43	0.03	0.44	1.15	4.05	7.07	57
		Feb, 2016	2.75	0.043	0.45	1.16	4.40	6.49	68
		March,	2.17	0.03	0.45	1.17	3.82	6.78	56
		April, 2016	2.08	0.036	0.46	1.18	3.76	6.89	55
		Mean	**2.39**	**0.03**	**0.45**	**1.17**	**4.04**	**6.72**	**60**

APPENDIX – 8

Results of exchangeable cations in Arial Khan river sediment

Location	Season	Month	Exchangeable cations (cmol/kg)						BSP*
			Na^+	K^+	Ca^{++}	Mg^{++}	TEB*	*CEC	
1	**Wet**	May,2013	2.56	0.12	0.56	1.62	4.86	9.21	53
		June,2013	2.07	0.14	0.97	1.71	4.89	9.71	50
		July,20113	2.70	0.12	0.78	1.87	5.47	9.83	56
		Aug,2013	2.76	0.11	0.78	1.81	5.46	9.77	56
		Sep,2013	2.17	0.21	0.84	1.46	4.68	9.88	47
		Oct,2013	2.66	0.15	0.62	1.64	5.07	11.98	42
		Mean	**2.49**	**0.14**	**0.76**	**1.69**	**5.07**	**10.06**	**50**
	Dry	Nov,2013	2.26	0.21	0.97	1.89	5.33	11.46	47
		Dec,2013	2.88	0.14	0.74	1.65	5.41	12.09	45
		Jan,2014	2.26	0.11	0.55	1.65	4.57	11.46	40
		Feb,2014	2.36	0.12	0.56	1.61	4.65	11.49	40
		Mar,2014	2.86	0.12	0.56	1.53	5.07	11.21	45
		April,2014	2.17	0.13	0.56	1.55	**4.41**	11.33	39
		Mean	**2.47**	**0.14**	**0.66**	**1.65**	4.91	**11.51**	**43**
2	**Wet**	May,2014	2.86	0.14	0.56	1.53	5.09	11.25	45
		June,2014	2.56	0.21	0.56	1.77	5.10	11.39	45
		July,2014	2.66	0.18	0.56	1.64	5.04	11.62	43
		Aug,2014	2.76	0.14	0.57	1.77	5.24	11.13	47
		Sep,2014	2.86	0.15	0.56	1.71	5.28	11.51	46
		Oct,2014	2.07	0.16	0.56	1.81	**4.60**	11.27	41
		Mean	**2.63**	**0.16**	**0.56**	**1.71**	5.06	**11.36**	**45**
	Dry	Nov,2014	2.17	0.12	0.69	1.77	4.75	11.63	41
		Dec,2014	2.27	0.15	0.67	1.53	4.62	11.48	40
		Jan,2015	2.17	0.14	0.85	1.79	4.95	12.10	41
		Feb,2015	2.49	0.13	0.95	1.58	5.15	12.27	42
		Mar,2015	2.59	0.18	0.69	1.71	5.17	11.87	44
		April,2015	2.66	0.15	0.67	1.74	**5.22**	11.87	44
		Mean	**2.39**	**0.15**	**0.75**	**1.69**	4.98	**11.87**	**42**
3	**Wet**	May,2015	2.26	0.13	0.57	1.89	4.85	11.63	42
		June,2015	2.17	0.15	0.55	1.74	4.61	10.95	42
		July, 2015	2.66	0.13	0.56	1.81	5.16	11.02	47
		Aug,2015	2.26	0.13	0.55	1.97	4.91	11.10	44
		Sep2015	2.96	0.14	0.56	1.81	5.47	11.63	47
		Oct 2015	2.07	0.15	0.56	1.81	**4.59**	11.37	40
		Mean	**2.40**	**0.14**	**0.56**	**1.84**	4.93	**11.28**	**44**
	Dry	Nov, 2015	2.07	0.15	0.56	1.75	4.53	11.16	41
		Dec, 2015	2.27	0.16	0.56	1.85	4.84	11.16	43
		Jan.,2016	2.26	0.14	0.56	1.91	4.87	11.93	41
		Feb, 2016	2.36	0.13	0.51	1.56	4.56	12.10	38
		March, 2016	2.17	0.15	0.56	1.55	4.43	11.31	39
		April, 2016	2.86	0.16	0.55	1.55	5.12	11.38	45
		Mean	**2.33**	**0.15**	**0.55**	**1.69**	**4.72**	**11.51**	**41**
	Grand Mean		**2.45**	**0.15**	**0.64**	**1.71**	**4.94**	**11.26**	**44**

