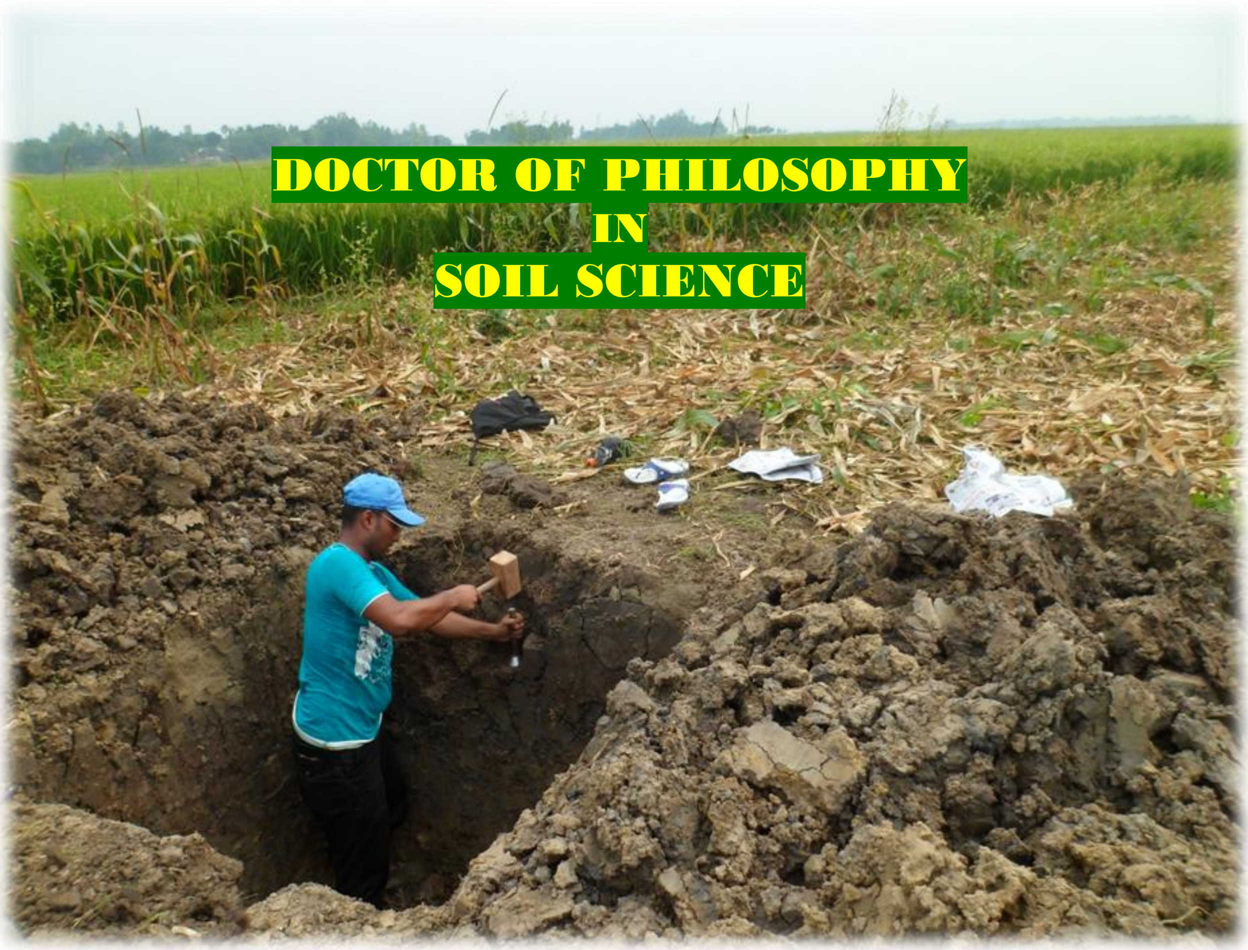
MORPHOGENETIC AND TAXONOMIC CHARACTERIZATION OF THE LOWER ATRAI BASIN SOILS OF BANGLADESH

A dissertation submitted to the Department of Soil, Water and Environment, University of Dhaka in partial fulfillment of the requirements for the degree of



DOCTOR OF PHILOSOPHY
IN
SOIL SCIENCE

BY

A. B. M. SAIFUL ISLAM
B.Sc. (Hons), M.S in Soil Science (DU)
Registration No: 22, Session: 2012-2013

Department of Soil, Water and Environment
University of Dhaka
Dhaka-1000, Bangladesh

March, 2017

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بسم الله الرحمن الرحيم

Bismillahirrahmanirrahim

(in the name of Allah, most gracious, most merciful)

Dedicated to…

My Parents
Wife, Son and Daughter

DECLARATION

I hereby declare that the research presented in this thesis entitled ***"Morphogenetic and Taxonomic Characterization of the Lower Atrai Basin Soils of Bangladesh"*** was carried out by me for the degree of Doctor of Philosophy (Ph.D.) in Soil Science under the guidance and supervision of **Professor Dr. Md. Aminur Rahman Mazumder** and **Professor Dr. Md. Zakir Hossain Khan,** of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh.

I further declare that for the present thesis, which I am submitting to the University of Dhaka, no academic degree or diploma or distinction was conferred on me before, either in this or in any other University. The books, articles and websites, which I have made use of are acknowledged at the respective place in the text.

Place: Dhaka
Date: 05/03/2017

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CERTIFICATE

*We have pleasure to certify that the thesis entitled **"Morphogenetic and Taxonomic Characterization of the Lower Atrai Basin Soils of Bangladesh"** is an original research work carried out by **Mr. A. B. M. Saiful Islam** 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. Mr. A. B. M. Saiful Islam successfully completed his course work and carried out his field study as well as laboratory work meticulously during the session 2012-2013.*

To the best of our knowledge, this is the researcher's own achievement and not a conjoint work. In our opinion, Mr. A. B. M. Saiful Islam has certainly classify the lower Atrai Basin soils of Bangladesh which will be useful to soil scientists, agronomists, farm research scientists and the agricultural extension workers involved in agricultural development as well as the agro-technology transfer programs for increasing agricultural production in the soils of lower Atrai basin.

We also certify that it is a bona fide research work of Mr. A. B. M. Saiful Islam under our direct supervision and the thesis is found satisfactory for submission to the Department of Soil, Water and Environment, University of Dhaka, Bangladesh.

(Prof. Dr. Md. Zakir Hossain Khan)
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BIOGRAPHICAL SKETCH OF THE AUTHOR

The author (A. B. M. Saiful Islam) was born on 05 October 1979 at Natore district of Bangladesh. He is the youngest son of Late Azim Uddin and Mrs. Morsheda Begum of Village- Bilpara, Upazilla- Bagatipara and District- Naore, Bangladesh. He has one brother and one sister. He passed the Secondary School Certificate (SSC) examination in 1995 from Ershad Public School Kadirabad Cantonment, Natore in first division with star marks under Rajshahi board in Science group and Higher Secondary Certificate (HSC) examination in 1997 from Kadirabad Cantonment College, Natore in first division with star marks under Rajshahi board in Science group. He obtained B. Sc. (Hon's) degree in Soil, Water and Environment in 2002 (Exam held in 2004) from Dhaka University with first class 4th position and MS degree in thesis group under the supervision of Professor Dr. Mohammad Sultan Hussain and Professor Dr. Md. Aminur Rahman Mazumder in 2003 (Exam held in 2006) in Soil Science from the same Department and University with first class 5th position. He was NST fellow during his MS program.

The author started his professional career on 1st March 2007 as a Lecturer and 28th February 2010 as Assistant Professor in the department of Soil Science, Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali, Bangladesh. The author has a keen interest to Soil Pedology and he carried out different Pedological research projects funded by PSTU, UGC, and MoST. In the mean time author has published one book and 20 articles in the different journals. Most articles are related to Pedology. He is a member of Soil Science Society of Bangladesh and Dhaka University Soil Science Alumni Association (DUSSAA).

He is happily married to Squadron Leader Kamrunnahar Islam and blessed with one son M. Aryaan Islam (Sameen) and one daughter Samairaa Sinthi (Rose).

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March, 2017 **Author**

ABSTRACT

The lower Atrai basin or the Chalan beel, as it is popularly known, is one of the large inland depressions in the northern part of Bangladesh, where a large quantity of Boro and Aman rice is grown. This basin was formed when the old Brahmaputra river changed its course into the Jamuna channel. The Jamuna river impeded the flow of the Padma, thereby causing the latter to deposit sediments at the mouths of the Karatoa and Atrai rivers. The diverted flow of these two rivers created the Chalan beel. The major portion of the basin extends over three adjacent districts of Sirajgonj, Natore and Naogaon and very small portion of Rajshahi and Bogra districts. It is located between 24^{0}21′ to 24^{0}51′ N latitudes and between 88^{0}49′ to 89^{0}23′E longitudes. The original area of the basin was about 108,800 ha which has been reduced to about 36,800 ha at present caused by siltation.

Eight extensive soil series, viz. Binsara, Taras 1, Jaonia, Taras 2, Hasnabad, Laskara, Manda and Mainam from the lower Atrai basin of Bangladesh were studied in the field as well as in the laboratory. The salient morphological features such as colour, colour patterns, texture, structure, mottles, consistency and flood coatings of the soils were studied in the field. In all the pedons prismatic to angular blocky structure developed in the subsurface horizons.

Silt was the dominant mechanical fraction of the soils followed by clay and sand fraction. The vertical distribution patterns of sand/silt ratio as well as the clay contents in the profiles were irregular which indicated the heterogeneous nature of the parent materials. Most of the soils were found to have higher bulk density in the Ap2 horizons (plough pan) due to compaction resulting from ploughing for rice cultivation.

The important chemical parameters of the soils such as pH, organic carbon, total nitrogen, cation exchange capacity, exchangeable bases, free oxides of Fe and Mn were determined. Moreover, fusion analysis of whole soils and the clay fraction thereof were done. The reaction of the soils was moderately acid to neutral. The ΔpH values of all the soils were negative and which ranged from -1.05 to -1.83 pH unit. The mean organic matter contents of the individual pedons varied from 0.39 to 1.26 percent with a grand mean of 0.96 percent. The organic matter and total nitrogen content in the present soils showed a general tendency of decrease with depth in all the pedons. The percent base saturation was high (71-99) and showed a tendency to increase with depth in all the profiles. Cation exchange capacity of the soils was medium to high with a mean value of 15.25cmol/kg. Free oxides of iron and

manganese in the soils were low due to their loss from the profile along with the draining water.

Results of fusion analysis of the soils indicate that SiO_2 contents in the whole soil were higher than that in the clay fraction in all the pedons. On the other hand the contents of Al_2O_3 and Fe_2O_3 in the whole soil were lower than that in the clay fraction. Both in soil and clay fraction SiO_2 was the dominant element followed by Al_2O_3 and Fe_2O_3. The distribution pattern of SiO_2, Al_2O_3 and Fe_2O_3 varied with depth. The silica sesquioxide molar ratios of the soils indicated that the soil parent materials were heterogeneous.

The soils had illitic mineralogical class except Hasnabad and Laskara pedon. The latter two soils had mixed mineralogy class. All the soils contained high content of mica followed by kaolinite, chlorite, vermiculite and interstratified minerals. The Hasnabad and Laskara soils had mixed mineralogical class consisting of mica, kaolinite, chlorite, vermiculite and moderate amount of interstratified mineral. The higher content of mica in the clay fraction suggested that the soils were well supplied with potassium and there is little need for application of potassic fertilizer. Electron micrographs were used to see the shapes and sizes of minerals in the clay fraction.

*The soils of the lower Atrai basin have been characterized as "**hydromorphic soils"** where **gleization** seemed to be the major pedogenic process. For classification the Manda and Mainam soils meet the requirements of the **Entisols** and Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara soils meet the requirements of the **Inceptisols** order of the US Soil Taxonomy. According to WRB system the Manda and Mainam soils were grouped in to **Fluvisols** and Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara soils were grouped into **Gleysols**. The soils were characterized in the family level of US Soil Taxonomy. This family level classification may facilitate the process of agro-technology transfer with other soils in Bangladesh.*

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ACRONYMS

AD	:	Air dry
AEZ	:	Agro ecological zone
AWC	:	Available water capacity
BARC	:	Bangladesh Agricultural Research Council
BCAS	:	Bangladesh Centre for Advanced Studies
BCSRI	:	Bangladesh Council of Scientific and Industrial Research
BMD	:	Bangladesh Meteorological Department
BSP	:	Base Saturation Percentage
BWDB	:	Bangladesh water development board
C/N ratio	:	Carbon nitrogen ratio
CARS	:	Centre of Advanced Research in Science
CEC	:	Cation Exchange Capacity
CEGIS	:	Centre for Environmental and Geographic Information Services
cm	:	Centimeter
cmol/kg	:	Centimoles per kilogram
Db	:	Bulk density
Dp	:	Particle density
EC	:	Electrical Conductivity
f	:	Porosity
FAO	:	Food and Agricultural Organization
FC	:	Field capacity
g	:	Gram
GIS	:	Geographical Information Centre
GMB	:	Ganges Meghna Brahmaputra river system
GPS	:	Global Positioning System
GST	:	General Soil Type
ha	:	Hectare
HM	:	Hygroscopic moisture
HYV	:	High Yielding Variety
kg	:	Kilogram
Km	:	Kilometer

LOI	:	Loss on ignition
m	:	Meter
m^2	:	Square meter
m^3/sec	:	Cubic meter per second
me/100g	:	Milli-equivalent per 100 grams
mm	:	Millimeter
MWHC	:	Maximum water holding capacity
NST	:	National Science and Technology
OC	:	Organic carbon
OD	:	Oven dry
OM	:	Organic mater
PET	:	Potential evapotranspiration
ppm	:	Parts per million
PSO	:	Principal Scientific Officer
PWD	:	Public Works Department
PWP	:	Permanent wilting point
SEM	:	Scanning electron microscopy
SO	:	Scientific Officer
Sq. km	:	Square kilometer
SRDI	:	Soil Resources Development Institute
SSO	:	Senior Scientific Officer
TEB	:	Total Exchangeable Base
Total N	:	Total nitrogen
UNDP	:	United Nations Development Programme
US	:	United State
USDA	:	United State Department of Agriculture
XRD	:	X-ray diffraction

Chapter One

INTRODUCTION

CHAPTER - 1

INTRODUCTION

In the long past Bangladesh was strewn with innumerable geosynclines of various sizes and shapes full with water in the monsoon season and partially dry in the dry season. These water bodies used to be locally known as beels. Chalan beel was one of those historically famous beels of north Bengal. Many of these beels after filling up with sedimentary deposits turned out to be wetlands and are used for producing rice.

The wetlands are one of the most productive ecosystems on the surface of the earth exhibiting a great diversity of environmental conditions. They are considered as “the kidneys of landscape” on the basis of their functions. They are also described as the “biological supermarkets” because of the extensive food webs and rich biodiversity they support (RAMSAR, 1971). Wetlands are part and parcel of human life. Without the existence of wetlands, the continuity of bio-diversity could not be possible. Human life as well as other biota is directly or indirectly linked with wetlands ecosystem.

Wetlands all over the world as well as the wetland ecosystems carry out a great role in the conservation of biodiversity and maintenance of ecological balance in the concerned regions. The wetlands are eco-environmentally very important for the maintenance of floral and faunal equilibrium in the aquatic-terrestrial habitats. The human life as well as its surrounding environment is highly at critical position and is under threat due to misuse of wetlands in Bangladesh. The important coastal and inland wetlands encompass the vast floodplain and delta system of the Ganges, the Meghna and the Brahmaputra rivers. The total area of the wetlands in Bangladesh has been estimated at seven to eight million hectares, or about 50% of the total land surface areas (Banglapedia, 2006).

Wetland is defined by an area that remains regularly wet or flooded and has a water table that stands at or near the land surface for at least part of the year, such as a bog, pond, fen, estuary, or marsh. Conventionally, in our country wetlands are considered as marshy lands such as *haor, baor, beels, jheels* etc. The areas of individual wetland types in Bangladesh are as follows: *beel* (about 2 lac ha), *baors* (600 ha), *haors* (8 lac ha), *tidal wetland* (6 lac ha), *inundable floodplains* (54 lac ha), *rivers* (4.7 lac ha), *mangrove wetlands* (60,000 hectares), *fish ponds* and *tanks* (about 115,000 ha) (Islam, 2003).

The lower Atrai basin or the Chalan beel, as it is popularly known, is one of the large inland depressions in the northern part of Bangladesh, where a large quantity of *Boro* and *Aman* rice is grown. This beel was formed when the old Brahmaputra river changed its course to the Jamuna channel. The Jamuna river impeded the flow of the Padma, thereby causing the latter to deposit sediments at the mouths of the Karatoa and Atrai rivers. The diverted flow of these two rivers created the beel. The major portion of the basin extends over three adjacent districts such as Sirajgonj, Natore and Naogaon and a very small portion of Rajshahi and Bogra districts. It is located between $24^{0}21'$ to $24^{0}51'$ N latitudes and between $88^{0}49'$ to $89^{0}23'$E longitudes. The original area of the Chalan beel was about 108,800 ha which was reduced to about 36,800 ha at present because of rapid siltation (Islam, 2003).

Chalan beel is rapidly silting up. During the last 150 years, the southern edge of the beel has shifted northwards by about 19 km as a result of siltation by the Padma river. In 1909, investigations conducted by the Public Works Department (PWD) revealed that siltation from distributaries of the Ganges have reduced the area of the beel. Only 8,600 ha of the beel remained under water all year round, and large areas had dried out and were under cultivation. It was estimted that about 4.8 million cu m of silt were being deposited in Chalan beel each year (Banglapedia, 2006). If distributed uniformly over the whole of 36,800 ha, it would have raised the level at the rate of 1.27 cm a year (Banglapedia, 2006). Another inquiry was made in 1910 to further ascertain the condition of the beel during the dry season. It too found that its area had been further reduced. A third investigation carried out in 1913, ascertained that only 3100 ha remained under water throughout the year (Banglapedia, 2006). Siltation is continuing at a rapid rate; an extensive but rather haphazard system of local dams and embankments has been constructed for irrigation and flood control. Land is constantly being reclaimed for agriculture, and new villages are springing up throughout the area. In June 1987, just prior to the onset of the monsoon, the beel was completely dry except for some small man-made water storage reservoirs (Banglapedia, 2006). However, the whole region continues to be flooded to a depth of 3-4 meters from August to October. Because of siltation Chalan beel is gradually shrinking in size and in the future may disappear and its surface may mix with the surrounding floodplains.

Almost the whole of the beel area has now been scatteredly settled and is under cultivation during the dry season. The Chalan beel which is geologically known as lower Atrai basin, is being used by about 5 million people, predominantly through fisheries and agricultural activities (Hossain *et al.,* 2009).

In the seasonally flooded soils of the lower Atrai basin, mottles and gleys are the important redoximorphic features. They are reliable indicators of aquic moisture regime (Saheed and Hussain, 1992) in the body of the soils. Fertility level of the Chalan beel soils is moderate to optimum which is believed to be enriched by annual siltation during flooding (Islam *et al*., 2008a). There are considerable changes in landuse along with changes in soil properties (Uddin, 2002). Flood coatings are also common and extensive in these seasonally flooded soils of Bangladesh. Gleization appears to be the dominant pedogenic process of lower Atrai basin soils. Soil textural condition of Chalan beel is very much appropriate for rice production which varied from silty clay to clay (Islam *et al*., 2008a). Islam and Hussain (2008b) noted that mica was the dominant clay mineral closely followed by quartz in the soils of Chalan beel.

As noted lower Atrai basin is a seasonally flooded area. The present research has been undertaken on some representative soils there. The use of soil data in the regional and national agricultural development planning has been progressively gaining importance for effective management of land resource in our land-hungry country. The importance of such information stems from the need to feed the rapidly booming population in the face of shrinking, and at the same time degrading land resource base in the country. In an appraisal of the productivity system of an area, one needs to have a sound knowledge of the type and nature of soils, their input needs for an expected output in relation to the application of inputs.

The present research has been undertaken to collect detail information on the lower Atrai basin soils for characterization of the soils at the family category of the US Soil Taxonomy, which will be useful to soil scientists, agronomists, farm research scientists and the agricultural extension workers involved in agricultural development as well as the agro-technology transfer programs for increasing agricultural production in the soils of lower Atrai basin. Pedogenic information about soils is a prerequisite for sound and sustainable land management (Buol *et al.,* 2004). It is in this context that these seasonally flooded soils assume importance in producing bulk of Bangladesh's staple grains – mainly rice.

This research work has been carried out with the following objectives:

1. To examine the characteristics of Atrai river sediments involving the formation of Chalan beel.
2. To study the morphological and physical properties of some selected lower Atrai basin soils.
3. To determine chemical and physico-chemical properties of the soils.
4. To determine clay mineralogical composition of the soils of lower Atrai basin.
5. To carry out electron micrographic study of the clay fraction of the studied soils.
6. To throw light on the genesis of these soils.
7. To characterize the soils according to US Soil Taxonomy and some other systems.

Chapter Two

REVIEW OF LITERATURE

CHAPTER - 2

REVIEW OF LITERATURE

It was felt essential to review the previous research works carried out on wetland soils elsewhere by scientist on the different aspect such as morphological, physical, physico-chemical, chemical and mineralogical properties. A brief discussion of available literature on the above properties of floodplain soils in general and with special reference to those on the Atrai river alluvium in Bangladesh in particular is presented below.

2.1 General considerations

Wetlands are considered as the kidneys of landscape. Without the existence of wetlands, the continuity of bio-diversity could not be imagined. Human life as well as other biota is directly or indirectly linked with wetlands ecosystem. The human life as well as its surrounding environment may be at high risk and under threat due to unjustified management and destruction of wetlands in the country.

The RAMSAR convention defines wetlands as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brakish or salt, including areas of marine water the depth of which at low tide does not exceed six meters".

There are numerous other definitions of wetlands at the individual level of the various authors and nature lovers. But the definition given by the *RAMSAR convention* is internationally the most accepted one. *RAMSAR* convention (Ramsar sites) is concerned with wetlands of international importance. The *RAMSAR convention* was signed in *RAMSAR* (Iran) in 1971, and came into force in December, 1975. This convention provides a frame work for international co-operation for conservation of wetland habitats. The *RAMSAR convention* was established to halt the continued destruction of wetlands, particularly those which support migratory waterfowls and to recognize the ecological, scientific, economic and recreational values of wetlands. The *RAMSAR convention* covers fresh water, estuarine and coastal marine habitats and includes more than 844 sites with a total area of more than 54 million hectare. Up to 1998, the 94 countries that have signed the *RAMSAR convention* agree to conserve and protect their wetland resources and designate for conservation purposes at least one wetland site of international significance (RAMSAR, 1971).

Bangladesh is full of wetlands. There are about 1,14,160 hectares of beels, 1,92,367 hectares of haors and about 5488 hectares of baors in Bangladesh (Islam, 2011). Conventionally in our country we mean by wetlands as marshy lands, haor, baor, beels, jheels etc. Wetlands are located at every major bio-climatic zones and include mangrove swamps, peat bogs, marshes and fens.

Chalan beel is wide repute and is by far the largest where the name applied to a series of beel**s** interconnected with one another by various channels to form more or less one continuous body of water in the rainy season covering an area of approximately 140 sq. miles.

The main constituent beels of lower Atrai basin or the Chalan beel are, from west to east: (1) Purba Maddhanagar beel, (2) Piprul beel, (3) Dangapara beel, (4) Laror beel, (5) Tajpur beel, (6) Niala beel, (7) Chalan beel, (8) Majhagaon beel, (9) Briasho beel, (10) Chonmohan beel, (11) Satail beel, (12) Khardaha beel, (13) Darikushi beel, (14) Kajipara beel, (15) Gajna beel, (16) Bara beel, (17) Sonapatila beel, (18) Ghugudaha beel, (19) Kuralia beel, (20) Chiral beel, (21) Dikshi beel and (22) Gurka beel.

The lower Atrai basin or the Chalan beel, as it is locally known, is so large a water body that it can be easily called a lake in the rainy season. It is located between $24^{0}21'$ to $24^{0}51'$ north latitude and $88^{0}49'$ to $89^{0}23'$ east longitude. The Basin extends over three adjacent districts of Natore, Naogaon and Sirajgonj and very small portion of it's extends over Rajshahi and Bogra district (Fig 1). The lower Atrai basin extends over 45 unions of 12 adjacent upazilas of five districts but the major parts of its covers an extensive area of Taras upazil a of Sirajgonj district, Singra upazila of Natore district and Atrai upazila of Naogaon district (Fig 2 and 3).

Some of the important characteristics of the lower Atrai basin soils are the intractably complex pattern, in which they often occur, their mineralogical composition, the rapidity of profile development, early formation of mottles, formation of subsoil flood coatings and the dominant influence of hydrology on their morphological features and their agricultural potentials.

Each year during monsoon season, the flood water carries with it new sediments which consists of sand, silt, clay and organic matter. These alluvial materials are derived from wide-range of igneous, sedimentary and metamorphic rocks. The minerals in alluvia weather rapidly under high temperature and alternate wet and dry conditions and release plant nutrients such as, K, Fe, Ca, Mg etc. As a result, soils become naturally fertile and productive. Hence, for the improvement of soil productivity siltation is to be encouraged.

In the lower Atrai basin areas of Bangladesh, silt content is usually high (Islam, 2011). Deposits of the Brahmaputra and the Meghna rivers have high silt content while in the Ganges floodplain clay is dominant in many places. Sediments of all the three rivers have high quantity of mica minerals (Islam, 2011).

Development of soil profile can be extraordinarily rapid, except in permanently wet sites and 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 (specially earth worms) destroys alluvial stratification to 5 -50 cm within

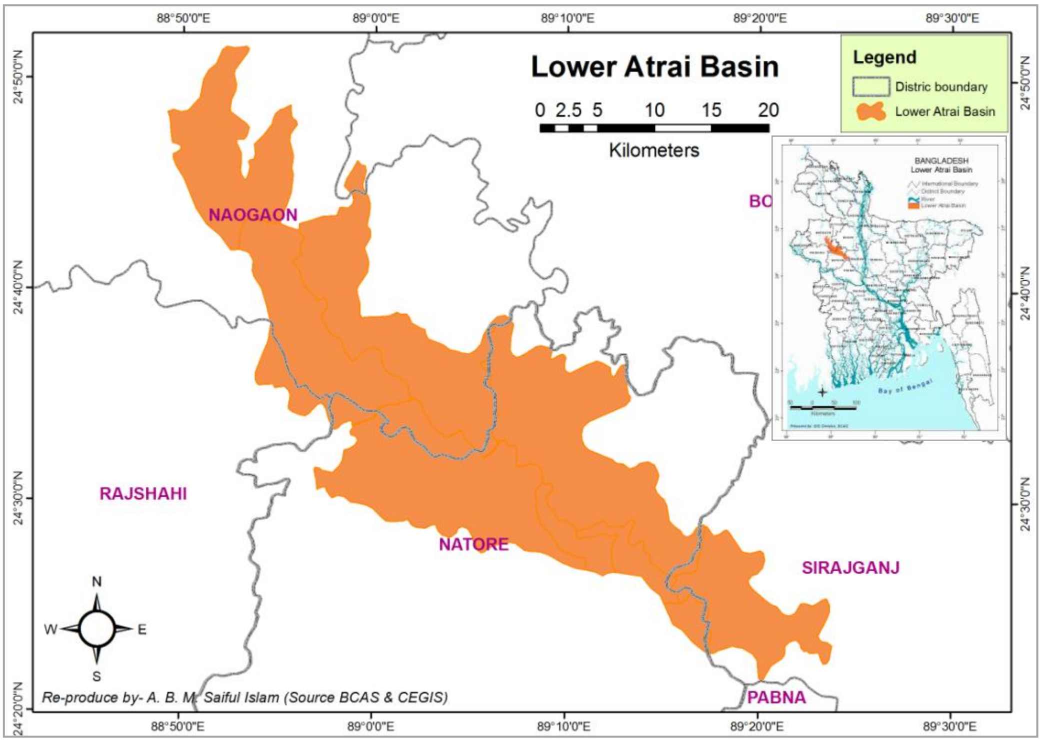


Fig 1. Map shows the lower Atria basin extends over five adjacent districts of Bangladesh.

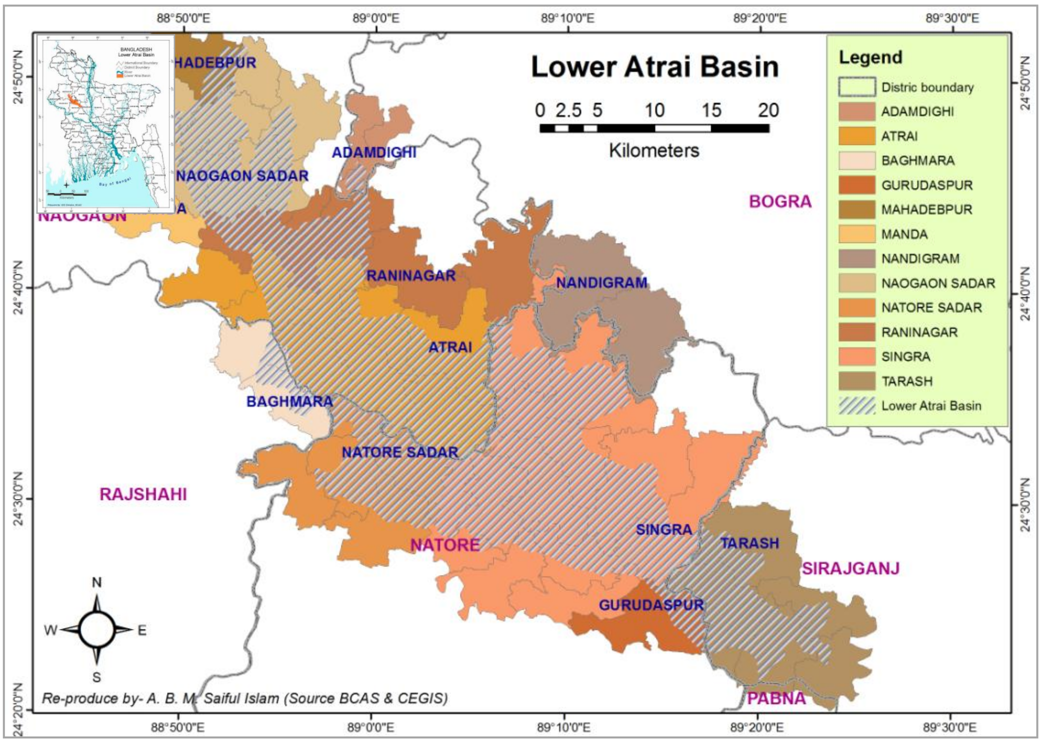


Fig 2. Map shows the lower Atria basin extends over 12 adjacent upazilas of five adjacent districts of Bangladesh.

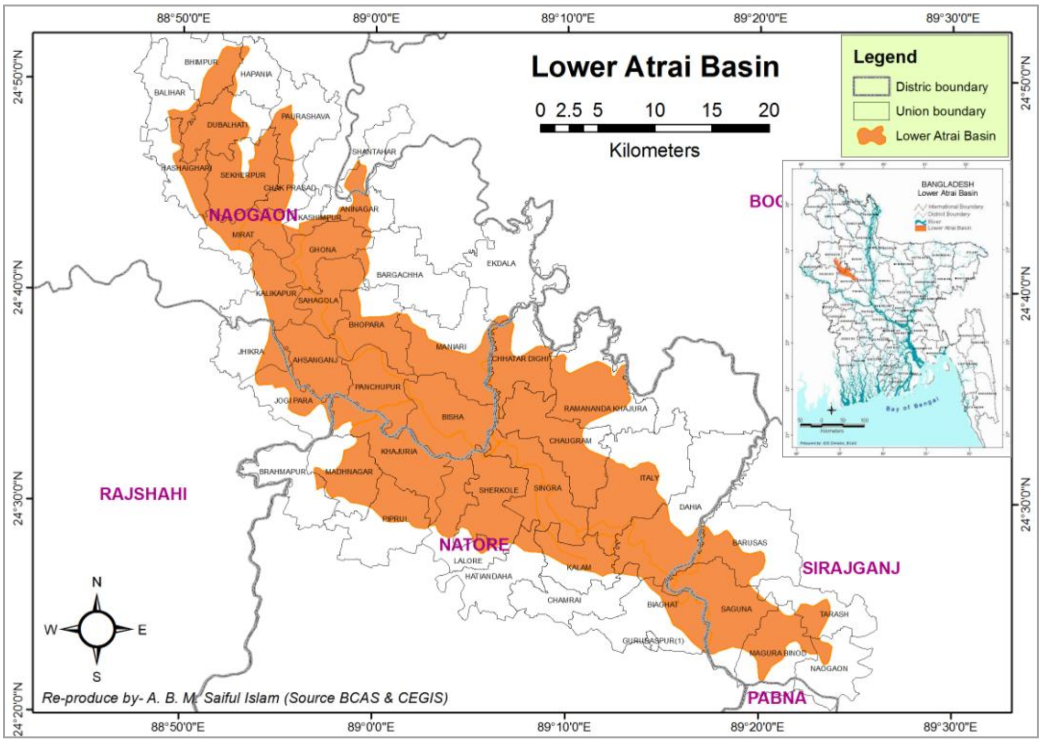


Fig 3. Map shows the lower Atria basin extends over 45 unions of 12 adjacent upazilas of five adjacent districts of Bangladesh.

Plate 1. Irrigated *Boro* paddy cultivation on lower Atrai basin soils.

about 25 years (Brammer, 1971). In materials heavier than light silt loams, prismatic structures develop in the subsoil under the influence of seasonal wetting and drying whereas clayey materials may develop a blocky structure. Ped rices quickly become coated with gleyans comprising unoriented clay, fine silt and humus eluviated from the top soil. Brammer (1971) pointed out that within a span of 5 years, a cambic horizon may form in floodplain sediments. Because of seasonal flooding and heavy rainfall, conditions in the kharif (rainy) season generally are better suited for growing wet land crops (especially rice). In the rabi season, permeable ridge soils generally are well suited for growing dry land crops. Heavy basin clays generally are better suited for boro paddy. Loamy and silty clay soils on intermediate positions may be suitable for both dry land crops and irrigated boro paddy cultivation (Plate 1).

The soil survey project has identified 17 general soil types in Bangladesh. Among them, lower Atrai basin includes ***Noncalcareous dark grey floodplain soils*** (FAO, 1971). These soils are slightly sticky when wet and noncalcareous crack widely when dry.

2.2 Properties of floodplain soils

2.2.1 Morphogenetic properties

The morphological features of soils are of prime importance for their identification and classification, because they represent the direct results of the past and present 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.

Soil colour

Among the conspicuous features of any soil, colour is the most important and highly useful for its identification and characterization. Colour is one of the first properties noted in the field description of soils. Colour involves an indirect identification of important characteristics of soil water regimes. Soil Scientists commonly use grey colours (Chroma<2) as an indicator of seasonally/permanently saturated and reduced soil conditions.

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 had chroma of 2 or less with mottles, whereas the latter had chroma of more than 2.

Sehgal *et al.* (1968) reported that the soils were light grey to light yellowish grey even when the soils were mostly poorly drained in the soils of the Sutlej floodplain area.

Hussain and Swindale (1970) studied a large number of profiles along the coast of the Hawaiian Islands having different degrees of drainage impedance. They noted that the grey hydromorphic soils of the Hawaiian island had hues ranging from 2.5 Y to 10 YR, values ranging from 3 to 6 and chromas ranging from 1 to 3.

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.

Daniel *et al.* (1971) have indicated that reducing conditions result in greyish colour in poorly drained soils and oxidizing conditions are responsible for the brighter colours in better drained soils. A large study of seasonal fluctuations of water table in soils have shown that soil colours can be used as a general indicator of saturated and reduced conditions, as well as movement of ground water table (Mackintosh and Hust, 1978; Zobeck and Ritchie, 1984; Pickering and Veneman, 1984; Evans and Franzmeir, 1986).

Buol *et al.* (1980) stated that since colours are good indicators of soil behaviour, and the environment in which they form, they may be helpful in arriving at conclusions concerning their best uses and management.

Usually in young soils colour is an indication of parent materials while in freely drained mature soils, it is an indication of climate. Generally low colour development equivalent in the floodplain soils is an interesting feature (Hussain and Chowdhuri 1981). This is due to their poor drainage conditions and annual flooding.

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).

Diwakar and Singh (1992) studied some Tal land soils developed on river-borne alluvium in Bihar in India and noted the development of dark brown to very dark grayish brown colours. The factors that appear to be responsible for this dark colour are high organic matter, high clay content and presence of sufficient iron and manganese compound.

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.

According to the above authors "perched" water tables are characteristic of "epi saturation". They are supplied by rainfall. The water is perched in the upper part of the soil on top of slowly permeable horizon. If the water saturates the horizon for enough to reduce iron and manganese, they will move vertically downward through cracks and macropores into lower unsaturated horizons where they will precipitate upon oxidation, in response to an increase in pH or, both.

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.

Sidhu *et al.* (1994) reported that some Entisols under different soil moisture regimes in Punjab had hues of 10YR. However, 2.5Y to 7.5YR hues were also observed in some subsurface horizons of the above soils. Values and chromas of these soils varied from 3 to 7 and 2 to 6, respectively.

Khan (1995) observed that the top soils colour generally ranged from grey to dark grey and the sub soils colour ranged from olive grey to grey when he studied some benchmark soils from the seasonally flooded recent floodplains of Bangladesh.

Mazumder (1996) elucidated from the study of some soil series developed on the Brahmaputra alluvium that topsoil colour ranged from grey to dark grey, while the subsoil colour is olive to grey with abundant mottles along the old and new root channels.

Begum *et al*. (2004) found that the colour of the Manpura Island soils of Bangladesh vary from very dark grey to 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.

Uddin *et al.* (2009b) 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. Islam *et al.* (2009) also found the same results in the Gangetic Alluvium in Bangladesh.

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 which caused by prolonged submergence during the monsoon season.

Hossain *et al.* (2011) reported that the soil matrix had a mixture of olive brown (2.5Y 4/4), light olive brown (2.5Y 5/4; 2.5Y 5/6), Grewish brown (5Y 4/1) and dark grey (5Y 4/1) colours of some soils from the Ganges river floodplain of Bangladesh.

Khan *et al.* (2012) elucidated from the study of three surface-water gley soils from the Meghna floodplain of Bangladesh 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 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, 2014).

Islam *et al.* (2014b) pointed out from the pedogenesis and characterization of some soils of Chalan beel of Bangladesh that the matrix colour is a combination of grey, dark grey and grayish olive. They further noted that above colours in the soils developed due to their seasonal submergence. They also found the similar results in some seasonally flooded soils of Bangladesh in another study.

Concretions and mottlings

Mottling an important property in the seasonally flooded soils in the floodplain areas, The matrix colours of the soil horizons, in conjunctions with the nature of the mottles, broadly reflect the different moisture regimes at the three sites although the distinction between imperfectly and poorly drained soils was not clear.

In pedogenic study of some benchmark soils of Bangladesh, Khan (1995) reported that the floodplain soils of Bangladesh are characterized by the presence of ped coatings and variously coloured mottles along the old root channels.

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 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.

Uddin *et al.* (2009b) 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. Islam *et al.* (2009) also found the similar results in Gangetic Alluvium of Bangladesh.

Hossain *et al.* (2011) observed that abundant quantities of variously coloured mottles prominent in the middle zone of the profiles of the Ganges river floodplain of

Bangladesh and they also reported that alternate wetting and drying conditions in these soils resulted in the reduction and subsequent release of iron oxides, which were accumulated in the form of brown, light olive brown, bark brown and dark yellowish beown mottles in the middle zone of the profile.

Hasan *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) elucidated from the study of three surface-water gley soils from the Meghna floodplain of Bangladesh that all the soils have dark brown to dark yellowish brown mottles prominent in the middle zone of the profile because of alternate oxidation reduction condition. Islam *et al.* (2014b) also found the same results in the Chalan beel area of Bangladesh.

Flood coatings

Flood coatings is an important property in the seasonally flooded soils in the floodplain areas, 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 colour. These shiny materials are composed of clay,fine silt and humus.

Brammer (1971), further reported that the colour of the flood coatings were same as that of the top soils, grey where the top soil is grey (moist); dark grey when the top soil is dark grey, This indicates that the materials have been derived from the top soil and not from suspended materials in the flood water. It also indicates that the flood coatings are not pressure coatings.

According to Brammer (1971) the flood coating materials are believed to move from the top soil under hydraulic pressure when the soils are flooded. The coatings are most prominently developed on horizontal as well as vertical ped surfaces in soils that are deeply flooded, and least developed in ridge soils that are only shallowly flooded for short periods. Flood coatings may develop in soils under cultivation, forest and grass land, and on floodplain as well as terrace land; the common factor in their occurrence being seasonal flooding (Brammer, 1971).

Particle orientations in flood coatings have not been studied well in the seasonally flooded soils of Bangladesh. They are quite extensive in the soils of the Ganges, Meghna and Brahmaputra floodplains. Brammer (1971) proposed the name gleyans for these coatings since the coating materials are always gleyed and usually have a grey colour (reduced).

Akter *et al.* (2004), Islam *et al.* (2009) observed that flood coatings were abundant in all the studied pedons in some seasonally flooded soils of Bangladesh.

Uddin *et al.* (2009b) reported that downward translocation of clay is thought to be minimal in soils. However, surface materials are found to move down through cracks forming flood coatings in Surma-Kushiyara floodplain soils of Bangladesh.

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 Brickman (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), Islam *et al.* (2009) 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). Islam *et al.* (2014b) also reported the similar results in the Chalan beel area of Bangledesh.

Plough pan

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

Joshua and Rahman (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 levee areas. This condition could be attributed to the structural breakdown and compaction of the soils due to ploughing under wet conditions.

SRDI Staff (1965-86) 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.

Cambic Horizon

Cambic horizon is a sub soil horizon with some weak indication of either an argillic or spodic horizon, but not enough to qualify as either for example less than 1.2 times as much clay as an overlying horizon. In these soils the cambic horizon is one of the important diagnostic horizon. The cambic horizon is an important horizon that does not have the dark colour and the organic matter content. Presence of an aquic moisture regime is an evidence of alternation of oxidation and reduction conditions.

Cambic horizons are subsurface soil layers of pedogenic change without appreciable accumulation of illuvial material (clay, Fe + Al + humus, carbonate or gypsum), and are part of the USDA Natural Resources Conservation Service's (formerly the USDA Soil Conservation Service) Soil Classification System "Soil Taxonomy" (Soil Survey Staff, 1999). The presence of the cambic horizon in a soil indicates a distinctive pathway of soil development (Smith, 1983; Brasfield, 1983). Cambic horizons are found in Inceptisol, Mollisol, Aridisol, Andisol, and Vertisol soils (Soil Survey Staff, 1999).