APPENDIX – 9

Results of total analysis of Bishkhali river sediment

Location	Season	Month	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/R_2O_3	MgO
			%			Molar ratio	%
1	Wet Season	May,2013	61	17.23	4.68	6.03	4.95
		june,2013	59	20.31	4.15	5.17	4.04
		July-13	59	19.12	3.25	5.72	4.06
		Aug,2013	58	17.21	4.96	5.89	4.35
		Sep,2013	59	19.24	5.59	5.11	4.32
		Oct,2013	59	20.11	4.96	4.98	4.56
		Mean	**59**	**18.87**	**4.60**	**5.48**	**4.38**
	Dry Season	Nov,2013	61	18.12	4.85	5.55	4.54
		Dec,2013	62	16.21	4.36	6.5	4.84
		Jan,2014	61	17.23	5.68	5.76	4.99
		Feb,2014	59	19.25	5.45	5.13	4.87
		Mar,2014	61	17.45	5.32	5.82	4.73
		April,2014	62	16.32	5.11	6.34	4.34
		Mean	**61**	**17.43**	**5.13**	**5.85**	**4.72**
2	Wet Season	May,2014	59	19.85	5.23	4.94	4.37
		June,2014	61	17.25	6.21	5.58	4.8
		July,2014	58	18.12	6.12	5.27	4.12
		Aug,2014	62	17.89	5.37	5.46	4.95
		Sep,2014	59	18.52	5.42	5.14	4.98
		Oct,2014	60	17.25	5.78	5.66	4.99
		Mean	**60**	**18.15**	**5.69**	**5.34**	**4.70**
	Dry Season	May-15	61	18.21	5.77	5.32	4.32
		June,2015	59	17.26	5.01	5.88	4.45
		July,2015	61	18.2	5.12	5.51	4.26
		Aug,2015	58	17.35	5.36	5.82	5.22
		Sep,2015	57	18.21	5.89	5.3	4.89
		Oct,2015	59	18.91	5.87	4.72	4.79
		Mean	**59**	**18.02**	**5.50**	**5.43**	**4.66**
3	Wet Season	May-15	61	18.26	5.77	5.32	4.35
		June,2015	60	17.32	5.01	5.88	4.45
		July,2015	62	18.35	5.12	5.51	4.56
		Aug,2015	61	17.45	5.36	5.82	4.22
		Sep,2015	59	18.35	5.89	5.3	4.85
		Oct,2015	58	19.85	5.87	4.72	4.89
		Mean	**60**	**18.26**	**5.50**	**5.43**	**4.55**
	Dry Season	Nov,2015	61	17.25	6.57	5.52	4.72
		Dec,2015	60	17.85	6.25	5.25	4.89
		Jan,2016	59	18.56	6.14	4.96	4.96
		Feb,2016	58	17.35	6.15	5.6	4.65
		March, 2016	62	15.36	6.35	6.32	4.14
		April,2016	61	16.68	6.28	5.57	4.85
		Mean	**60**	**17.18**	**6.29**	**5.54**	**4.70**

APPENDIX – 10

Results of total analysis of Bishkhali river sediment

Location	Season	Month	CaO	K_2O	P_2O_5	TiO_2
			%			
1	Wet Season	May,2013	2.31	1.72	0.19	0.44
		June,2013	2.35	1.85	0.18	0.41
		July-13	2.36	1.58	0.18	0.41
		Aug,2013	2.51	1.61	0.19	0.44
		Sep,2013	2.31	1.55	0.14	0.32
		Oct,2013	2.28	1.46	0.18	0.41
		Mean	**2.35**	**1.63**	**0.18**	**0.41**
	Dry season	Nov,2013	2.41	1.61	0.15	0.34
		Dec,2013	2.46	1.65	0.18	0.41
		Jan,2014	2.36	1.68	0.23	0.53
		Feb,2014	2.51	1.69	0.21	0.48
		Mar,2014	2.49	1.54	0.22	0.5
		April,2014	2.42	1.58	0.24	0.55
		Mean	**2.44**	**1.63**	**0.21**	**0.47**
2	Wet Season	May,2014	2.18	1.51	0.24	0.55
		June,2014	2.35	1.36	0.26	0.6
		July,2014	2.15	1.49	0.27	0.62
		Aug,2014	2.11	1.62	0.21	0.48
		Sep,2014	2.16	1.49	0.22	0.5
		Oct,2014	2.14	1.61	0.26	0.6
		Mean	**2.18**	**1.51**	**0.24**	**0.56**
	Dry Season	May-15	2.63	1.59	0.21	0.48
		June,2015	2.12	1.62	0.21	0.48
		July,2015	2.52	1.65	0.19	0.44
		Aug,2015	2.45	1.58	0.22	0.5
		Sep,2015	2.41	1.56	0.19	0.44
		Oct,2015	2.52	1.5	0.23	0.53
		Mean	**2.44**	**1.58**	**0.21**	**0.48**
3	Wet Season	May-15	2.44	1.58	0.21	0.48
		June,2015	2.23	1.62	0.23	0.53
		July,2015	2.16	1.54	0.25	0.57
		Aug,2015	2.19	1.58	0.28	0.64
		Sep,2015	2.45	1.62	0.27	0.62
		Oct,2015	2.54	1.58	0.29	0.66
		Mean	**2.34**	**1.59**	**0.26**	**0.58**
	Dry season	Nov,2015	2.41	1.38	0.24	0.55
		Dec,2015	2.56	1.33	0.26	0.6
		Jan,2016	2.32	1.32	0.25	0.57
		Feb,2016	2.52	1.36	0.25	0.57
		March, 2016	2.45	1.42	0.24	0.55
		April,2016	2.31	1.51	0.23	0.53
		Mean	**2.43**	**1.39**	**0.25**	**0.56**
	Grand Mean		**2.36**	**1.55**	**0.22**	**0.51**