Soil Taxonomy (Soil Survey Staff, 1999) defines a cambic horizon as a nonsandy zone of weak pedogenic development. Cambic development is manifested primarily as soil structure, color change, or the loss of carbonates. The definition also excludes cemented horizons and horizons with argillic, kandic, oxic, or spodic properties from cambic horizons. As indicated by Guy D. Smith (the author of Soil Taxonomy) the cambic horizon definition was an attempt to define a subsurface horizon that was found in a large number of soils that were excluded from other soil orders such as Alfisols, Oxisols, etc. (Brasfield, 1983; Smith, 1983; Smith, 1986). Generally cambic horizon soils show weak B horizon development. Because of the wide array of genetic pathways encompassed in soils with cambic horizon, the cambic definition tends to be cumbersome and less quantitative than the definition of other Soil Taxonomy subsurface horizons (e.g., argillic and spodic horizons).

Ciolkosz and Waltman (1995) reported that blocky (angular and subangular) and prismatic are the most common B horizon structural types in the Pennsylvania floodplain soils with cambic or other subsurface horizons. In B horizons it is frequently observed that blocky structure will occur in the upper B and with depth it will grade into prismatic with blocky or massive interiors.

Color or more correctly the change in color in cambic horizon development stems from two sources. The first source is the oxidation of primary minerals in well drained soils and the accumulation of iron from the primary minerals as the free iron oxide minerals goethite and hematite. These iron oxides give the cambic horizon its yellowish-brown (goethite) or red (hematite) color (Ciolkosz and Dobos, 1990).

2.2.2 Physical properties

Soil texture

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

Swindale (1958) observed that the hydromorphic soils generally contain more clay than the associated better drained soils. He further added that the increase in clay is probably due, at least in the intrazonal gley soils, to the deposition of clay washedout of the surrounding high lands and hills. However, it might be that there was more clay formation in the gley soils than in the better drained soils because of neutral to alkaline reaction and the presence of greater amount of Ca^{++} and Mg^{++} ions. The heavy accumulation of clay near the surface was also reported by George *et al.* (1958) for the same humic gley soils in Ohio.

Goel and Agarwal (1959) reported that sand content in two soils of Gangetic alluvium near Kanpur was high at the surface and only very slight illuviation of clay was observed. Variation in the silt content was slight in the different horizons. On the other hand, the soils exhibited considerable illuviation of clay from surface downward.

SRDI Staff (1965-86) 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 clays in older floodplain areas were very heavy and cracked widely when dry and flood coatings were also quite common in them. SRDI Staff (1970) found that the soils of ridge and inter-ridge depressions of the old Ganges meander floodplain have loamy to clayey textures. They also reported that most ridge soils in the old Brahunaputra floodplain are silt loam to silty clay loam and in the interridge depressions and channels they are mostly silty clay loam to silty clay.

Sehgal *et al.* (1968) found that the soils of the Sutlej floodplain have textures of loamy sand to silt loam. SRDI Staff (1970) reported that the soils on ridges and interridge depressions of the young Ganges meander floodplain, are silt loam to silty clay. On the other hand, the soils of ridges and interridfes depressions of the old ganges floodplain have loam to clayey texture.

Brammer (1971) stated 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.

Hussain and Chowdhury (1981) reported that the physical properties of a number of cracking clay soils and observed that clay was the dominant fraction followed by sand and silt. The mean clay content of the soils was 55 percent. Joshua and Rahman (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) studied morphological features of some soils from the Manpura Islad in Bangladesh and concluded that the dominant texture of the soils is silt loam.

Uddin *et al.* (2009b) 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. Akter *et al.* (2011), Islam, *et al.* (2009) 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.

Khan *et al.* (2012) elucidated from the study of three surface-water gley soils from the Meghna floodplain of Bangladesh that the soils are medium to fine textured, where textural class ranged between silt loam and silty clay. Hasan *et al.* (2012) also found the same result from the study of some soils from the Ganges floodplain of Bangladesh.

Soil structure

The importance of soil structure in soil classification and soil productivity can hardly be overemphasized (Soil Survey Staff, 2014). The plant growth capability of any soil and its response to management depends much on its structure.

Bear (1965) stated that alternate wetting and drying situations play an important role in soil structure formation. Wetting which leads to expansion and gelation and drying which leads to construction and degelation are extremely important phenomena in structure formation, and hence, in profile differentiation with respect to structure development. Wetting and drying and expansion and contruction affect structure formation because they affect orientation of the clay particles with respect to one another and also with respect to the plant roots (Bear, 1965).

SRDI Staff (1970) 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.

Sharma and Dev (1985) observed blocky structure in the B horizon of soils formed on different geomorphic surfaces in a flood plain of the Punjab.

Brammer (1996) stated that polygons provide the prismatic structure which is typical of most loamy and clayey floodplain soils. Clay material cracks horizontally and usually develop both blocky and prismatic structure. Prismatic structure may be broken to angular blocky or subangular blocky in less clayey materials.

Mazumder (1996) studied some Brahmaputra floodplain soils and found that prismatic to angular blocky structure developed in the subsurface horizons of the profiles whereas the surface soils were massive because of prolonged ploughing.

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 Uddin *et al.* (2009b) in the Surma-Kushiyara floodplain, Khan *et al.* (2012) in the Meghna floodplain, Islam *et al.* (2009) in the Gangeic Alluvium, Islam *et al.* (2014a) in some seasonally flooded soils in Bangladesh.

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.

Ali *et al.* (1966) found that most of the water was released with 1 to 2 atmospheric tensions in alluvial soils. The moisture retention was mainly a function of amount and nature of clay and to some extent to organic matter.

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.

"Soil moisture retention characteristics are the most unique among the physical properties of soils. They provide useful information about soils tilth, its structural stability, pore size distribution and magnitude and rate of water movement within the soils" (Sekhon and Arora, 1967). It has also the prime importance in soil water management practices especially for policy planning in irrigations purpose (Velayutham and Raj, 1977)

The variation in water content at different tensions within the profiles may be due to variation in nature and amount of clay minerals and organic matter content of the soils. Diwakar and Singh (1992) suggested that clay fractions might be dominant modifier of the water content at higher energies of retention.

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.

2.2.3 Chemical and Physico-chemical properties

The chemical properties mainly deal with the chemical composition of the soil materials and indicate the nature and extent of weathering and stage of development of soils. They also indicate the mineralogical composition of the soil materials. These properties give an idea about the nutritional status of soils.

Soil reaction (pH)

Soil reaction is the most important single chemical characteristic which have 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.

Mujib *et al.* (1969) and Brammer and Brinkman (1977) concluded that the increase of pH with depth is a common feature in the seasonally flooded soils of Bangladesh. Hussain and Swindale (1970) noted that the increase of pH with depth is a characteristic property of the gley soils.

On flooding the pH values of soils may undergo change. Ponnamperuma (1975) reported that the upland soils, unlike the submerged soils, are not able to adjust their pH levels to the favorable range of 6.5 to 7.0. This means that manganese and aluminum toxicities can occur in strongly acid soils and iron deficiency in alkaline soils.

Hussain and Chowdhury (1980) studied the physico-chemical properties of some soils from the moribund Ganges delta in Bangladesh and found that the reaction of the soil is neutral to slightly alkaline with a pH in the range of 6.7 to 8.0. The pH values increased slightly with depth. Rahman *et al.* (1992) observed similar feature in some soils from calcareous Gangetic alluvium. In the noncalcareous soils of Bangladesh this feature is even more regular (Brammer, 1971).

Kumar *et al.* (1981) found that after one week of submergence the pH of hill soils increased and that of "tarai" soils decreased. After the third week, the pH of all the soils approached neutrality (6.9 to 7.2). The range of initial pH of the hill soils was from 6.0 to 6.6 and that of "Tarai" soil was from 7.3 to 7.6.

Hussain *et al.* (1982) studied the properties and genesis of some pedons from the Tiperra surface abd observed that the soils were very strongly acid at the surface and the pH gradually increased with depth in the pedons. The gradual increase of pH with depth was an important characteristic feature of all the floodplain soils in Bangladesh (Brammer, 1971).

Khamparia *et al.* (1984) stated that the pH of the alluvial soils (Entisols) of Gird region of Madhya Pradesh ranges between 6.7 and 9.2. Chakraborty *et al.* (1984) studied the morphology and physico-chemical properties of some alluvial soils of Assam and reported that the pH of the soils increased with profile depth.

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.

Khan (1995) in his study on some Benchmark soils of Bangladesh observed that the pH of Gangachara and sonatola soil series of Brahmaputra floodplains ranged from 5.99 to 7.08. In each of these soil profiles, there was a trend of increasing pH values with depth.

Mazumder *et al.* (1997) found the pH of the Chalan beel soils of Bangladeshnd ranges from 4.8 to 8.9 there was a trend increasing pH with depth. 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 pH of the soil ranges from 6.21 to 8.15 and there is a gradual rise in pH with depth in the soil profiles.

From the study of pedological and edaphological aspect of the Monpura Iland in coastal area of Bangladesh Begum *et al.*(2004) pointed out that the reaction of the soils are alkaline with a mean value of 8.0. Islam (2007) elucidated from the pedological study of some representative soils from the Chalan Beel of Bangladesh that the ranges of soil pH from 6.2 to 7.1 with a mean of 6.60 and the vertical distribution of pH showed an increasing trend with depth.

Islam *et al*. (2008a) 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. Uddin *et al*. (2009b) 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) conclude from the pedogenic study of the seasonally flooded soils of Bangladesh that the pH values of the soils ranges from 5.4 to 7.0 and the values shows increasing trends with the increase of depth.

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. Islam *et al*. (2014a) found the similar results in some seasonally flooded soils of Bangladesh.

Organic matter

Many important soil properties including absorption and retention of water, reserves of exchangeable bases, capacity to supply N, P and other nutrient elements to growing crops, stability of soil structure, adequacy of aeration and the innumerable reactions that occur during pedogenesis are influenced to some degree by the organic matter content in soils.

The function of organic matter in the soil is both direct and indirect. Its direct role is concern with the provision of plant nutrients through decomposition and mineralization. Its indirect role is Associated with humification and effects on most of the chemical and biochemical processes, by which the chemical, physic-chemical, physical and mineralogical properties of soils are influenced (Neue and Mamaril, 1985)

Mujib (1968) reported 1.37 percent organic matter in some soil of Brahmaputra as well as Meghna alluvium of Bangladesh. SRDI (1965-86) analyzed about a large number of samples from many representative soil profiles covering almost all the areas of Bangladesh and found that the organic matter content of soils were generally low; ranging from 0.3 to1.5 percent in upland soils, 1.5 to 2.0 in medium low land areas and 2.0 to 3.5 percent in the low land areas. In beel areas, the organic matter content was about 4.0 percent (Rahman *et al*, 1992).

Hussain and Chowdhury (1981) studied the pedochemistry of some cracking clay soils in the basin areas of Dhaka and Comilla districts and observed that organic matter in the surface horizon was quite high and decreased with profile depth. Gupta *et al.* (1984) found organic carbon in decreasing order with depth in the profiles of some dark grey hydromorphic soils of lower Gangetic plains in India.

According to the classification proposed by BARC (1989), the percentage of organic matter within the limit of 1.0 -1.7 fell in the low range. Huq (1990) commented that most agricultural soils of Bangladesh have low organic matter content.

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 trend 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.

Mazumder *et al.* (1997) concluded from the study of the soils of Chalan beel of Bangladesh that the organic matter content of the soils ranged from 0.16 to 8.64 with a mean value of 1.77 percent. They also point out that the organic matter percentage were rather higher at the surface soils but showed a rapid fall with depth and the average content of organic matter in the surface soil was 3.5%.

From the study of some hydromorphic soils from the Ganges delta in Bangladesh Ferdous *et al.* (2005) concluded that the organic carbon content ranges from 0.14 to 6.97 percent with a mean value of 1.30 percent and organic carbon content shows decreasing trend with depth. Begum *et al.* (2004) reported that the organic carbon content showed a mean value of 0.76 percent from the pedological and edaphological study of Monpura Island in Bangladesh.

Islam *et al*. (2008a) concluded from their study of some low land rice soils of the lower Atrai basin of Bangladesh that the organic matter content of the soils varied from 0.58 to 2.40 percent with a mean value of 1.38 percent. He also noted that the organic matter content showed a general tendency of decrease with depth and the decrease is more or less gradual.

Uddin *et al.* (2009b) 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 and Islam *et al.* (2014a) in some seasonally flooded soils of Bangladesh

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.

Total Nitrogen

The total nitrogen content of soils ranges from <0.02% in some subsoils to >2.5% in some peats of Bangladesh (SRDI Staff, 1965-1986). The surface layer of most cultivated soils in Bangladesh contains between 0.06 and 0.5% total N (Bremner and Mulvaney, 1982)

The total and other forms of nitrogen increase with increase in altitude and decrease with depth (Singh and Datta, 1988). Das *et al.* (1992) observed that the nitrogen content in soil decrease due to cultivation. Soil subjected to air drying before flooding, high temperature and puddling stimulate mineralization of soil N (Patnaik and Rao, 1979).

From the study of the vertical distribution pattern of NPK in some alluvial soils with aquic moisture regime in Bangladesh, Hussain *et al.* (1983) reported that the total and available nitrogen content varied in the pedons and showed an irregular distribution pattern in the profile. Saheed and Hussain (1992) reported that the total nitrogen contents in the wet mineral soils in Bangladesh were low and decreasing tendency with depth.

Mazumder (1996) elucidated from the pedogenic study of some soils from the Brahmaputra floodplain of Bangladesh that the total nitrogen content ranges from 0.02 to 0.13 percent with a mean value of 0.06 percent, he also point out that the total nitrogen content shows a general tendency of decrease with depth but the decrease is, however, not gradual. He further noted that the total nitrogen content of surface horizon of the pedon is higher than those in the subsurface horizon.

Mazumder *et al.* (1997) concluded from the study of the soils of Chalan beel of Bangladesh that the total nitrogen content of the soils ranged from 0.01 to 0.56% with a mean value of 0.11%. They also point out that the organic matter percentages were rather higher at the surface soils and progressive decreases of total nitrogen content from the surface downwards were noticeable.

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.

Islam *et al*. (2008a) concluded from their study of some low land rice soils of the lower Atrai basin of Bangladesh that the total nitrogen content ranges from 0.06 to 0.17 percent with a mean value of 0.11 percent. They also reported that the low nitrogen content of the soil may be attributed to the loss through denitrification. The denitrification was probably due to poor drainage condition of the soils.

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), Islam *et al.* (2014a) conclude 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.

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.

C/N ratio

From the pedogenic study of some soils from the Brahmaputra Floodplain of Bangladesh, Mazumder (1996) postulated that the C/N ratio ranges from 4 to 12and distribution pattern of C/N ratio value in the soil profiles from the surface downward show an irregular pattern with depth, this irregular distribution of C/N ratio in the profiles is due to the degree of decomposition at various horizon. Mazumder *et al.* (1997) point out from their study of the soils of Chalan beel of Bangladesh that the C/N ratio of the soils ranged from 8 to 11 with a mean value of 10.

Ferdous *et al.* (2005) concluded from the study of some hydromorphic soils from the Ganges delta in Bangladesh that the C/N ratio in the profile ranges from 5 to 15 with a mean value of 10. This indicates that the organic matter fraction is highly oxidized even if these soils remains flooded for more than three months. They also noted that the vertical distribution pattern of C/N ratio of the studied soils show an irregular trend.

Islam *et al*. (2008a) reported that the C/N ratio of the soils ranges from 5 to 9 with a mean value of 7 from their study of some low land rice soils of the lower Atrai basin of Bangladesh. Rahman *et al.* (2009) pointed out that the C/N ratio is slightly higher in the Ganges river sediments.

Hoque *et al.* (2009) stated that the C/N ratio of the Ganges tidal floodplain soils of Bangladesh ranges from 8 to 12, this indicate that microbial activity in these soils appear to be quite vigorous. Islam *et al.* (2009) also found the same result of the Gangetic alluvium soils.

Cation exchange capacity (CEC)

Cation exchange phenomena are the most important properties in soils. Cation exchange phenomena are considered as an index of soil fertility as well as soil quality. It plays an important role in the genetic processes of soils.

Karim and Islam (1956) reported that the average CEC of clay and silt fractions of some soils and sediments of Bangladesh were 27 and 12 cmol/kg soil, respectively.

Rahman *et al.* (1968) in a comparative study of the soils developed on younger and older gangetic alluvium in Rajshahi district observer higher cation exchange capacity in the older soils (average 26.3 cmol/kg soil) as compared to the younger soils (average 15.8 cmol/kg soils)

Lavit *et al.* (1969) stated that cation exchange capacity of soils significantly correlated with clay, silt and organic matter. Contribution of clay towards the CEC values of soils was a dominant feature.

Gupta and Misra (1970) point out that the cation exchange capacity of some soils from Gwalior ranged from 11.4 to 21.3 cmol/kg soil having textures from clay

to sandy loam.

SRDI Staff (1970) 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 CEC of some soils ranged 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.

Uddin *et al.* (2009b) 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.

Exchangeable cations

Wright *et al.* (1955) stated that the cations such as Ca^{++}, Mg^{++}, Na^{+} and K^{+} are known to be sensitive to leaching during weathering and soil formation. In well drained normal soils Ca^{++} is the dominant cation.

Kanehiro and Chang (1956) noted that as the gleization process progresses, the exchangeable Ca^{++}/Mg^{++} ratio tends to approach unity. It has been reported that under the gleization process of soil formation, exchangeable Mg^{++} becomes the dominant cations in the exchange complex (Sunders, 1959).

Ponnamperuma (1972) reported that submergence of a soil causes an increase in the concentration of ions in the soil solution, as indicated by the rise in specific conductance. In a reduced soil, these ions are chiefly Ca^{++}, Mg^{++}, K^{+} and Na^{+} which is not involved in the reduction process, the increase in their concentration is a secondary effect of submergence and reduction.

Brinkman (1970) reported that during the anaerobic phase of soils, free iron is reduced with concurrent oxidation of organic matter and formation of hydroxyl ions. The Fe^{++} ion displaces the cations and the displaced cations are leached out.

Hussain and Swindale (1970) studied the grey hydromorphic soils of Hawaii and reported that the average exchangeable Ca^{++}/Mg^{++} ratio was 1.5.

Islam and Islam (1973) studied some submerged soils of Bangladesh and found that the exchangeable Ca^{++} concentration first increased after submergence and then decreased. He noted that the velocity and magnitude of increase of exchangeable Ca^{++} varied in different soils. In all soils, the peak values were obtained in the ninth week of submergence.

In a study on the physic-chemical characteristics of some coastal saline soils of Bangladesh, Hussain and Rahman (1983) observed that among the exchangeable cations Ca^{++} and Mg^{++} were the dominant.

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.

Uddin *et al.* (2009b) 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^{+}.

Base saturation percentage

According to the SRDI staff (1965-86) the base saturation of Brahmaputra floodplain soils ranged between 50 and 100 percent. Bychenko and Komarovskaya (1971) reported 90% base saturation in the floodplain soils of Afanasiev area of Kirov region.

Khan (1995) found the base saturation percentage of Brahmaputra floodplain soils was ranged from 53 to 100 and the mean value was 77 percent. Increase of base saturation with depth was reported by Mazumder (1996) in some deep water rice soils of Bangladesh. Ali (1994) observed high degree of saturation in some alluvial soils of Brahmaputra and Gangetic floodplains. 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.

Free iron and manganese oxides

Free oxides of iron and manganese are a striking feature of seasonally flooded soils. The amount of free oxides in soils is very important in evaluating the mineral weathering and pedogenic changes in soils (Mckeague and Day, 1966; Hussain, 1968; Blume and Schwertmann, 1969; Hussain and Swindale, 1974 and Santos *et al.,* 1986). The accumulation or impoverishment of iron oxides in soils are important pedochemical processes (Blume and Schwertmann 1969), Daniel *et al.* (1962) stated that, poor drainage condition was probably the important factor that caused the decrease in free manganese oxide content of the top soils.

Oades (1963) stated that the primary iron bearing minerals in soils in the soils usually occurred in the coarser fraction and separation of the clay fraction will serve to exclude most primary iron mineral. The iron oxide, iron salts and iron associated with organic matter are collectively termed free iron in soils. Oades (1963) further stated that the most commonly occurring iron oxides were goethite, hematite, magnetite and lepidocrocite.

Mckeague (1965) reported that the low content of free iron oxide is neither due to leaching of iron nor to the accumulation of iron in mottles but presumably resulting from reduction.

Joffe (1966) stated that the surface enrichment of free iron oxide was probably due to the fact that ferrous iron is oxidized easily to form free iron oxide at the surface, while in the subsoil ferrous iron does not change easily.

Soilen and McCraken (1967) in an experiment on iron oxide and coloration in certain well drained coastal plain soil in relation to the soil properties and classification concluded that iron oxide is the dominant factor in influencing hue of soils in the coastal plain area.

Kojima and Kawaguchi (1968) studied iron oxide minerals occurring in mottles found in rice soils of Japan and tropical Asia. Hematite was not positively detected even in the samples from tropical Asia, while goethite was found in many samples regardless of their origin. Lepidocrocite was dominant in most Japanese rice soil samples but was not detected in samples from tropical Asia.

Brinkman (1970) reported that during the anaerobic phase of soils, free iron is reduced with concurrent oxidation of organic matter and formation of hydroxyl ions. The ferrous iron displaces other cations and the displaced cations are leached from the soils. Ottow (1973) reported that in waterlogged rice soils Fe^{++} ions are formed by reducing ferric oxides by different heterotrophic organisms.

Hussain and Swindale (1970) reported that under the gleization process of soil formation, free iron and free manganese were found to be concentrated near the surface and above the fluctuating ground water table.

Karim and Hussain (1970) in a study on the distribution of different forms of iron oxide in some soil profiles found that average free iron oxide content in the upland soils was higher than that of the lowland soils. They further noted that the distribution of free iron oxide content was irregular in valley soils. The free iron oxide contents were higher in the mottled zone of the soils.

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 (Garrels 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. Thus soil coilur, as determined by the type and distribution of iron oxides within the profile, is helpful in explaining the soil genesis and is also an important criterion for naming and classifying 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.

The movement of manganese oxide and its distribution in the soil profiles was a significant criterion in a pedogenic study as it behaves like iron oxide (Joffe, 1966). Mandal (1960) however, noted that the course of transformation of manganese was different from that of iron.

Bhattacharya and Gosh (1986) studied a number of soils from India representing Entisols, Alfisols, Vertisols and Uitisols. They found that Entisols contained relatively lower amount of oxalate soluble iron oxides, while Alfisols and Vertisols contained higher amount of amorphous iron oxides.

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) hoever, stated that the course of manganese transformationin soil was somewhat different from that of iron.

Khan (1995) and Mujib (1968) 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.

Hassan (1999) studied the relationship between the Munshell Hue and free iron content in Bangladesh soils and noted that in well drained soil iron mineral have been synthesized in-situ, redistributed by pedochemical processes and showed positive correlation with Hues.

Rahman (2001) postulated that the free iron and manganese oxide contents of the major river sediments of the Bangladesh were low and found the mean free iron oxide in soils was around 1.38 percent and manganese oxide contents was 0.038 percent.

2.2.4 Total analysis

The chemical analyses of soils consisted of total chemical analysis of the soils as a whole, which include both products and reactants are important for the purpose of evaluating soil development. It could be assumed that the nonclay fractions represent the reactants and the clay fractions represent the products (Barshad, 1964).

Silicon

Silicon is the second most abundant element in the earth's crust and in most soils. Driskall (1954) worked on three profiles of Mississippi river floodplains and found variation in the distribution of the oxides of silicon, iron, Magnesium, potassium and calcium in the soil profiles. There were variations in molar ratios of SiO_2/R_2O_3, SiO_2/Al_2O_3, Al_2O_3/Fe_2O_3 in clay fraction of different soil series. He concluded that these soil generally different in their chemical and mineralogical properties.

Hussain and Swindale (1974) reported 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.

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 (Arnaud and Whiteside, 1963; Borchardt *et al.*, 1968; Hill and Shearin, 1969; 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.

Quartz has been utilized by numerous investigators to assess the uniformity of parent material as an index of quantitative evaluation of soil formation and as a stable member of a mineral ratio which expresses the degree of weathering (Arnaud and Whiteside, 1963; Barshad, 1964; Al-Janabi and Drew, 1967; Redmond and Whiteside, 1967; Sudom and Arnaud, 1971).

Hallmark *et al.* (1982) reported that the quality and distribution of Si in soils are influenced by parent materials, climate, vegetation, texture, pedogenesis and intensity of weathering.

From a study of the genesis of soils on different geomorphic surfaces in a riverine plain of Punjub, Sharma and Dev (1985) pointed out that silicon was the most abundant element (39.8 to 74.0% SiO_2) comprising more than half of the total mineral matter in these soils, and the other major elements in decreasing order of abundance were Al, Fe, Na, K, Ca, and Mg. They also observed irregular vertical distribution patterns of these elements in the soil profiles.

Pedochemistry of four soil series developed on terrace materials of BARI farm at Gazipur, Rahman *et al.* (2004) was found the SiO_2 content ranged from 60.2 to 72.9% and the average value was 65.7%.

Morphogenesis and characterization of some representative soils from the old Brahmaputra floodplain in Bangladesh Mazumder *et al.* (2010) elucidated that Silicon is the most abundant element (64.5 to 74.70%) comprising a large part of the elemental composition of these soils. The other dominant elements in the decreasing order of abundance are: aluminium > iron > calcium > magnesium > potassium > titanium > phosphorus. They also found that the vertical distribution of SiO_2 content in the profiles shows an irregular decrease with depth. From the irregular vertical distribution pattern of these elements, it may be inferred that the parent materials of these soils are to some extent heterogeneous in nature.

Aluminium

Hsu (1977) pointed out that a number of crystalline aliminium hydroxides, oxyhydroxide and oxides were found in nature. Among the three polymorphs of aluminium hydroxides, only gibbsite was common in soils and in bauxitic deposits. Bayerite and nordstrandite have also been identified in some soils (Goldbery and Loughman, 1970; Davis and Hill, 1974).

Gotho (1976) studied the behavior of Fe, Mn Al in the developmental stages of polder lands through their distribution in the profile at different reclamation stages. He found that all the soils showed rather narrow range of total and extractable Al_2O_3 from horizon to horizon when compared with that of Fe and Mn. Total Al_2O_3 ranged from 7.96 to 13.22% with a mean value of 11.64%. 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.

Pedochemistry of four soil series developed on terrace materials of BARI farm at Gazipur, Rahman *et al.* (2004) was found the Al_2O_3 content ranged from 8.5 to 11.2% with a mean value of 10.03%.

Potassium

Potassium status of soils depends largely on soil parent material as well as the degree of weathering (Graham and Fox, 1971). 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.

The total K_2O content in the soils of the Brahmaputra floodplain and in the Surface Water Gley soils of grey terrace areas ranged from 1.39–2.29 percent, respectively (Habibullah *et al.,* 1980). Total K_2O status of 12 extensively occurring agricultural soils from northern region of Bangladesh was determined and the total K_2O was found to range from 1.53 to 3.04 percent (Elahi *et al.*, 1993). Chowdhury *et al.* (1992) indicated that soils of Bangladesh were rich in total K (ranges between 1.0 to 3.2 percent with a mean of 2.2 percent) but poor in available K_2O.

Phosphorus

Phosphorus is the twelfth most abundant element of the earth's crust (Nartea, 1990), and it has important roles in plant nutrition and soil formation. Khan (1995) observed that the total P content in the surface soil was lower than that in the surface soil. Uehara *et al.* (1974) determined total analysis of some sediments and soil of Mekong delta and observed that total P content of sediments was higher than that in the soils. Egashira and Yasmin (1990) studied the distribution of total phosphorus in the surface soils of some floodplain areas of Bangladesh and stated that the available P of the floodplain soils was above the critical level. Hussain *et al.* (1983) in a study of NPK distribution of eight pedons found that total P content of the soils ranged from 300 to 600 ppm. The vertical distribution pattern of P_2O_5 indicated that it was more uniform in epipedons. Variation of P_2O_5 in the lower horizon of the profiles was very wide and also irregular.

Titanium

The importance of titanium (TiO_2) as an index mineral in pedogenesis has been recognized long ago. Since then many authors have worked on the profile distribution of this element in different soils and their respective clay fraction.

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. Islam (1970) determined TiO_2 in the clay fractions of some soils of Bangladesh and found the average value of TiO_2 as 0.84 percent.

Hussain and Swindale (1974) reported that TiO_2 in soils ranged from 0.6 to 2.0 percent. From the study of eight land types viz. foot hills, alluvial fans, sand-bars, covered floodplain, upper terrace, lower terrace, channel and river floodplain in the north east of Punjab, Sharma and Dev (1985) observed that TiO_2 content of the whole soils ranged from

0.27 to 2.16 percent. The distribution of TiO_2 content from the surface downward followed closely the sequence of sand/silt ratio which was irregular in nature. The irregular distribution pattern of TiO_2 content indicated wide-spread stratification's.

Gielman (1920) observed that some soil clays are rich in titanium, the content of which may reach 1.0 percent mark. He noted that the titanium contents in sandy and loamy soils are less than that in the clayey soils.

Mazumder (1976) worked on some deep water rice soils of Bangladesh and noted that TiO_2 content of the clay fraction of the soils was around 1.49 percent. He also 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 soils and clays from Bangladesh and reported the mean TiO_2 contents as 0.67 and 1.14 percent for the soils and clays, respectively.

It is generally known that the TiO_2 content in highest in the finer fraction of soils (Jackson and Sherman, 1953; Brain, 1976; Hutton, 1977 and Hussain and Islam, 1979). The resistance of pedochemical weathering of titanium has been attributed to its very low solubility. The acidity must be very high before titanium can goes into solution. Titanium may also combine readily with other constituents in the soil. Joffe (1966) mentioned the possibility of the formation of Fe TiO_2 (ilmenite). Hance, the movement of TiO_2 in solution during pedogenesis would not be expected to occur. However, the accumulation of TiO_2 in the B-horizon of certain soils was possible through mechanical movement.

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. TiO_2 is very resistant to pedochemical weathering processes. The transfer of TiO_2 in soils occurs mechanically. The accumulation of TiO_2 in the B-horizon of certain soils often occurs mechanically.

2.2.5. Mineralogical properties

The mineralogical composition of clay fraction in soils is a function of dominant factors of weathering like climate and parent material. It reflects the nature of weathering process in soil and indicates the efficiency of climatic factors.

Tropical and Sub-tropical soils showed a large variation with the climatic conditions with respect to clay minerals. Matsusks and Sherman (1950) observed that kaolinite was dominant in sub-tropical soils.

In some Grey Hydromorphic soils of Hawaii, Hussain and Swindale (1970) reported a direct relationship between the degree of Hydromorphism and the occurrence of iron-rich smectite. Since under hydromorphic conditions, solubility of Fe^{2+} increases manifold, it might enter into the octahedral layer of smectites by isomorphous substitution. In the soils of the Gangetic alluvium, this mechanism of mineral transformation might have been taken place (Saheed and Hussain, 1992).

Floodplain soils contain varying quantities of sand, silt and clay fractions. Each of these fractions contains a number of minerals. Huizing (1971) studied the mineralogy of sand and silt fractions of a large number of soils from some major floodplains of Bangladesh and noted that in the old Brahmaputra sediments, sand fraction is relatively uniform in composition. He found that the quantity of weatherable minerals in the sand fraction of the Brahmaputra and the Meghna floodplains varied between 28 and 29 percent. According to him, the weatherable minerals are higher in Gangetic alluvium that is about 40 percent. He reported that quartz was the dominant mineral in Meghna floodplain but all the floodplain soils contain huge amount of Quartz in the sand and silt fractions. He also reported that mica, feldspar and chlorite are the other dominant minerals.

Habibullah *et al.* (1971) studied the clay mineralogy of some seasonally flooded soils of East Pakistan and noted that mica and kaolinite were present in all the soils but vermiculite was present only in a few of them.

Brinkman (1977) reported that in the soils of the old Brahmaputra sediment the easily weatherable minerals comprise about 30 percent, one third of which was mica. He found from x -ray diffraction analysis that vermiculite accounts for about 45% of the clay fraction in the lowest horizon; and this was progressively upward replaced by soil chlorite which finally increased to 30 percent in the surface horizon. He roughly estimated 30 percent illite, 40 percent kaolinite, 20 percent vermiculite and 10-20 percent inter-stratified minerals in the clay fraction of the above soils.

Hassan and Razzaq (1981) studied 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.

Kapoor *et al.* (1982) studied the clay mineralogical composition of soils from four profiles developed on some alluvial soils of India by using X-ray diffraction technique and found dominance of illite followed by mixed layer minerals, chlorite, smectites, chloritized smectite and vermiculite. The illite present in the soils was found to consist of both the dioctahedral and nioctahedral varieties and the latter appeared to have undergone transformation to smectite like minerals through intermediate stage of (10-14Å) interstratification.

Puri *et al.* (1983) studied the silt and clay mineral composition in some alluvial soils from Uttar Pradesh. They found that these soils were moderately fine textured and moderately to well drained with a predominance of mica followed by chlorite, smectite and vermiculite. They concluded that the origin of these minerals were pedogenic rather than geogenic.

Vinayak *et al.* (1984) investigate the clay mineralogy of three typical salt-affected soils of the Indo-Gangetic plains by X-ray diffraction and chemical techniques. They found that illite was the dominant clay mineral in all the soils. He characterized the above saline soils by the presence of smectite as a second mineral. Minor amounts of chlorite and kaolinite were present in all the soils. According to them, imperfect drainage might have resulted in the transformation of illite to smectite in these soils. Illite, kaolinite and chlorite in these soils were probably inherited. The differences in clay mineralogy between the salt affected soils and the associated cultivated soils appeared to be pedogenic rather than lithogenic.

Amin (1984) studied the clay mineralogy of some soils from Brahmaputra alluvium and noted that illite, kaolinite and mixed layer smectites-illite were the dominant minerals in the clay fraction.

White (1985) studied the clay mineralogy of a large number of soils of the Brahmaputra-Ganges-Meghna floodplains of Bangladesh. From the X-ray diffractographic data he reported that among the Brahmaputra floodplain soils, an exclusive combination of mica-kaolinite-vermiculite was found in the younger members of the soils. He stated that apparently most of these kaolinite and vermiculite minerals are parts of the original alluvial deposition, while chlorite is the product of *in situ* weathering. The relatively older soils of the old Brahmaputra floodplain, with a mild acidic environment have traces of chlorites but no smectite.

White (1985) also reported that the Gangetic alluvium were calcareous and occurred mainly as meander floodplains, ridges, basins and old channels. They are dominated by mica, vermiculite and smectite minerals in clay fractions. The soils of the Ganges tidal floodplain were dominated by mica with some kaolinite and smectite.

Saheed (1985) reported three groups of mineralogical association in Bangladesh soils: mica, vermiculite and kaolinite in most floodplain soils; smectite along with mica in Ganges floodplain soils; and mica and halloysite in terrace soils. His observation is similar to that of White (1985)

Park and Han (1985) studied the distribution of clay minerals in some recent alluvial soils of Korea and noted that there were 50% illite, 21% kaolinite, 17% interstratified minerals and 8% chlorite.

Yoothong *et al.* (1986) reported that the clay mineralogy of the alluvial soils consisted mainly of kaolinite, montmorillonite and illite with kaolinite. Some interstratified clay minerals, vermiculite, chlorite, goethite and quartz were also present in small quantities in the alluvial soils.

Islam and Lotse (1986) identified smectite along with mica as the dominant mineral in the clay fraction of some soils developed on the Gangetic alluvium. However, Subramanium and Jha (1988) reported abundance of kaolinite followed by illite and chlorite in the fresh water zone of Hoogly eastuary in West Bengal. Research on clay mineralogical composition of some soils from the Indus River in Punjab was carried out by Razzak and Herbillon (1979).

Islam *et al.* (1988) reported the clay mineralogical composition of 18 soil profiles and found that mica was dominant in all soils, kaolinite and vermiculite in almost all soils, while halloysite in terrace soils and smectite in Ganges fioodpla soils, His description has similarity with the reports of White (1985) and Saheed (1985),

Egashira (1988) studied the mineralogical composition of five soil profles from terrace areas and reported that the clay fractions were dominated by mica and kaolinite while in the sand and silt fractions quartz was dominant. In addition, some interstratified minerals like mica-vermiculite-smectite and kaolinite-smectite were detected. The transformation sequence of mica in terrace soils was outlined as follows: mica > interstratified mica-vermiculite-smectite > interstratified kaolinite-srnectite > kaolinite.

Esu (1989) studied the soils within the levees, backswamps and terraces of the Hadejia river in NIgreia. He stated that kaolinite, smectite, mica, polygorskite, quartz and K-feldspers were the dominant minerals in the clay fraction.

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 probably allogenic in origin.

Mian (1990) noted that Sonatala and Ghatail soil series of Brahmaputra alluvium contained almost equal amounts of kaolinite and illite. These soils also contained small amount of vermiculite and chlorite. He reported that the Sara and Ghior soil series of the Ganges floodplain contained 40-60% illite and 20-40% kaolinite with considerable quantity of smectite.

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.

Hassan (1991a) reported the clay mineralogical composition of four floodplain soils, two terrace soils and two hill soils. Hill and terrace soils were dominated by mica and kaolinite; Ganges floodplain soil by mica and smectite, and Brahmaputra, Meghna and Tista floodplain soils by mica and vermiculite.

Sawhney and Sehgal (1992) studied the clay mineral composition of some alluvial soils of the Punjab and concluded that illite is the predominant mineral in all the soils. This was due to the presence of micas in the alluvium. Kaolinite was the dominant mineral in the soils of inter-channel areas. The presence of kaolinite throughout the profiles in all the soils suggested that the mineral has been brought along with alluvium which formed the parent material of these soils. A critical perusal of the report showed that Alfisols had low kaolinite content than the less developed Inceptisols.

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

Smectite and expandable minerals, in general are the major products of weathering under weathering conditions of medium intensity in the temperate climate where the drainage is poor to moderately good (Velde, 1985; and Jackson 1959). The attaintment of fully expandable species by weathering is frequently observed to be preceded by a mixed layered structure. Both di-and trioctahedral mixed-layer minerals are known to occur in soils. At times, regularly ordered interlayering between micas or ahlorites and expanding layers are found (Churachman, 1980). A weathering sequence for phyllisilicates has been established and this indicates that their relative stabilities in soils are as follows: mica, chlorite > mixed layered expandable, non expandable > fully expandable smectite > kaolinite + Al, Fe oxides (Jackson, 1959). This sequence has been illustrated in Figure 4.

Velde (1985) further pointed out that the use of phase diagram canbe made in order to explain the apparently paradoxical relationship between dioctahedral mica and vermiculites and montmorillonites in weathering and diagenesis. It was observed that illite and dioctahedral micas are degraded or altered to form montmorillonites during weathering (Millot, 1964; Weaver, 1959 and Dunoyer de Segonzac *et al.,* 1970). Upon burial and initial diagenesis, the smectite fraction decreases, being replaced apparently by illite.

There is an apparent symmetry observed in weathering and diagenetic processes. This observation has led to the idea that smectite represents a metastable form of mica which may return to its initial form when exposed to sea water sedimentation and burial; it becomes reconstituted upon diagenesis (Weaver, 1959). Figure 5 shows two arrows representing possible paths taken by individual phases during the two alteration processes. Arrow a shows the evolution of the mica component as alkalis, principally when potassium is removed from the mineral via weathering processes and as the bulk composition of the system allows the formation of first a mixed layered phase then a smectite.

This sequence has been observed in many weathering profile soils. The removal of alkalis from the mica is not only a change necessary to produce smectite. In order to maintain charge balance, the octahedral ions must become more positive in charge, either by ionic substitution (divalent or trivalent ions) or by oxidation of iron in the natural system. As the total alkalis dismish beyond the limit of smectite bearing assemblages, kaolinite becomes apparent in the clays. Should the weathering be rapid, that is should alkali removal be rapid, kaolinite could appear with only a small amount of the compositionally intermediate smectite phase present in narrow horizon. However, in slower processes an apparent degradation sequence has been traced on the phase diagram (Velde, 1985).

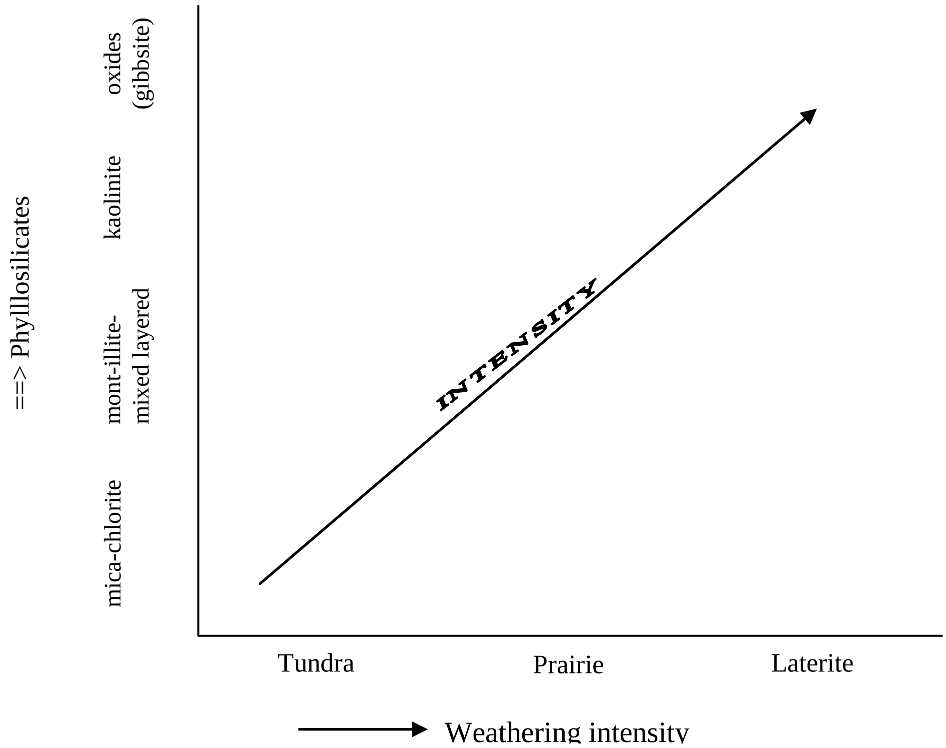


Fig 4. Sequence of relative phyllosilicate stabilities shown as a function of relative weathering intensity (After Jackson, 1959)

Acquaye *et al.* (1992) studied some soil profiles from the Accra plains of Ghana and found smectite as the dominant clay minerals in all the soils. They reported that the presence of smectite in agreement with the CEC and swelling properties of the soils. The level to very gently undulating landscape, the semi-arid conditions, high pH and poor drainage of the soils for a long period of might have ensured the accumulation of base and therefore, the formation of smectite.

Okusami and Rust (1992) studied some hydromorphic soils from inland depressions, alluvial plains and coastal sediments in Nigeria and noted that kaolinites dominated the clay mineralogy in the surface soils, although the subsoils of some pedons formed in alluvium and coastal sediments were rich in smectite.

Alam *et al.* (1993 a,b) and Alam (1994) studied the clay mineralogical composition of 20 soils over the country, Hill soils were dominated by mica and hydroxy-Al interlayered verrniculite with low smectite, vermiculite, kaolinite and chlorite contents. Terrace soils had higher mica and kaolinite but trace amounts of smectite, chlorite and vermiculite. All floodplain soils were rich in mica and contained kaolinite and chlorite; the mica content was higher in noncalcareous soils than in calcareous soils; calcareous soils contained smectite in large quantities while noncalcareous soils were rich in vermiculite.

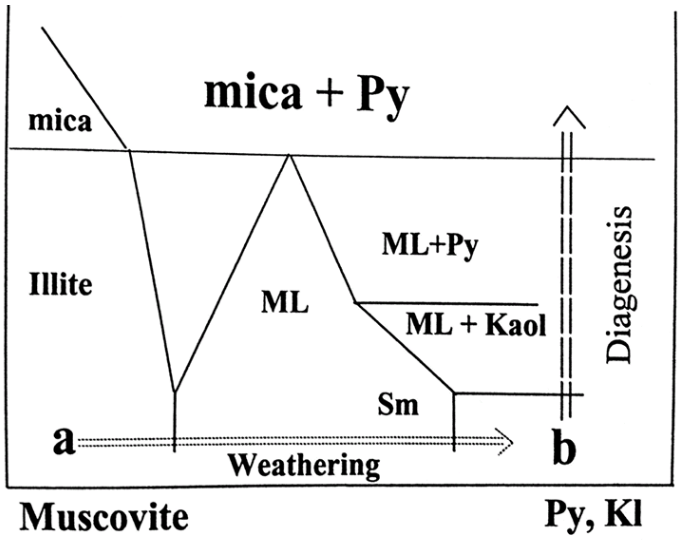


Fig 5. Representation of a simplified mineral weathering system.
(Mineral evolution due to chemical weathering is indicated by arrow a. Phase assemblage is indicated by arrow b which occurs during burial diagenesis. Phases represented are illite, mica; Py = pyrophyllite; ML = mixed layered smectite-illite; Sm = Smactite; Kl = kaolinite).

Ali (1994) studied the effects of alternate wetting and drying cycles on pedogenic processes of some representative Bangladesh soils. He stated that the Gangetic alluvial soils were found to contain clay minerals like smectite, illite, chlorite and kaolinite. Their contents varied with respect to location and management.

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.

Khan (1995) studied some selective pedons of seasonally flooded soils from Brahmaputra and Ganges floodplain and found that the dominant clay minerals were mica, kaolinite, vermiculite and a small amount of chlorite and interstratified minerals. An appreciable quantity of smectite was also found in the Gangetic alluvium.

Mazumder (1996), in some alluvial soils from the Brahmaputra floodplain, reported the occurrence of mica, kaolinite, vermiculite and a small amount of chlorite. A small amount of smectite was also detected in the subsoils of Sonatala soil series.

Aramaki (1996) studied 11 soil profiles for the clay mineralogical composition and reported that mica was dominant in all soils, smectite in Ganges fioodplain soils, interstratified mica-vermiculite-smectite, and interstratified kaolinite-smectite or kaolinite in terrace soils. Kaolinite was rich in hill soils and even greater than mica, while Old Brahmaputra and Meghna fioodplains soils contained good amounts of chlorite and vermiculite.

Khan *et al.* (1997) studied five benchmark soil profiles from different floodplains of Bangladesh and found that mica was the dominant mineral in all soils. Smectite was dominant in Ganges floodplain soils only. Varying amounts of kaolinite and vermiculite were present in all soils.

Silt and clay mineralogy of ten soil series, three from terrace areas and seven from floodplains, were studied by Moslehuddin and Egashira (1996) Silt fractions were dominated by quartz in all soils. Terrace soils had very high quartz content and low mica, chlorite and plagioclase contents. Floodplain soils contained relatively low quartz and high mica, chlorite and plagioclase. Mica was present in large amounts in the clay fraction of all the soils. Smectite was dominant in 3 out of 4 soils from Ganges floodplain while the other soil of the same floodplain situated on the non-flooded highland contained interstratified mica-vermiculite-smectite and verrniculite as dominant minerals. Interstratified kaolinite-smectite and mica-vermiculite-smectite were present in all terrace soils in significant amounts. Either interstratified mica-vermiculite or mica-chlorite was present in most soils but in smaller amounts, but a soil of Old Himalayan Piedmont Plain was dominated by interstratified mica-chlorite.

Smectite separated from three soils of Silty Ganges Alluvium, Dumuria and Barisal series of Ganges River and Tidal Floodplains, was characterized by Moslehuddin and Egashira (1997) the smectite content in the fine clay fractions was in the range between 62 and 88%. Expansion to 1.8 nm by the Greene-Kelly test and the (060) spacing around 0.150 nm suggested that the smectite was mainly of the beidellite-type elemental composition calculated from total chemical analysis showed that the smectite had layercharge of tetrahedral-origin and was rich in Fe. The structutal formula for the smectite of Silty Ganges Alluvium which is hardly subjected to decalcification, was calculated as $(Si_{6.90}Al_{1.10})(A1_{2.46} Fe_{0.99} Mg_{0.76})O_{20}(OH)_4 X_{1.25}$. The smectite was estimated net to be the alteration product of mica but to be derived from the sediment.

Eleven soil profiles of Ganges floodplains soils, covering soils from different levels of decalcification were studied to investigate the clay mineralogical composition and to clarify the relationship between disappearance of smectite and decalcification of calcareous floodplain soils occurring in these areas (Moslehuddin *et al.*, 1998a). In general, the mineralogical composition of calcareous floodplain soils was dominated by mica and smectite, and in some cases by vermiculite, Chlorite and kaolinte was also present. Amjhupi and Gangni series on ridge and Ghior series on basin had the lower smectite and carbonate contents in the Ap and B2 horizons than in the C horizon. However, all soils having the low carbonate content did not always show the lower smectite content, possibly due to neutral pH or to difference in the rate between decalcification and disappearance of smectite. Complete disappearance of smectite was observed in Tahirpur series and partial disappearance in Baradi series. Both are situated on the non-flooded highland and were thoroughly decalcified and considered to be the oldest soil in the Ganges floodplains of Bangladesh. Based on the assigned age of the soils, smectite disappearance was estimated to be in the order of 2500-3000 years.

Mineralogical study of some Meghna Floodplains soils was carried out to determine the contribution of different river sediments as the parent material (Moslehuddin *et al.*, 1998b). 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. Due to the predominance of smectite in the Ap and B horizons or Ap horizon, soils of the part of Old Meghna Estuarine Floodplain which is surrounded by Ganges Floodplains were estimated to consist of the Ganges sediments in the upper horizons and of the Meghna/Old Brahmaputra sediments in the lower horizons.

Identification of kaolinite as a dominant mineral in most floodplain soils was a matter of great controversy among the reports, Mian (1990), White (l985), Saheed (1985), Ali (1994), Islam and Lotse (l986), Mazumder (1996) and Khan *et al*, (1997) reported high quantity of kaolinite in different floodplains soils while others found smaller amounts of kaolinite in those soils, Identification and quantification of kaolinite is somewhat complex as the first-order peak of kaolinite (0.715 nm) coincides with the second-order peak of chlorite (0.708 nm). One solution to this problem is to consider the second-order peak of kaolinite (0.357 nm) and the fourth-order peak of chlorite (0.354 nm) in calculation (Egashira and Yasmin, 1990), which was not followed by those scientists who got high amounts of kaolinite. High amounts of kaolinite might be misinterpreted for chlorite. Another controversial result was the presence of halloysite in terrace soils as reported by White (1985) and Saheed (1985) which is possibly interstratified kaolinite-smectite as was mentioned by Egashira (1988) Instead of smectite that was reported to be dominant in some terrace soils by White (l985), interstratified mineral containing smectite may be the more appropriate expression (Egashira, 1988)

Moslehuddin *et al.* (1999) have been compiled available clay mineralogical data and summarized for making a clay mineralogical map of Bangladesh on the national basis. Mica was the predominant clay mineral in almost all the soils. Other major minerals were smectite (mainly iron-rich high-charge beidellite), chlorite, vermiculite, kaolinite, and interstratified mica-chlorite, mica-vermiculite-smectite and kaolinite-smectite, depending on the physiographic location of the soils. The proposed clay mineralogical map has eight mapping units: namely, Mc-Ch*, Mc-St, Mc-Vt*-Kt, Mc-Ch-Vt*, Mc-Mx-Kt, Kt-Mc, Mc-Kt-Vt* and Mc-Kt-Vt*, where the symbols Mc, Ch, St, Vt, Kt, and Mx indicate mica, chlorite, smectite, vermiculite, kaolinite and mixed layer minerals, respectively, and asterisk (*) means partial chloritization of some vermiculite or partial degradation of some chlorite.

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.

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.

Moslehuddin *et al.* (2008) elucidated from their mineralogical study of Karatoya-Bangali Floodplain that mica was the predominant minerals followed by kaolinite and very small amount of vermiculite was found.

From the mineralogical study of clay fraction of Chalan beel soils of Bangladesh Islam and Hussain (2008b) concluded that mica was the dominant clay mineral in all the soils, followed by quartz. They also found small quantities of kaolinite all the soils.

Uddin *et al.* (2009a) postulated from the mineralogical study of the Surma-Kushiyara floodplain of Bangladesh that vermiculite and mica was the dominant minerals in the clay fraction closely followed by kaolinite. A small quantities of montmorillonite, quarts and interstratified minerals also found in all the soils.

Khan and Ottner (2010) 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. They also noted that the occurrence of considerable quantities of 18Å vermiculite in clay fraction of Bangladesh soils was not detected by earlier workers (Islam and Lotse, 1986; Egashira and Yasmin, 1990; Hassan, 1991a). Earlier scientist did not report presence of any 18Å vermiculite in their study; hence soil vermiculite (18Å vermiculite) might have been misinterpreted in the floodplain soils of Bangladesh. When the peak at 14Å in the Mg-saturated specimen expands to 17Å in the Ma-saturated and glycerol solvated specimen then it indicates presence of smectite and soil vermiculite but if contracted to 10Å in the K-saturated specimen then it is 18Å vermiculite or soil vermiculite, which might have been overlooked by earlier scientist who did not find soil vermiculite (18Å vermiculite) in the floodplain soils of Bangladesh.

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, 2010).

Reza *et al.* (2013) pointed out from their mineralogical study of some soils of lower Purnabhaba floodplain in Bangladesh 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).

Akter *et al.* (2015) elucidated from mineralogical characterization of clay fraction of some Young Meghna Estuarine Floodplain soils of Bangladesh 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 of Bangladesh.

2.2.6 Genesis and classification of floodplain soils

2.2.6.1 Pedogenesis of floodplain soils

It is important to know as to how soil has been formed. The soils in the floodplain areas in many cases remain seasonally water saturated and they are dry in the rest of the year if not irrigated. The periods of water saturation vary from soil to soil depending on location in the landscape. The ground water table in these soils fluctuates very widely. The fluctuating ground water tables play important role in the genesis of these soils. The stages and pedogenetic processes are varied and complex in the seasonally flooded soils.

The most important horizon in a hydromorphic soil is the gley horizon. Thorp and Smith (1949) introduced the new name ***"gleys"*** as a great soil group in the soil classification system of the United States. It was defined as, "*an intrazonal group of poorly drained Hydromorphic soil with dark coloured organic horizon of moderate thickness underlain by mineral gley horizon".*

According to Joffe (1949) the popular Russian idea of *gley* is *"a more or less compact, sticky loam or clay material which is not, however, as sticky as the loam or clay, frequently with more or less clearly pronounced light greenish blue tinge"*.

In the Soil Survey Manual (Soil Survey Staff, 1993), *a gley horizon has been defined as "a layer of intense reduction, characterized by the presence of ferrous iron and neutral grey colour that commonly change to brown upon exposure to the air"*. The gleization process involves saturation of the soils with water for long period in the presence of organic matter.

In English *gley* is *"Yellow and grey mottling in the soil produced by partial oxidation and reduction of iron caused by intermittent waterlogging"*. The definition in German, Spanish, Portuguese, Italian and Dutch languages are essentially the same as above.

In France it is a *"Greenish grey coloration produced in the soils by the partial reduction of iron compounds under the influence of an-aerobic conditions created by intermittent presence of water."*

Features of weak gleization are expressed by the presence of mottles, which are caused by alternate oxidation and reduction conditions. The characteristic morphological features of hydromorphic soils may be counted as follows:

- Dark coloured organic mineral of moderate thickness.
- Presence of reddish brown and yellowish brown mottles and grey coating along ped faces.
- Greenish grey or bluish grey gley horizons in the subsoil zone.
- Brown or greyish brown B-horizon enriched in sesquioxide; often not present.
- Cloddy structure in the topsoil.
- Absence of any structure in the subsoil.

In Bangladesh, the stages of development of morphological features of seasonally flooded soils have been recounted as follows:

i. Initial deposition of alluvium.

ii. Ripening.

iii. Eal1y development of mottles.

iv. Homogenization.

v. Development of structure in the subsoil.

vi. Formation of subsoil coatings (flood coatings).

vii. Acidification and decalcification of topsoils.

viii. Ferrolysis, if the soil is acidic.

ix. Formation of plough pan.

Dudal and Moormann (1964) termed the artificial man - induced water regime as "anthraquic" and the superficial soil horizon that formed under this water regime was called "anthraquic epipedon". The above authors defined an anthraquic epipedon as the surface soil layer altered by ploughing in soils used for wetland crops production especially rice. Anthraquic epipedon comprises both the cultivated layer and the underlying plough pan. Both the layers are puddled, have grey base colours and are strongly iron stained along root channels. The cultivated layer is strongly reduced when waterlogged or flooded.

In the waterlogged soils of Bangladesh, there is commonly a strong oxidized layer and in places a coating of iron oxides, but no iron pan, at the base of the ploughpan (Brammer, 1971). Karmanov (1966), Wada and Matsumoto (1973) and Mitsuchi (1974) found that poorly drained low land soils do not change much, when used as paddy land.

Soil Survey Staff (1999) reported that when reducing condition prevails due to water saturation for a long period of time, and the regime is defined as aquic moisture regime. The aquic soil moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated with ground water or by water of the capillary fringe.

Brinkman (1977) noted that surface water gley soils are extensively developed on seasonally flooded landscapes. They are acid hydromorphic soils with albic horizons and containing less clay than the deeper horizons, and with a seasonally fluctuating pH in the sunface horizon. The oldest of the Holocene floodplain landscapes in Bangladesh have soils in which only the upper 10 or 15 cm have less clay and contain some albic materials. Soils on younger floodplain were alluvial sedimentation is insignificant have seasonally acid A horizons, without substantial loss of clay. On old landscape, puddling for rice cultivation apparently accelerates the process giving rise to the albic horizon and concentrates them in the ploughed and plough pan.

The formation of a horizon having albic properties has been reported in paddy soils, particularly in the recent sedimentary formation in which the majority of paddy soils are distributed by Brinkman (1977). He considered it premature to attempt a classification of paddy soils with an expression of ferrolysis.

The surface water gley soils also occur on many other floodplains in Bangladesh (Brammer and Brinkman, 1977). The Tista, the old Brahmaputra and the northeastern part of the Meghna river floodplains as well as the old Meghna estuarine floodplains contain soils in which the surface horizon has an anomalously low clay content and seasonally fluctuating pH.

Soils in some other floodplains, such as the older basin clays in the Ganges river and tidal floodplains and most soils in the Jamuna (Young Brahmaputra) floodplains show a seasonally fluctuating pH in the surface horizon but have no evidence of clay loss.

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.

When reducing condition due to water saturation prevails for a long period of time the regime is defined as the ***"aquic soil moisture regime"*** (Soil Survey Staff, 1999). The aquic soil moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated with ground water or by water of the capillary fringe. Reduction and gleying processes that result from biological activity under anaerobic environments constitute only part of the properties diagnostic for soils with aquic moisture regime (Smith, 1965).

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, 1992).

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, 1999). 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.

In Germany, redoximorphic (or hydromorphic) soils are differentiated according to their water regimes into surface water influenced soils, ground water influenced soils, and subhydric-soils (Miickenhausen, 1977; Blume and Schlichting, 1985; Working group on soil systematic, 1985). Typical surface-water influenced soils are the pseudogleys (surface water gleys), typical ground-water influenced are the Grundwasserboden (ground-water gleys). There are pronounced differences in the morphology of pseudogleys and gleys, induced by different air and water regimes, and also in their ecology and utilization (Schlichting, 1972). Other soil classification systems also differentiated between them; e.g., in France (Duchaufour, 1977) and in Britain (Avery, 1980).

According to Blume (1988) in a typical pseudogley the aggregate surface of the clayey B horizon are bleached and depleted of Fe/Mn oxide, whereas the cores are enriched with brown to orange Fe and blackish Mn oxides. The matrix of the less clayey and/or dense topsoil, however, is grey and Fe/Mn are concentrated in concretions of different sizes. Thus the distribution pattern of Fe/Mn oxides is internally oriented against the ped and the soil surface (=inped-redoximorphism). Pedogenic $Fe^{(ii)}/Mn^{(ii)}$ compounds are absent. In contrast to this pattern, the permanently wet subsoils of a typical ground-water gley is low in Fe and Mn or is enriched with pedogenic Fe (ii) compounds (=reductomorphism). Further up in the profile, with oxidizing conditions, Fe/Mn oxides are concentrated on aggregate surfaces and walls of larger pores (=exped-redoximorphism). In some pseudogleys exped-redoximorphism as well as inped-redoximorphism can be observed. This is typical for intergrades between pseudogleys and gleys. Also, above a dense plough pan, rusti surfaces of aggregates can be observed after a heavy rainfall, not only in pseudogleys, but also in well drained soils. In this dense subsoil, roots and microbs concentrated on the surface of the peds. This favours reductive conditions during water stagnation, and reduced Fe and Mn diffuse into the cores and will be oxidized there. Slow changes between reductive and oxidative conditions will favour the formation of weak mottles, while quicker changes favour concretions. Total bleaching of the topsoils (typical for strong gleys) will occur during prolonged water saturation because Fe will leave the soil laterally under these circumstances.

Mitsuchi (1992) pointed out that in well drained soils with a non-aquic moisture regime, qualitatively new processes start to operate when the soil is used for wet cultivation of rice. Some of these processes are (a). Surface gleying and subsurface grayizations, (b). Development of iron (and manganese) accumulation horizon, (c). formation of plaugh pan, (d). accumulation of poorly humified organic matter, (e). chloritization of 2:1 type clay minerals and (f). redistribution of exchangeable bases. Among these, surface gleying and subsurface grayization that extend from the surface downward and the development of iron (and manganese) accumulation horizons are most important and readily visible.

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.

Uddin *et al.* (2009b) characterized the Surma-Kushiyara floodplain soils of Bangladesh as “Hydromorphic” and among the soil forming processes “Gleization” is the dominant processes of soil formation. On the basis of soil reaction, the studied soils can be placed under slightly acidic to neutral in nature. He also noted that all the soils have hyperthermic temperature regime and have medium to heavy textured soils.

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. Hossain *et al.* (2011), Khan *et al.* (2012) also concluded that “Gleization” seems to be the dominant pedogenic processes in the floodplain soils of Bangladesh.

2.2.6.2 Classification of floodplain soils

Soils are classified by common properties for the purpose of systematizing knowledge about soils and determining the processes that control similarity within a group and dissimilarities among groups (Gupta 1981). There are many international soil classification systems of which USDA soil taxonomy (Soil Survey Staff, 1999) is widely used and have been found useful for agrotechnology transfer. This system has been very widely followed for classification of Bangladesh 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 proportion of mottles with chromas higher than 2 and covering more than 40 percent of matrix were classified in the aerie 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, 1999). 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 ording 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), hydromorphic associates of the respective great soil groups (Sivarajasingham, 1963), 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 (Otowa, 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. This idea closely resembles that of Matsui (1966).

Rice soils are mostly found on the floodplains and alluvial lowlands in humid regions. This implies that in the genesis of rice soils the soil material factor is of primary importance. Rice soils are inundated in natural way or water is easily introduced by gravity. Therefore, most rice soils are either Entisols or Inceptisols, which have undergone little soil formation (Kyuma, 1978).

Murthy (1978) stated that rice is the most extensively cultivated food crop of India, and grows under a wide range of rainfall and on a wide variety of soils. The most important of them are the floodplains and the alluvial - derived soils. In India the Sutlej-Ganga alluvial plain runs first in rice production.

Paramananthan (1978) stated that the areas where wetland rice was traditionally cultivated were alluvial soils and floodplains or simply as rice growing areas. Rice growing 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 j_c gleys and in the Hydromorphous sub-order of Intrazonal soils. Ng (1968) tempted to classify the rice soils of peninsular Malaysia according to the system eposed by Kanno (1962).

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 (1974-1975) 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.

The term anthraquic is used to denote a soil moisture regime that is man-induced and is mainly caused by artificial submergence. It seems appropriate to consider the soils with an anthraquic moisture regime at the subgroup level, as has been proposed by several authors (Dudal and Moorman 1964; Dudal, 1965; Kawaguchi and Kyuma, 1974, Moormann, 1980; and Moorman *et al.*, 1985). The level of subgroup seems adequate because the man-induced moisture regime is merely superimposed and does not entail substantial changes in the basic soil characteristics, especially as regards the subsoil. Moreover, the land use can readily be changed from rice to dryland crops, causing the surface gley features to become relict or even to disappear.

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" I 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.

Singh *et al.* (1989) studied the genesis and classification of soils in an alluvial complex of Varanasi district of Uttar Pradesh and classified the soils as Typic Ustitfluvents, Vertic Ustochrepts, Fluventic Ustochrepts. Aquic and Udic Haplustalf and Aerie Ochraqualfs under USDA soil taxonomy. These soils qualify for placement under Eutric Fluvisols, Eutric Cambisols, Gleic Cambisols, Vertic Cambisols and Brunic Luvisols according to FAO/Unesco soil legends. Suggestion for inclusion of Thapto subgroup in Ustifluvents in soil taxonomy to classify some soils has been made.

Sawhney and Sehgal (1989) studied the taxonomy of rice and associated non-rice cultivated soils of Punjab and observed that the rice growing soils have little morphological difference with soils not growing rice to influence their taxonomy. Rice cultivations under Punjab conditions, does not alter the diagnostic features of the soils, except affecting the surface horizon(s). Hence their classifications may not differ from their non-rice associates upto at least the first four categories. The soils studied have been classified in two orders (Inceptisols and Alfisols), two sub-orders (Ochrepts and Ustalfs), great groups (Ustochrepts and Haplustalfs) and five subgroups of Aquic, Ustochrepts, Ustochrepts , Typic Ustochrepts, Typic Haplustalfs and Udic Haplustalfs. For a rational classification of rice soils, new phase, viz., "anthraquic" has been introduced within the system to highlight man induced reduction conditions in the surface horizon of these soils.

Walia and Chamuah (1992) stated that the upland soils of the flood affected areas of Brahmaputra 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.

Deturck and Somasiri (1992) studied the rice soils of Sri Lanka with Anthraquic tures and emarked that the submergence of Aquic Hapludult and Aquic Haplustalfs paddy rice cultivation results in the formations of a surface gley horizon and this forms a continuum with groundwater gley horizons. These soils with man-induced aquic conditions cannot be distinguished readily from soils with an endoaquic soil moisture regime. Therefore, they do not require a new taxa.

D'costa and Muchena (1992) stated that the wet soils in Kenya are soils which are saturated with water at some period or throughout the year in most years. They showed evidence of reducing conditions and endoaquic, epiaquic, or both conditions. These soils generally occupy flat or depressed areas, plains, and valleys, including seasonal swamps and marshes with poor or restricted drainage. The wet soils in Kenya cover about 5 million hectares or about 8.3% of Kenya's land surface. They are developed from diverse materials of variable age, compositions, mineralogy, texture, soil reactions and fertility, largely from sediments brought from higher grounds. The major wet soils, according to the USDA soil taxonomy system, can be classified in eight suborders as follows: Fibrists, Hemists, Saprists , Aquents, Aquepts, Aquolls, Aqualfs, and Aquults.

Szogi and Hudnall (1992) stated that the term "aquic condition" was defined by the International Committee on Aquic Moisture Regime (ICOMAQ Committee) to replace the "aquic regime" in Soil Taxonomy and the keys of Soil Taxonomy. The "endo-, epi-, anthric saturation" terms have been proposed as part of the modifications to the regime." In classifications of soils in Louisiana according to "Endoaquic and Epiaquic" concepts the objectives of study of the above authors were : 1) to identify endo" and "episaturations" and ii) to identify the co-existance of epi- and endosaturation in the same profile, based on the measurement of saturation and reduction and the Presence of redoximorphic features. Three soils Commerce silt loam (fine-silty, mixed non-acid, thermic, Typic Fluvaquents), Crowley silt loam (fine, montmorillonitic, Typic Albaqualfs) with an irrigated and nonirrigated variant, and Verdum silt loam (fine-silty, mixed, thermic, Glossic Natraqualfs), were investigated with tensiometers, and platinum electrodes at different soil depths and with rain Reduction was tested with ά-ά dipyridyl as an indicator of reduced iron in the The Commerce silt loam was determined to be endosaturated. It was affected by a eround water table above 50 cm in 31% of the observations. The Crowley silt loam was classified as having episaturations or, alternatively, as being anthric saturated. This soil Vas under controlled flooding conditions and fulfilled one of the ICOMAQs definitions for anthric saturation: a surface horizon having colour value >4 and chroma <2. The nonirrigated variant also was considered as having aquic conditions, since a failure in the drainage system returned the soils to aquic conditions temporarily. The Verdun silt loam had both a perched and a ground water table that merged in the winter. It was classified as endosaturated. They further proposed that these soils will be classified in the aquic suborder if the aquic conditions (reduction, saturation, and redoximorphic features) are present in at least 1 out of 10 years.

Mitsuchi (1992) remarked that rice soils having iron and manganese accumulation horizon and/or thick "greyzed" subsurface horizons should be separated at the great group level. Separation at sub-group level seems appropriate for rice soils where only surface horizons are affected by seasonal gleying.

Okusami and Rust (1992) studied some hydromorphic soils from inland depressions, alluvial plains and coastal sediments of Nigeria, and classified most of the soils as Inceptisols and Entisols. According to them the Entisols and Inceptisols of the humid tropical world may needed a new prefix at the subgroup level so as to differentiate the soils that have significant horizon differentiation attributable to hydromorphic status. Equivalent

FAO-UNDP (1988) units are Fluvisols, Gleysols, and Planosols. A classification stagnosols is suggested as a replacement for the Planosols. This is an alternative to a classification of Gleysols with orthic and stagnic sub-units.

Adegbite and Ogunwale (1994) were studied three soil profiles at Abugi in the flood plains of river Niger, Kogi State, Nigeria, and classified the soils as Inceptisols order.

Khan (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 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.

Bhatta *et al.* (2005) were characterized and classified some soils of budhadudhiani irrigation project in Nayagrah district of Orissa and found that the soils are classified under three soil orders viz., Entisol, Inceptisol and Alfisol.

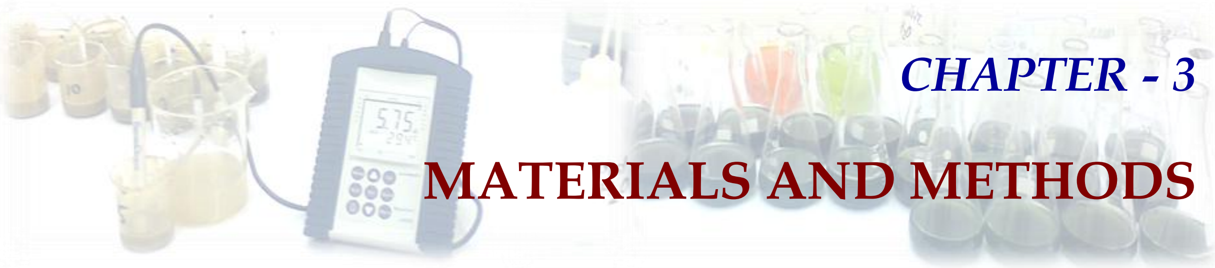
Uddin *et al.* (2009b) classified some wetland soils of the Surma-Kushiyara floodplain of Bangladsh. Accoring to US Soil Taxonomy the wetland soils classified into the Inceptisol order, Aquepts suborder and Endoaquepts great groups. At the subgroup level they are classed as Typic Endoaquept.

Mazumder *et al.* (2010) classified some representative soils from the old Brahmaputra floodplain in Bangladesh and found that all the soils except Melandaha series show mark of profile development that have resulted in the formation of a cambic horizon along with an ochric epipedon. Hence, these soils were classified under Inceptisol order. They also found Melandaha soils was young and signs of stratification are 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 suborders: Aquents, Aquepts and Udepts on the basis of properties associated with wetness.

Hossain *et al.* (2011) concluded from the characterization and classification of some soils from the Ganges river floodplain of Bangladesh that all the soils show some marks of profile development that have resulted in the formation of a cambic horizon along with an ochric epipedon. Therefore, these soils were characterized under Inceptisol order. On the basis of properties associated with wetness and the presence of an ochric epipedon the studied soils were placed into two suborders: Aquepts and Ochrepts.

Chapter Three

MATERIALS AND METHODS



CHAPTER - 3

MATERIALS AND METHODS

This chapter includes relevant information about the soils collected for the investigation together with the short accounts of the experimental methods that were followed in the laboratory analysis of the soils.

3.1 Materials

The soils of the lower Atrai basin have been surveyed under the reconnaissance soil survey (RSS) scheme by the SRDI Staff (1965-1986). The major portion of the basin extends over three adjacent districts of Sirajgonj, Natore and Naogaon and very small portions covers Rajshahi and Bogra districts. All over the lower Atrai basin area total 23 soil series were identified SRDI Staff (1965-86); Hassan (1999); Hussain *et al. (*2003); Rahman (2005); SRDI Staff (2010); SRDI Staff (2013) (Table 1). Seven extensive soil series have been included for the present study that comprises about 70% of the total basin area. Because of extensiveness Taras series was found from two different places. These eight soil series also form a part of the seasonally flooded soils of Bangladesh. These soils are remains submerged for long durations. Both the flooding depths and duration, flooding varies from year to year and place to place. The individual soil sampling sites were selected as accurately as possible to have representative pedons.

The list of the selected soils series, their period and depth of inundation during the year and the area covered by them are given in Table 2. The reconnaissance soil survey reports (SRDI Staff, 1965-86), upazila land resources utilization guide by SRDI of Taras, Singra, Natore sador, Atrai, Raninagar, Naogaon Sador upazila and the soil maps of the greater Rajshshi and Bogra district were used as the base materials for field work in this study. Toposheets and available aerial photographs were also used during the field work.

3.1.1 Location of the soils sampling sites in lower Atrai basin

The sampling sites lay approximately $24^{0}21'$ to $24^{0}51'$ north latitude and $88^{0}49'$ to $89^{0}23'$ east longitudes.

The sampling site of Binsara series lies in village Kundoil under Taras Upazila of Serajgonj district (Fig 6). The sampling site is located at 24º 25′ 310″ north latitude and 89º 17′ 598″ east longitude.

The Taras series (1) were sampled from Boro chaugram village under Singra Upazila of Natore district (Fig 6). It lies at 24º 31′ 566″ north latitude and 89º 10′ 424″ east longitude.

The sampling area of Jaonia series lies in village Akdala under Natore sador Upazila of Natore district (Fig 6). It lies at 24º 32′ 005″ north latitude and 89º 00′ 404″ east longitude.

The soil samples of Taras series (2) were collected from village Hingolkandi under Atrai Upazila of Naogaon district (Fig 6). It lies at 24º 35′ 485″ north latitude and 89º 04′ 594″ east longitude.

Table 1. A list of soil series identified in the lower Atrai basin of Bangladesh.

No.	Soil Series	Area (ha)	Parent material
1	Beola	4719	Atrai river alluvium
2	Bhutlia	320	Atrai river alluvium
3	**Binsara***	**7383**	**Tista river alluvium**
4	Deopara	2420	Atrai river alluvium
5	Digli	17821	Tista river alluvium
6	**Hasnabad***	**4238**	**Tista river alluvium**
7	Elanga	6933	Atrai river alluvium
8	Halti	14406	Atrai river alluvium
9	Hulibari	3232	Atrai river alluvium
10	**Jaonia***	**16228**	**Atrai river alluvium**
11	Kanil	1609	Atrai river alluvium
12	Lalor	368	Atrai river alluvium
13	**Laskara***	**19834**	**Tista river alluvium**
14	Malikka	299	Atrai river alluvium
15	Payna	1609	Atrai river alluvium
16	**Mainam***	**11307**	**Atrai river alluvium**
17	Piprul	907	Atrai river alluvium
18	Safapur	4511	Atrai river alluvium
19	**Taras***	**44678**	**Atrai river alluvium**
20	Saluka	1910	Tista river alluvium
21	Satbaria	3232	Atrai river alluvium
22	Serkol	907	Atrai river alluvium
23	**Manda***	**5350**	**Atrai river alluvium**
23	**- Total area =**	**174221**	

Source: SRDI Staff (1965-86); Hassan (1999); Hussain *et al.*(2003); Rahman (2005); SRDI Staff (2010); SRDI Staff (2013).
***** Soil Series selected for the present study.

The soil samples of Hasnabad series were collected from village Jatamrul under Atrai Upazila of Naogaon district (Fig 6). It lies at 24º 36′ 386″ north latitude and 88º 58′ 004″ east longitude.

The soil samples of Laskara series were collected from village Ataikula under Raninagar upazila of Naogaon district (Fig 6). It lies at 24º 42′ 191″ north latitude and 88º 55′ 009″ east longitude.

The soil samples of Manda series were collected from village Chakprasad under Naogaon Sador Upazila of Naogaon district (Fig 6). It lies 24º 46′ 171″ north latitude and 88º 55′ 630″ east longitude.

The soil samples of Mainam series were collected from village Jalkorgandi under Naogaon Sador Upazila of Naogaon district (Fig 6). It lies at 24º 47′ 250″ north latitude and 88º 51′ 180″ east longitude.

Sampling location shows by aerial photograph in figure 7 and figure 8 demonstrate the elevation of each sampling point of the lower Atrai basin.

3.2 The methods

3.2.1 Methods for the field study of soils

A pit of 1m × 2m upto parent material or not extending up to depth 150 cm was dug at each soil sampling site.

For recording the detailed properties, the soil profiles were studied and described morphologically *in situ* following the guidelines of FAO (FAO, 2006) and Soil Survey Manual (Soil Survey Staff, 1993). Each horizon of the profiles was studied with respect to properties such as colour, texture, structure, consistence, field pH, boundary, vegetation etc. The lower horizon (parent material) of all soil series were collected by augering due to the presence of ground water table at the time of field work.

A total of 49 soil samples, on genetic horizon basis, from the eight soil profiles were collected for laboratory analysis.

3.2.2 Laboratory methods

Soil samples from each horizon of the profile were collected in thick double polythene bags. The bags were sealed properly precluding moisture loss from the sample and transferred as quickly as possible to the laboratory for their processing.

Prior to analysis, the representative soil samples were spread on a piece of polythene paper and big lumps were broken and sun dried under shade. The sun dried soil samples were ground in a mortar and pestle and pass the ground soil sample through a 10 mesh (2mm) sieve for physical analysis and 2.5 mesh (0.5mm) sieve and mixed thoroughly.

Table 2. Sampling location and environmental characteristics of the studied soils from the lower Atrai basin of Bangladesh.

Soil Series	Location	Latitude & Longitude	Elevation (meter)	Flooding Depth (meter)	Flooding Duration (months)	Land Type	General Soil Type	Parent Material	Area* (ha)
Binsara	Village –Kundoil Union - Saguna Upozila - Taras District –Serajgonj	24º 25′ 310″ **N** 89º 17′ 598″ **E**	11.28	3.0-3.6	4-5	Very low land	Noncalcareous dark grey Floodplains	Tista River alluvium	7383
Taras (1)	Village - Boro chaugram Union - Chaugram Upozila - Singra District – Natore	24º 31′ 566″ **N** 89º 10′ 424″ **E**	13.11	1.5-2.1	4-5	Medium low land	Noncalcareous dark grey Floodplains	Atrai River alluvium	44678
Jaonia	Village - Akdala Union - Khajuria Upozila - Natore sador District – Natore	24º 32′ 005″ **N** 89º 00′ 404″ **E**	11.89	2.1-2.7	5-6	Low land	Noncalcareous dark grey Floodplains	Atrai River alluvium	16228
Taras (2)	Village - Hingolkandi Union - Patisar Upozila - Atrai District – Naogaon	24º 35′ 485″ **N** 89º 04′ 594″ **E**	13.72	1.5-2.1	4-5	Medium low land	Noncalcareous dark grey Floodplains	Atrai River alluvium	44678
Hasnabad	Village - Jatamrul Union – Ahsanganj Upozila - Atrai District – Naogaon	24º 36′ 386″ **N** 88º 58′ 004″ **E**	14.63	1.5-2.1	4-5	Medium low land	Noncalcareous dark grey Floodplains	Tista River alluvium	4238
Laskara	Village - Ataikula Union - Mirat Upozila - Raninagar District –Naogaon	24º 42′ 191″ **N** 88º 55′ 009″ **E**	14.02	1.8-2.4	4-5	Low land	Noncalcareous dark grey Floodplains	Tista River alluvium	19834
Manda	Village - Chakprasad Union - Chakprasad Upozila-Naogaon Sador District – Naogaon	24º 46′ 171″ **N** 88º 55′ 630″ **E**	16.28	0.3-0.6	1-2	Shallowly flooded	Noncalcareous dark grey Floodplains	Atrai River alluvium	5350
Mainam	Village - Jalkorgandi Union – Dubal Hati Upozila-Naogaon Sador District – Naogaon	24º 47′ 250″ **N** 88º 51′ 180″ **E**	16.43	0.3-0.7	1-2	Shallowly flooded	Noncalcareous dark grey Floodplains	Atrai River alluvium	11307

*Source: SRDI Staff (1965-86) and Hussain *et al*. (2003)

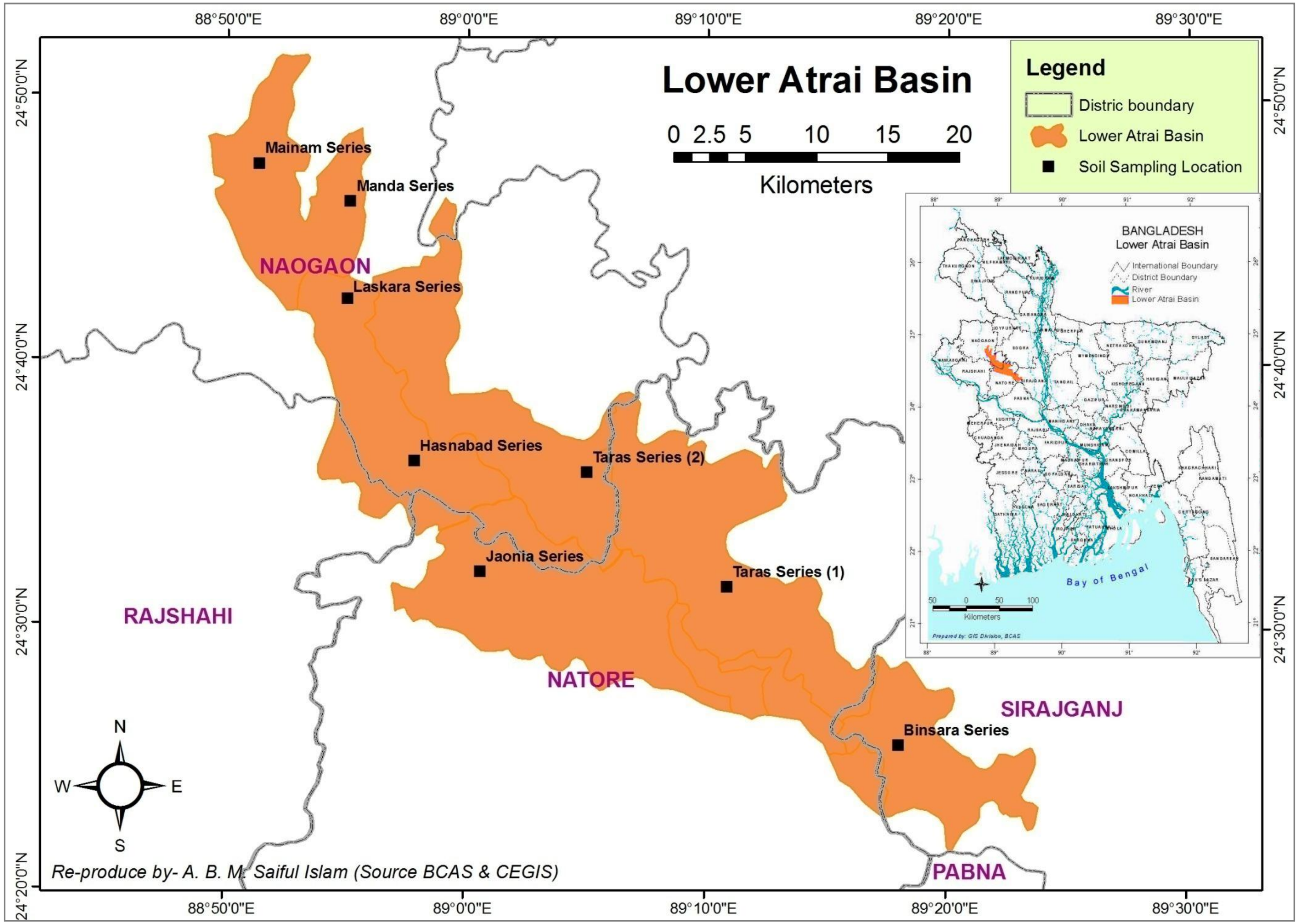


Fig 6. Map showing the sampling sites of the lower Atria basin in Bangladesh.

Fig 7. Aerial photograph showing the sampling location of the lower Atrai basin area of Bangladesh.