APPENDIX – 11

Results of total analysis of Arial Khan river sediment

Location	Season	Month	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/R_2O_3 (molar-ratio)	MgO (%)
			%				
1	**Wet Season**	May,2013	61	18.23	4.86	3.95	3.95
		June,2013	63	16.65	4.35	4.04	4.04
		July-13	64	19.32	3.01	3.06	3.06
		Aug,2013	62	18.12	5.96	3.89	3.89
		Sep,2013	62	17.21	6.57	3.99	3.99
		Oct,2013	61	19.32	5.61	3.56	3.56
		Mean	**62**	**18.14**	**5.06**	**3.75**	**3.75**
	Dry season	Nov,2013	62	17.21	5.88	4.54	4.54
		Dec,2013	62	17.75	5.33	4.39	4.39
		Jan,2014	62	17.98	6.33	4.07	4.07
		Feb,2014	63	16.84	4.25	4.87	4.87
		Mar,2014	62	18.21	5.21	4.73	4.73
		April,2014	62	17.65	5.23	4.05	4.05
		Mean	**62**	**17.61**	**5.37**	**4.44**	**4.44**
2	**Wet Season**	May,2014	61	19.21	5.23	4.37	4.37
		June,2014	62	18.36	6.21	4.81	4.81
		July,2014	61	19.21	6.12	3.84	3.84
		Aug,2014	61	18.39	5.37	3.95	3.95
		Sep,2014	60	18.54	5.42	4.84	4.84
		Oct,2014	61	15.68	5.78	4.54	4.54
		Mean	**61**	**18.23**	**5.69**	**4.39**	**4.39**
	Dry Season	May-15	61	18.69	5.62	4.26	4.26
		June,2015	61	17.68	5.87	4.41	4.41
		July,2015	59	18.25	5.86	4.48	4.48
		Aug,2015	60	19.62	5.69	4.45	4.45
		Sep,2015	59	18.64	5.96	4.65	4.65
		Oct,2015	58	16.65	5.98	4.52	4.52
		Mean	**60**	**18.26**	**5.83**	**4.46**	**4.46**
3	**Wet Season**	May-15	62	16.35	5.77	4.01	4.01
		June,2015	61	17.65	5.01	4.52	4.52
		July,2015	60	18.65	5.12	4.21	4.21
		Aug,2015	62	16.25	5.36	4.89	4.89
		Sep,2015	60	18.31	5.89	4.99	4.99
		Oct,2015	59	18.32	5.87	4.26	4.26
		Mean	**61**	**17.59**	**5.50**	**4.48**	**4.48**
	Dry season	Nov,2015	59	18.35	5.01	4.48	4.48
		Dec,2015	62	16.26	5.26	4.39	4.39
		Jan,2016	62	15.23	5.24	4.41	4.41
		Feb,2016	60	17.85	5.84	4.56	4.56
		March, 2016	62	18.23	5.36	4.14	4.14
		April,2016	60	17.32	5.24	4.12	4.12
		Mean	**61**	**17.21**	**5.33**	**4.35**	**4.35**
	Grand Mean		**61**	**17.84**	**5.46**	**5.60**	**4.31**

APPENDIX – 12

Results of total analysis of Arial Khan river sediment.