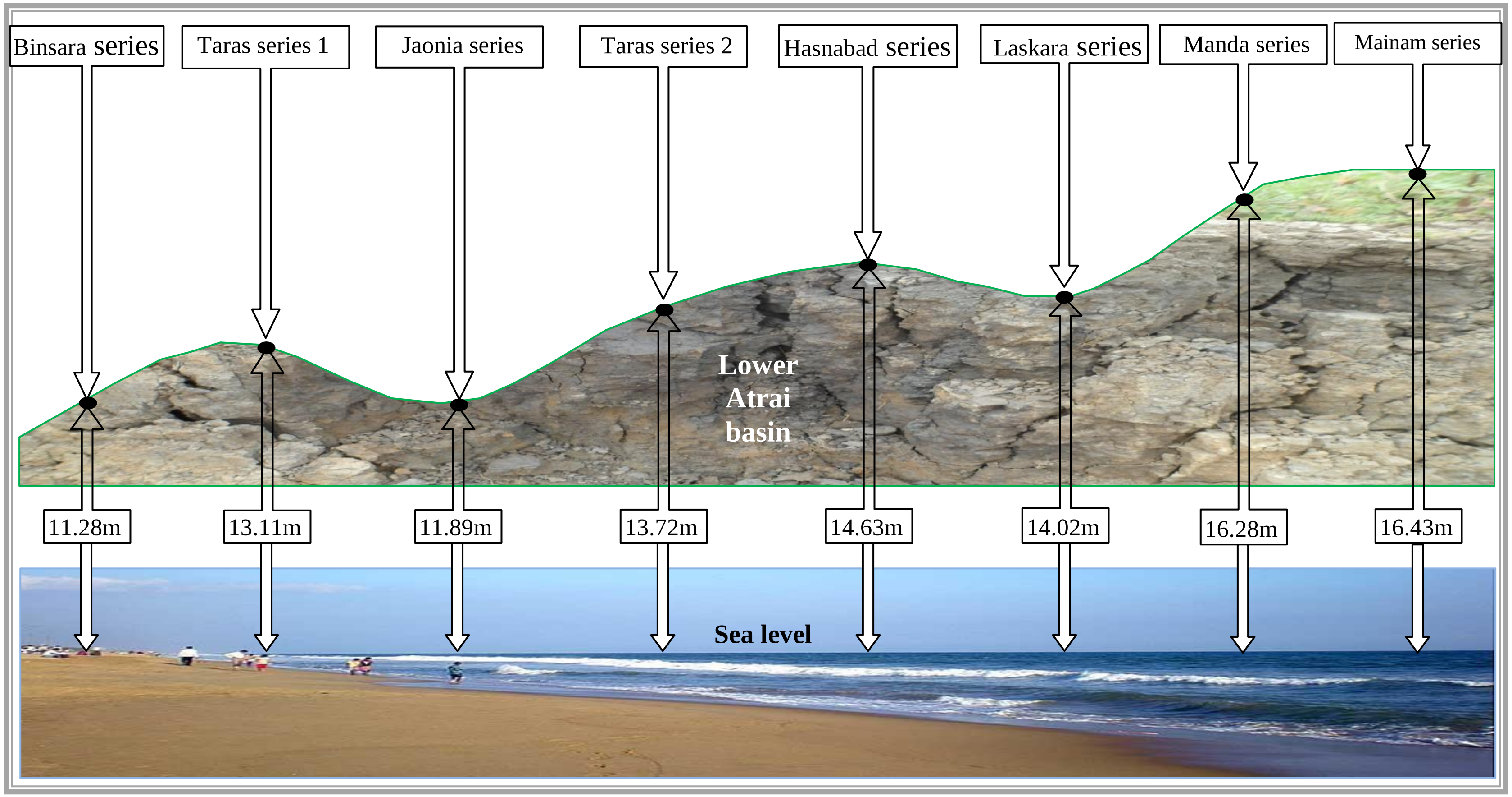


Fig 8. Elevation (height from sea level) of the sampling points of the lower Atrai basin of Bangladesh.

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.

3.2.2.1 Physical analyses

i) Bulk density (Db): Bulk density of soil was determined by core method as describe by Blake (1965a).

ii) Particle density (Dp): Particle density of soil was determined by core method as describe by Blake (1965b).

iii) Total porosity (f): Total porosity of soil was calculated from the data of particle density and bulk density using the formula below as described by Stikling (1956) according to the following formula:

$$\% \text{ porosity} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100$$

iv) Hygroscopic moisture: Hygroscopic moisture content of soils was determined by drying the air-dried soils in an oven at $105^{o}C$-$110^{o}C$ for 24 hours (Black, 1965).

v) Particle size distribution: The particle size analysis of soils was carried out by combination of sieving and hydrometer methods as described by Day (1965). Textural classes were determined by Marshall's triangular coordinate curve as devised by USDA (1975).

vi) Loss on ignition (LOI): Loss on ignition of soils and clay was determined by using muffle furnace and ignited for 2 hours at $900^{o}C$ (Piper, 1966)

vii) n-value:The n-value was calculated using the formula below:

$$n = (A - 0.2R)/(L+3H)$$

Where, A is the percentage of water in the soil at field condition, calculated on a dry-soil basis; R is the percentage of silt plus sand; L is the percentage of clay; and H is the percentage of organic matter (USDA, 1975).

3.2.2.2 Chemical analyses

i) Soil reaction (Soil pH): The pH_{water} of soils was determined at soil water ratio of 1:2.5 using a pH meter. A same ratio of soil 1N KCL solution was used for determination of pH_{KCl}.

ii) Organic carbon: The organic carbon content of soils was determined volumetrically by wet-oxidation method as described by Jackson (1967).

iii) Total Nitrogen: The total nitrogen in soils was determined by Kjeldahl's method as described by Jackson (1967).

iv) Free Iron and Manganese: Free iron and manganese in soils were extracted by sodium dithionite-citrate system buffered with sodium bicarbonate following the method of Mehra and Jackson (1960). Iron and manganese in the extract were determined by atomic absorption spectrophotometer.

3.2.2.3 Physico-chemical analyses

i) Cation exchange capacity (CEC): Cation exchange capacity of soils was determined with 1N NH_4Oac method buffered at pH 7 as described by Jackson (1967).

ii) Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, K^+): Exchangeable cations were determined from 1N NH_4OAc (pH-7) extract as described by Jackson (1967). Ca^{++} and Mg^{++} were determined by atomic absorption spectrophotometer, while Na^+ and K^+ were analysed by flame photometer.

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

$$\text{Base saturation percent (BSP)} = \frac{\text{Exch. } Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}}{\text{Cation exchange capacity}} \times 100$$

3.2.2.4 Fusion analysis of whole soil and clay fraction

Fusion analysis entails the determination of total elemental composition of the inorganic components of the soil and clays by fusion method (Piper 1966; Jackson 1967). Clay fraction was separated by dispersion and separation method by Jackson 1967. The clay fraction thus obtained were dried, ground and pass through 100 mesh sieve. A weighed amount of this purified clay was used for fusion analysis.

i) Silica (SiO_2): Silica present in soil and clay samples were determined by the method of silicate analysis by Jackson (1967), which involves sodium carbonate (Na_2CO_3) fusion, Double evaporation of the HCl extract of the fuse and dehydrate, ignition and purification by HCl acid.

ii) Total Phosphorus: Total phosphorus content in the extract of the HCl fused was determined by Shimadzu spectrophotometer (UV-120-02 model) at 460 mμ wavelengths, after developing the yellow colour with molybdate-vanadate, as describe by Jackson (1967).

iii) Total Potassium: Total potassium content in the fusion extract of the HCl fused was determined by Flame photometer (Jackson, 1967).

iii) Total Titanium: Total titanium in the fusion extract was determined colorimetrically by developing yellow colour with 30% hydrogen peroxide (Black 1965).

vi) Total Iron, Manganese, Aluminum, Calcium and Magnesium: Total Iron, Manganese, Aluminum, Calcium and Magnesium in the soils were determined from sodium carbonate fusion extract as describe by Jackson (1967). Elements in the extract were determined by atomic absorption spectrophotometer.

3.2.2.5 Mineralogical analysis of clay fraction (<2µm)

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 and scanning electron microscopy (SEM) was done for observe the shape and size of minerals in clay fraction.

3.2.2.5.1 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 carbonates and organic matter: The soil sample were treated with 1N NaOAc-acetic acid buffer (pH 5) to destroy the free carbonates and Organic matter was destroyed by 30% H_2O_2 treatment (Jackson, 1967).

 # Removal of iron and manganese oxides: Free oxides of Fe and Mn were removed from soils by the citrate–bicarbonate–dithionite extraction method, as was described by and Mehra and Jackson (1960).

After removing soluble salts, carbonates, organic matter, MnO_2 and Fe_2O_3, the soils were dispersed with 5% Calgon solution (Jackson, 1975) and the clay fraction (<2μm) was separated by repeated stirring-sedimentation-siphoning processes as described by Jackson (1975).

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 (<2μm) in 10 ml centrifugal tube. Washing by centrifugation and decantation was carried out twice with 8 ml of an equal mixture of 1M 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 three times with 8 ml of 1M KCl and 0.5M $MgCl_{2,}$ 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 clay suspension was dropped onto a glass slide (28×48 mm), covering two-third of its area, air dried, and X-rayed (parallel powder mount). XRD patterns were obtained using a Rigaku X-ray diffractometer (RINT 2100V, Rigaku) with Ni-filtered CuKα radiation at 40kV, 20 mA and at a scanning speed of $2^{\circ}\ 2\theta$ per minute over a range of 3 to $30^{\circ}\ 2\theta$. 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 ºC for two 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 intensities ratio of two components *P* and *Q* in a multi-component mixture can be related to their weight ratio as follows:

$$Ip/Iq = Kp.q\ (wp/wq)$$

Where, *Ip* and *Iq* are the intensities of the *P* and *Q* components, respectively in XRD, *wp* and *wq* are the weight proportion of *P* and *Q* components, respectively and *Kp.q* a constant value, is the intensity-weight coefficient of *P* and *Q* components (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; Aramaki, 1996) listed in *Appendix 10*, the weight ratios of all the pairs were calculated. Assuming that the sum of the weight ratios is one, the weight proportion of all the minerals in the <2µm 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. 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.

3.2.2.5.2 Scanning electron microscopy (SEM) of clay fraction.

Clay fraction of the Ap horizon (surface) of each profiles were selected for SEM analysis. SEM was done by the method of Laird *et al*. (2001). Details of clay separation have been described in method of XRD analysis (Jackson 1967). Briefly, the soil was mechanically dispersed in distilled water and a bulk sample of the soil clay (<2 μm particle-size fraction) was separated by sedimentation and air dried. In this study, H_2O_2 treated samples were analyzed by scanning electron microscopy (SEM) using a JEOL JSM-6490LA at CARS. The SEM was operated at 20 kV and the final aperture was removed to enhance signal collection.

JEOL JSM-6490LA Microscope

Chapter Four

ENVIRONMENTAL SETTINGS AND FIELD STUDIES

CHAPTER – 4

ENVIRONMENTAL SETTINGS AND FIELD STUDIES

4.1 Environmental settings of lower Atrai basin

Information about the soil environment is critically necessary for the correct assesement of any pedological investigation of an area.Wih this view an attempt has been made to record the available information regarding physiography, agroecological zones, parent material, climate, hydrology, vegeation and land use of the area under ivestigation.

4.1.1 Physiography

Bangladesh has three distinct and broad physiographic regions. On the basis of significant variations in regional or local topography, hydrology, source and nature of sediments and soil characteristics as identified and differentiated by the reconnaissance soil surveys carried out during the period from 1964 to 1974 (SRDI, 1965-1986). The percentage compositions of these three physiographic regions are as follows-

Physiographic regions	Percentage
A. Recent floodplains	79.1
B. Pleistocene terraces	8.4
C. Hill areas	12.5

Brammer (1996) has divided recent floodplains of Bangladesh into 20 physiographic units. The “**Lower Atrai basin”** is one of the physiographic unit of recent floodplains region (Fig 9). This small unit occupies a low-lying area where mixed sediments from the Atrai and Ganges rivers and from the Barind tract overlie the down-warped southern edge of the Barind tract. The landscape north of the Atrai river is mainly smooth, but floodplain ridges and extensive basins occur to the south of the river. Heavy clay soils predominate but loamy soils occur on ridge in the south and west. Drainage from this unit becomes impeded when the exit through the Hurasagar channel is impaired by high river level in the river Jamuna.Seasonal flooding was formerly deep, and extensive areas in Chalan beel used to remain wet throughout the year. Since 1960s drainage has improved to some extent. However, deep flooding still occurs within as well as outside polders when there is heavy rainfall locally and when flash floods flow down the river Atrai or off the adjoining Barind tract, causing natural or man-made beaches of embankments (Brammer, 1996).

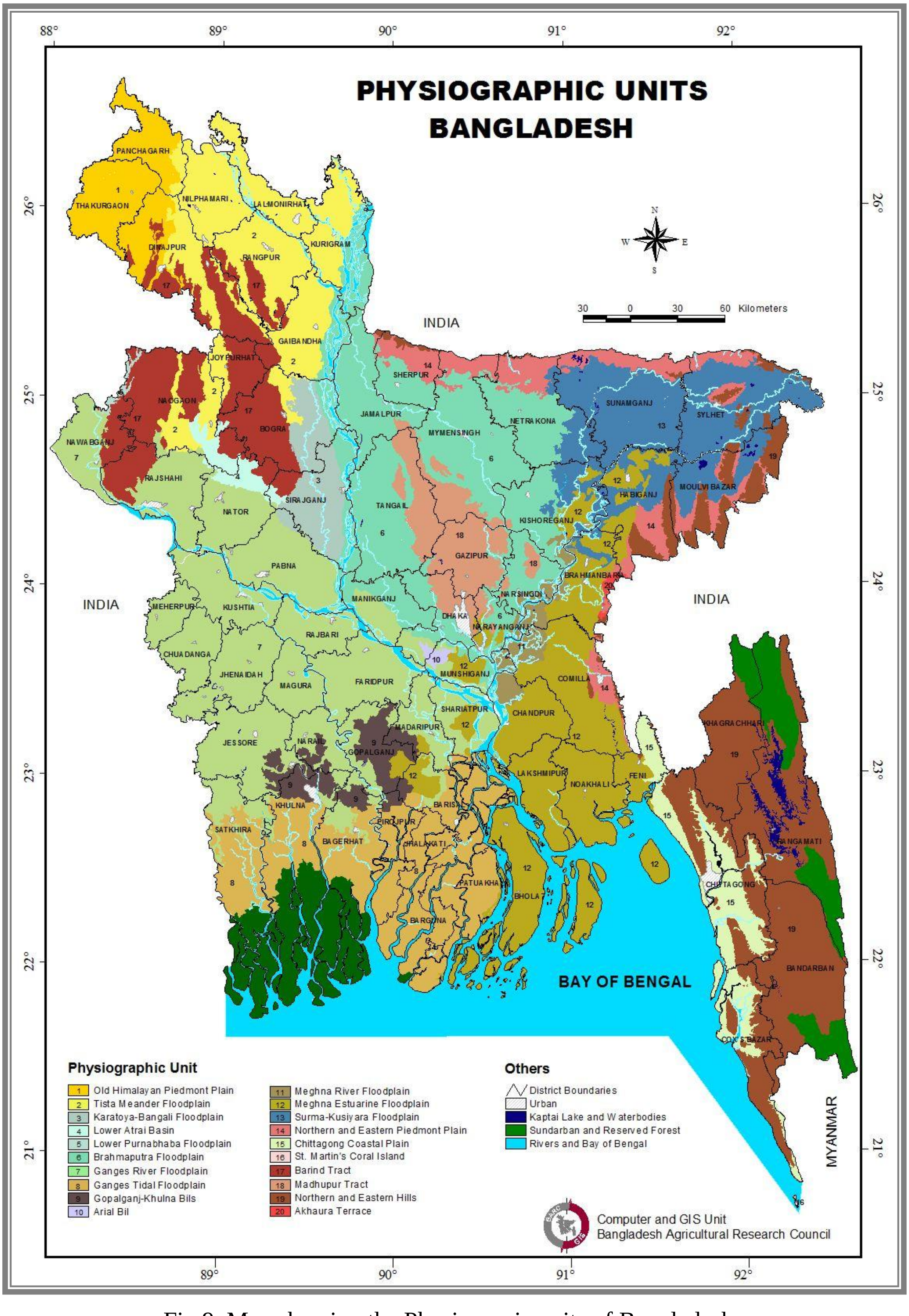


Fig 9. Map showing the Physiograpic units of Bangladesh.

4.1.2 Agro-ecological Zone (AEZ)

Agroecological Zones of Bangladesh has been published by FAO-UNDP in 1988 (FAO-UNDP, 1988) on the basis of the works done by the project, "Land Resource Appraisal" by Brammer and others.

The following four layers of information were superimposed one after another for defining and delineating the Agroecological Zones of Bangladesh. These are-

i. Physiography
ii. Soil
iii. Depth and duration of seasonal flooding
iv Climate

Bangladesh has been divided into 23 physiograpic units and 34 physiograpic subunits. These physiograpic subunits have been rearranged to obtain the Agroecological Zones. A total of 30 Agroecological Zones hae been identified in Bangladesh which vary both in size and shape (FAO-UNDP, 1988). The "**Lower Atrai basin"** (Fig 10) is one of the Agroecological Zones of Bangladesh which number is 5. The total area of this zone is 85,100 hectares (FAO-UNDP, 1988). The Lower Atrai Basin comprises the low–lying area between the Barind Tract and Ganges River Floodplain. Smooth, low–lying basin land occupies most of the region. Areas bordering the Ganges, Lower Atrai and Little Jamuna Floodplains have some ridges penetrating into the basin; and the relief is locally irregular near river channels.

4.1.3 General Soil Type

General Soil Types is the latest classification scheme on Bangladesh soils. H. Brammer in 1971 presented this system and called it General Soil Type (GST) syetem of classification (FAO, 1971). A general soil type was defined as "a group of soils formed in the same way and having a broadly similar appearance". It was intended to be a nontechnical grouping of soils made originally to enable nonspecialists to make use of technical soils information generated through the reconnaissance soil survey works. Most of the information on the soils of Bangladesh that were used for this classification were collected by the Soil Resources Development Institute (SRDI Staff, 1965-1986). The general soil type names apply specially to the soils of Bangladesh. The system offers single category of 21 general soil types with no higher or lower category. Originally 17 general soil types in Bangladesh were proposed (FAO, 1971) but the number was increased to 21 in subsequent revisions (FAO-UNDP, 1988). The general soil types are distributed on three geomorphological units, belonging to three distinct ages. Fourteen general soil types have been identified on foodplain areas, one on hilly areas and six on terraces. Among the 14 general soil types of floodplains area lower Atrai basin covers only one general soil type.

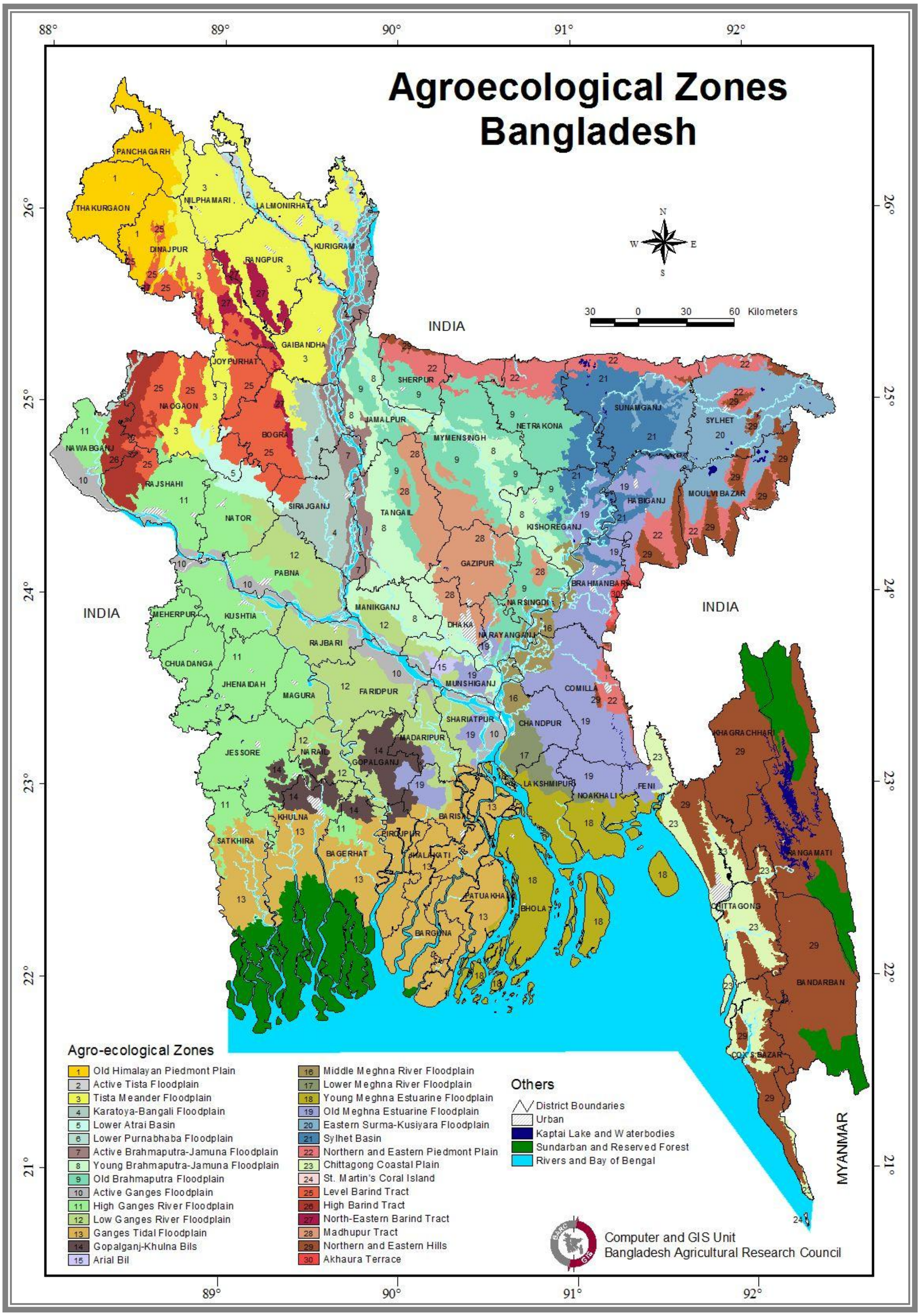


Fig 10. Map showing the Agroecological Zones of Bangladesh.

Most of the soils of the lower Atrai basin area belongs to ***Noncalcareous dark grey floodplain soil*** (Brammer, 1971) (Fig. 11). They are seasonally flooded and have dark grey to black flood coatings along subsoil cracks and pores. Their colours are grey to dark grey, and have yellow to brown mottles along root channels. These soils are noncalcareous throughout the profile.

4.1.4 Parent Material

The materials on which the seasonally flooded soils have developed are primarily those carried by the big rivers, like the Ganges, the Brahmaputra and the Meghna. It has been estimated that around 2.5 billion tons of sediments are carried down by these and other rivers to Bangladesh (Nishat and Bhuiyan, 1995). Part of this sediments are deposited on the seasonally flooded areas while the rest is carried first to the off shore areas and to the deep sea to the south. The parent materials of the presently studied soils are Tista River Alluvium and Atrai River Alluvium.

4.1.5 Climate

Climate is one of the most important soils forming factor. According to Jenny (1960), the depth of carbonates and clay contents in soil solum increases as rainfall increases. Water table fluctuation of a soil depends on rainfall. According to Manalo (1975), the climates of the investigated area have been classified as humid tropical monsoon. In general, four distinct seasons are experienced in this region. The dry hot period prevails during the months of March-May, the hot humid rainy season during the months of June-August. The autumn covering the months of September-November and the winter comprising the months of December-February. The coldest month of the year is January while the hottest month is April. Lowest winter temperature sometimes goes below 10^0C in the month of January whereas the highest temperature seldom reaches above 40^0C in the months of April-May.

In Bangladesh, the tropic of Cancer passes through the middle from east to west. So, the country is located in the tropical monsoon region. The Himalayan mountain chain also helps directly in the country's climatic variation. The climate of Bangladesh is characterized by high temperature, heavy rainfall, often excessive humidity and fairly marked seasonal variations. In the study area, there is a distinct seasonal pattern in the annual cycle of rainfall as well as temperature. The winter season is very dry and accounts for only 2-4% of the total annual rainfall. Rainfall during this season is less than 20 mm and the average temperature is below than 20^0C. As the winter season progresses into the pre-monsoon hot season, rainfall increases due to intense surface heat and the influx of moisture from the Bay of Bengal. The average temperature is 30^0C and the amount of average rainfall at this time is 100 mm. In the rainy season (July–October) the average rainfall is more than 220 mm.

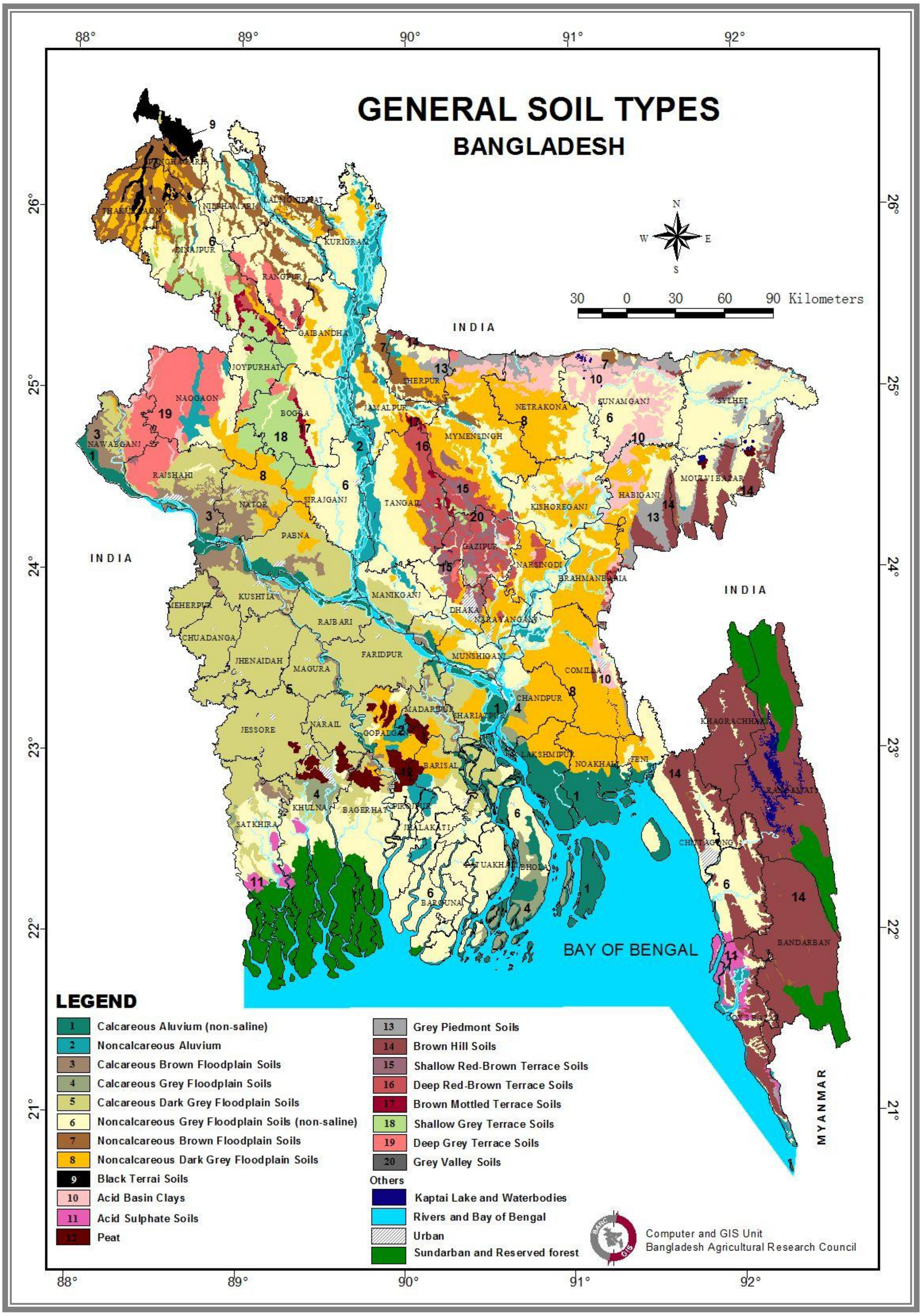


Fig 11. Map showing General Soil Types of Bangladesh.

More than 80% of the total rainfall occurs in this season when a huge moist air of the monsoon sweeps up the Bay of Bengal from the Indian Ocean. The study area is nearest to Rajshahi and Bogra Meteorological station. The data from the two places are included in the present study (Tables 3 & 4; and figures 13-20). The total annual rainfalls are 1705 mm and 1142 mm respectively for Rajshahi and Bogra (Table 3). During the monsoon months rainfall is frequent and occasionally heavy. The investigated area receives highest rainfall in the months of June, July, August and September, while in December and January the area receives no or very little rainfall (Figs 13 & 14). The distribution of rainfall in Bangladesh varies widely throughout the year and also from place to place which is shown in Figure 12. The north eastern part receives the highest mean annual rainfall reaching a maximum of 5500 mm at Lallakhal in Sylhet district. Another high rainfall concentration belt occurs near Cox's Bazar with a maximum of around 3000 mm. There is a gradual decrease of rainfall towards west reaching as low as 1500 mm at Chapai Nawabgonj. According to MPO report (1985), the mean annual rainfall over the entire country is about 2300 mm. In central Bangladesh, especially in the area under the present investigation, the rainfall variability is very limited. The maximum temperature ranges from 23^{o}C to 38^{o}C with a mean annual maximum temperature of 31^{o}C for Rajshahi and from 22^{o}C to 35^{o}C with a mean annual maximum temperature of 31^{o}C for Bogra. The minimum temperature ranges from 12^{o}C to 27^{o}C with a mean annual maximum temperature of 22^{o}C for Rajshahi and from 12^{o}C to 29^{o}C with a mean annual maximum temperature of 20^{o}C for Bogra. Temperature varies with season, being the highest in the premonsoon and monsoon seasons (April to July), and lowest in the winter season (December to January) (Figs. 13 & 14). The temperature regimes can be described by the mean annual soil temperature, the average seasonal fluctuation from the mean and the mean worm or cold seasonal soil temperature gradient with in the main root zone from a depth of 5 to 100 cm. In order to estimate the soil temperature we may add 1^{o}C to mean annual air temperature. Six soil temperature regime are used in defining at verious categoric levels in soil taxonomy like *Pergellic, Cryic, Frigid, Mesic, Thermic and Hyperthermic*. In Bangladesh only one regime is applicable that is ***hyperthermic*** (Hussain, 1992).

The mean annual soil temperature of studied area is 26.5 ^{o}C and 25.5 ^{o}C respectively for Rajshahi and Bogra, and the difference between mean winter and summer is more than 6 ^{o}C at 50 cm depth. This data also prove that the thermal regime of lower Atrai basin may, therefore, be characterized as ***hyperthermic***.

Mean monthly relative humidity is the highest during the monsoon months of May upto October, when it ranges from 75 to 87 percent for Rajshahi and from 78 to 86 percent for Bogra, Respectively. This gradually comes down during the winter months and finally to the lowest, from 63 to 65 percent for Rajshahi and 66 to 72 percent for Bogra, respectively

Table 3. Some monthly meteorological data (2012) of Rajshahi and Bogra stations.

Station	**Parameter**	**← Month →**												**Annual**
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Rajshahi	Maximum Temp. °C	23.4	28.4	33.8	35.5	38.3	33.1	33.3	34.2	33.5	32.4	28.2	23	31.4
	Minimum Temp. °C	11.5	12.2	17.5	21.5	25.9	26.9	26.4	26.7	26.1	21.9	16.4	11.8	21.6
	Humidity (%)	78	71	63	65	75	83	87	86	86	83	78	78	78
	Rainfall (mm)	6	0	59	70	17	136	316	718	186	94	65	1	1705
	PET* (mm)	39.5	66.3	100.6	115.8	119.7	90.1	91.4	98.3	86.6	90.2	90.0	65.3	1053.8
	Water Surplus						45.9	224.6	619.7	99.4	3.8			
	Water Deficit	33.5	66.3	41.6	45.8	102.7						25.0	64.3	
Bogra	Maximum Temp. °C	23.9	28.0	32.6	34.4	35.2	30.9	32.9	33.2	32.2	32.6	29.3	21.9	30.8
	Minimum Temp. °C	12.2	14.0	19.5	28.9	25.6	26.4	26.6	26.9	26.4	22.9	17.3	13.0	20.4
	Humidity (%)	77	76	66	72	78	84	86	85	86	82	77	77	79
	Rainfall (mm)	19	0	0	74	94	148	185	167	360	59	36	0	1142
	PET* (mm)	40.3	67.4	102.6	117.0	120.2	91.1	92.3	97.3	85.6	86	58.3	34.2	992.3
	Water Surplus						56.9	92.7	69.7	274.4				
	Water Deficit	21.3	67.4	102.6	43	28.2					27	22.3	34.2	

*PET = Potential Evapotranspiration (Source: Bangladesh Meteorological Department)

Table 4. Some annual meteorological data of Rajshahi and Bogra stations from 2000 to 2012.

Station	Parameter	Year													
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Mean**
Rajshahi	Total Rainfall (mm)	1730	1350	1444	1444	1786	1405	1145	2018	1315	1043	792	1475	1705	1435
	Max. Temp. °C (Mean)	34	37	36.0	35.8	34.6	36.0	35.3	34.0	31.0	31.95	32.6	31.0	31.4	34
	Min. Temp. °C (Mean)	12.7	9.6	12.5	8.4	18.4	11.3	10.6	20.6	21.2	20.7	21.0	20.5	21.6	16
	Humidity (%)	75	69	80	78	77	76	79	78	80	76	77	80	78	77
Bogra	Total Rainfall (mm)	1644	1414	2036	1688	2157	2091	1106	1919	1791	1410	1271	1721	1142	1645
	Max. Temp. °C (Mean)	32	34	31.6	33.3	32	33.4	33.6	30.6	30.5	31.3	31.1	30.6	30.8	32
	Min. Temp. °C (Mean)	11.9	10.7	11.8	9.4	13.4	12.1	11.9	21.0	12.8	21.2	21.6	20.9	20.4	15
	Humidity (%)	74	68	78	80	77	76	76	77	79	76	76	77	79	76

(Source: Bangladesh Meteorological Department) during March to April (Figs 15 & 16). The mean annual evapotranspiration is 1053 mm for Rajshahi and 992 mm for Bogra, respectively and the rate of monthly evapotranspiration is highest during March to May (101-120 mm for Rajshahi and 102-120 mm for Bogra, Respectively) (Table 3).During the months of Jun to September the rate of rainfall exceed the rate of evapotranspiration, in this period water is surplus in the soils on the other hand during the months of October to May the rate of evapotranspiration exceed the rate of rainfall, in this period water is deficit in the soils of the study area (Figs 17 & 18). The soils of the study area remain moist for most part of the year and hence the area qualifies as ***aquic moisture regime***. The intermittently and seasonally flooded fine loamy to clayey soils of Bangladesh prevails Aquic moisture regime (Saheed and Hussain, 1992). The mean annual rainfall, temperature and humidity of the last 14 years in Rajshahi and Bogra meteorological station are presented in the Table 4. Figures 19 and 20 shows the mean annual rainfall and maximum temperature of both station is decreasing tendency but minimum temperature is increasing tendency from 2000 to 2012 in both station.

Winds in Bangladesh blow from two directions and are usually light throughout the year but stronger winds may blow occasionally in the pre-monsoon and monsoon seasons in association with thunder storms and Tornadoes. These storms locally known as "kala baishakhi" and tropical cyclones cause colossal damage to the crops and properties. From tables 3 and 4 it is evident that the rainfall in the area is high. Such high rainfall indicates that leaching can take place in the soils under present study for part of the year. As the rainfall is high its distribution pattern is important for the proper evaluation of the effectiveness of moisture throughout the year. The temperature remains pretty high all through the year. The period of high temperature corresponds to the period of high rainfall which means that the wet season is attended by the warmer months of the year and the dry season by the winter months. As a result, the pedochemical weathering processes are more active during a substantial part of the year.

4.1.6 Hydrology

Hydrology is the most important determinant for the establishment and maintenance of wetland processes and is a critical element of wetland conservation effort. It is the dynamic nature of the hydroperiods that influences the diversity and productivity of wetland plants and animal communities and allows wildlife to exploit the resources with changing water levels. Wetlands within small watersheds are dominated by the local hydraulic conditions whereas those within larger watersheds may have little hydraulic coupling to the local conditions. The patterns of activity in crop production, fisheries and transportation follow an annual cycle of water from over abundance to scarcity. Eighty percent of rainfall is concentrated in four monsoon months during which about two thirds of the country becomes vulnerable to floods. Wetlands can diminish the destructive onslaught of floods

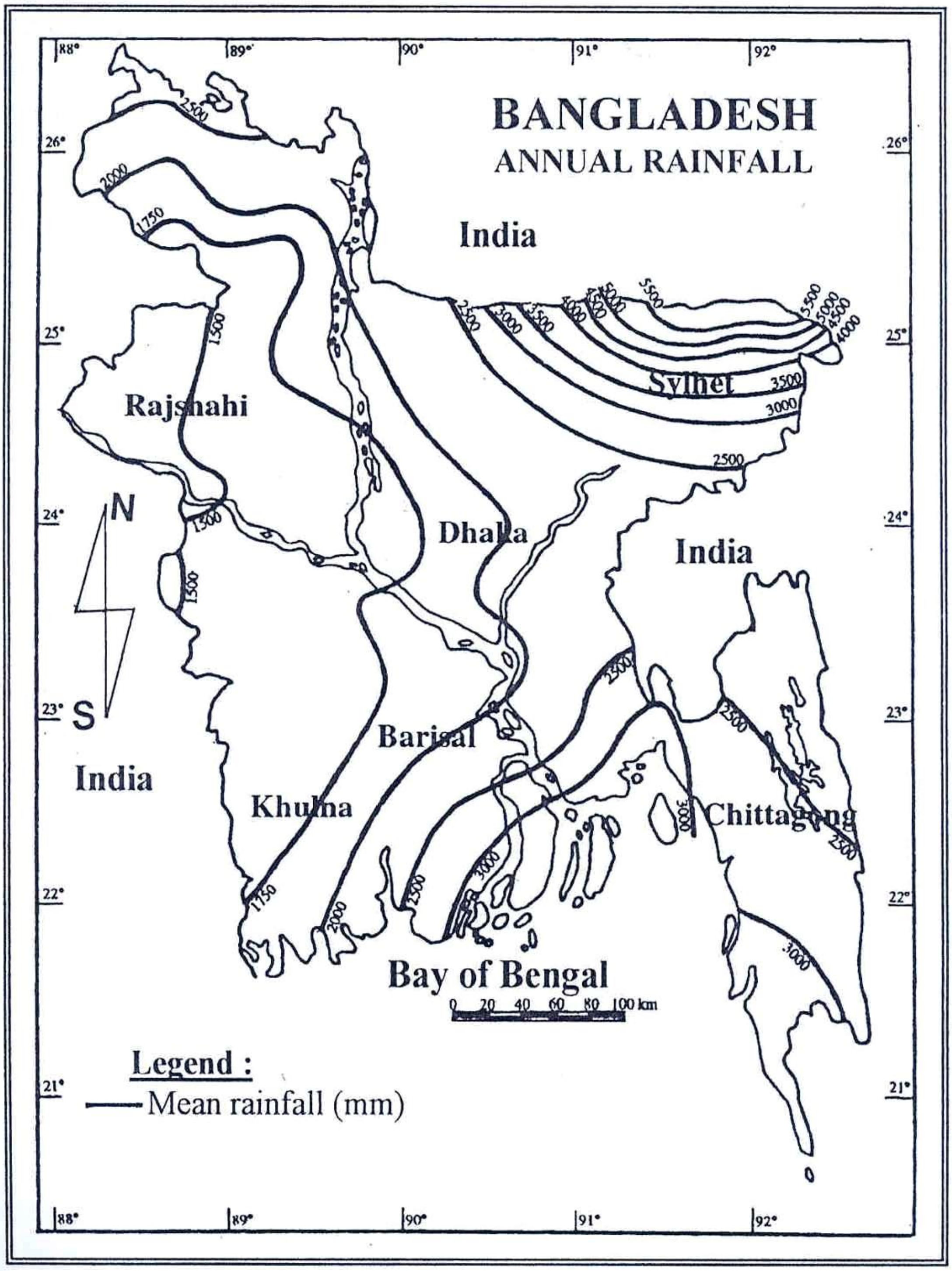


Fig 12: Map showing the distribution of annual rainfall of Bangladesh.

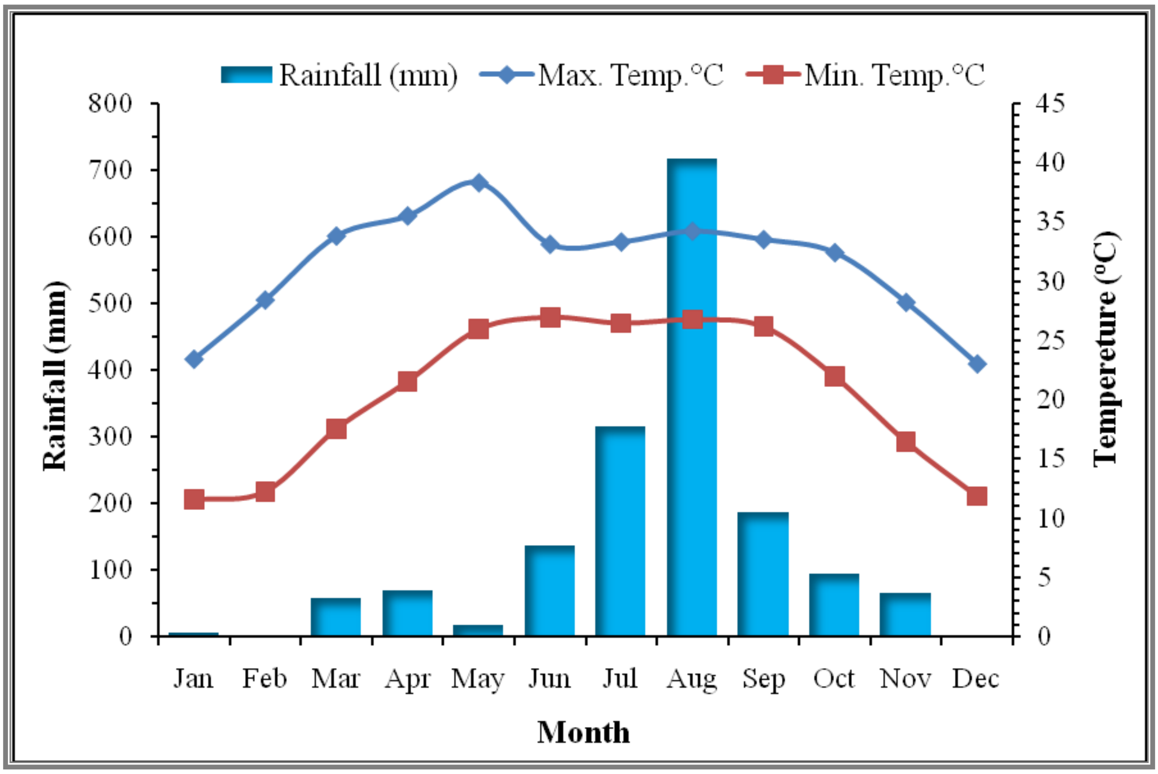


Fig 13. Climatic data of Rajshahi showing monthly rainfall and temperature.