Location	Season	Month	CaO	K_2O	P_2O_5	TiO_2
			%			
1	Wet Season	May,2013	2.31	1.72	0.25	0.79
		June,2013	2.35	1.03	0.21	0.98
		July-13	2.36	1.58	0.15	0.93
		Aug,2013	2.51	1.61	0.18	0.99
		Sep,2013	2.31	1.25	0.21	0.95
		Oct,2013	2.28	1.46	0.21	1.02
		Mean	**2.35**	**1.44**	**0.20**	**0.94**
	Dry season	Nov,2013	2.41	1.61	0.18	0.93
		Dec,2013	2.46	0.99	0.19	1.04
		Jan,2014	2.36	1.02	0.21	1.02
		Feb,2014	2.51	1.05	0.23	1.03
		Mar,2014	2.49	0.98	0.24	1.02
		April,2014	2.42	0.98	0.25	1.03
		Mean	**2.44**	**1.11**	**0.22**	**1.01**
2	Wet Season	May,2014	2.18	1.51	0.34	1.02
		June,2014	2.35	1.36	0.32	0.97
		July,2014	2.15	1.02	0.31	0.96
		Aug,2014	2.11	1.62	0.29	0.99
		Sep,2014	2.16	1.49	0.28	1.06
		Oct,2014	2.14	1.61	0.28	1.02
		Mean	**2.18**	**1.44**	**0.30**	**1.00**
	Dry Season	May-15	2.63	1.59	0.39	1.08
		June,2015	2.12	1.79	0.41	0.97
		July,2015	2.52	1.65	0.35	1.01
		Aug,2015	2.45	1.58	0.37	0.94
		Sep,2015	2.41	1.56	0.32	0.87
		Oct,2015	2.52	1.5	0.25	1.21
		Mean	**2.44**	**1.61**	**0.35**	**1.01**
3	Wet Season	May-15	2.44	1.58	0.32	1.01
		June,2015	2.23	1.62	0.31	1.2
		July,2015	2.16	1.82	0.36	1.08
		Aug,2015	2.19	1.75	0.32	0.99
		Sep,2015	2.45	1.78	0.34	1.02
		Oct,2015	2.54	1.79	0.32	1.05
		Mean	**2.34**	**1.72**	**0.33**	**1.06**
	Dry season	Nov,2015	2.95	1.58	0.27	0.99
		Dec,2015	2.89	1.52	0.29	0.95
		Jan,2016	2.32	1.42	0.3	1.03
		Feb,2016	2.52	1.42	0.31	1.02
		March, 2016	2.45	1.43	0.32	1.01
		April,2016	2.31	1.57	0.34	0.99
		Mean	**2.57**	**1.49**	**0.31**	**1.00**
	Grand Mean		**2.39**	**1.47**	**0.28**	**1.00**

APPENDIX – 13

Abbreviation and notation and coded morphological properties of the studied soils.

1. Soil colors (Matrix)

According to Munsell notations the arrangement of color is by hue, value and chroma. Hue is the dominant spectral (Rainbow) color (5Y, 2.5 Y, 10YR).

Value refers to the relative lightness of color and is a function of light. Chroma is the relative purity or strength of the spectral colors. Value and Chroma are represented by number (V/C).

2. Mottling

Mottles are spots or blotches of different colors or shades of color interspersed with the dominant colour of the soil. They indicate that the soil has been subject to alternate wetting (reducing) and dry (Oxidizing) conditions**.** Mottling of the soil matrix or groundmass is described in terms of abundance, size, contrast, boundary and color. In addition the shape, position or any other feature may be recorded**.** Description of the mottling patterns may be noted as follows:

Color of mottles: the colour of the mottles is described in general terms, corresponding to the Munsell Soil Color Charts.

Dyb = dark yellowish brown; ob = olive brown; yr = yellowish red; drb = dark reddish brown; db = dark brown; b= brown; yb = yellowish brown; sb = Strong brown; o = olive.

Abundance of mottles: The abundance of mottles is described in terms of classes indicating the percentage of the exposed surface that the mottles occupy.

Classification of the abundance of mottles

Notation	characteristics	%
N	None	0
V	Very few	0-2
F	Few	2-5
C	Common	5-15
M	Many	15-40
A	Abundant	>40

Classification of the contrast of mottles

fa	Faint	Evident only on close examination
Dt	Distinct	Mottles are readily seen, although not striking
pr	Prominent	Mottles are conspicuous.

3. Carbonates.

N	0%	Non-calcarious	No effervescence
SL	0-2	Slightly calcarious	Audible effervescence but not visible
MO	2-10	Moderately calcarious	Visible effervescence
ST	10-25	Strongly calcarious	Strong Visible effervescence. Bubbles form a low foam.
EX	>25	Extremely calcarious	Extremely strong reaction.

4. Field soil pH

Soil pH expresses the activity of hydrogen ions in the soil solution. The field soil pH should not be a substitute for a laboratory determination. In the field, pH is estimated by the Hellige indicator liquids.

6. Soil structure

Soil structure refers to the natural organization of soil particles into discrete soil units that result from pedogenic processes. For the description of soil structure, a large lump of the soil should be taken from the profile from various parts of the horizon. It is described in the field in terms of grade, size and type of aggregates.

Codes for types of soil structure

RS	Rock structure
SS	Stratified structure
SG	Single grain structure
MA	Massive (Coherent)
PM	Porous massive
BL	Blocky
AB	Angular blocky
AS	Angular and subangular blocky
SB	Subangular blocky
PR	Prismatic
PL	Platy
GR	Granular
CR	Crumbly.

Codes for Grade of soil structure

0	Structureless
1	Weak
2	Moderate
3	Strong.

7. Horizon boundary

Horizon boundaries provide information on the dominant soil- forming processes that have formed the soil. Most soil boundaries are zones of transition rather than sharp line of division.

Classification of horizon boundaries, by distinctness and topography

Distinctness			Topography		
A	Abrupt	0-2 cm	S	Smooth	Nearly plane surfaces
C	Clear	2-5 cm	W	Wavy	Pockets less deep than wide
G	Gradual	5-15 cm	I	Irregular	Pockets more deep than wide
D	Diffuse	>15 cm	B	Broken	Discontinuous

8. Soil Texture

Soil texture refers to the proportion of the various particle size classes n a given soil volume and is described as soil textural class

Textural class

S	Sand
LS	Loamy sand
SL	Sandy loam
SCL	Sandy clay loam
SiL	Silt loam
SiCL	Silty clay loam
CL	Clay loam
L	Loam
Si	Silt
SC	Sandy clay
SiC	Silty clay
C	Clay
HC	Heavy clay

9. Consistence

Consistence refers to the degree of cohesion or adhesion of the soil mass. A recording of consistence is required for the dry, moist and wet states.

Consistence of soil mass when moist

LO	Loose	Non- coherent
VFR	Very friable	Crushes under very gentle pressure
FR	Friable	Crushes easily under gentle to moderate pressure between thumb and forefinger
FI	Firm	Crushes easily under moderate pressure between thumb and forefinger but resistance is distinctly noticeable.
VFI	Very firm	Crushes easily under strong pressure
EFI	Extremely firm	Crushes only under very strong pressure ; cannot be crushed between thumb and forefinger

Consistence of soil mass when moist: Stickiness and Plasticity

Classification of soil stickiness

NST	Non- sticky	After release of pressure, practically no soil material adheres to thumb and finger
SST	Slightly sticky	After pressure, soil materials adheres to both thumb and finger but comes off one or other rather cleanly.
ST	Sticky	After pressure, soil materials adheres to both thumb and finger and tends to stretch somewhat and pull apart rather than pulling free from either digit. one or other rather cleanly
VST	Very sticky	After pressure, soil materials strongly to both thumb and finger and are directly stretched ehen they are separated.

Classification of soil plasticity

NPL	Non-plastic	No wire is formable.
SPL	Slightly plastic	Wire formable but breaks immediately if bent into a ring. Soil mass deformed by very slight pressure
PL	Plastic	Wire formable but breaks if bent into a ring. Slight to moderate forced required for deformation of the soil mass.
VPL	Very plastic	Wire formable and can be bent into a ring, Strong to very strong force is required for deformation of the soil mass.

APPENDIX – 14

Some meteorological data of Barisal, Bhola ,Patuakhali and Khepupara stations. (Source: Bangladesh Meteorological Department, 2012)

Item	Station		Year												Mean
			2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	
Annual Total Rainfall in (mm)	Barisal		2230	2469	1693	2529	1943	1998	2382	1864	1820	1662	1909	1836	2028
	Bhola		2538	2324	1819	3080	2366	2189	3381	2012	1920	1774	2015	1484	2242
	Khepupara		3469	2825	1758	2472	3348	2648	3231	3024	2289	2568	3092	2625	2779
	Patuakhali		2915	2704	2210	2647	2703	2287	2857	2514	2309	2167	2414	1920	2471
Average Max. and Min.Temp. in Celcius	Barisal	Max.	30.9	30.8	30.5	30.5	31.1	33.5	30.5	30.6	31.5	31.8	30.2	30.8	31
		Min.	20.9	21.3	21.7	21.6	22.0	12.2	21.4	22.2	21.6	22.2	21.4	21.0	21
	Bhola	Max.	30.2	30.5	30.2	30.0	30.9	33.5	30.1	30.2	31.0	31.2	31.1	30.3	31
		Min.	21.6	21.6	21.7	21.1	22.0	12.7	21.6	22.3	21.9	22.3	21.5	21.5	21
	Khepupara	Max.	30.5	30.7	30.3	30.4	30.6	34.7	30.5	31.0	31.0	31.4	30.8	28.3	31
		Min.	22.1	22.3	24.4	21.9	22.4	12.8	22.0	22.2	22.7	22.8	21.8	21.8	22
	Patuakhali	Max.	31.1	28.5	30.7	30.7	31.2	33.8	30.7	30.8	31.6	32.0	31.1	31.1	31
		Min.	21.83	21.8	21.9	21.9	22.2	13.5	21.8	22.4	22.2	22.5	21.5	21.6	21

APPENDIX – 15

Table . Average meteorological data of the studied coastal area Source : Bangladesh meteorological Department (2012).