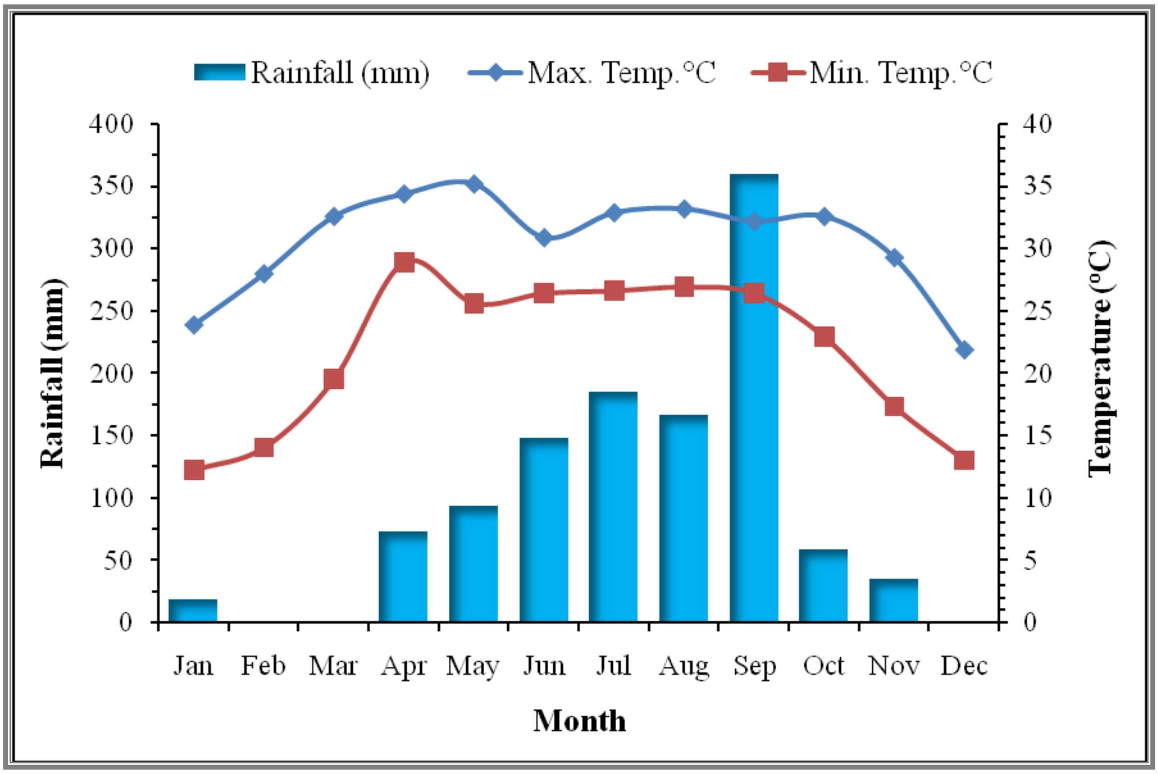


Fig 14. Climatic data of Bogra showing monthly rainfall and temperature.

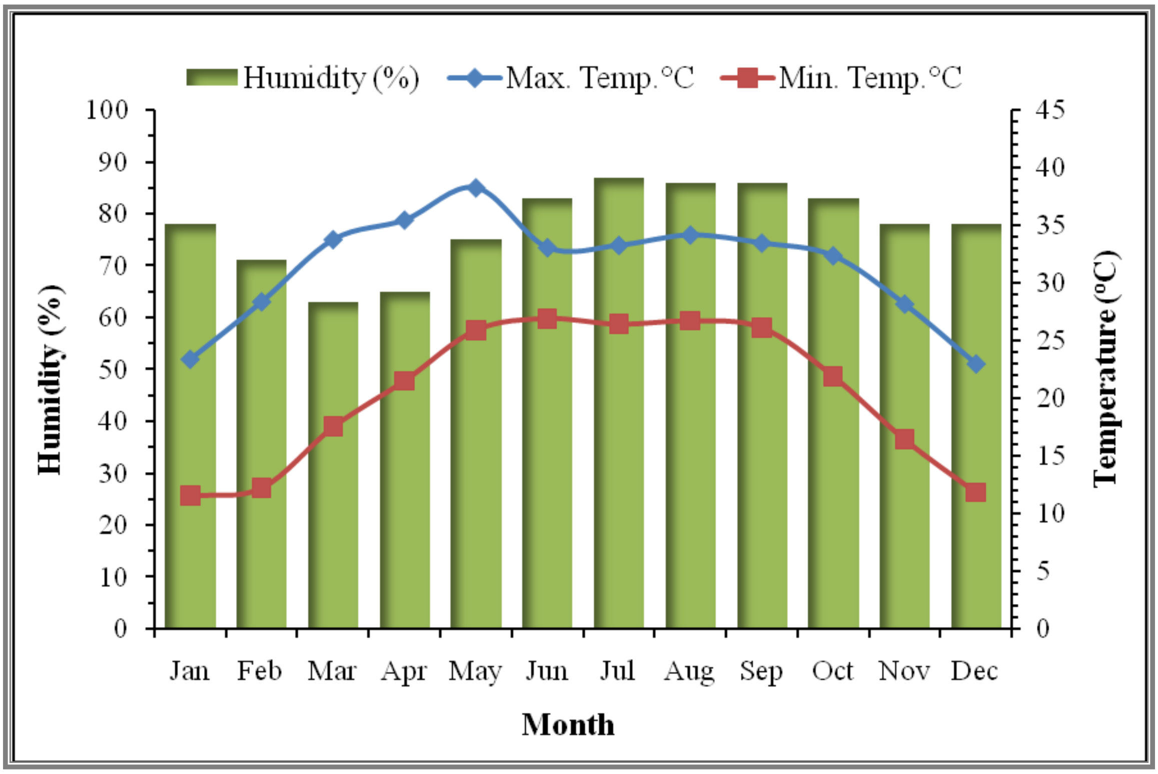


Fig 15.Climatic data of Rajshahi showing monthly relative humidity and temperature.

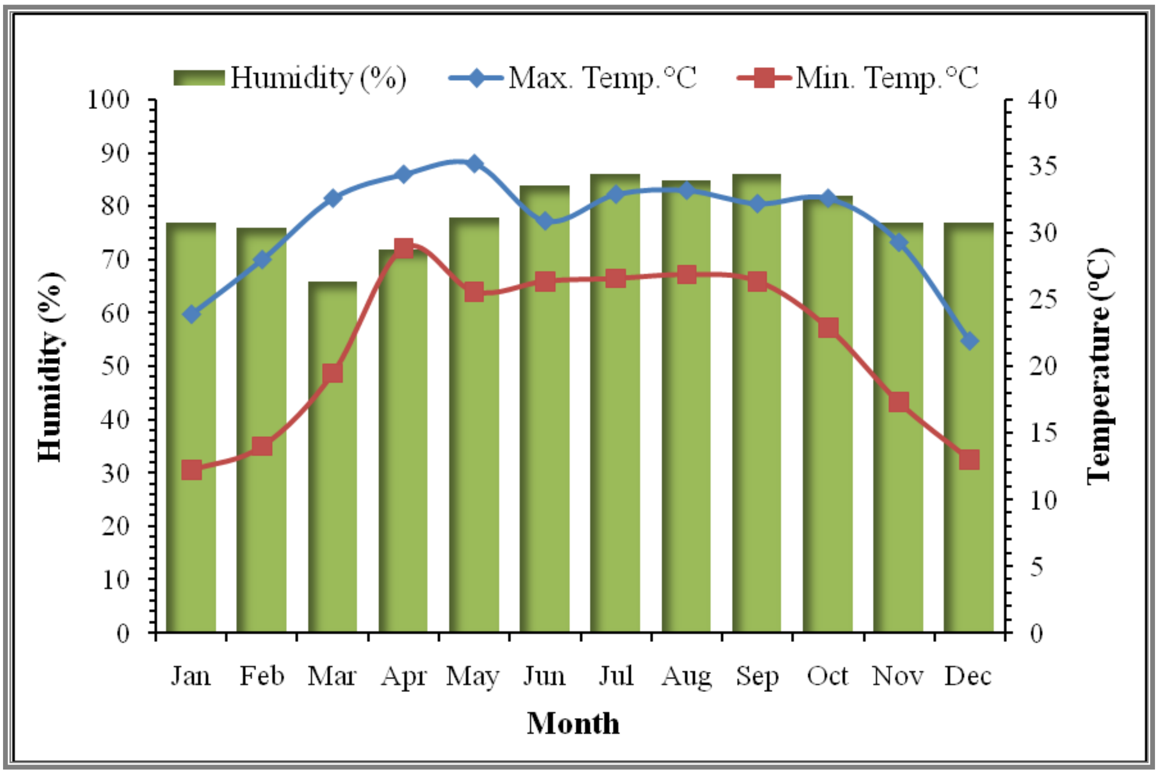


Fig 16. Climatic data of Bogra showing monthly relative humidity and temperature.

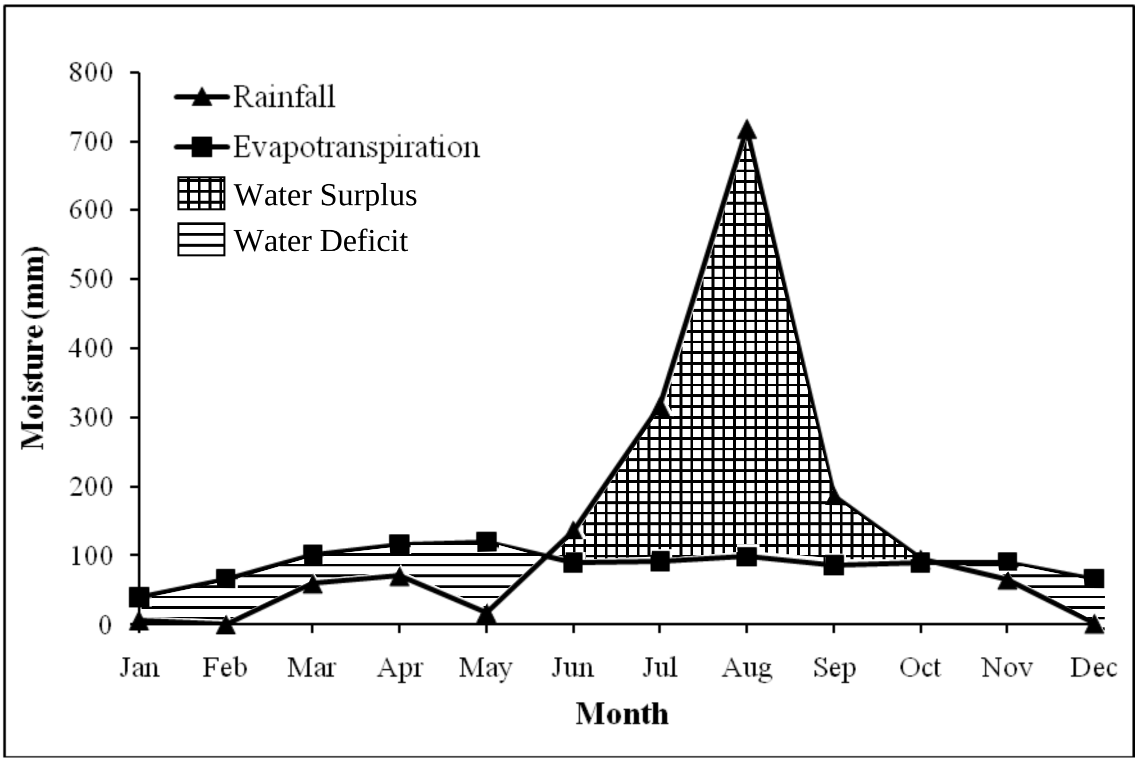


Fig 17. Climatic data and the soil water balance of Rajshahi station (2012) of Bangladesh.

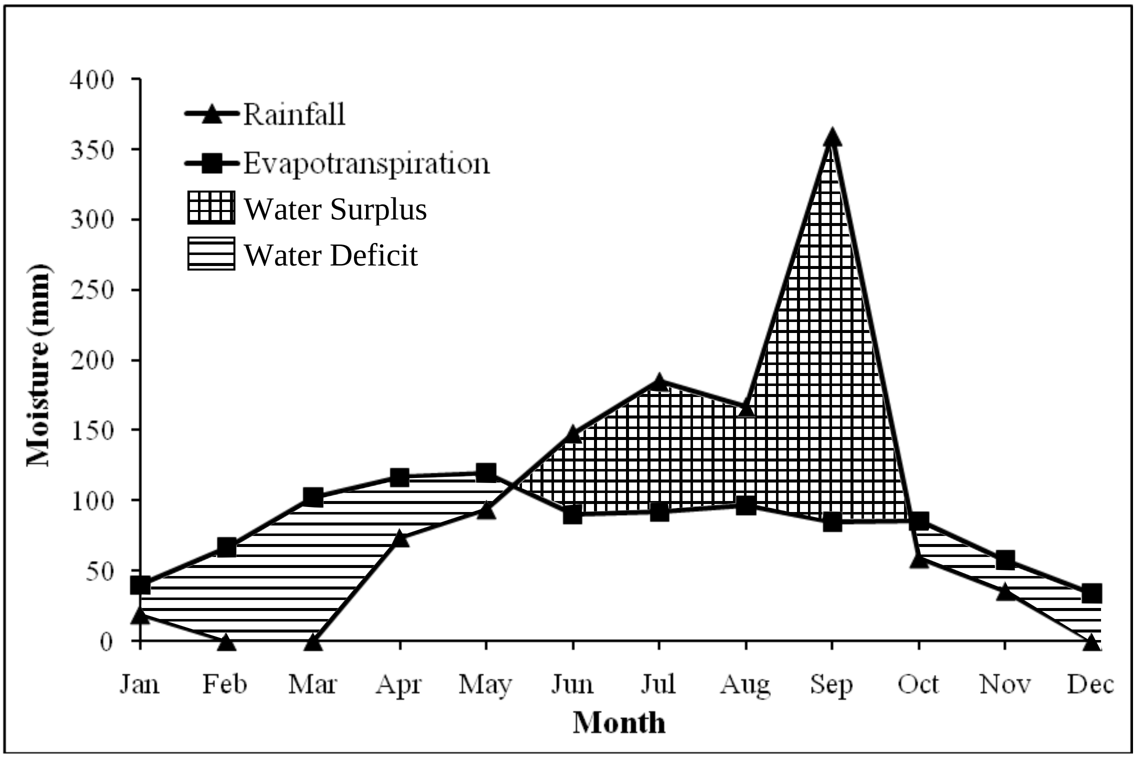


Fig 18. Climatic data and the soil water balance of Bogra station (2012) of Bangladesh.

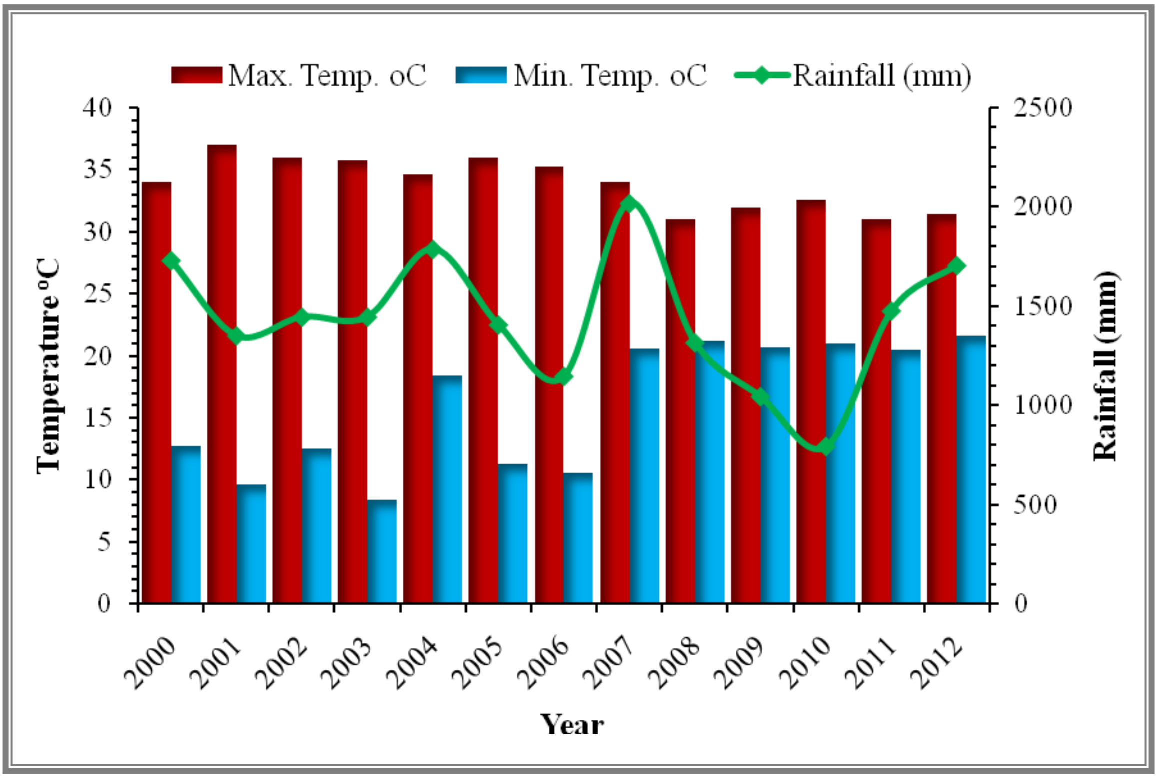


Fig 19. Climatic data of Rajshahi showing yearly rainfall and temperature from 2000 to 2012.

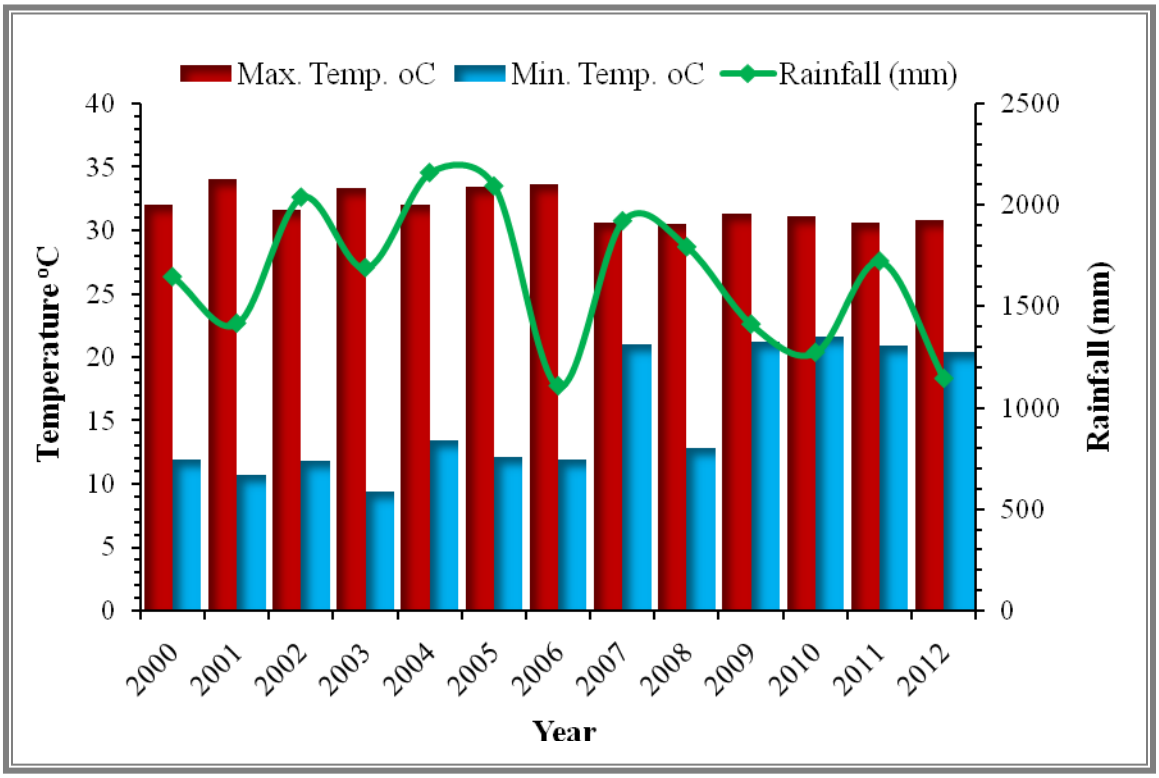


Fig 20. Climatic data of Bogra showing yearly rainfall and temperature from 1999 to 2012.

thus eliminating the necessity of costly construction of dams and reservoirs. Nevertheless, the widespread development of flood and drainage projects in Bangladesh have considered basically of embankments, river closures, excavation of drainage channels and drainage control structures. The average discharge of water in Bangladesh delta in the flood season is more than five million cusecs. The area provided with flood control and drainage facilities by Bangladesh Water Development Board has grown steadily to about 3.37 million ha in mid-sixties through the construction of 7,555 km of embankments (coastal: 3,674 km, upland: 3,881 km), 7,907 hydraulic structures and 1082 river closures. The present trend of water development activities would bring about changes in agricultural practices in wetlands including large scale utilization of surface and ground water for irrigation that would greatly reduce the wetland areas.

Although hydrology can be simply defined as the science of water, such a broad definition is rather misleading. Usage has tended to restrict hydrology to the study of water as it occurs on, over and under the earth's surface as stream flow, water vapour, precipitation, soil moisture and ground water. The water is essential to life and that its distribution and availability are closely associated with the development of human society

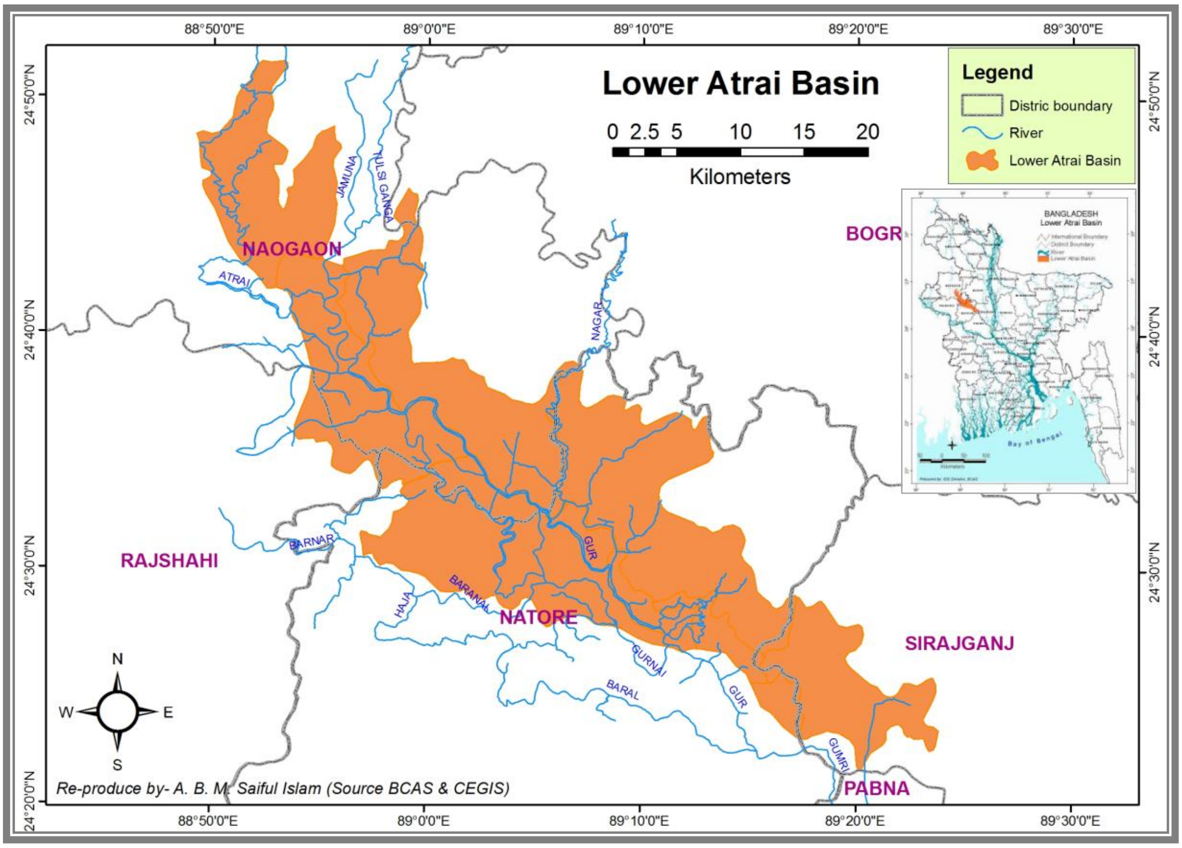


Fig 21. Map showing the river distribution over the lower Atrai basin.

seems so obvious as to be a fundamental aspect. This being so it was almost inevitable that the development of water resources preceded any real understanding of their origin and formation (Ward, 1967). Archaeological discoveries and later documentary evidence emphasize significant part played by the location and magnitude of water supplies in the lives of, for example, the people of the Chalan beel area.

Bangladesh, known as a riverine country, comprises a large network of rivers, streams and canals, which total at least twenty four thousand kilometers in length. It consists of magnificent rivers and their tributaries and distributaries. There are many large and small rivers and canals in the *Chalan beel* region those are the main source of water body of the *beel*.

The main river of the lower Atria basin is Atrai (Fig 21). The Karotoya -Atrai is west of the little Jamuna. It is the western most tributary of the Brahmaputra. Its main source is the Dinajpur Karatoa, which changes its name in Khanshama Upazila to Atrai; this channel bifurcates north-west of Chirirbandar and reunites south-west of it. The western is called Gabura and the eastern is called Kankra. The re-united river once again the Atrai, which flows almost due to Manda Upazila separating the East-central and West-central Barinds. (Rashid, 1991).

In the deltaic part of the Ganges is 1.6 to 8.0 km wide having a discharge of about 7,50,000 m^3/sec during the rainy season and low level discharge of the order 15,000 m^3/sec. The discharge ranges from a low flow of about 10000 m^3/sec to a one in 100 year flood of about 160,000 m3/sec. Due to some obvious reasons overall discharge of water and flow in the Padma-Jamuna channel has been showing quite highly variable or of fluctuating behaviour. The water discharges readily at the Hardinge Bridge, Baral-Rly-Bridge and Malanchi Station of River Ganges, Baral, Gunami, Atrai and Korotoya significantly influence the lower Atrai basin area (Fig 21). In 1998, the highest monthly water discharge at the Hardinge Bridge, September, was 74278.49 m^3/sec and the annual average discharge increases naturally during the flood. And in 1988, the highest monthly water discharge was in September, was 71800 m^3/sec. The water level at the Hardinge Bridge Station of the river Ganges was in September in 1980, '90 and 2000 was 14.82, 13.58 and 14.2 meter of the PWD respectively.

Table 5: Length, area and average water discharge of the padma (Ganges), the Brahmaputra (Jamuna) and the Meghna rivers (GMB river system).

Name of river	**Length (km)**	**Drainage area (million acres)**	**Average discharge (MAF/year)**
Ganges (Padma)	2600	386	875
Brahmaputra (Jamuna)	2800	142	501
Meghna	800	416	275

Source: BWDB (1979)

The combined flow of the Padma and the Jamuna meets the Meghna. Most of the waters and sediments of these rivers pass through the confluence area. The erratic flow of water of the Padma-Meghna can be attributed mainly to the hydrological and morphological conditions of the lower Atrai basin. The drainage area and the average discharge of these streams are shown in the Table 5.

4.1.7 Geological History: Origin and Evolution

In the Jurassic Period (194 to 136 million years ago), the Indian portion of the Gondwana mass split off and began moving north towards Asia. The Indian and Australian portion of Gondwana were believed to be on the same plate, known as the Indo-Australian plate. However the movement in different directions of the two portions, and the obvious

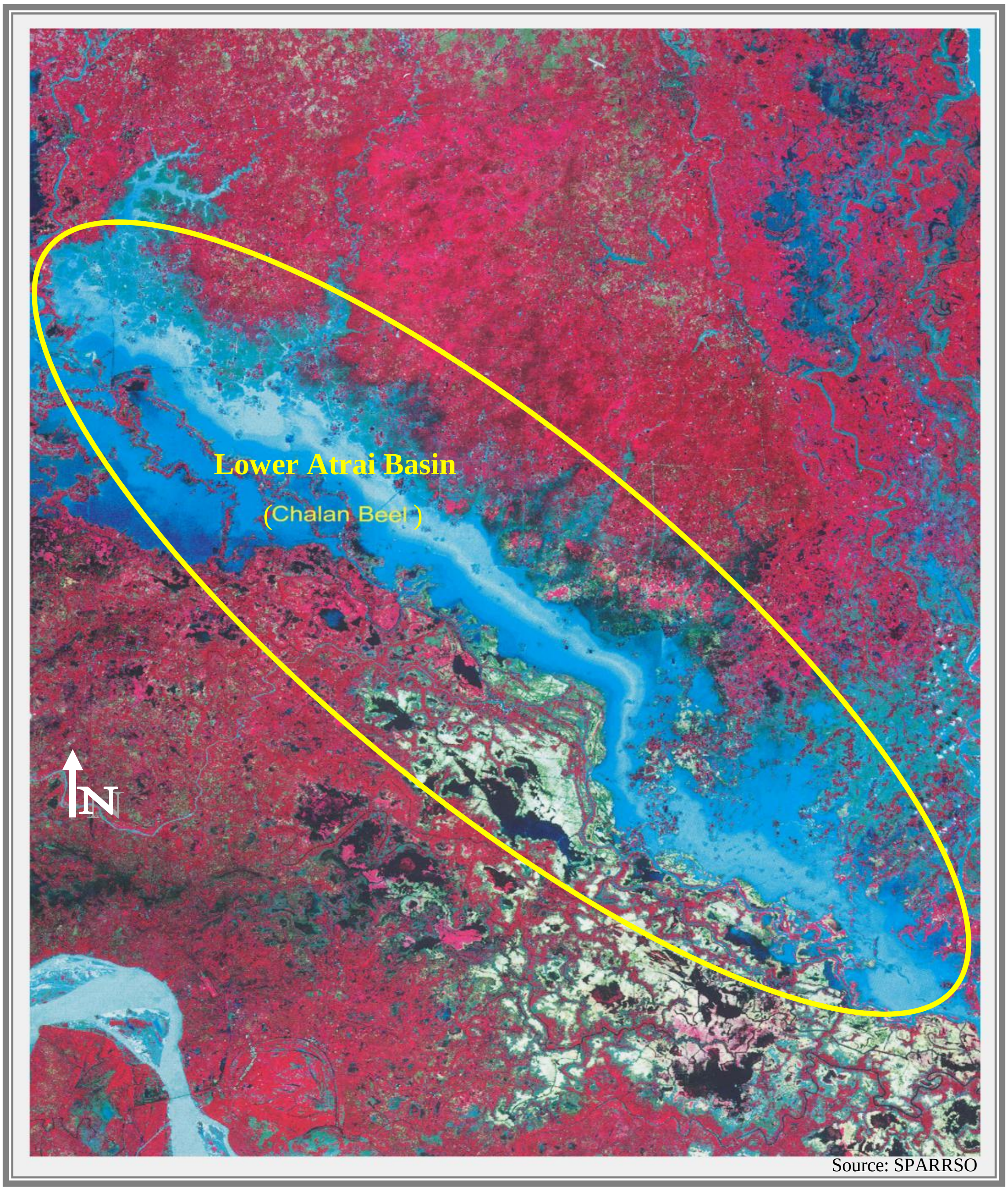


Fig 22. Aerial view of lower Atrai Basin of Bangladesh.

split in the plate along the 90 degree east longitude, makes it certain that the Indian and Australian portion are on separate plates since Late Cretaceous (circa 65-75 million years ago). The Indian portion of the Gondwana moved north relatively fast and collided with the European Asian (Hercynian) and East Asian (cathausian) plates in the Eocene period (54 to 38 million years ago). This collision was on such a tremendous scale that the Indian plate moved some 2000 km. into the cathaysian plate, which resulted in the uplift of the Himalayan System and the large Tibetan plateau, and very considerable faulting in China. The Indian plate is subducted under the East Asian Plate along the line of the Himalyas, but under the Arakan Yomas the two plates are rubbing against other along a transform fault. In the Oligocene period (38 to 26 million years ago), sometime after the plates collided, a portion of the northeastern part of India fractured and sank below sea-level. This portion was gradually filled up the part of Bengal Basin. The Bengal Basin has been filled by sediments wash down from the highlands on three sides of it, and especially from the Himalayas, where the slopes are steeper and the rocks less consolidated. The greater part of this land-building process must have been due to the Ganges and Brahmaputra rivers (Rashid, 1991). The aerial view of lower Atrai basin is shows in Fig 22 (source: SPARRSO).

Chalan beel was formed when the old Brahmaputra diverted its water into the new channel of the Jamuna. *Chalan beel* was probably a back swamp before it was greatly expanded with the Karotoya and the Atrai and became a vast lake. The formation of the *Chalan beel* is historically linked with the demise of the Atrai and the Baral. The Atrai or the Gur was the principal feeder channel of *Chalan beel*, which used to drain the districts of Dinajpur and northern Rajshahi. The Baral worked as an outlet of the *beel* and eventually found its way into the Jamuna. It was about 1088 sq.km (108,800 ha) in area at the time it was formed but now it is about 368 sq.km (36,800 ha) (Islam, 2003).

4.1.8 Land use and vegetation

The area under investigation is heavily popu1ated and the land is used for agriculture. No natural vegetation is present in the area as the land is under cultivation, except some small patches in the basins, where there are remnants of tall grasses and reeds (SRDI Staff 1970). Rice was the principal crop (Plate 2 & 3). The present land use is mainly determined by the elevation of the land in relation to the duration and depth of seasonal flooding and by the availability of soil moisture in the rainy season. Shallowly flooded areas where water can be kept by small bunds are used mainly for boro followed by transplanted aman. Broadcast (deep water) aman paddies are the major kinds of rice grown, but transplanted aman and boro paddies are locally important, too. On medium highland, broadcast aman paddy is the commonest practice. Where flooding becomes too deep for transplanted aman or where rapid rise of flood level may cause loss of crops in most years,

Plate 2. Rice is the main crop in the lower Atrai basin area.

Plate 3. Ripend rice field in the lower Atrai basin area.

deep water aman (broadcast), sometimes mixed with aus is grown. Minor area in basin depressions which remains wet in most part of the dry season or where the standing water is used for boro. Where sufficient dry season moisture is available, dry land crop is often grown after the amon harvest. On high land where water cannot be kept on the land, only aman followed by a dry land rabi crop is grown. Rabi crops mainly include mustard *(Brassica Juncea coss),* Khesari *(Lathyrus sativa),* mesta *(Hibiscus canabinus),* Lentil *(Lens esculenta L),* Chillis *(Capsicum frutescenus L),* Potatoes *(Solanun tuberoseum* C), Maize, Bringal, Groundnut etc. Homestead sites or artificially raised platforms, are intensively used for bananas, betel leaf (pan), year round vegetables, fruits trees and rice nurseries. The dominant aquatic plants include *Trapa natans, Vallisneria sp, Potamogeton sp, Enhydra sp, Utricularia* sp and *Nymphaea* spp. The terrestrial vegetation includes *Tamarix sp, Acacia nilotica, Bombax ceiba, Ficus sp, Dendrocalamus sp, Melia azadirachta, Calamus sp, Borassus flabellifer, Phoenix sylvestris, Musa* sp and *Ipornoea spp.*

4.2 Field description of the studied soils

All the eight soil proiles were subjected to detailed morphogenetic study in the field. The general morphogenetic properties of the soil profiles are presented below:

4.2.1 BINSARA SERIES

Binsara series includes poorly drained, seasonally flooded soils developed in fine textured sediments (Madhupur clay), occurring on the nearly level to very gently undulating Barind tract. These soils are characterized by dark grey, heavy clays, iron stained topsoil grading into a thin, strongly mottled horizon which overlies grey, heavy clay, and irregular wedge-shaped peds with prominent slickensides characterize the lower layer. Iron-manganese concretions occur throughout the profile. Top soils are moderately acid to neutral lower layers. The soils remains flooded up to 3.0- 3.6 meter deep for 4–5 months in the monsoon season and dry out slowly in the dry season. Landscape and vegetation around Binsara soil profile site is shown in Plate 4 and profile of the Binsara series formed on the lower Atrai basin is shown in Plate 5.

Soil Series **: Binsara Series**

Location **:** Vill – Kundoil, Union – Saguna, Upozila – Taras, District – Serajgonj.

Physiography **:** Nearly level broad basin

Parent material : Tista River Alluvium

Land use **:** Broadcast aman - fallow

Drainage **:** Poorly drained. Flooded up to 3.0- 3.6 meter deep for about 5 months in the monsoon season. Topsoils retain moisture for a relatively short period and dry out early in the dry season.

Horizon	Depth (cm)	Description
Ap1g	0 – 8	Dark grey (5Y4/1, moist) with common fine to medium distinct yellowish brown (10YR5/6) mottles; **clay**; massive breaking; hard dry, firm moist, very sticky, very plastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 5.5.
Ap2g	8 – 13	Very dark grey (5Y3/1, moist) common fine to medium distinct yellowish brown (10YR5/6) mottles; **clay;** massive breaking; very hard dry, extremely firm moist, very sticky, very plastic wet; broken thin dark grey cutans along vertical and horizontal

Horizon	Depth (cm)	Description
		ped faces; common vary fine and fine tubular pores; clear smooth boundary; pH 5.5.
Bw1g	13 – 47	Dark grey (5Y4/1, moist) with many fine to medium distinct and many fine to medium prominent dark brown (7.5YR3/4) mottles; **clay**; strong medium prismatic; very firm moist, very sticky, very plastic wet; patchy thin grey cutans along vertical ped faces, common fine tubular pores; clear smooth boundary; pH 5.5.
Bw2g	47 – 70	Dark grey (5Y4/1, moist) with common fine to medium prominent strong brown (7.5YR4/6) mottles; **clay**; strong medium prismatic; firm moist, very sticky, very plastic wet; thin patchy grey cutans along, vertical ped faces; common fine tubular pores; clear smooth boundary; pH 5.6.
Bw3g	70 – 94	Grey (5Y5/1, moist) with many fine to medium distinct and many fine to medium prominent light yellowish brown (10YR6/4) mottles; **silty clay loam**; moderate course angular blocky; firm moist, sticky, plastic wet; patchy thin grey cutans along vertical ped faces; many fine and very fine tubular pores; clear smooth boundary; pH 7.0.
C1g	94 – 105+	Grey (5Y6/1, moist) with many fine to medium distinct and many fine to medium prominent light yellowish brown (10YR6/4) mottles; **silty clay loam**; moderate course angular blocky; firm moist, sticky, plastic wet; continuous moderately thick gray cutans along vertical and horizontal ped faces; pH 7.0.

Plate 4. Landscape and vegetation around Binsara soil profile site.

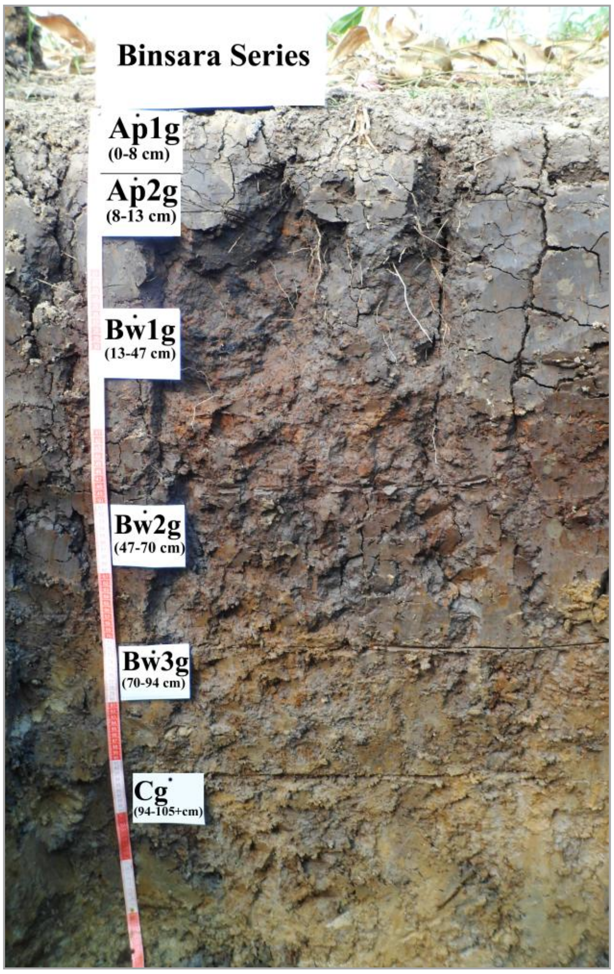


Plate 5. Profile of the Binsara soil series formed on the lower Atrai basin.

4.2.2 TARAS SERIES 1

Taras soil series includes seasonally flooded, poorly drained, mixed dark grey or grey and yellowish brown clays with moderate sub angular blocky in the B horizon. They usually overlie weathered Madhupur clay below about 2 feet. These soils are probably developed in the old Atrai alluvium and Barind tract sediments. They occupy nearly level, broad basin areas included in the physiograpic unit named as 'Old floodplain basin'. They are flooded up to 1.5-2.1 meter deep, sometimes up to more than 3 meter deep, for 4-5 months in the monsoon season. Part of these soils remains saturated, sometimes under shallow water, for about 2 months in the dry season. Landscape and vegetation around Taras 1 soil profile site is shown in Plate 6 and profile of the Taras series 1 formed on the lower Atrai basin is shown in Plate 7.

Soil Series **: Taras Series 1**

Location **:** Vill- Boro chaugram, Union- Chaugram, Upozila- Singra, Dist- Natore.

Physiography **:** Nearly level broad basin

Parent material : Atrai River Alluvium

Land use **:** Irrigated boro-fallow

Drainage **:** Poorly drained. Flooded 1.5-2.1 meter deep for about 5 months in the monsoon season. Remains unsaturated for about 5 months in the dry season.

Horizon	Depth (cm)	Description
Ap1g	**0 – 6**	Dark grey (5Y4/1, moist) with iron stains along root channels; **clay**; massive breaking; very hard dry, firm moist, sticky, plastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 7.5.
Ap2g	**6– 10**	Dark grey (5Y4/1, moist) with common fine to medium distinct and common fine to medium prominent dark brown (7.5YR3/4) mottles; **clay;** massive breaking; very hard dry, very firm moist, sticky, Plastic wet; broken thin dark grey cutans along vertical and horizontal ped faces; common vary fine and fine tubular pores ; clear smooth boundary; pH 6.5.
Bw1g	**10 – 38**	Dark grey (5Y4/1, moist) with many fine to medium distinct

Horizon	Depth (cm)	Description
		and many fine to medium prominent strong brown (7.5YR4/6) mottles; **silty clay**; medium strong angular blocky; firm moist, sticky, plastic wet; patchy thin grey cutans along vertical ped faces, common fine tubular pores; clear smooth boundary; pH 5.5.
Bw2g	**38 – 60**	Grey (5Y5/1, moist) with many fine to medium distinct and many fine to medium prominent dark yellowish brown (10YR4/4) mottles; **silty clay loam**; medium strong angular blocky; friable moist, sticky, Plastic wet; thin patchy grey cutans along, vertical ped faces; common fine tubular pores; clear smooth boundary; pH 7.0.
Bw3g	**60 – 75**	Grey (5Y5/1, moist) with many fine to medium distinct and many fine to medium prominent yellowish brown (10YR5/8) mottles; **silty clay loam**; moderate medium angular blocky; soil mass friable moist, sticky, plastic wet; patchy thin grey cutans along vertical ped faces; many fine and very fine tubular pores; clear smooth boundary; pH 7.0.
C1g	**75 – 100+**	Grey (5Y6/1, moist) with many fine to medium distinct light yellowish brown (10YR6/4) mottles; **silty clay loam**; moderate medium angular blocky; soil mass friable moist, very sticky, very plastic wet; continuous moderately thick gray cutans along vertical and horizontal ped faces; pH 7.0.