	Barisal station												Total
Met. Parameter	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Rainfall in mm	31	12	11	210	276	256	282	263	381	70	44	0	1836
PET in mm	46	71.7	99	113.6	115.5	92.3	90.0	95.9	87	83	59.8	47	83.4
Max. Temp. ˚ C	25	29.3	32.4	33.3	33.8	32.3	31.8	31	31.7	32.9	30.3	26.1	30.83
Min. Temp. ˚ C	10.9	15.3	20.1	23	25.2	26.3	26.4	25.9	25.9	24.5	18.4	15	21.40
Wind speed in Km/hr	0.37	0.56	0.36	1.67	4.26	2.59	2.04	2.59	0.06	0.74	0.74	0.37	
Relative Humidity (%)	81	78	76	80	83	88	90	89	89	87	84	83	77
	Patuakhali station												
Rainfall in mm	7	2	48	84	128	285	406	425	345	114	71	5	1920
PET in mm	45	69.7	101	120	122.4	96.5	88	89	97	92	69	65	87.88
Max. Temp. ˚ C	25.3	29.8	33.3	34.4	34.2	32.4	32.2	31.4	31.4	33.1	30.6	26.3	31.2
Min. Temp. ˚ C	12.1	15.8	20.4	23.3	25.3	26.2	26.2	25.8	25.7	24.5	18.8	15	21.59
Wind speed in Km/hr	2.41	3.15	5.13	5.13	8.7	8.7	7.4	7.96	3.15	4.26	6.11	2.41	
Relative Humidity (%)	78	76	76	81	83	88	90	89	89	86	82	80	83.16
	Bhola station												
Rainfall in mm	7	4	8	90	190	264	300	272	190	123	35	1	1484
PET in mm	44	72.5	102.0	115	121.0	98.0	95	99	92	89	65	52	87.04
Max. Temp. ˚ C	24.2	28.9	31.7	32.9	32.9	31.6	30.9	30.8	31.1	32.7	29.8	26	30.29
Min. Temp. ˚ C	11.4	15.4	20.2	23.1	25	26.1	26.2	25.8	25.9	24.6	18.6	15.1	21.45
Wind speed in Km/hr	0.5	0.5	5.13	6.29	8.88	29.6	8.51	10.36	3.33	2.59	1.67	0.56	
Relative Humidity (%)	81	77	77	81	84	88	90	89	89	86	83	82	83.91
	Khepupara station												
Rainfall in mm	9	0	49	96	131	418	656	398	533	259	69	7	22625
PET in mm	48	70.0	102.3	121.4	123.5	99.7	95.4	90.8	99.6	95.9	70.6	67.8	90.41
Max. Temp. ˚ C	25.4	29.4	32.3	33.1	33	32	31.7	30.9	31.5	33.1	30.6	26.8	30.81
Min. Temp. ˚ C	12.3	16.2	20.7	23.9	25.1	26.3	26	26	26.1	24.9	19.3	15	21.81
Wind speed in Km/hr	2.21	3.5	6.66	4.44	7.13	7.7	6.4	8.5	3.51	3.22	6.18	2.84	
Relative Humidity(%)	76	75	76	79	81	86	88	87	87	85	81	78	

APPENDIX – 16

Classification of Land Types (FAO-UNDP, 1988)

Highland	Land which is above normal flood-level.
Medium highland	Land which normally is flooded up to about 90 cm deep during the flood season.
Medium lowland	Land which normally is flooded between 90 and 180 cm deep during the flood season
Lowland	Land which normally is flooded between 180 and 300 cm deep during the flood season
Very low land	Land which normally is flooded above 300 cm during the flood season

Source: Bangladesh Agricultural Research Council (BARC). 2012. Fertilizer Recommendation Guide, 2012.