Plate 6. Landscape and vegetation around Taras 1 soil profile site.

Plate 7. Profile of the Taras 1 soil series formed on the lower Atrai basin.

4.2.3 JAONIA SERIES

Jaonia series comprises seasonally flooded, poorly drained, dark grey, mottled yellowish brown, heavy clays. These soils are probably developed in the Atrai river Alluvium. These soils occupy rather narrow, low-lying areas included in the physiograpic unit named as 'Old floodplain basin'. The origin of the sediment is not clearly known. The soils remains flooded up to 2.1- 2.7 meter deep for 5–6 months in the monsoon season and dry out slowly in the dry season. Landscape and vegetation around Jaonia soil profile site is shown in Plate 8 and profile of the Jaonia series formed on the lower Atrai basin is shown in Plate 9.

Soil Series **: Jaonia Series**

Location **:** Vill - Akdala, Union - Khajuria, Upozila - Natore sador, Dist - Natore.

Physiography **:** Edge of beel

Parent material : Atrai River Alluvium

Land use **:** Irrigated boro - fallow

Drainage **:** Poorly drained. Flooded 2.1- 2.7 meter deep for about 5 months in the monsoon season. Remains unsaturated for 3-4 months in the dry season.

Horizon	Depth (cm)	Description
Apg	0 – 8	Dark grey (5Y4/1, moist) with iron stains along root channel; **clay**; massive breaking; hard dry, firm moist, sticky, plastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 5.5.
Bw1g	8 – 32	Very dark grey (5Y3/1, moist) with iron staining along root channel; **clay;** strong course prismatic; very hard dry, very firm moist, very sticky, very plastic wet; broken thin dark grey cutans along vertical and horizontal ped faces; common vary fine and fine tubular pores; clear smooth boundary; pH 6.5.
Bw2g	32 – 62	Dark grey (5Y4/1, moist) with many fine to medium distinct and many fine to medium prominent yellowish brown (10YR5/4) mottles; **clay**; strong course prismatic; friable moist, very sticky, very plastic wet; patchy thin grey cutans along vertical ped faces, common fine tubular pores; clear

Horizon	Depth (cm)	Description
		smooth boundary; pH 7.0.
Bw3g	62 – 90	Dark grey (5Y5/1, moist) with common fine to medium prominent strong brown (7.5YR4/6) mottles; **silty clay loam**; moderate course prismatic; friable moist, very sticky, very plastic wet; thin patchy grey cutans along, vertical ped faces; common fine tubular pores; clear smooth boundary; pH 7.0.
Bw4g	90 – 100	Grey (5Y6/1, moist) with many fine to medium distinct and many fine to medium prominent light yellowish brown (10YR6/4) mottles; **silty clay loam**; strong medium angular blocky; friable moist, sticky, plastic wet; patchy thin grey cutans along vertical ped faces; many fine and very fine tubular pores; clear smooth boundary; pH 7.0.
Cg	100–120+	Grey (5Y6/1, moist) with many fine to medium distinct and many fine to medium prominent light yellowish brown (10YR6/4) mottles; **silty clay loam**; strong medium angular blocky; friable moist, sticky, plastic wet; continuous moderately thick gray cutans along vertical and horizontal ped faces; pH 7.0.

Plate 8. Landscape and vegetation around Jaonia soil profile site.

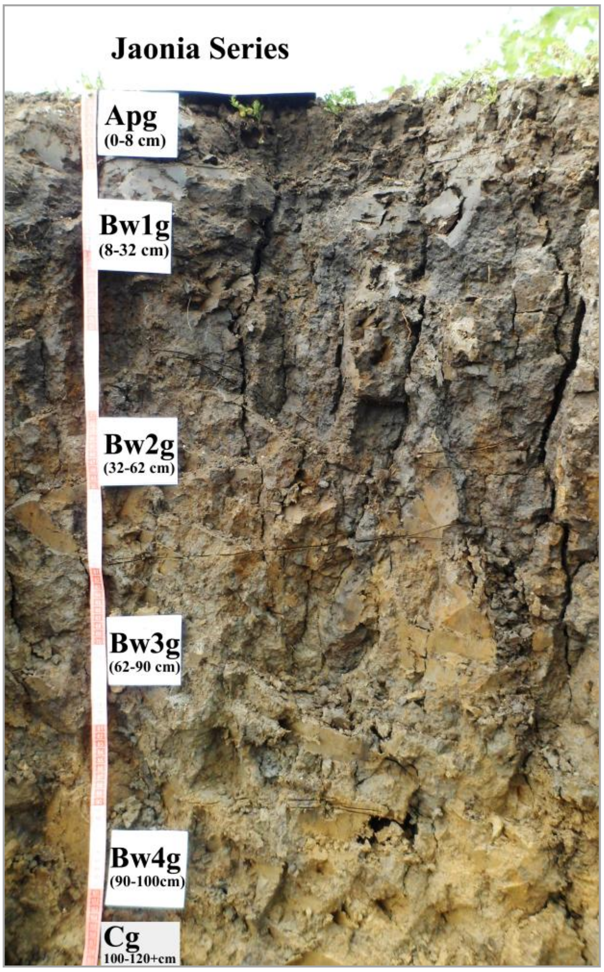


Plate 9. Profile of the Jaonia soil series formed on the lower Atrai basin.

4.2.4 TARAS SERIES 2

Taras soil series includes seasonally flooded, poorly drained, mixed dark grey or grey and yellowish brown clays with moderate sub angular blocky in the B horizon. They usually overlie weathered Madhupur clay below about 2 feet. These soils are probably developed in the old Atrai alluvium and Barind tract sediments. They occupy nearly level, broad basin areas included in the physiograpic unit named as 'Old floodplain basin'. They are flooded up to 1.5-2.1 meter deep, sometimes up to more than 3 meter deep, for 4-5 months in the monsoon season. Part of these soils remains saturated, sometimes under shallow water, for about 2 months in the dry season. Landscape and vegetation around Taras 2 soil profile site is shown in Plate 10 and profile of the Taras series 2 formed on the lower Atrai basin is shown in Plate 11.

Soil Series **: Taras Series 2**

Location **:** Vill - Hingolkandi, Union - Patisar, Upozila - Atrai, District - Naogaon.

Physiography **:** Nearly level broad basin

Parent material **:** Atrai River Alluvium

Land use **:** Irrigated boro-fallow

Drainage **:** Poorly drained. Flooded 1.5-2.1 meter deep for about 5 months in the monsoon season. Remains unsaturated for about 5 months in the dry season.

Horizon	Depth (cm)	Description
Ap1g	**0 – 6**	Dark grey (5Y4/1, moist) with common fine prominent strong brown (7.5YR4/6) mottles; **clay**; massive breaking; very hard dry, firm moist, sticky, plastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 6.5.
Ap2g	**6– 9**	Dark grey (5Y4/1, moist) common fine prominent dark brown (7.5YR3/4) mottles; **clay;** massive breaking; very hard dry, very firm moist, sticky, Plastic wet; broken thin dark grey cutans along vertical and horizontal ped faces; common vary fine and fine tubular pores ; abrupt smooth boundary; pH 7.0.
Bw1g	**9 – 30**	Grey (5Y5/1, moist) with many fine to medium distinct and many fine to medium prominent dark brown (7.5YR3/4) mottles; **clay**; strong medium angular blocky; firm moist,

Horizon	Depth (cm)	Description
		very sticky, very plastic wet; patchy thin grey cutans along vertical ped faces, common fine tubular pores; clear smooth boundary; pH 7.0.
Bw2g	**30 – 59**	Grey (5Y6/1, moist) with many fine to medium distinct and many fine to medium prominent strong brown (7.5YR5/8) mottles; **clay loam**; strong medium angular blocky; friable moist, sticky, Plastic wet; thin patchy grey cutans along, vertical ped faces; common fine tubular pores; clear smooth boundary; pH 7.0.
Bw3g	**59 – 86**	Grey (5Y6/1, moist) with many fine to medium distinct and many fine to medium prominent yellowish brown (10YR5/6) mottles; **silty clay loam**; moderate medium angular blocky; friable moist, sticky, plastic wet; patchy thin grey cutans along vertical ped faces; many fine and very fine tubular pores; clear smooth boundary; pH 7.0.
C1g	**86 – 100+**	Grey (5Y6/1, moist) with many medium distinct light yellowish brown (10YR6/4) mottles; **silty clay loam**; moderate medium angular blocky; firm moist, sticky, plastic wet; continuous moderately thick gray cutans along vertical and horizontal ped faces; pH 7.0.

Plate 10. Landscape and vegetation around Taras 2 soil profile site.

Plate 11. Profile of the Taras 2 soil series formed on the lower Atrai basin.

4.2.5 HASNABAD SERIES

Hasnabad series comprises seasonally shallowly or intermittently flooded, imperfectly to poorly drained soils developed in Tista alluvium. They are olive grey, silty clay loams with moderate sub angular blocky to angular blocky structure in the B horizon. These soils are developed in the flood sediments on the older Tista meander floodplain. They usually occupy very gently undulating low ridges and basin margins. They are usually flooded up to 1.5 – 2.1 meter for 4 – 5 months in the rainy season. Some minor areas are only intermittently flooded. Landscape and vegetation around Hasnabad soil profile site is shown in Plate 12 and profile of the Hasnabad series formed on the lower Atrai basin is shown in Plate 13.

Soil Series **: Hasnabad Series**

Location **:** Vill - Jatamrul, Union - Ahsanganj, Upozila - Atrai, District - Naogaon.

Physiography **:** Very gently undulating low ridges and basin margins.

Parent material : Tista River Alluvium

Land use **:** Irrigated boro - fallow

Drainage **:** Imperfectly to poorly drained. Flooded 1.5 - 2.1 meter deep for about 4 months in the monsoon season. Remains unsaturated for 3-4 months in the dry season.

Horizon	Depth (cm)	Description
Ap1g	0 – 8	Olive grey (5Y4/1, moist) with few fine distinct strong brown (7.5YR4/6) mottles; **silt loam**; massive breaking; slightly hard dry, friable moist, slightly sticky, slightly plastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 5.5.
Ap2g	8 – 12	Olive grey (5Y4/2, moist) with few fine to medium distinct dark brown (7.5YR3/4) mottles; **silt loam;** massive breaking; hard dry, friable moist, slightly sticky, slightly plastic wet; broken thin dark grey cutans along vertical and horizontal ped faces; common vary fine and fine tubular pores; clear smooth boundary; pH 5.5.
Bw1	12 – 30	Dark grey (5Y4/1, moist) with many fine to medium distinct and many fine to medium prominent brown (7.5YR4/4)

Horizon	Depth (cm)	Description
		mottles; **silty clay loam**; moderate medium angular blocky; firm moist, sticky, plastic wet; patchy thin grey cutans along vertical ped faces, common fine tubular pores; clear smooth boundary; pH 6.5.
Bw2	30 – 69	Olive grey (5Y5/2, moist) with many fine to medium distinct and many fine to medium prominent strong brown (7.5YR4/6) mottles; **silty clay loam**; moderate medium angular blocky; firm moist, sticky, plastic wet; thin patchy grey cutans along, vertical ped faces; common fine tubular pores; clear smooth boundary; pH 7.0.
Bw3	69 – 97	Grey (5Y5/1, moist) with many fine to medium distinct and many fine to medium prominent light yellowish brown (10YR6/4) mottles; **silty clay loam**; moderate medium angular blocky; friable moist, slightly sticky, slightly plastic wet; patchy thin grey cutans along vertical ped faces; many fine and very fine tubular pores; clear smooth boundary; pH 7.0.
Bw4	97 – 110	Light olive grey (5Y6/2, moist) with many fine to medium faint light yellowish brown (10YR6/4) mottles; **silt loam**; moderate medium angular blocky; friable moist, slightly sticky, slightly plastic wet; continuous moderately thick gray cutans along vertical and horizontal ped faces; clear smooth boundary; pH 7.0.
C1	110 – 120+	Light olive grey (5Y6/2, moist) with many fine to medium faint light yellowish brown (10YR6/4) mottles; **silt loam;** moderate medium angular blocky; friable moist, slightly sticky, slightly plastic wet; many fine and very fine tubular pores; pH 7.0.

Plate 12. Landscape and vegetation around Hasnabad soil profile site.

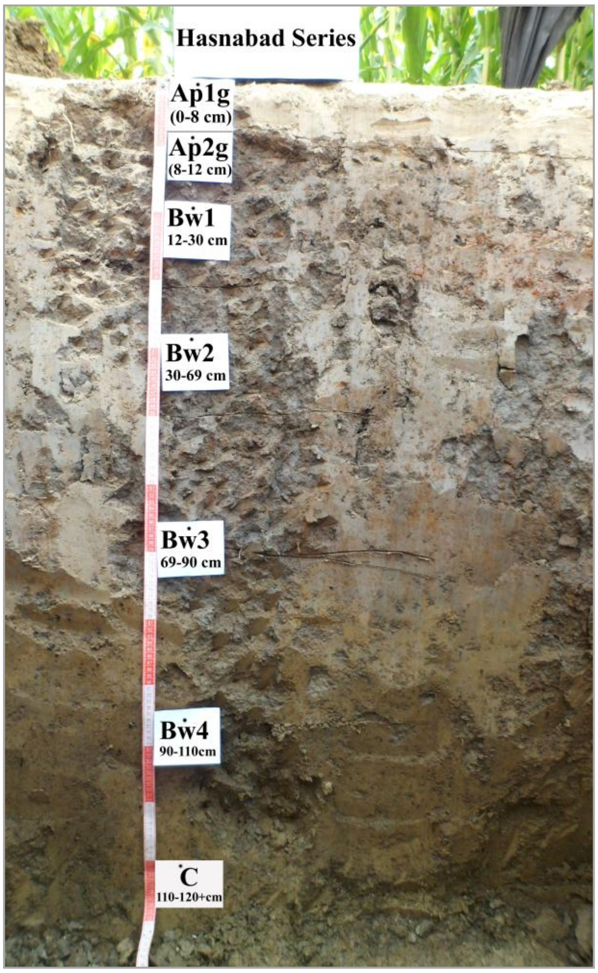


Plate 13. Profile of the Hasnabad soil series formed on the lower Atrai basin.

4.2.6 LASKARA SERIES

Laskera series comprises seasonally flooded, poorly drained soils developed in the older Tista alluvium. They have dark grey mottled yellowish brown, clay to silty clay loams with strong prismatic and sub angular blocky to angular blocky structure having thick dark grey cutans in the B horizon. These soils are developed in the floodplain sediments in the older Tista meander floodplain. They occupy middle to lower slope of gently sloping basins and depressions. They are usually flooded upto 1.8 – 2.4 meter for 4 – 5 months in the rainy season and dries out very slowly in the dry season. Landscape and vegetation around Laskara soil profile site is shown in Plate 14 and profile of the Laskara series formed on the lower Atrai basin is shown in Plate 15.

Soil Series : Laskara Series

Location : Vill – Ataikula, Union – Mirat, Upozila – Raninagar, Dist –Naogaon.

Physiography : Broad basin.

Parent material : Tista River Alluvium

Land use : Broadcast aman - fallow

Drainage : Poorly drained. Flooded 1.8 – 2.4 meter deep for about 5 months in the monsoon season and dries out very slowly in the dry season.

Horizon	Depth (cm)	Description
Ap1g	0 – 10	Dark grey (5Y4/1, moist) with few fine distinct yellowish brown (10YR5/6) mottles; **clay**; massive breaking; hard dry, firm moist, very sticky, very plastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 6.5.
Ap2g	10 – 16	Grey (5Y5/1, moist) with common fine to medium distinct and common fine to medium prominent strong brown (7.5YR4/6) mottles; **clay;** massive breaking; very hard dry, firm moist, sticky, plastic wet; broken thin dark grey cutans along vertical and horizontal ped faces; common vary fine and fine tubular pores; clear smooth boundary; pH 5.5.
Bw1g	16 – 36	Grey (5Y46/1, moist) with many fine to medium distinct and many fine to medium prominent yellowish brown (10YR5/4) mottles; **silty clay loam**; strong course prismatic; very firm moist, slightly sticky, slightly plastic wet; patchy thin grey cutans along vertical ped faces,

Horizon	Depth (cm)	Description
		common fine tubular pores; clear smooth boundary; pH 7.0.
Bw2	36 – 57	Grey (5Y46/1, moist) with many fine to medium distinct and many fine to medium prominent yellowish brown (10YR5/4) mottles; **silty clay loam**; strong course prismatic; very firm moist, slightly sticky, slightly plastic wet; patchy thin grey cutans along vertical ped faces, common fine tubular pores; clear smooth boundary; pH 7.0.
Bw3g	57 – 75	Grey (5Y6/1, moist) with many fine to medium distinct and many fine to medium prominent strong brown (7.5YR4/6) mottles; **silty clay loam**; strong course prismatic; friable moist, sticky, plastic wet; patchy thin grey cutans along vertical ped faces; many fine and very fine tubular pores; clear smooth boundary; pH 7.0.
Bw4g	75 – 90	Dark grey (5Y4/1, moist) with many fine to medium distinct and many fine to medium prominent brown (7.5YR4/4) mottles; **silty clay loam**; moderate course angular blocky; firm moist, sticky, plastic wet; continuous moderately thick gray cutans along vertical and horizontal ped faces; many fine and very fine tubular pores; clear smooth boundary; pH 7.0.
C1g	90 – 110+	Dark grey (5Y4/1, moist) with many fine to medium distinct and many fine to medium prominent light yellowish brown (10YR6/4) mottles; **silty clay;** moderate course angular blocky; firm moist, sticky, plastic wet; continuous moderately thick gray cutans along vertical and horizontal ped faces; many fine and very fine tubular pores; pH 7.0.

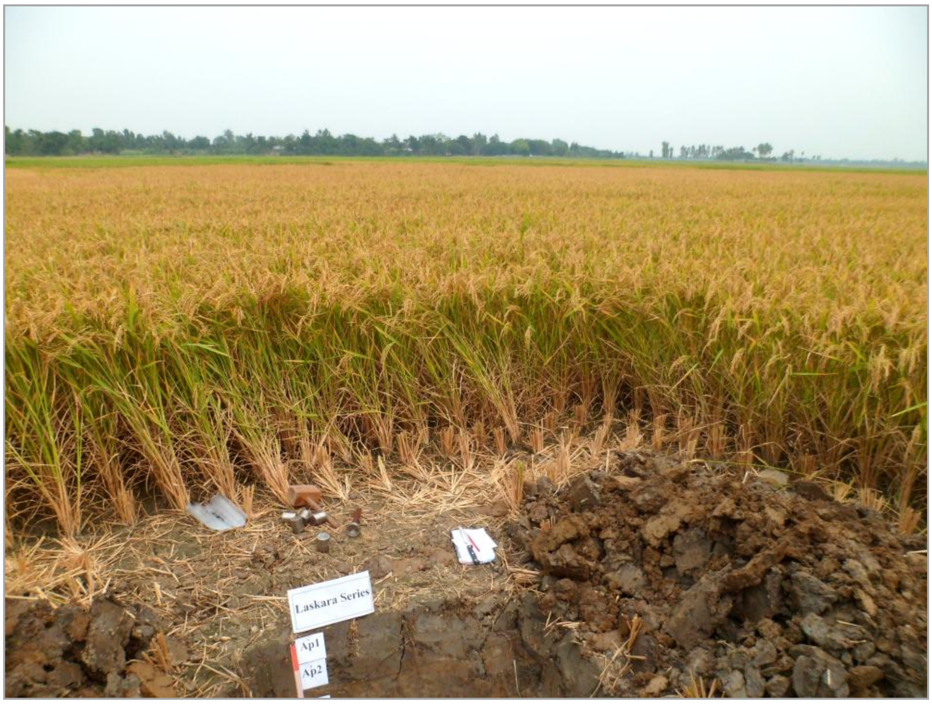


Plate 14. Landscape and vegetation around Laskara soil profile site.

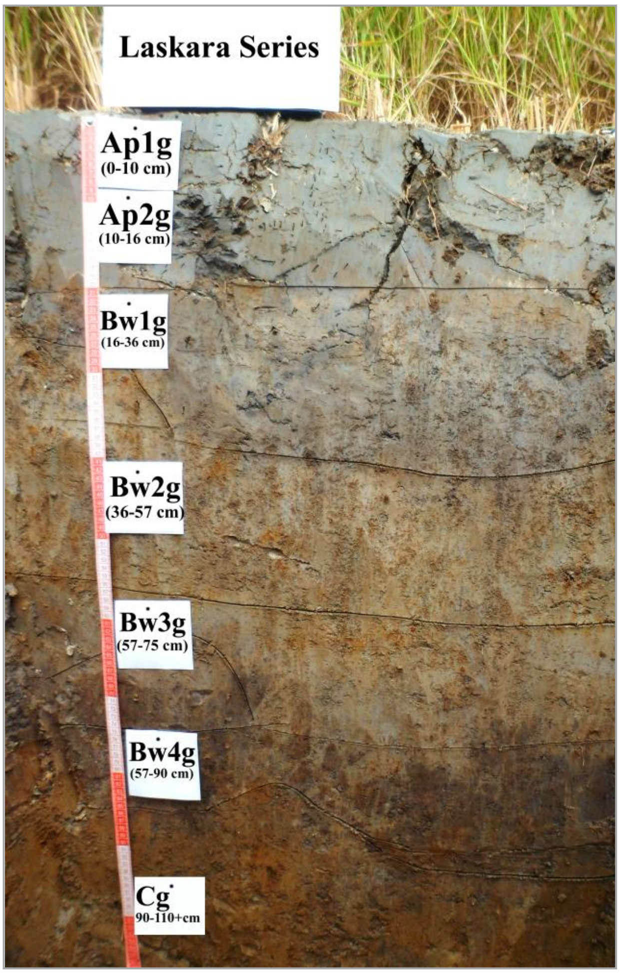


Plate 15. Profile of the Laskara soil series formed on the lower Atrai basin.

4.2.7 MANDA SERIES

Manda series comprises intermittently to shallowly flooded, imperfectly to poorly drained, light olive grey to olive grey, finely stratified silt loams overlying a grey, loose sandy substratum within 0.30 meter from the surface. These soils are developed in young Atrai as well as in little Jamuna levee deposits, now occupying upper part of ridge on the young Atrai and little Jamuna meander floodplains. They are usually non-flooded or intermittently flooded by rain water up to less than 0.15 meter deep in the monsoon season. Locally they are seasonally flooded up to 0.3 to 0.6 meter deep for 1-2 months. Landscape and vegetation around Manda soil profile site is shown in Plate 16 and profile of the Manda series formed on the lower Atrai basin is shown in Plate 17.

Soil Series : **Manda Series**

Location : Vill - Chakprasad, Union - Chakprasad,
Upozila- Naogaon Sador, Dist – Naogaon.

Physiography : Very gently undulating floodplain ridge.

Parent material : Atrai River Alluvium

Land use : Aus – rabi crops

Drainage : imperfectly drained. Flooded 0.3 – 0.6 meter deep for about 2 months in the monsoon and remains unsaturated for about 7 months in the dry season.

Horizon	Depth (cm)	Description
Apg	0 – 8	Olive grey (5Y5/2, moist) with common fine to medium distinct brown (7.5YR4/4) mottles; **silt loam**; massive breaking; loose, friable moist, nonsticky, nonplastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 5.5.
AC	8 – 21	Olive grey (5Y5/2, moist); **silt loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; common vary fine and fine tubular pores; clear wavy boundary; pH 6.5.
C1	21 – 54	Light olive grey (5Y6/2, moist); **very fine sandy loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; common vary fine and fine tubular pores; clear wavy boundary; pH 7.0.
C2	54 – 74	Light olive grey (5Y6/2, moist); **silt loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; common vary fine and fine tubular pores; clear wavy boundary; pH 7.0.
C3	74 – 95+	Light grey (5Y7/2, moist); **silt loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; pH 7.0.

Plate 16. Landscape and vegetation around Manda soil profile site.

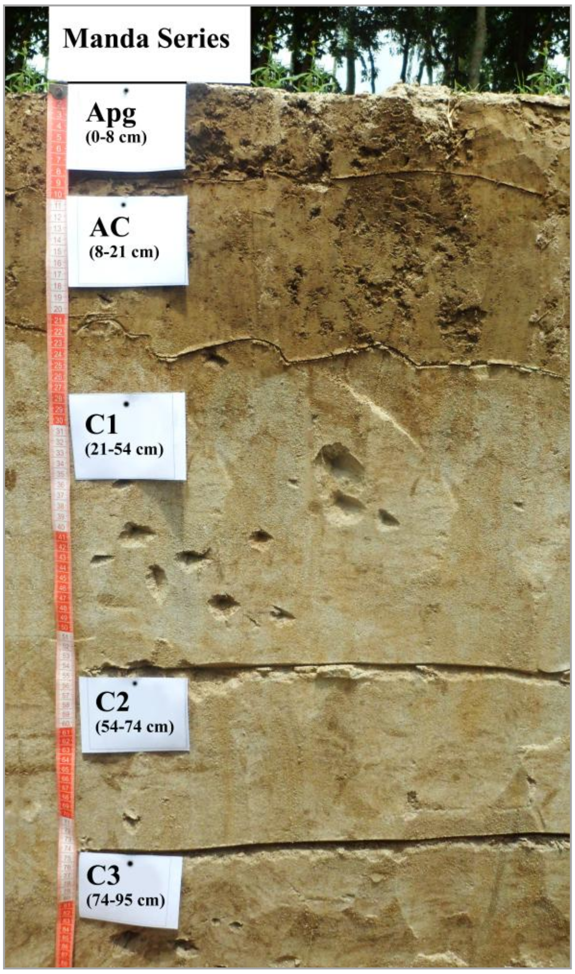


Plate 17. Profile of the Manda soil series formed on the lower Atrai basin.

4.2.8 MAINAM SERIES

Mainam series includes intermittently and seasonally flooded, imperfectly to poorly drained, olive, finely stratified sandy loams, loose sandy substratum within 0.30 meter from the surface. These soils are developed in young Atrai levee deposits, now occupying upper part of very gently undulating ridge on the young Atrai meander floodplains. They are usually non-flooded or intermittently flooded by rain water up to less than 0.15 meter deep or flooded up to 0.3 to 0.7 meter deep for 1-2 months in the monsoon season. Landscape and vegetation around Mainam soil profile site is shown in Plate 18 and profile of the Mainam series formed on the lower Atrai basin is shown in Plate 19.

Soil Series : **Mainam Series**
Location : Vill - Jalkorgandi, Union - Dubal Hati, Upozila- Naogaon Sador, Dist – Naogaon.
Physiography : Upper slopes of very gently undulating floodplain ridge.
Parent material : Atrai River Alluvium
Land use : Aus – rabi crops
Drainage : imperfectly drained. Flooded 0.3 – 0.7 meter deep for about 2 months in the monsoon and remains unsaturated for about 7 months in the dry season.

Horizon	Depth (cm)	Description
Ap1g	0 – 8	Olive grey (5Y5/2, moist) with common fine to medium distinct brown (7.5YR4/4) mottles; **silt loam**; massive breaking; loose, friable moist, nonsticky, nonplastic wet; common fine and very fine tubular pores, abrupt smooth boundary; pH 6.0.
Ap2g	8 – 17	Olive grey (5Y5/2, moist) with common fine to medium distinct brown (7.5YR4/4) mottles; **very fine sandy loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; common vary fine and fine tubular pores; clear wavy boundary; pH 6.5.
AC	17 – 28	Light olive grey (5Y6/2, moist); **very fine sandy loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; common vary fine and fine tubular pores; clear waavy boundary; pH 7.0.
C1	28 – 39	Light olive grey (5Y6/2, moist); **very fine sandy loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; common vary fine and fine tubular pores; clear smooth boundary; pH 7.0.
C2	39 – 56	Light olive grey (5Y6/2, moist); **very fine sandy loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; clear smooth boundary; pH 7.0.
C3	56 – 99+	Light grey (5Y7/2, moist); **sandy loam;** massive breaking; loose, very friable moist, nonsticky, nonplastic wet; pH 7.0.

Plate 18. Landscape and vegetation around Mainam soil profile site.

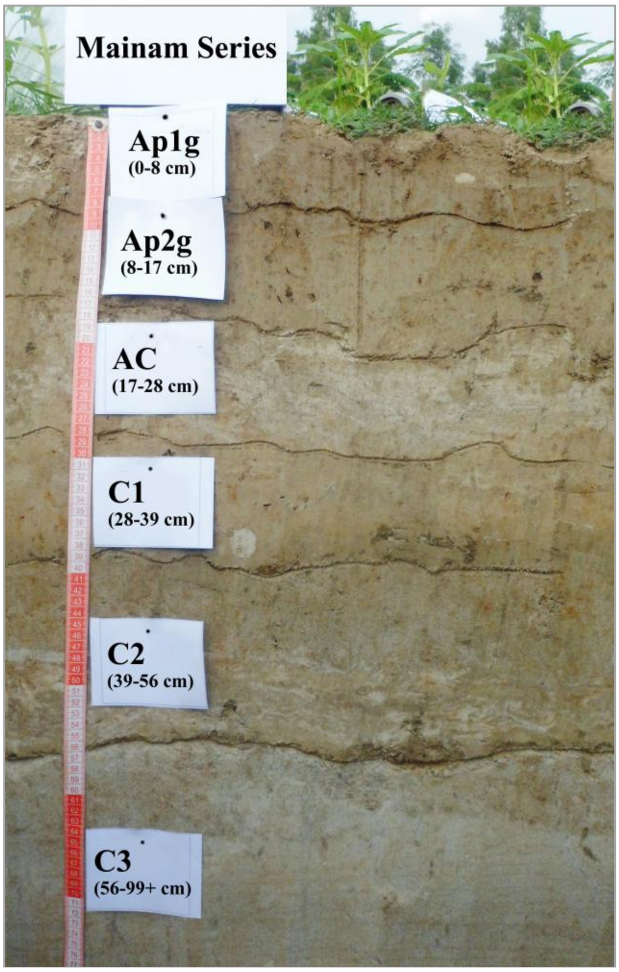


Plate 19. Profile of the Mainam soil series formed on the lower Atrai basin.

Chapter Five

RESULTS AND DISCUSSION

CHAPTER - 5

RESULTS AND DISCUSSION

5.1 Morphogenetic characteristics

Detailed morphogenetic descriptions of the soil profiles from the *Lower Atrai basin* area of Bangladesh have been presented in the previous chapter. From that morphogenetic description it is evident that an incipient B horizon has developed in all the soils except Manda and Mainam series. 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. This fact has been taken into consideration at the time of characterization of these soils.

The coded morphogenetic properties of the studied soils have been presented in Table 2. 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.

Colour

The matrix colour of the present soils is a combination of grey to very dark grey and olive grey to light olive grey colours. Under moist condition, the colour of the surface horizon in the studied soils was found to be dark gray (5Y4/1) in, Binsara, Taras (1), Jaonia, Taras (2) and Laskara series (Fig 23). However, it was olive grey (5Y5/2) in Hasnabad, Manda and Mainam series. The above colours were developed due to prolonged seasonal submergence of the soils. The soils have low chroma which is < 2 in most of them (Table 6).

On the basis of Chroma these seasonally flooded pedons can be called hydromorphic soils (Soil Survey Staff, 2014). The cause of hydromorphism is that all these soils remain inundated for few months every year by both rain and river waters which caused formation of grey colour in soils. This grey colour of the soils is caused by removal of free iron oxides from these soils by draining water. Free iron oxides in the floodplain soils of Bangladesh have been determined by many authors. Amounts of free iron oxide in the seasonally flooded soils have been reported to be low (Khan *et al.*, 1997; Mujib *et al.*, 1969). The presence of olive grey colour of the Hasnabad, Manda and Mainam soils indicates the existence of somewhat free drainage condition. Binsara, Taras (1), Jaonia, Taras (2) and

Table 6. Morphogenetic properties of the studied soils of the lower Atrai basin of Bangladesh*.

Soil Series	Horizon	Depth (cm)	Munsell Colour notation		Texture (Field)	Structure	Consistence	Boundary	Special feature
			Matrix (moist)	Mottles					
Binsara	Ap1g	0 – 8	5Y4/1 dg	C1-2D yb	C	MA	VST,VPL,FI	AS	Dark gray coatings on ped faces
	Ap2g	8 – 13	5Y3/1 vdg	C1-2D yb	C	MA	VST,VPL,EFI	CS	
	Bw1g	13 – 47	5Y4/1 dg	M1-2D,M1-2P db	C	ST,ME,PR	VST,VPL,VFI	CS	
	Bw2g	47 – 70	5Y4/1 dg	M1-2D,M1-2P stb	C	ST,ME,PR	VST,VPL,FI	CS	
	Bw3g	70 – 94	5Y5/1 g	M1-2D,M1-2P lyb	SiC	MO,CO,AB	ST,PL,FI	CS	
	C1g	94 – 105+	5Y6/1 g	M1-2D,M1-2P lyb	SiC	MO,CO,AB	ST,PL,FI	-	
Taras (1)	Ap1g	0 – 6	5Y4/1 dg	F1D yb	C	MA	ST,PL,FI	AS	Fe- staining along root channel; Cracking in dry season.
	Ap2g	6 – 10	5Y4/1 dg	M1-2D,M1-2P db	C	MA	VST,VPL,VFI	AS	
	Bw1g	10 – 38	5Y4/1 dg	M1-2D,M1-2P stb	SiC	ST,ME,AB	ST,PL,FI	CS	
	Bw2g	38 – 60	5Y5/1 g	M1-2D,M1-2P dyb	SiCL	ST,ME,AB	ST,PL,FR	CS	
	Bw3g	60 – 75	5Y5/1 g	M1-2D,M1-2P yb	SiCL	ST,ME,AB	ST,PL,FR	CS	
	C1g	75 – 100+	5Y6/1 g	M1-2D,M1-2P lyb	SiCL	MO,ME,AB	VST,VPL,VFI	-	
Jaonia	Apg	0 – 8	5Y4/1 dg	F1D yb	C	MA	ST,PL,FI	AS	Fe- staining along root channel; dark gray coatings on ped faces; Cracking in dry season
	Bw1g	8 – 32	5Y3/1 vdg	F1D yb	C	ST,CO,PR	VST,VPL,VFI	CS	
	Bw2g	32 – 62	5Y4/1 dg	M1-2D,M1-2P yb	C	ST ,CO,PR	VST,VPL,FI	CS	
	Bw3g	62 – 90	5Y5/1 dg	C1-2P stb	SiCL	MO,CO,PR	VST,VPL,FI	CS	
	Bw4g	90 – 100	5Y6/1 g	M1-2D,M1-2P lyb	SiCL	ST,ME,AB	ST,PL,FR	CS	
	Cg	100–120+	5Y6/1 g	M1-2D,M1-2P lyb	SiCL	ST,ME,AB	ST,PL,FR	-	

* The abbreviations are used according to FAO guidelines (FAO, 2006) and Soil Survey Manual (Soil Survey Staff, 1993)

Continued next page

Continue…

Table 6. Morphogenetic properties of the studied soils of the lower Atrai basin of Bangladesh*.

Soil Series	Horizon	Depth (cm)	Munsell Colour notation		Texture (Field)	Structure	Consistence	Boundary	Special feature
			Matrix (moist)	Mottles					
Taras (2)	Ap1g	0 – 6	5Y4/1 dg	C1P stb	C	MA	ST,PL,FI	AS	Fe- staining along root channel; Cracking in dry season
	Ap2g	6 – 9	5Y4/1 dg	C1P db	C	MA	ST,PL,VFI	AS	
	Bw1g	9 – 30	5Y5/1 g	M1-2D,M1-2P db	C	ST,ME,AB	VST,VPL,FI	CS	
	Bw2g	30 – 59	5Y6/1 g	M1-2D,M1-2P stb	CL	ST,ME,AB	ST,PL,FR	CS	
	Bw3g	59 – 86	5Y6/1 g	M1-2D,M1-2P yb	SiCL	MO,ME,AB	ST,PL,FR	CS	
	C1g	86 – 100+	5Y6/1 g	M1-2D,M1-2P lyb	SiCL	MO,ME,AB	ST,PL,FI	-	
Hasnabad	Ap1g	0 – 8	5Y5/2 og	F1D stb	SiL	MA	SST,SPL,FR	AS	-
	Ap2g	8 – 12	5Y4/2 og	F1-2D db	SiL	MA	SST,SPL,FR	AS	-
	Bw1	12 – 30	5Y4/1 dg	M1-2D,M1-2P b	SiCL	MO,ME,AB	ST,PL,FI	CS	-
	Bw2	30 – 69	5Y5/2 og	M1-2D,M1-2P stb	SiCL	MO,ME,AB	ST,PL,FI	CS	-
	Bw3	69 – 97	5Y5/1g	M1-2D,M1-2P lyb	SiCL	MO,ME,AB	SST,SPL,FR	CS	-
	Bw4	97 – 110	5Y6/2 log	M1-2F lyb	SiL	MO,ME,AB	SST,SPL,FR	CS	
	C1	110 – 120+	5Y6/2 log	M1-2F lyb	SiL	MO,ME,AB	SST,SPL,FR	-	-
Laskara	Ap1g	0 – 10	5Y4/1dg	F1D yb	C	MA	VST,VPL,FI	AS	Fe- staining along root channel
	Ap2g	10 – 16	5Y5/1 g	C1-2P,C1-2P stb	C	MA	ST,PL,FI	CS	
	Bw1g	16 – 36	5Y6/1 g	M1-2D,M1-2P yb	SiCL	ST,CO,PR	SST, SPL, VFI	CS	
	Bw2	36 – 57	5Y6/1 g	M1-2D,M1-2P yb	SiCL	ST,CO,PR	SST, SPL, FI	CS	
	Bw3g	57 – 75	5Y6/1 g	M1-2D,M1-2P stb	SiCL	ST,CO,PR	ST,PL,FR	CS	
	Bw4g	75 – 90	5Y4/1 dg	M1-2D,M1-2P b	SiCL	MO,CO, AB	ST,PL,FI	CS	
	C1g	90 – 110+	5Y4/1 dg	M1-2D,M1-2P lyb	SiC	MO,CO,AB	ST,PL,FI	-	

* The abbreviations are used according to FAO guidelines (FAO, 2006) and Soil Survey Manual (Soil Survey Staff, 1993)

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Table 6. Morphogenetic properties of the studied soils of the lower Atrai basin of Bangladesh*.

Soil Series	**Horizon**	**Depth (cm)**	**Munsell Colour notation**		**Texture (Field)**	**Structure**	**Consistence**	**Boundary**	**Special feature**
			Matrix (moist)	**Mottles**					
Manda	Apg	0 – 8	5Y5/2 og	C1-2D b	SiL	MA	NST,NPL,FR	AS	-
	AC	8 – 21	5Y5/2 og	-	SiL	MA	NST,NPL,VFR	CW	-
	C1	21 – 54	5Y6/2 log	-	LVFS	MA	NST,NPL,VFR	CS	-
	C2	54 – 74	5Y6/2 log	-	SL	MA	NST,NPL,VFR	CS	-
	C3	74 – 95+	5Y7/2 lg	-	SL	MA	NST,NPL,VFR	-	
Mainam	Ap1g	0 – 8	5Y5/2 og	C1-2D b	SiL	MA	NST,NPL,FR	AS	-
	Ap2g	8 – 17	5Y5/2 og	C1-2D b	LVFS	MA	NST,NPL,VFR	CW	-
	AC	17 – 28	5Y6/2 log	-	LVFS	MA	NST,NPL,VFR	CS	-
	C1	28 – 39	5Y6/2 log	-	LVFS	MA	NST,NPL,VFR	CS	-
	C2	39 – 56	5Y6/2 log	-	LVFS	MA	NST,NPL,VFR	CS	-
	C3	56 – 99+	5Y7/2 lg		SL	MA	NST,NPL,VFR	-	-

* The abbreviations are used according to FAO guidelines (FAO, 2006) and Soil Survey Manual (Soil Survey Staff, 1993)

Colour: lg = light grey, g = grey, dg = dark grey, vdg = very dark grey, og = olive grey, log = light olive grey. ***Mottles:*** F = few, C = common, M = many, 1= fine, 2= medium, 3= course, D = distinct, P = prominent, b = brown, stb = strong brown, yb = yellowish brown, lyb = light yellowish brown, dyb = dark yellowish brown. ***Texture*:** C = clay, SiL = silt loam SiCL = silty clay loam, SiC = silty clay, SL = sandy loam, LVFS = loamy very fine sand. ***Structure:*** WE= weak, MO= moderate, ST= strong, FI = fine, ME = medium, CO = course, AB = angular blocky, PR = prismatic, MA = massive. ***Consistence:*** VST = moist very sticky, ST = moist sticky, SST = moist slightly sticky, NST = non-sticky, VPL = moist very plastic, PL = moist plastic, SPL = moist slightly plastic, NLP = non-plastic, EFI = moist extremely firm, VFI = moist very firm, FI = moist firm, VFR = moist very friable, FR = moist friable. ***Boundary:*** AS = abrupt smooth, CS = clear smooth, CW = clear wavy.

Laskara soil series have uniform grey matrix colours throughout the profile with gleyed layer or g-horizon but Hasnabad, Manda and Mainam series the gleyed layer or g-horizon found only upper part of the profile. This indicates that these all soils remain wet and in reduced condition during the major period of the year (Joffe, 1966).

Under reduced condition, the soils usually appear grey or bluish grey in colour. It must be remembered that the relict colours, that is, those inherited from the parent materials, may be present in some soils. The variation of soil colours may be related to variation in duration of flooding period, reduction and movement of iron from the surface downward as well as the quantity of organic matter (Brammer, 1971; Danil *et al.,* 1971; Diwakar and Singh, 1992; Begum *et al.,* 2004). The drainage condition is directly thus responsible for variation in soil colour.

Colour patterns and mottles

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.

Due to the alternate wetting and drying condition abundant quantities of mottles have formed in all the soil profiles (Table 6) except Manda and Mainam soils. The colour of mottles was a combination of dark brown to strong brown and light yellowish brown to yellowish brown. These colour patterns might have been 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. The size and contrast of mottles showed variation from soil to soil. This is due possibly to the intensity and duration of oxidation-reduction conditions in the soils (Mazumder *et al.,* 2010, Hossain *et al.,* 2011, khan *et al.,* 2012; Islam *et al.,* 2014). The presence of mottled horizons in the subsurface zone is the characteristics of hydromorphic soils (Joffe, 1966).

The gleying phenomenon in the surface-water gley soils in Bangladesh were described by Brammer (1971) and Brinkman (1977). The surface water gleys are quite wide spread and are known by different names in different parts of the world, such as hydromorphic soils in Southeast Asia (Vander, 1972); degraded rice soils in Burma (Karmanov, 1968) and Aquarizams in Japan (Kyuma and Kawaguchi, 1966). These soils developed properties diagnostic of soils with aquic moisture regime (Smith and Beecroft 1983).

Consistence

Consistence is the term used to describe the resistance of a soil at various moisture contents to mechanical stresses or manipulations. It represents the composite expression of the forces of cohesion and adhesion that determine the ease with which a soil can be reshaped or ruptured. Results of soil consistence are important for soil management especially during tillage operations. This assumes importance when the soils are ploughed in wet condition. The consistence of the studied soils was determined under two moisture conditions -moist and wet.

The consistence of surface soils of all the studied profiles was found to be considerably slightly sticky to very sticky and slightly plastic to very plastic when wet (Table 6) except Manda and Mainam soils. In moist condition, the consistence of topsoil was firm in Binsara, Taras (1), Jaonia, Taras (2), and Laskara series, while in Hasnabad, Manda and Mainam series it was friable (Table 6).

The difference in consistence of the soils of the various horizons is thought to be due to several characteristics of the soils such as textural class and the quantity and type of clay minerals (Brammer, 1971).

Texture

Soil texture refers to the relative proportion of sand, silt and clay. The size of particles in a soil mineral is not subjected to change readily. Thus a sandy soil remains sandy and a clay soil remains clayey for an indefinite period.

The field texture of the soils was determined by "feeling method". The field texture of surface soils of Binsara, Taras (1), Jaonia, Taras (2), and Laskara series was clay and subsoil was silty clay to silty clay loan, while in the surface soils of Hasnabad, Manda and Mainam series in which the texture was silt loam (Fig 23) and subsoil of Manda and Mainam was very fine sandy loan but in Hasnabad series the texture of subsoil was silty clay loam (Table 6). Brammer (1971) reported that the textures in Bangladesh soils changes from coarse to fine along the north-south direction.

Structure

Structure refers to the aggregation of individual soil particles into larger units or peds with planes of weakness between them. The structure of the soils was massive in all the surface horizons of the studied soils. Structure did not develop in the surface as this layer has been ploughed for many years with puddling. The subsoil of Binsara, Jaonia and Laskera series showed strong moderate to course prismatic structure but Taras (1), Taras (2) and Hasnabad series showed moderate to strong medium angular blocky structure. In Manda and Mainam series massive structure was found all over the profiles.

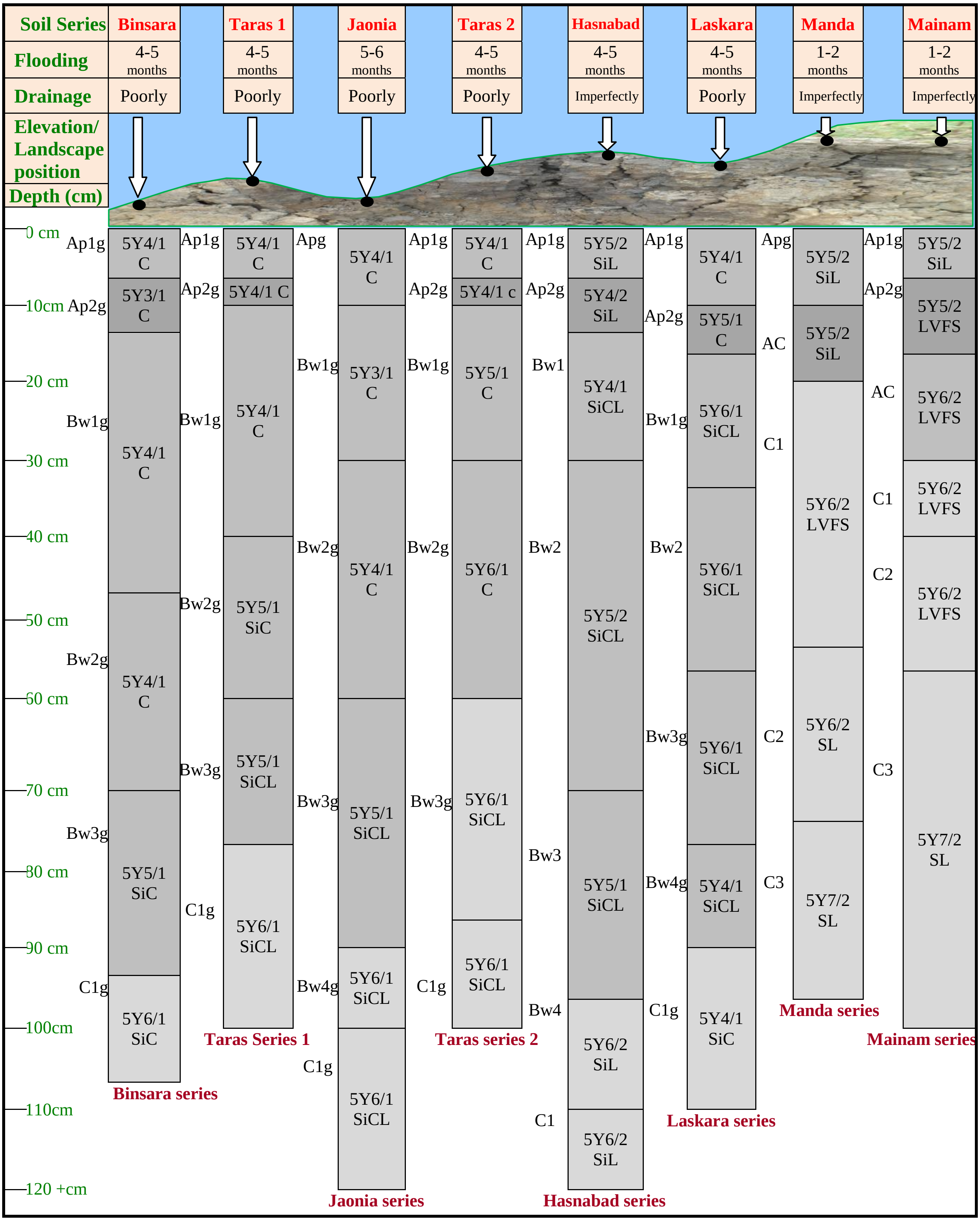

Fig 23. Some morphogenetic properties of the studied pedons.

From the studied soils, it may be concluded that in the moderate to strong medium angular blocky and strong moderate to course prismatic structure is dominate in the Lower Atrai basin soils of Bangladesh.

Flood coatings

Brammer (1971) defined flood coatings as the shiny surfaces of soil cracks and pores formed by deposition of materials washed from the surface soils under seasonally flooded condition. The flood coatings are clearly different from the clay cutans. The colour of the flood coatings are same as that of the topsoil; grey where the topsoil is grey (when wet); dark grey when the topsoil is dark grey, This indicates that the material have been derived from the topsoil and not from suspended materials in the floodwater.

Continuous thick dark grey to very dark grey cutans along vertical and horizontal ped faces were found in the subsoils all the soil profiles except Manda and Mainam series. 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).

Pores and roots

The pore space of a soil is that portion of the soil volume occupied by air and water. The size, shape and continuity of the pore space determine to a large extent the movement of air and water in the soil. Many fine to common fine tubular pores were found in Jaonia series. Common very fine to fine tubular pores were observed in Binsara, Taras (1), Laskara and Taras (2) series. In, Hasnabad, Manda and Mainam seies common fine to few fine tubular pores were found. Many fines to common fine roots and iron staining along root channels were found in Taras (1), Jaonia Taras (2) and Laskara series. Common fine to few fine roots were observed in Mandan ad Mainam series. In Binsara series, dark grey coatings were found in ped faces. It was noticed that the quantity and distribution of roots in the soil profile depends on the crop type as well as the cultural practices of the soils.

Horizon boundaries

Horizon boundaries are important morphological features in soil profiles. In Binsara, Taras (1), Jaonia, Taras (2), Hasnabad and Laskara series, abrupt smooth and clear smooth boundary was found. Abrupt smooth, clear weavy, clear smooth boundary was also found in the horizons of the Manda and Mainam series. With respect to horizon boundaries, the soils under the present investigation are more or less similar.

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

- ➢ The surface soils of all profiles have silt loam to clay with dark grey (5Y 4/1, moist) to olive grey (5Y 5/2, moist) colours and were slightly acidic in reaction.
- ➢ The subsoil horizons were characterized by slightly acidic to neutral in reaction. The colour ranges from grey to olive grey with common fine distinct strong brown to yellowish mottles. Their texture varies from silty clay to silty clay loam. Some grey cutions along the vertical ped faces are present.
- ➢ The profiles also showed the presence of flood coatings and mottles (mostly raddish brown) along the old root channels and pore walls.
- ➢ Strong, coarse to medium angular blocky and moderate strong to course strong prismatic structure were seen in the subsoil.

A brief account of the pertinent soil forming factors prevailing in the area under investigation is given below:

- ❖ The climate of the area is humid tropical monsoon with a mean annual rainfall in 2300 mm.
- ❖ As the top soils of the area are presently under cultivation natural vegetation could not be traced.
- ❖ The area has nearly level broad basin.
- ❖ Parent materials consist of unconsolidated alluvium of recent age.
- ❖ Age is at least 220 years. (Brammer, 1964)
- ❖ Poor internal and external drainage condition exists in these soils and they are irrigated during the dry season for production of rice.

5.2 Physical properties

The physical parameters along with the chemical, physico-chemical and mineralogical characteristics are the most essential criteria to characterize the soils. These are also very useful criteria in the landuse and management. Some of these properties were studied in the field as well as in the laboratory. Results of physical properties of the studied soils are presented in Table 7.

5.2.1 Particle size distribution

The studied soils are generally medium to fine textured and showed a wide range in textural class from loamy sand to clay among the horizons (Table 7). This variation in textural classes of soils is a common feature in many of the floodplain areas of Bangladesh (Islam *et al.,* 2009). Usually the soils of the ridge areas are loamy sand to silt loams and those in the basins are clays (Brammer, 1971; SRDI Staff 1965-86). The studied soils are located in basin margins and bottom lands of seasonally flooded areas and therefore the soils are mostly silty clay in textured.

5.2.1.1 The non-colloidal fraction

Generally the sand and silt fractions of the soils are considered as the non-colloidal fraction whose particle sizes range from 2 to 0.002 mm.

i. Sand fraction

Results of particle size distribution indicate that the sand fraction in the studied soils vary within a very wide limits and ranges from 1 to 88 percent with a mean value of 18 percent (Table 7). These results are in agreement with the findings of SRDI Staff (1965-86); Brammer (1971); Islam *et al.* (2014a); Islam *et al.* (2014b).

The highest value of sand is found in the soils of the Manda series while the lowest value is found in the soils of the Laskera series (Fig 24). Based on the sand content, the studied pedons show the following gradation:

Manda > Mainam > Taras 2 > Taras 1 > Binsara > Hasnabad > Jaonia > Laskara

The trends of vertical distribution of sand fraction in the various soil profiles are presented in Figs 25 & 26. The vertical distribution of sand indicates that its content is almost uniform in Binsara, Taras 1, Taras 2, Binsara, Hasnabad and Laskara series. In Mainam and Manda soil the sand fraction is dominant and the percentages are higher than those of the upper horizons. This irregularity in sand distribution pattern is thought to be related to the depositional process of the parent material. In other words the irregularity is geogenic rather than pedogenic in nature. However, this fact also indicates that the soil materials of these profiles can be considered as more or less uniform. On the basis of the

Table 7. Particle size distribution and textural classes of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	Depth (cm)	Particle Size Distribution % Sand (2 – 0.05mm)	%Silt (0.05 – 0.002mm)	%Clay (< 0.002mm)	Textural Class*	Sand/Silt ratio	Silt/Clay ratio
Binsara	Ap1g	0 – 8	8	57	35	SiCL	0.14	1.63
	Ap2g	8 – 13	3	46	51	SiC	0.07	0.90
	Bw1g	13 – 47	8	36	56	C	0.22	0.64
	Bw2g	47 – 70	10	34	56	C	0.29	0.61
	Bw3g	70 – 94	8	36	56	C	0.22	0.64
	C1g	94–105+	14	41	45	SiC	0.34	0.91
	Mean		**8**	**42**	**50**	**SiC**	**0.19**	**0.84**
Taras (1)	Ap1g	0 – 6	10	47	43	SiC	0.21	1.09
	Ap2g	6 – 10	8	39	53	C	0.21	0.74
	Bw1g	10 – 38	13	39	48	C	0.33	0.81
	Bw2g	38 – 60	8	41	51	SiC	0.20	0.80
	Bw3g	60 – 75	11	56	33	SiCL	0.20	1.70
	C1g	75–100+	7	34	59	C	0.21	0.58
	Mean		**9**	**43**	**48**	**SiC**	**0.21**	**0.90**
Jaonia	Apg	0 – 8	3	56	41	SiC	0.05	1.37
	Bw1g	8 – 32	2	39	59	C	0.05	0.66
	Bw2g	32 – 62	2	32	66	C	0.06	0.48
	Bw3g	62 – 90	2	34	64	C	0.06	0.53
	Bw4g	90–100	3	80	17	SiL	0.04	4.71
	Cg	100–120+	14	71	15	SiL	0.20	4.73
	Mean		**4**	**52**	**44**	**SiC**	**0.08**	**1.24**
Taras (2)	Ap1g	0 – 6	6	53	41	SiC	0.11	1.29
	Ap2g	6 – 9	16	39	45	C	0.41	0.87
	Bw1g	9 – 30	9	46	45	SiC	0.20	1.02
	Bw2g	30 – 59	11	46	43	SiC	0.24	1.07
	Bw3g	59 – 86	13	49	38	SiCL	0.27	1.29
	C1g	86–100+	13	28	59	C	0.46	0.47
	Mean		**11**	**44**	**45**	**SiC**	**0.25**	**0.98**

Continued next page

*C = clay, SiC = silty clay, SiCL = silty clay loam, SiL = silt loam, SL = sandy loam, LS = loamy sand, L = loam.

Continue…

Table 7. Particle size distribution and textural classes of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	Depth (cm)	Particle Size Distribution % Sand (2 – 0.05mm)	%Silt (0.05 – 0.002mm)	%Clay (< 0.002mm)	Textural Class*	Sand/Silt ratio	Silt/Clay ratio
Hasnabad	Ap1g	0 – 8	9	61	30	SiCL	0.15	2.03
	Ap2g	8 – 12	6	51	43	SiC	0.12	1.19
	Bw1	12 – 30	6	53	41	SiC	0.11	1.29
	Bw2	30 – 69	1	51	48	SiC	0.02	1.06
	Bw3	69 – 97	4	61	35	SiCL	0.07	1.74
	Bw4	97–110	3	79	18	SiL	0.04	4.39
	C1	110–120+	6	74	20	SiL	0.08	3.70
	Mean		**5**	**61**	**34**	**SiCL**	**0.08**	**1.79**
Laskara	Ap1g	0 – 10	3	59	38	SiCL	0.05	1.55
	Ap2g	10 – 16	1	56	43	SiC	0.02	1.30
	Bw1g	16 – 36	3	64	33	SiCL	0.05	1.94
	Bw2	36 – 57	4	69	27	SiCL	0.06	2.56
	Bw3g	57 – 75	1	79	20	SiL	0.01	3.95
	Bw4g	75 – 90	5	39	56	C	0.13	0.70
	C1g	90–110+	5	44	51	SiC	0.11	0.86
	Mean		**3**	**59**	**38**	**SiCL**	**0.05**	**1.55**
Manda	Apg	0 – 8	30	56	14	SiL	0.54	4.00
	AC	8 – 21	30	58	12	SiL	0.52	4.83
	C1	21 – 54	86	5	9	LS	17.20	0.56
	C2	54 – 74	88	3	9	LS	29.33	0.33
	C3	74–95+	86	5	9	LS	17.20	0.56
	Mean		**64**	**25**	**11**	**SL**	**2.56**	**2.27**
Mainam	Ap1g	0 – 8	15	68	17	SiL	0.22	4.00
	Ap2g	8 – 17	16	70	14	SiL	0.23	5.00
	AC	17 – 28	66	25	9	SL	2.64	2.78
	C1	28 – 39	30	58	12	SiL	0.52	4.83
	C2	39 – 56	48	43	9	L	1.12	4.78
	C3	56–99+	88	3	9	LS	29.33	0.33
	Mean		**44**	**44**	**12**	**L**	**1.00**	**3.66**
	Grand Mean		**18**	**46**	**36**	**-**	**0.39**	**1.27**

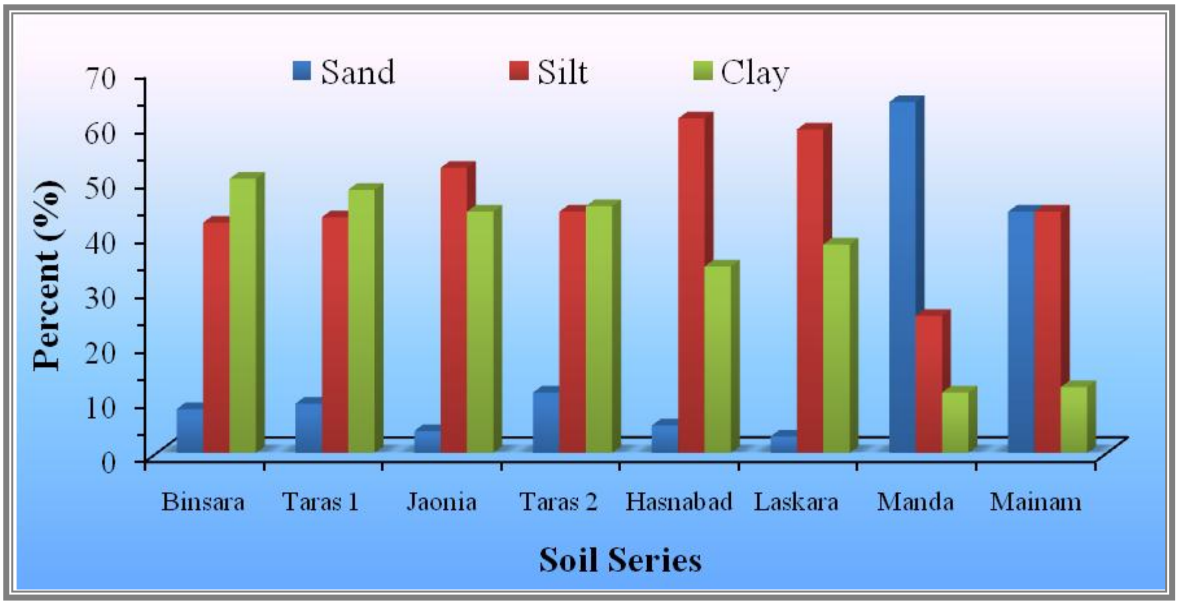

Fig 24. Graph shows the mean value of sand, silt and clay of the studied soil series.

vertical distribution of sand it may be generally concluded that the parent materials of the present soils are heterogeneous. The parent materials of these soils were deposited by running water and the cause of this heterogeneity may be related to their depositional location.

ii. Silt fraction

The silt content has assumed a significant status in these soils. The general level of silt content is high ranging from 3 to 80 percent with a mean value of 46 percent (Table 7). Silt is the dominant fraction in Jaonia, Hasnabad and Laskara soils but in the Binsara, Taras 1, Taras 2 soils the clay content exceeds the silt content. The highest mean silt content within the profile is observed in the Hasnabad soil (61 percent) whereas the lowest in the Manda soil (25 percent) (Fig 24). Such a high level of silt is due to their geogenic origin. Based on the percent silt content, the pedons show the following gradation:

Hasnabad > Laskara > Jaonia > Mainam > Taras 2 > Taras 1 > Binsara > Manda

The distribution pattern of silt fraction in the pedons shows an irregular trend (Figs 25 & 26). There is no significant trend in the distribution of silt in the profiles except in the Mainam and Manda profile. The sand/silt ratios of the present soil profile ranges from 0.01 to 29.33 with a mean of 0.39 (Table 7). The highest mean of sand/silt ratio was found in the Manda soil whereas the lowest ratio was found in the Laskara soil. The vertical distribution pattern of this ratio is irregular and heterogeneous. This shows that the soil materials that were deposited at different time had variation during the deposition. This leads to conclude that parent materials are stratified.

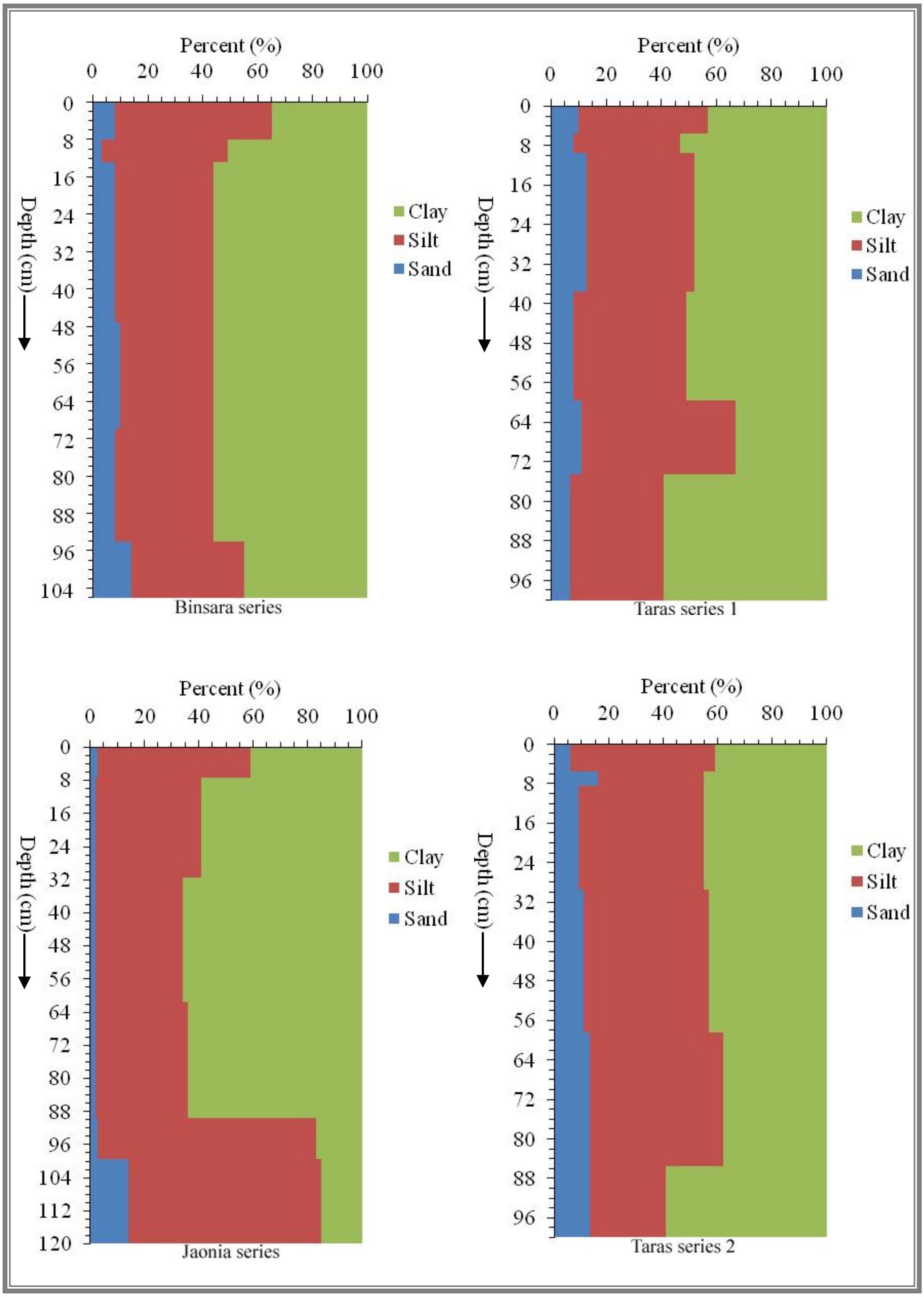

Fig 25. Verticle distribution of sand, silt and clay of Binsara and Taras 1, Jaonia and Taras 2 series.

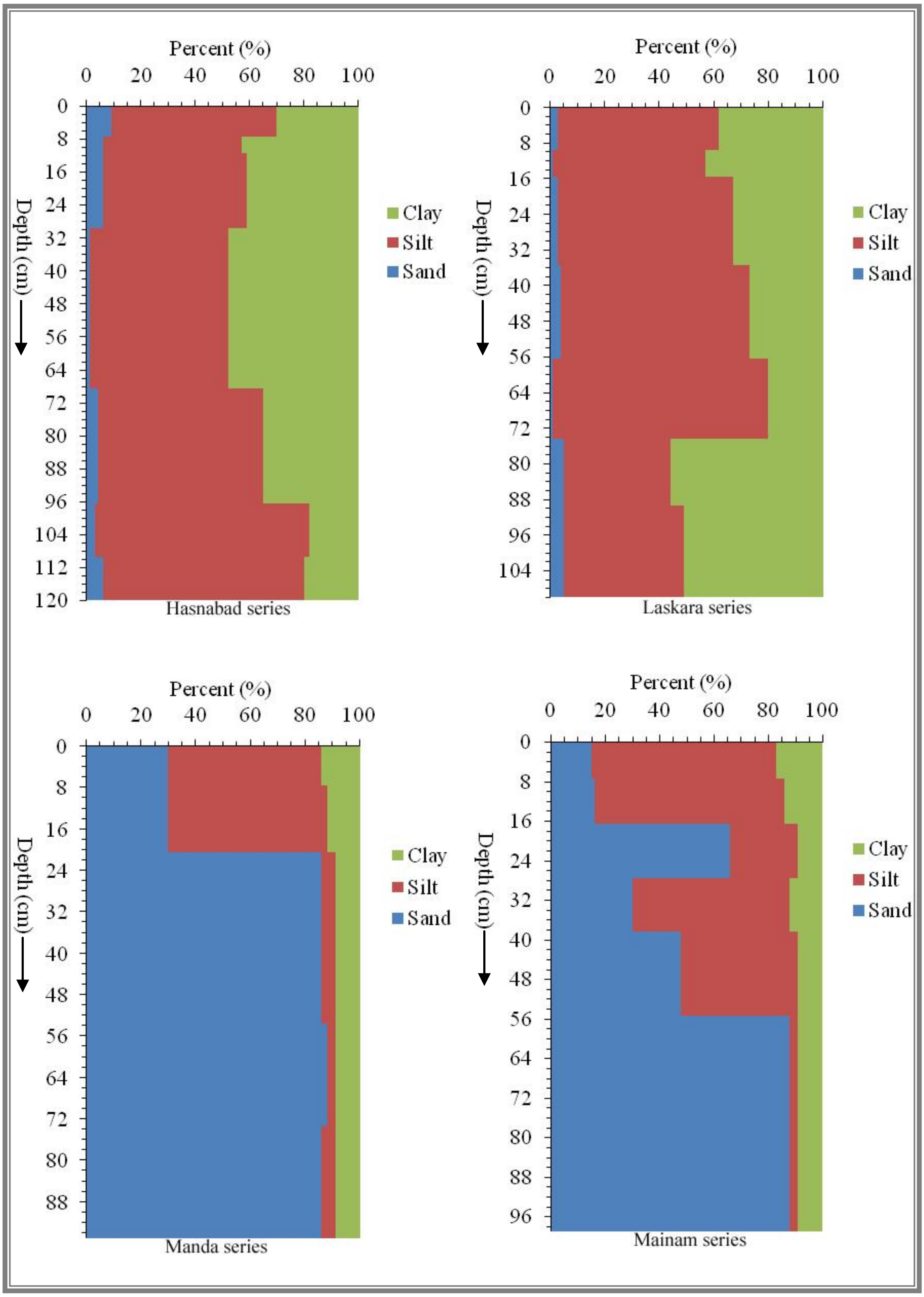

Fig 26. Verticle distribution of sand, silt and clay of Jaonia and Hasnabad, Laskara, Manda and Mainam series.

5.2.1.2 The clay fraction

The particle size fraction <0.002 mm represents the clay fraction in soils. The clay contents of the studied soils ranges from 9 to 66 percent with a mean value of 36 percent (Table 7). Clay is the dominant fraction in Binsara, Taras 1, Taras 2 soils but in the Jaonia, Hasnabad and Laskara soils the silt content exceeds the clay content. The highest mean value for clay is observed in the Binsara profile (50%), whereas the lowest value was in the Manda profile (11%) (Fig 24). Based on the clay content, the studied pedons shows the following gradation:

Binsara > Taras 1 > Taras 2 > Jaonia > Laskara > Hasnabad > Mainam > Manda

The clay contents in the Taras 1, Taras 2 and Lankara soils may be attributed to the higher clay content in their parent materials. As has been stated before these soils have formed in the lower part of the depressions where more clay is accumulated as compared to that in the levees.

The vertical distribution of clay content is irregular in all the soil profiles (Figs 25 & 26). Perhaps, this is the results of restricted movement downward due to poor drainage condition and the shortage of clay. This irregularity in the clay distribution in the profiles may be attributed to sedimentation processes rather than the pedological ones.

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 except Manda and Mainam profiles, surface impoverishment of clay is quite a noticeable feature. But it is difficult to predict if this impoverishment has been caused by the ferrolysis process.

The silt/clay ratio of the studied soils ranges from 0.33 to 5.0 with a mean value of 1.27. The distribution patterns of this ratio down the profiles are not equally uniform in all the soils under the present investigation (Table 7). 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 subsequent accumulation in the B horizon.

The textural class of the soil under investigation shows a wide variation. It ranges from loamy sand to clayey texture (Fig 27). This variation in textural classes of soils is a common feature in many of the floodplain areas of Bangladesh. Usually the soils of the ridge areas are loamy sand to silt loams and those in the basins are clays (Brammer, 1971). From Marshall textural triangle (Fig 27) it is clear that most of the studied soils are silty clay, clay and silty clay loam texture, among them silty clay is the dominant textural class. Among the 49 studied soils 15 soils are silty clay, 13 soils are clay, 9 soils are silt loam, 8 soils are silty clay loam, 2 soils are loamy sand, 1 soil is sandy loam and 1 soil is loam textural class.

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

a. Silty clay is the dominant textural class of all the studied soils except the Manda and Mainam soil series.
b. The parent materials of the soils under the investigation can be considered as more or less heterogeneous.
c. The vertical distribution of the sand, silt and clay fractions in the studied profiles are more or less irregular.
d. The sand content is low in all the soils except the Manda and Mainam soil series.
e. Silt is the dominant size fraction and the vertical distribution of silt in the studied profiles is quite irregular.
f. The grand mean of sand, silt and clay contents in the studied soils are 18, 46 and 36 percent respectively.

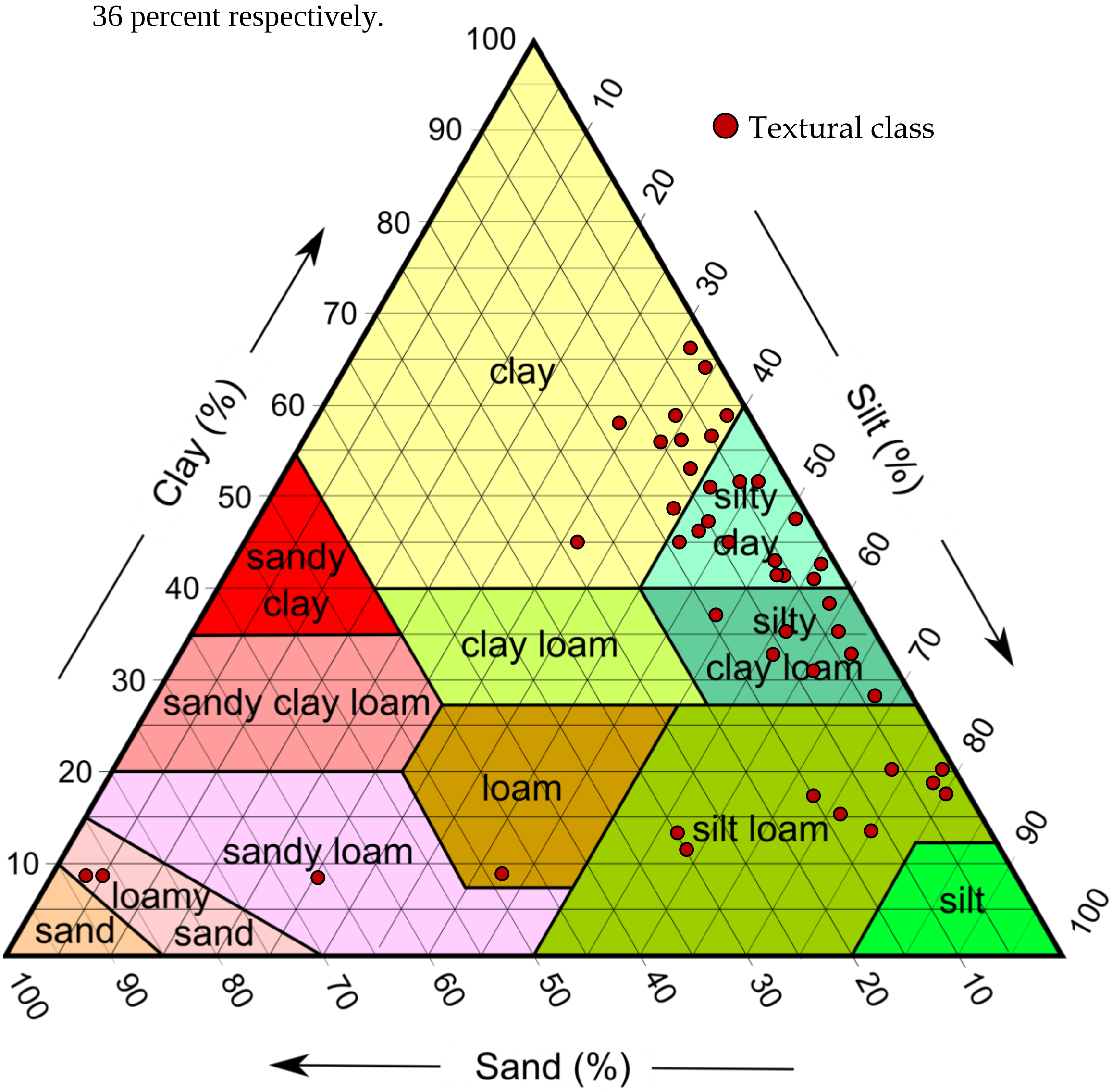

Fig 27. A projection of the textural classes of the soils developed on the lower Atrai basin.

5.2.2 Moisture at field condition

The moisture contents at field condition of the studied pedons ranges from 18 to 36 percent with a mean value of 27 percent (Table 8). The highest mean moisture of the profile is observed in the Laskara soil whereas the lowest mean moisture is observed in Hsanabad soils (Fig 27). Burrows and Kirkham (1958) observed variation in field moisture values with the variation in texture of different soils. They stated that the increases of field moisture of the soils can be attributed to the increase of clay content with depth (Diwakar and singh, 1992; Josua and Rahman, 1983). During the collection of soil samples, the lower horizons were wet, whereas the upper horizons were relatively dry. The vertical distribution pattern of the moisture at field condition is more or less uniform within the profile (Figs 29 & 30).

5.2.3 Hygroscopic moisture

Hygroscopic moisture of the soils varies from 0.1 to 4 with a mean value of 2 percent (Table 8). The hygroscopic moisture content in the present soils, in general, is rather low. The highest hygroscopic moisture percent are recorded in the Laskara series where as the lowest hygroscopic moisture is found in Mainam series (Fig 28). Such a variation in moisture content retained by air dry soils possibly due to the difference in their clay and organic matter contents. The vertical distribution pattern of the hygroscopic moisture is more or less uniform within the profile (Figs 29 & 30). The relationship between the hygroscopic moisture contents and the amount of clay in the soils is presented in Fig 31. From the figure it is clear that the clay contents of the soils show a positive correlation ($r = +0.862^{**}$) with the Hygroscopic moisture.

The oven dry/air dry (OD/AD) ratio of the present soils varies within the ranges of 0.96 to 1 with a mean value of 0.98 (Table 8). The highest mean of oven dry/air dry ratio among the profiles are found in Manda and Mainam series and the ratio of the other series are same except Hasnabad series. The OD/AD ratio is dependent on the quantity and type of clay minerals present in the soil. A significant negative correlation ($r = -0.817^{**}$) was found between OD/AD ratio and the percent clay of the soils under the present study (Fig 32). As stated previously the oven dry soils is controlled by the clay content of the soils (Diwakar and singh, 1992; Josua and Rahman, 1983).

5.2.4 Loss on ignition (LOI)

The LOI ranges from 1 to 10 percent with a mean value of 7 percent (Table 8). The highest mean value of loss on ignition is found in the Jaonia soils which also contain higher percentage of clay where as Manda soils have the lowest value which have low contents of clay (Fig 28). The vertical distribution pattern of the LOI shows a decreasing trend with

Table 8. Physical properties of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	OD*/AD* ratio	Moisture at field condition (%)	Hygroscopic Moisture (%)	LOI* (%)	n-value
Binsara	Ap1g	0.97	23	3	10	0.25
	Ap2g	0.97	26	3	9	0.29
	Bw1g	0.97	34	4	9	0.43
	Bw2g	0.97	35	3	9	0.45
	Bw3g	0.97	34	3	8	0.43
	C1g	0.98	34	2	7	0.51
	Mean	**0.97**	**31**	**3**	**9**	**0.39**
Taras (1)	Ap1g	0.96	24	4	10	0.24
	Ap2g	0.97	24	3	10	0.26
	Bw1g	0.97	23	3	9	0.24
	Bw2g	0.97	25	3	7	0.30
	Bw3g	0.97	23	3	7	0.30
	C1g	0.96	29	4	7	0.35
	Mean	**0.97**	**25**	**3**	**8**	**0.28**
Jaonia	Apg	0.97	26	3	10	0.29
	Bw1g	0.97	23	4	9	0.24
	Bw2g	0.97	28	3	10	0.31
	Bw3g	0.96	28	4	8	0.31
	Bw4g	0.97	20	3	8	0.16
	Cg	0.98	18	2	8	0.04
	Mean	**0.97**	**24**	**3**	**9**	**0.23**
Taras (2)	Ap1g	0.97	35	3	10	0.47
	Ap2g	0.97	26	3	10	0.29
	Bw1g	0.98	26	2	9	0.31
	Bw2g	0.98	27	2	6	0.34
	Bw3g	0.97	26	3	6	0.34
	C1g	0.97	33	4	6	0.42
	Mean	**0.97**	**29**	**3**	**8**	**0.36**

*AD = Air dry, *OD = Oven dry, *LOI = Loss on ignition

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Continue…

Table 8. Physical properties of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	OD*/AD* ratio	Moisture at field condition (%)	Hygroscopic Moisture (%)	LOI* (%)	n-value
Hasnabad	Ap1g	0.98	19	2	7	0.14
	Ap2g	0.98	19	2	7	0.16
	Bw1	0.98	20	3	7	0.18
	Bw2	0.97	26	3	6	0.31
	Bw3	0.98	21	2	6	0.21
	Bw4	0.98	22	3	7	0.28
	C1	0.97	21	3	7	0.23
	Mean	**0.98**	**21**	**2**	**7**	**0.22**
Laskara	Ap1g	0.97	35	3	9	0.49
	Ap2g	0.97	36	3	9	0.51
	Bw1g	0.98	32	3	8	0.50
	Bw2	0.98	30	2	9	0.52
	Bw3g	0.98	31	2	8	0.68
	Bw4g	0.96	31	4	8	0.37
	C1g	0.96	36	4	8	0.48
	Mean	**0.97**	**33**	**3**	**9**	**0.51**
Manda	Apg	0.99	30	1	5	0.74
	AC	0.99	27	1	5	0.71
	C1	1.00	25	0.4	3	0.72
	C2	1.00	25	0.3	3	0.71
	C3	1.00	25	0.2	1	0.71
	Mean	**1.00**	**26**	**0.5**	**3**	**0.72**
Mainam	Ap1g	0.99	32	1	5	0.73
	Ap2g	0.99	29	1	6	0.75
	AC	1.00	25	0.4	3	0.75
	C1	0.99	26	1	3	0.67
	C2	0.99	25	1	3	0.68
	C3	1.00	25	0.1	1	0.71
	Mean	**0.99**	**27**	**0.5**	**4**	**0.72**
	Grand Mean	**0.98**	**27**	**2**	**7**	**0.43**

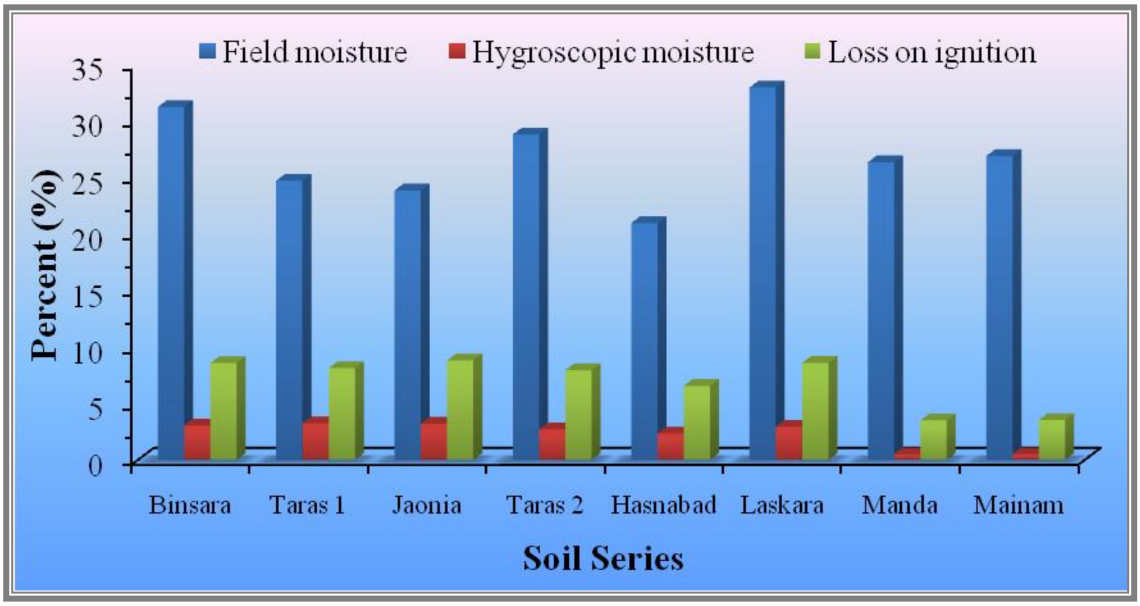

Fig 28. Graph shows the mean value of field moisture, hygroscopic moisture and loss on ignition of the studied soil series.

depth (Figs 29 & 30). The LOI values have been found to be positively correlated (r = +0.704**) with the percent clay content in the studied soils (Fig 33). A significant positive correlation (r = +0.682**) is also found between loss on ignition and organic matter contents of the soils (Fig 34). A suspicious examination of loss on ignition (LOI) of soils shows that higher values are encountered in the surface soil where organic carbon too has registered higher values than the subsurface soils. This is an agreement with the findings of Karim (1954) who noted 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 loss on ignition is usually dependent on a number of factors such as organic matter, $CaCO_3$ and the type and relative abundance of the clay minerals (Khan, 1954; Quasem, 1956 and Hussain, 1961).