APPENDIX – 17

Classification of soils on the basis of the electrical conductivity (EC) values

Soil Salinity class		**EC range (dS/m)***	**Crop reaction**
S_0	Salt free (Non-saline)	0-2.0	Salinity effects are mostly negligible
S_1	Very slightly saline	2.1-4.0	Salinity effects are mostly negligible except for the most sensitive plant
S_2	Slightly saline	4.1-8.0	Yields of many crops restricted
S_3	Moderately saline	8.1-12.0	Only tolerant crops yield satisfactorily
S_4	Strongly saline	12.1-16.0	Only very tolerant crops yield satisfactorily

*1 dS/m = 640 ppm (Approx.) Source: Bookers Tropical Soil Manual, 1991

APPENDIX – 18

Classification of soils on the basis of Organic matter Content and Cation Exchange Capacity

Class	Organic matter (%)	CEC (meq/ 100g)
Very high	>5.5	> 30
High	3.5-5.5	16-30
Medium	1.8-3.4	7.6-15
Low	1.0-1.7	3-7.5
Very low	< 1.0	<3

Source: Bangladesh Agricultural Research Council (BARC). 2012. Fertilizer Recommendation Guide, 2012.

APPENDIX – 19

Values used for classification soil acidity and alkalinity

Soil reaction class	**pH**
Very strongly acidic	< 4.5
Strongly acidic	4.6-5.5
Slightly acid	5.6-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	<9.0

Source: Bangladesh Agricultural Research Council (BARC). 2012. Fertilizer Recommendation Guide, 2012

APPENDIX – 20

Correlation coefficient between parameter of the studied soils.

Parameters	Calculated Correlation coefficient (r)	Level of significance (%)
Clay content Vs Soil moisture (Hygros).	**+0.691**	**1**
Clay content Vs Oven dry/ Air dry (OD/AD)	**+0.691**	**1**
Clay content Vs Loss on ignition	**+0.607**	**1**
Organic matter Vs Loss on ignition	**+0.609**	**1**
Bulk density Vs Porosity	**+0.933**	**1**
Clay content Vs Cation Exchange Capacity (CEC).	**+0.710**	**1**
Percent clay Vs percent alumina	**+0.391**	**1**
pH (H_2O) Vs pH (KCl).	**+0.879**	**1**
Percent organic matter Vs Total nitrogen	**+0.928**	**1**
Percent Fe_d Vs Percent Mn_d	**+0.467**	**1**
Organic matter Vs Cation Exchange Capacity (CEC).	**+0.676**	**1**
Total Fe Vs Free Fe	**+0.469**	**1**
Sediment Vs soil (Silica)	**+0.691**	**1**

APPENDIX – 21

Types of drainage condition

Well drained	Water is removed from the soil readily but not rapidly.
Moderately well drained	Water is removed from the soil somewhat slowly. Profile remains moist for a significant period of time.
Imperfectly drained	Water is removed from the soil slowly. Soils remain wet sometimes during the rainy season but water don't stand more than 15 days consecutively
Poorly drained	Water is removed so slowly that the soil remains wet for longer period of time. The land sometimes remains wet after the monsoon season. Water table near the surface of the soil.
Very poorly drained	Water table near the surface of the soil for a longer period of time. The soil remains wet for eight months of a year.

APPENDIX – 22

Factors for the conversion of Conductivity Values to 25°C

Temperature in °C	Factor
15	1.25
16	1.22
17	1.19
18	1.16
19	1.14
20	1.11
21	1.09
22	1.06
23	1.04
24	1.02
25	1.00
26	0.98
27	0.96
28	0.94
29	0.93
30	0.91
31	0.89
32	0.87
33	0.86
34	0.84
35	0.83

Reference: Dewis, J and F. Fretas. 1970. Physical and chemical methods of soil and water analysis. Appendix 8. F.A.O. of the United Nations, Rome.

APPENDIX – 23

Important carbonate contents for classification

Free lime class	Percent (%)
Non-calcaric	0 to 2 %
Calcaric	2.1 to 15 %
Calcic horizon	>15 %

APPENDIX – 24

Approximate d-spacing of first order basal reflection after different treatments for identification of clay minerals.

Clay minerals	Mg Saturated Air dry	Mg Saturated and glycerol solvated	K Saturated Air dry	K Saturated Heated at 300°C	K Saturated Heated at 550°C
Kaolinite	7.15*	7.15	7.15	7.15	Disappears
Smectite	15.0	17.7	12.5	10.0	10.0
Vermiculite	14.2	14.2	1.0	10.0	10.0
Illite	10.0	10.0	10.0	10.0	10.0
Chlorite	14.2	14.2	14.2	14.2	14.2
Ch-Vt	14.2	14.2	14.2	14-10	10.0
Mi/Ch	12.1	12.1	12.1	12.1	12.1
Kt/Sm	8.0	8.0	8.0	8.0	Disappears
Mi/Vt	12.0	12.0	10.0	10.0	10.0
Quartz	4.25, 3.34	4.25, 3.34	4.25, 3.34	4.25, 3.34	4.25, 3.34
Feldsped	3.25, 3.19	3.25, 3.19	3.25, 3.19	3.25, 3.19	3.25, 3.19
Geothite	4.18	4.18	4.18	Disappears	Disappears
Lepidocrocite	6.27	6.27	6.27	Disappears	Disappears
Gibbsite	4.48	4.48	4.48	Disappears	Disappears
*all values unit is Angstrom (Å)			Source: Aramaki (1996)		

APPENDIX – 25

Identification of peak in X-ray diffractograms for clay minerals

Clay minerals	Peak Identification
Smectite	Smectite was identified based on the peak intensity at 17Å in the Mg-saturation-glycerol solvated samples and the peak contracted to 14Å in the K-saturated specimen
Chlorite	With all treatments the peak remains at 14Å. After heating at 550°C the peak remains at 14Å with stronger intensity due to primary chlorite mineral.
Vermiculite	The peak at 14Å that collapsed when heated at 550°C is an indication of the presence of 14Å vermiculite. Vermiculites collapse after K-saturation to 10Å.
Mica	In all treatments peak remains at 10Å. The peak at 10Å in the Mg-saturated specimen is considered for illite. Illite shows peak at 10Å only after Mg-saturation without other clay minerals. After heating at 550°C the peak remains at 10Å confirmed the presence of illite mineral.
Kaolinite	The X-ray diffraction peak at 7Å after all treatments is due to kaolinite. The peak at 7Å disappear on heating the K-saturated samples at 550°C confirmed the presence of kaolinite mineral.
Interstratified minerals	A number of small and hazy peaks in the region of 10-14Å on glycerol salvation of the clay samples presumably are indication of some interstratified or intergraded clay minerals

APPENDIX – 26

Semi-quantative estimation of minerals from X-ray diffractogram

1. Peak notation at Mg-gly, K-air and K550 treatment		
Mg-gly	**K-air**	**K-550**
18 Å = A		
14 Å = B	14 Å = L	
12 Å = C		
10 Å = D		10 Å = N
8 Å = E		
7 Å = F		
6.27 Å = G		
4.84 Å = K		
4.25 Å = H		
4.16 Å = I		
3.2 Å = J		
3.57Å/3.54 Å = 1/P		

2. *Values for the coefficient **Kp.q** employed for the estimation of clay mineral content in the clay fraction.*

Mg-gly	**K-air**	**K-550**
Sm (18 Å) = 3	Ch (14 Å) = 1.5	Mi (10 Å) = 1
Vt (14 Å) = 1.5	Vt-Ch (14 Å) = 1.5	Vt (10 Å) = 1.5
Ch (14 Å) = 1.5		Sm (10 Å) = 1.5
Vt-Ch (14 Å) = 1.5		Vt-Ch (10 Å) = 1.5
Mi/Vt (12 Å) = 1.5		Mi/Vt (10 Å) = 1.5
Mi/Ch (12 Å) = 1.5		Mi/Vt/Sm (10 Å) = 1.5
Mi (10 Å) = 1		
Kt/Sm (8 Å) = 1.5		
Ch (7 Å) = 2		
Kt (7 Å) = 2		
Lp (6.27 Å) = 1		
Qr (4.25 Å) = 1/6		
Gt (4.16 Å) = 1		
Fd (3.2 Å) = 1/2		
Gb (4.8 Å) = 1		

3. *Total Peak weight*
3WSm = A 1.5WVt + 1.5WCh + 1.5WVt-Ch = B 1.5WMi/Vt = C or 1.5WMi/Ch = C WMi = D 1.5WKt/Sm = E 2WCh + 2WKt = F WLp = G WQr = 6H WGt = I WFd = 2J 1.5WCh + 1.5WVt-Ch = L WMi + 1.5WVt + 1.5WVt-Ch + 1.5WMi/Vt + 1.5WMi/Vt/Sm = N WKt/WCh = 1/P WGb = K
4. *Weight proportion*
WMi = D WSm = A/3 WVt = (B-L)/1.5 WKt = F/2(1+P) WVt-Ch = (((L-(1.5FP)/(2(1+P)))/1.5)) WMi/Vt = C/1.5 or WMi/Ch = C/1.5 WMi/Vt/Sm = (N-D-B-A/2+1.5FP/2(1+P)-C)/1.5 WKt/Sm = E/1.5 WLp = G WQr = 6H WGt = I WFd = 2J WGb = K
We plotting this formula in excel sheet to find out the individual minerals and by addition of individual minerals we get total minerals, then we calculate the percentage of each mineral

Source: Aramaki (1996)