5.2.5 n-value

Results of n-value have been presented in Table 8. According to Soil Taxonomy (Soil survey Staff, 1999) the n-value refers to the relation between the quantity of water at field condition and the quantities of clay and humus contents in the soils.

Soils included in the present study have the n-value ranging from 0.04 to 0.75 with a mean value of 0.42 percent (Table 8). The highest n-value among the profiles is found in Manda and Mainam soils and the lowest in Hasnabad soils. This value is dependent on the clay percent in the soil. The n-value has been used as a criterion for separation of the soils of Inceptisol and Entisols (Pons and Zonneveld, 1965). The soil of Entisol should have, between 20-50 cm below the mineral soil surface and n-value of 0.7 or more in one or more

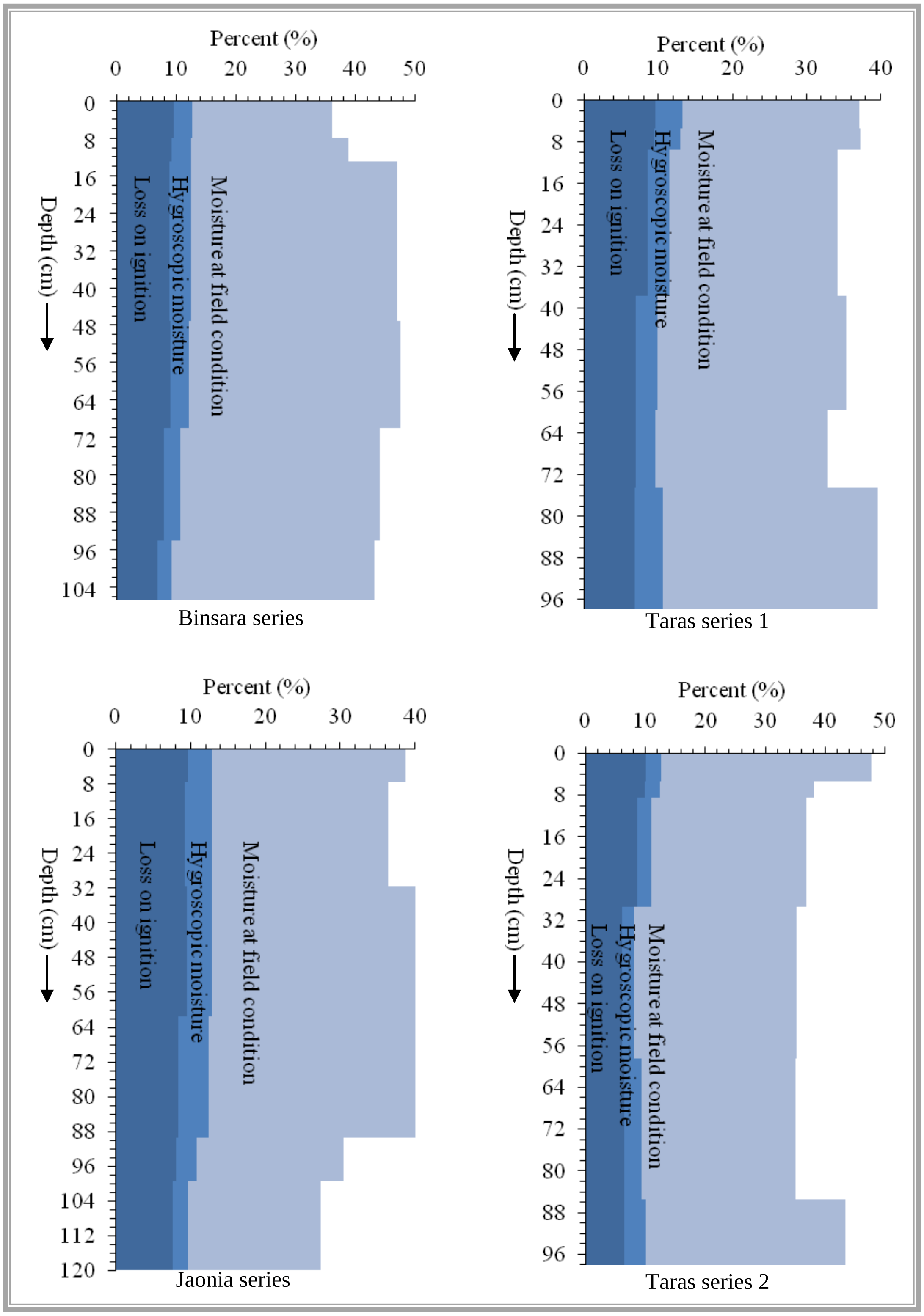

Fig 29. Vertical distribution of field moisture, hygroscopic moisture and loss on ignition of Binsara, Taras 1, Jaonia and Taras 2 series.

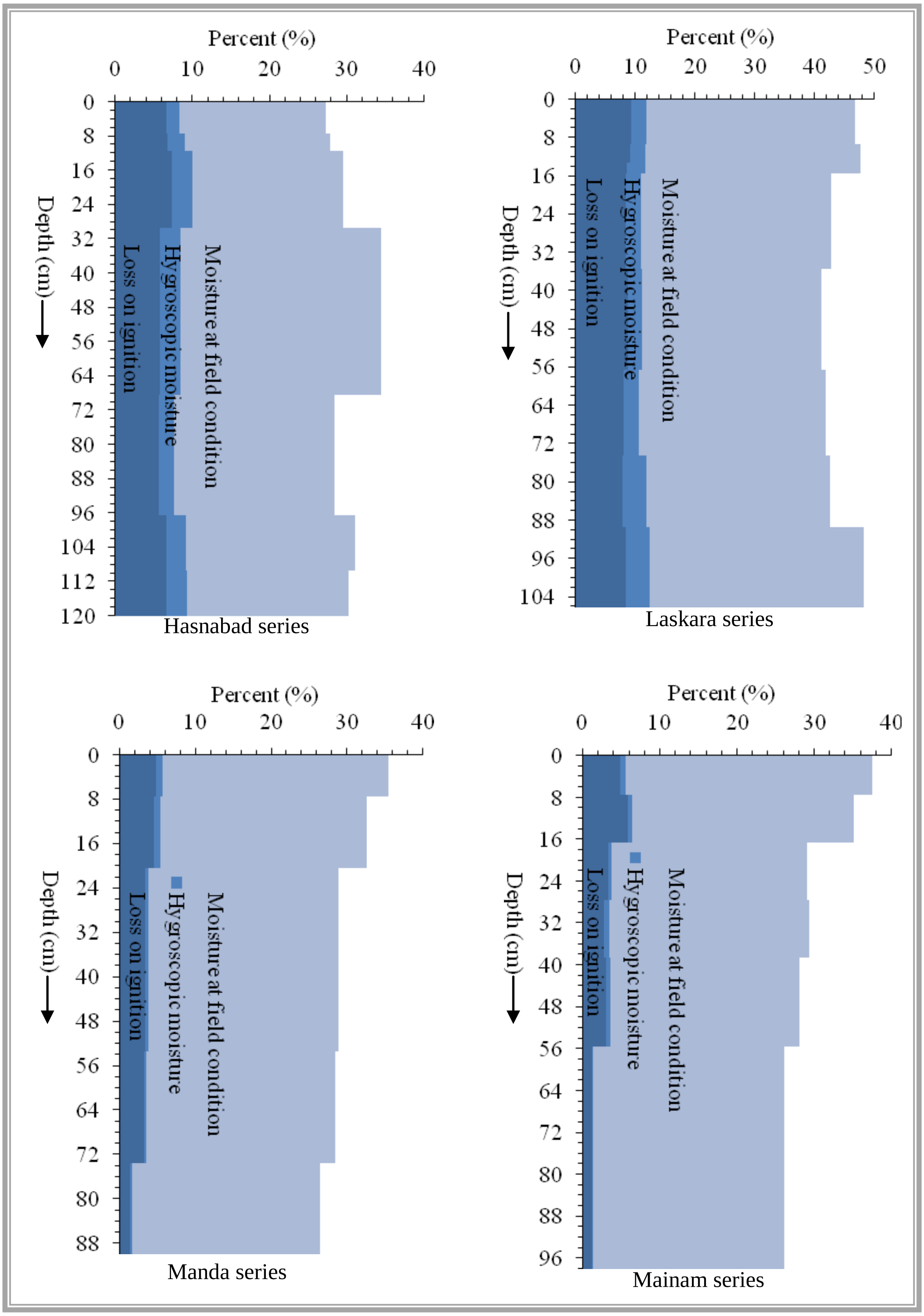

Fig 30. Vertical distribution of field moisture, hygroscopic moisture and loss on ignition of Hasnabad, Laskara, Manda and Mainam series.

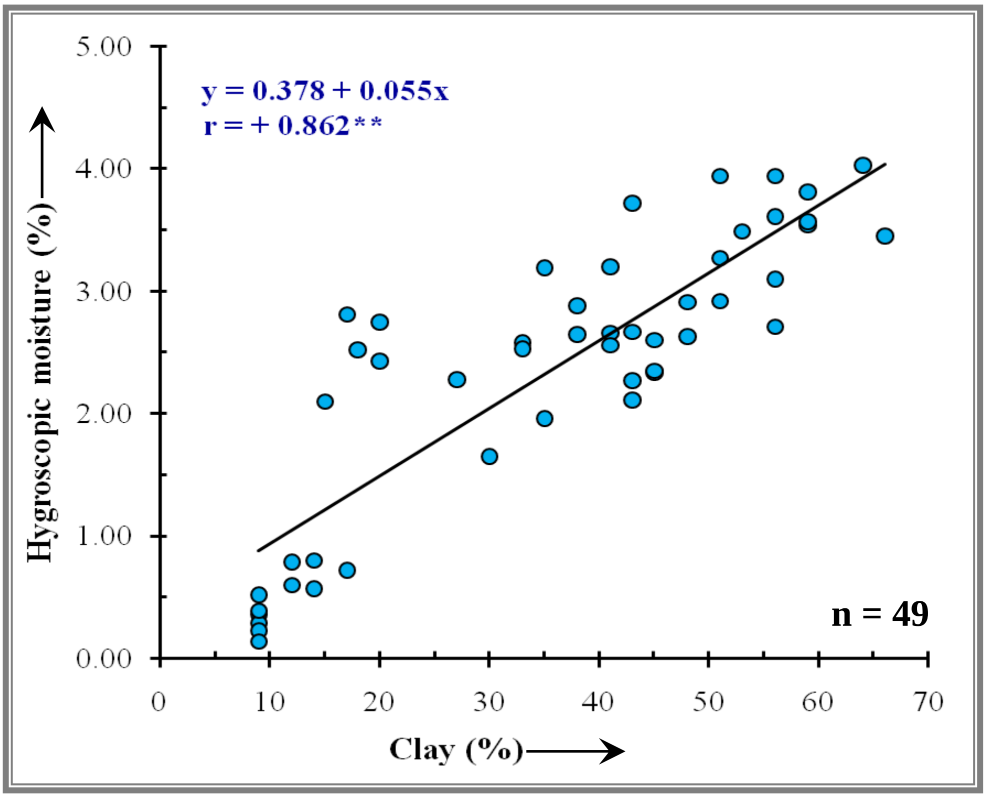

Fig 31. Correlation between percent clay and hygroscopic moisture in the soils under investigation.

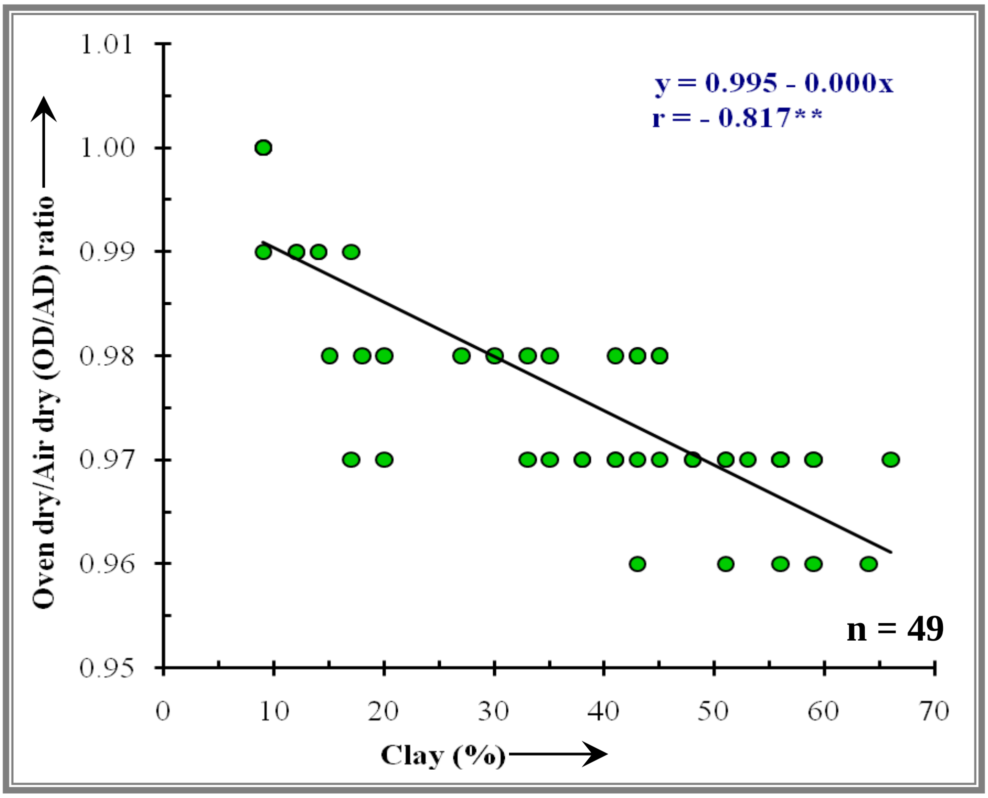

Fig 32. Correlation between percent clay and oven dry/air dry (OD/AD) ratio of the studied soils.

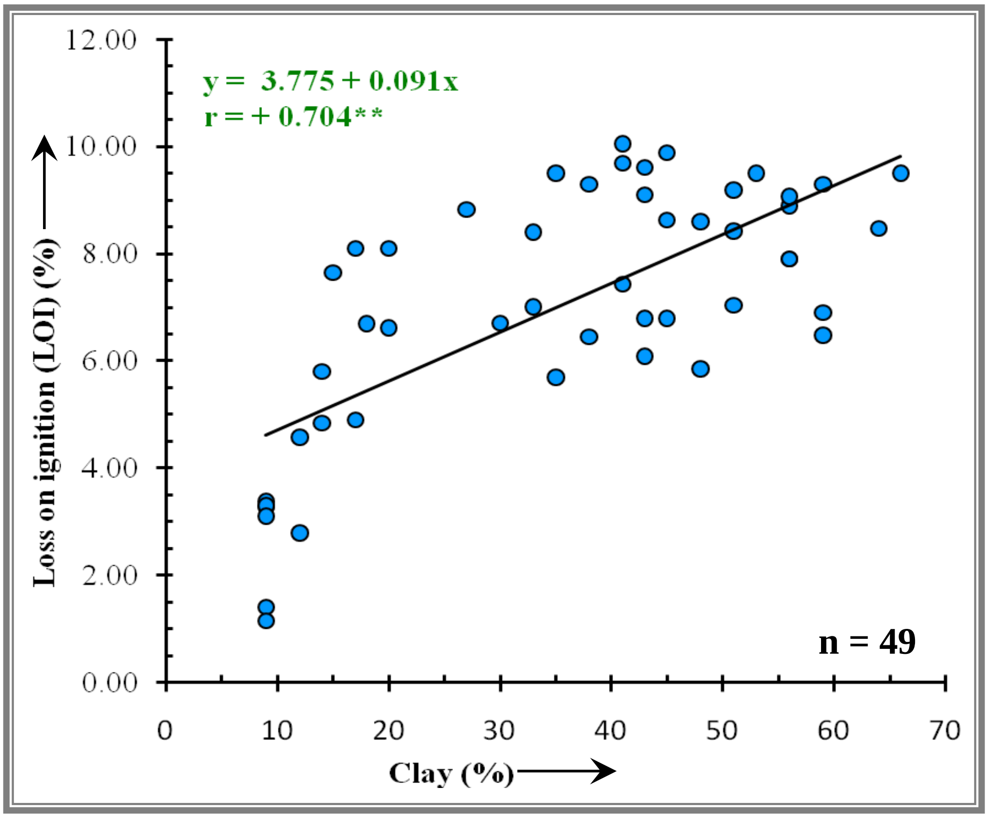

Fig 33. Relationship between percent clay and loss on ignition (LOI) percent in the soils under investigation.

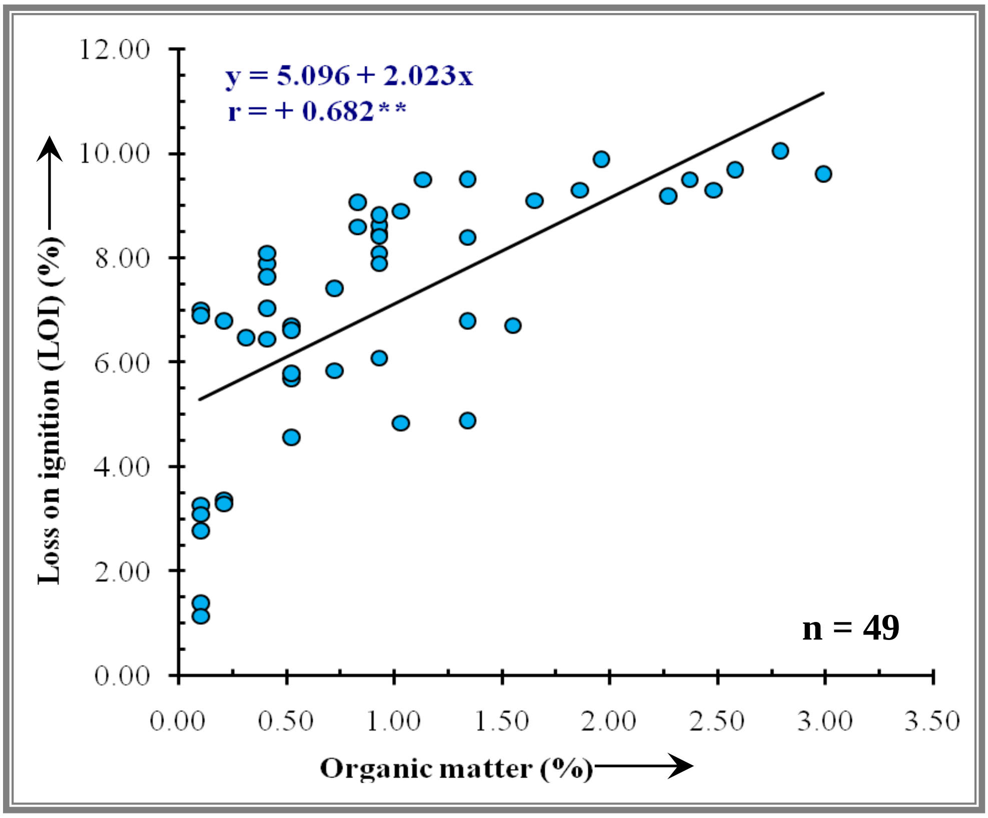

Fig 34. Correlation between percent organic matter (OM) and percent loss on ignition (LOI) of the soils under investigation.

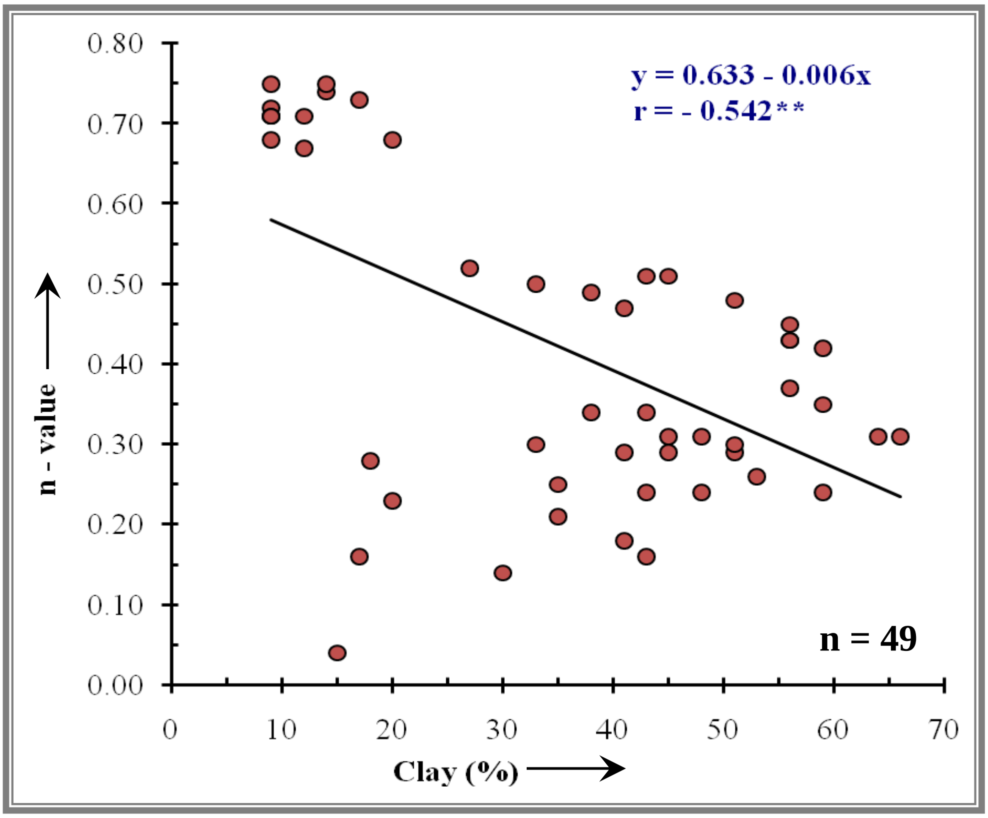

Fig 35. Relationship between percent clay and n-value of the studied pedons.

sub-horizon. On the other hand, Inceptisols have n-value of <0.7 to a depth of at least 50 cm. Thus, all the soils under present investigation except Manda and Mainam series can be placed in the Inceptisols order and the Manda and Mainam series in the Entisols order. There is a negative relationship (r = - 0.542**) between clay content and the n-value (Fig 35).

5.3 Chemical properties

5.3.1 Soil reaction (pH)

Reaction is one of the outstanding chemical characteristics of any soil that is subjected to seasonal flooding. The pH value indicates whether any soil is acidic, alkaline or neutral. It plays a very important role in grouping the soils into different reaction classes. It has a profound influence on many factors connected with the suitability of a soil for agricultural use and hence special importance has been given to it (Truog, 1961).

The pH value of the seasonally flooded soils from the lower Atrai basin ranges from 5.60 to 7.42 with a mean of 6.66 (Table 9). All the pedons, therefore, are moderately acid to neutral in reaction. The highest mean value of pH is found in Taras 2 profile whereas the lowest mean in found in the Hasnabad profile (Fig 36).

Table 9. Chemical properties of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	pH		ΔpH*	OC* (%)	OM* (%)	Total N* (%)	C/N ratio
		H_2O	N KCl					
Binsara	Ap1g	5.61	4.10	-1.51	1.38	2.37	0.18	8
	Ap2g	5.65	4.13	-1.52	1.32	2.27	0.15	9
	Bw1g	5.72	4.02	-1.70	0.60	1.03	0.14	4
	Bw2g	6.16	4.56	-1.60	0.48	0.83	0.08	6
	Bw3g	6.5	4.82	-1.68	0.24	0.41	0.04	6
	C1g	6.61	5.00	-1.61	0.12	0.21	0.02	6
	Mean	**6.04**	**4.44**	**-1.60**	**0.69**	**1.19**	**0.10**	**7**
Taras (1)	Ap1g	6.48	5.10	-1.38	1.74	2.99	0.15	12
	Ap2g	6.62	5.08	-1.54	0.66	1.13	0.14	5
	Bw1g	6.50	4.90	-1.60	0.48	0.83	0.09	5
	Bw2g	6.77	5.27	-1.50	0.24	0.41	0.05	4
	Bw3g	6.95	5.55	-1.40	0.06	0.10	0.02	3
	C1g	7.26	5.45	-1.81	0.06	0.10	0.02	3
	Mean	**6.76**	**5.23**	**-1.54**	**0.54**	**0.93**	**0.08**	**7**
Jaonia	Apg	6.00	4.76	-1.24	1.50	2.58	0.17	9
	Bw1g	6.80	5.24	-1.56	1.08	1.86	0.13	8
	Bw2g	7.19	5.46	-1.73	0.78	1.34	0.07	11
	Bw3g	7.22	5.50	-1.72	0.54	0.93	0.04	13
	Bw4g	7.23	5.55	-1.68	0.24	0.41	0.03	9
	Cg	7.36	5.67	-1.69	0.24	0.41	0.01	16
	Mean	**6.97**	**5.36**	**-1.60**	**0.73**	**1.26**	**0.08**	**9**
Taras (2)	Ap1g	6.40	5.05	-1.35	1.62	2.79	0.16	10
	Ap2g	6.82	5.30	-1.52	1.14	1.96	0.11	11
	Bw1g	7.07	5.50	-1.57	0.54	0.93	0.08	6
	Bw2g	7.24	5.70	-1.54	0.54	0.93	0.07	7
	Bw3g	7.25	5.70	-1.55	0.24	0.41	0.03	8
	C1g	7.42	5.65	-1.77	0.18	0.31	0.02	9
	Mean	**7.03**	**5.48**	**-1.55**	**0.71**	**1.22**	**0.08**	**9**

*OC = Organic carbon, *OM = Organic matter, *Total N = Total nitrogen, *ΔpH = ($pH_{KCl} - pH_{water}$)

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Table 9. Chemical properties of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	pH		ΔpH*	OC* (%)	OM* (%)	Total N* (%)	C/N ratio
		H_2O	N KCl					
Hasnabad	Ap1g	5.60	3.8	-1.80	0.90	1.55	0.11	8
	Ap2g	5.68	4.01	-1.67	0.78	1.34	0.14	5
	Bw1	6.11	4.35	-1.76	0.42	0.72	0.05	8
	Bw2	6.51	4.73	-1.78	0.42	0.72	0.05	9
	Bw3	6.50	5.06	-1.44	0.30	0.52	0.03	10
	Bw4	6.70	5.36	-1.34	0.30	0.52	0.03	10
	C1	7.09	5.4	-1.69	0.30	0.52	0.03	10
	Mean	**6.31**	**4.66**	**-1.65**	**0.49**	**0.84**	**0.06**	**8**
Laskara	Ap1g	5.85	4.50	-1.35	1.44	2.48	0.17	8
	Ap2g	6.28	4.63	-1.65	0.96	1.65	0.16	6
	Bw1g	6.70	4.95	-1.75	0.78	1.34	0.10	8
	Bw2	6.90	5.10	-1.80	0.54	0.93	0.06	9
	Bw3g	6.90	5.09	-1.81	0.54	0.93	0.07	8
	Bw4g	6.92	5.09	-1.83	0.54	0.93	0.07	8
	C1g	6.95	5.15	-1.80	0.54	0.93	0.08	7
	Mean	**6.64**	**4.93**	**-1.71**	**0.76**	**1.31**	**0.10**	**8**
Manda	Apg	6.30	4.60	-1.70	0.60	1.03	0.08	8
	AC	6.45	4.85	-1.60	0.30	0.52	0.04	7
	C1	6.76	5.15	-1.61	0.12	0.21	0.01	12
	C2	6.76	5.28	-1.48	0.06	0.10	0.01	6
	C3	7.10	5.40	-1.70	0.06	0.10	0.01	6
	Mean	**6.67**	**5.06**	**-1.62**	**0.23**	**0.39**	**0.03**	**8**
Mainam	Ap1g	6.40	4.95	-1.45	0.78	1.34	0.09	9
	Ap2g	6.84	5.15	-1.69	0.30	0.52	0.05	6
	AC	6.90	5.26	-1.64	0.12	0.21	0.01	12
	C1	6.95	5.30	-1.65	0.06	0.10	0.01	6
	C2	7.20	5.45	-1.75	0.06	0.10	0.01	6
	C3	7.30	5.60	-1.70	0.06	0.10	0.01	6
	Mean	**6.93**	**5.29**	**-1.65**	**0.23**	**0.40**	**0.03**	**8**
	Grand Mean	**6.66**	**5.04**	**-1.62**	**0.56**	**0.96**	**0.07**	**8**

The vertical distribution of pH (H_2O) in the studied soils showed an increasing trend with depth (Figs 37 & 38). It is low near the surface and gradually increases with depth. This increase of pH with depth is a common feature in many of the seasonally flooded soils of Bangladesh and elsewhere (Mujib *et al*, 1969; Brammer, 1971; Hussain *et al.*, 1982; Chakraborty *et al.*, 1984; Ponnamperuma, 1985; Walia and Chamuah, 1992; Matin, 1972; Khan, 1995; Mohiuddin *et al.*, 1997; Islam, *et al.*, 2008a; Uddin *et al.*, 2009b; Mazumder *et al.*, 2010; Hossain *et al.*, 2011; Akter *et al.*, 2011; Khan *et al.*, 2012; Islam *et al.*, 2014a&b). This increase has been attributed to the alternate oxidation and reduction conditions in the seasonally flooded, poorly drained soils (Ponnamperuma, 1985). With the receding of the ground water table, 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 have only restricted movement where the internal drainage is poor. As a result, the pH in the subsoils tends to remain at a higher level as compared to that in the surface soils. The variations observed in soil pH were related to variations in exchangeable calcium, magnesioum, iron, aluminium, free iron oxide and organic matter of the soils (Islam 1971).

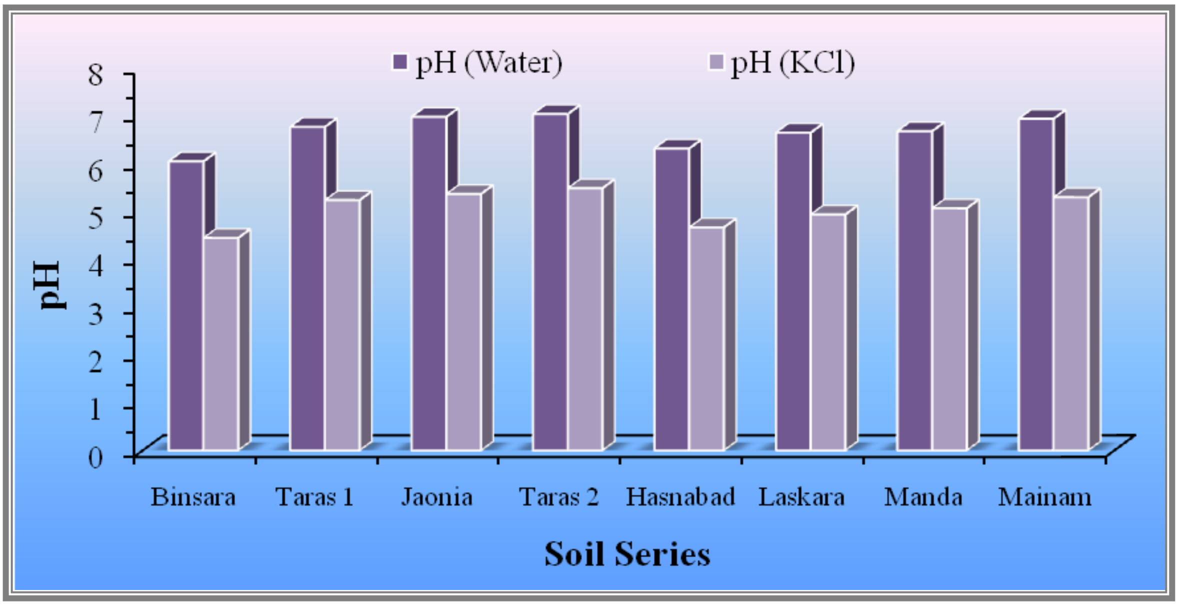

Fig 36. Graph shows the mean value of pH (H_2O) and pH (KCl) of the studied soil series.

When 1N KCl solution was used in place of water for determination of pH in the soils, there was a decrease in pH value in all the soils (Figs 37 & 38). This decrease in pH value has been designated as ΔpH. The ΔpH values of all the soils under the present study are negative. This indicates that the lower Atrai basin soils of Bangladesh contain clay minerals having negative charge some of which are occupied by ex-H^+ ion. The ΔpH value in the present soils ranges from -1.05 to -1.83 with a mean of -1.62 pH unit (Table 9). This indicates that the soils contain very high quantity of reserve acidity.

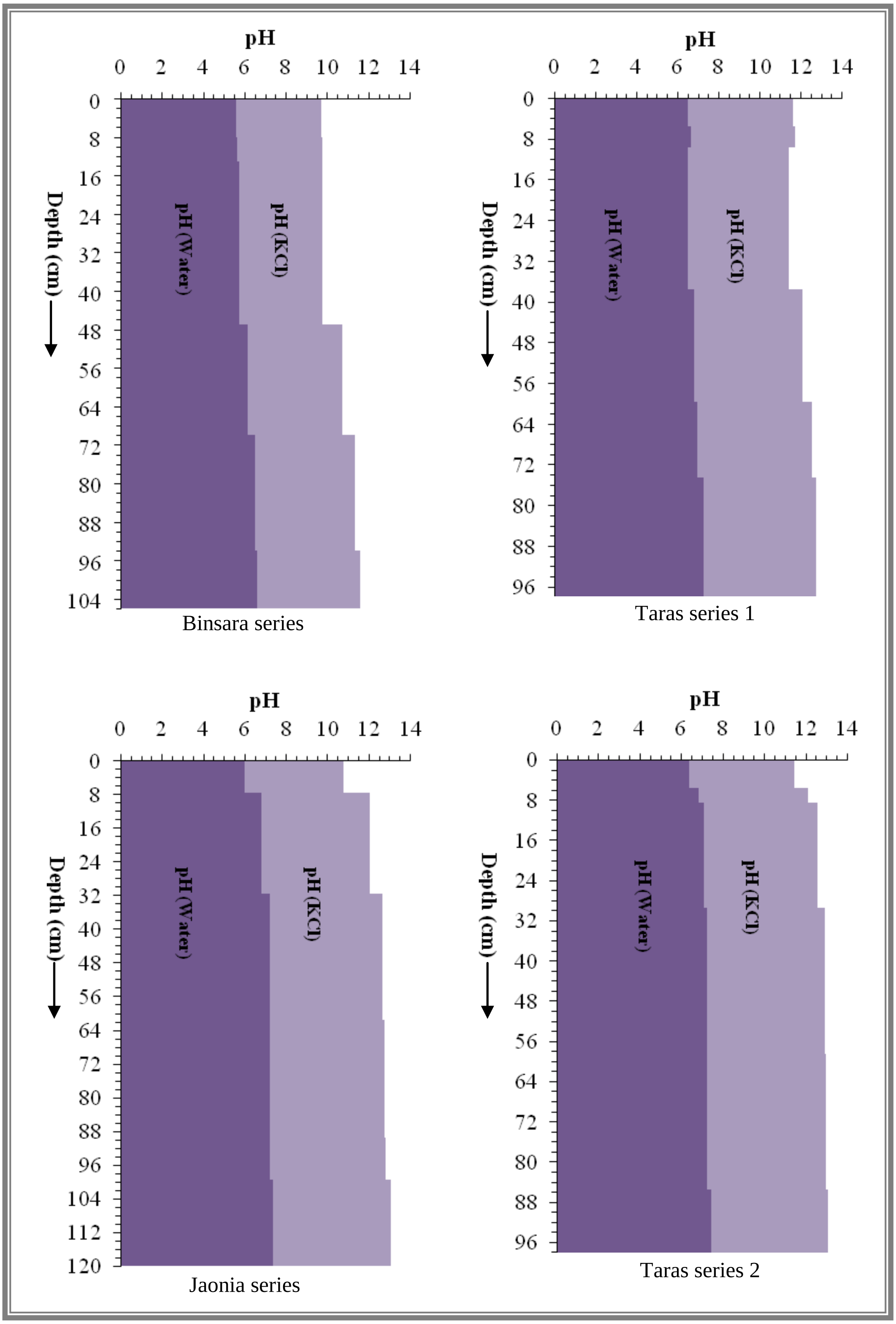

Fig 37. Vertical distribution of pH (H_2O) and pH (KCl) of Binsara, Taras 1, Jaonia and Taras 2 series.

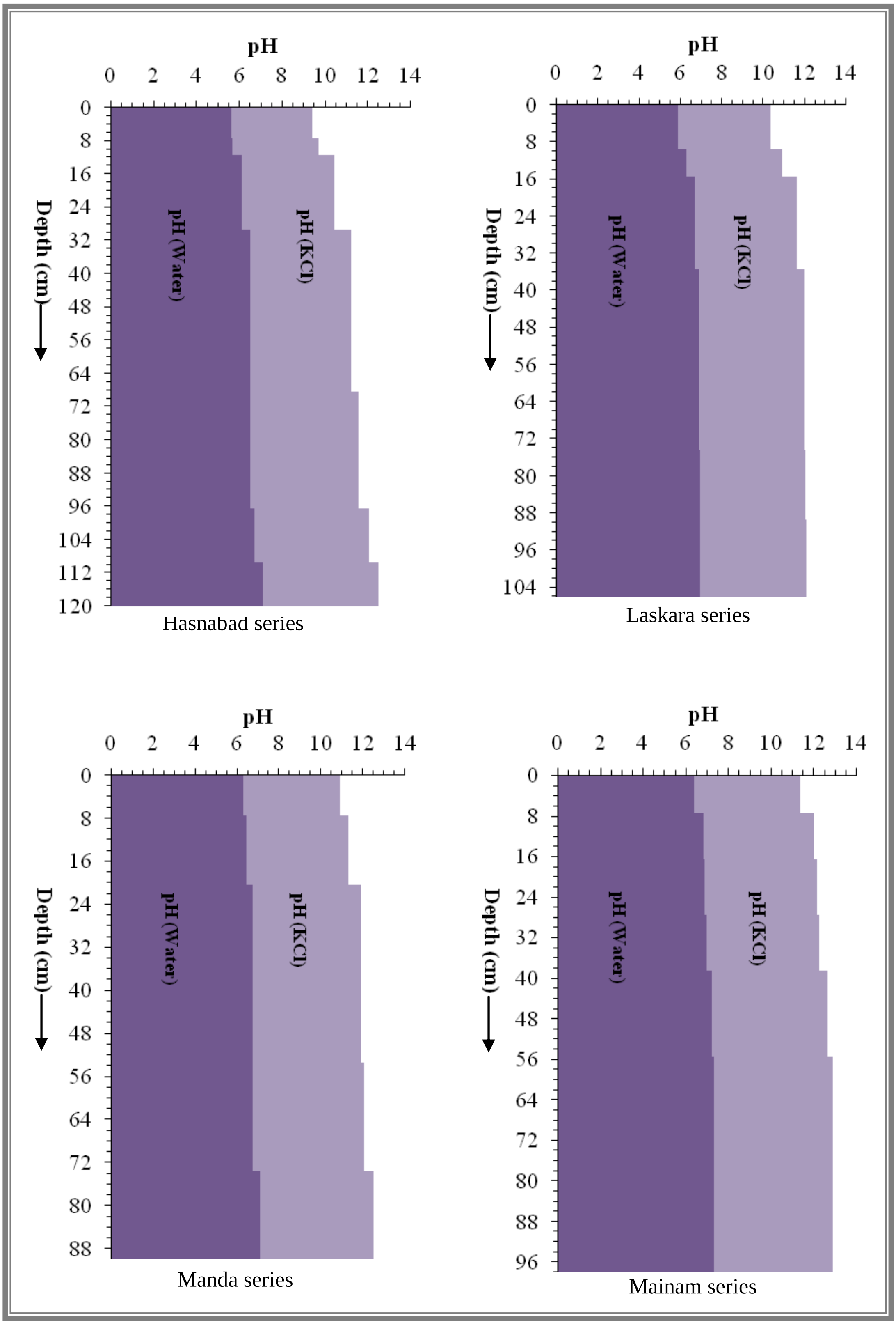

Fig 38. Vertical distribution of pH (H_2O) and pH (KCl) of Hasnabad, Laskara, Manda and Mainam series.

The highest mean ΔpH value within the profiles is found in Laskara soils and the lowest in the Taras 1 soils. The distribution patterns of ΔpH values within the soil profiles are more or less regular. The ΔpH value is lower in the surface soils than in the subsoils. A slight rise in ΔpH values with increasing depth is observed in all the studied soils (Table 9).

One of the main objectives of the determination of ΔpH was to get a measure of exchangeable H^+ ion on the surfaces of the clay. A portion of the exchange sites on the surface of clay is occupied by exchangeable H^+. Under this circumstances when 1N KCI is added to the soil, there would be a decrease of pH value as the K^+ ion will replace exchange H^+ ion from the clay surface. The displaced H^+ ion after coming in the solution phase will depress the pH of the soil-water suspension. Nye *et al.* (1961) in their study of ion exchange reactions reported that high content of Al^{3+} from the octahedral layer of 2:1 type expanding lattice clays was replaced by K^+ ion in the exchange sites of clays. This Al^{3+} undergoes a reaction with water molecules as follows:

$$Al^{3+} + 3H_2O = 3\ Al\ (OH)_3 + 3\ H^+$$

This H^+ ion thus produced will help in depressing the pH values of the external soil solution further. When ΔpH values are plotted against pH (H_2O) a significant negative correlation (r = -0.587**) is observed (Fig 39). A highly significant positive correlation (r = +0.962**) was found between pH (H_2O) and pH (KCI) (Fig 40).

5.3.2 Organic matter

Organic matter is the life of soil as it is regarded as the store house of plant nutrients. It is responsible for influencing the physical, chemical and physico-chemical properties of soils. Role of organic matter in improvement of soil structure, water and nutrient holding capacities in light soils, release of available nutrients from native sources, control of soil erosion and supply of food and energy for beneficial soil microbes are well established facts (Islam, 1993). Organic matter is a key diagnostic criteria of these soils in which organic matter accumulation in the soil is a dominant pedogenic processes (Buol *et al.* 1980).

The organic matter content reflects the effect of vegetation in soil genesis. The organic matter content of the lower Atrai basin soils ranges from 0.10 to 2.99 with a mean value of 0.96 percent (Table 9). The Laskara soil series contains high amount of organic matter throughout the profile. The highest mean value of organic matter occurs in the soils of Laskara series whereas the lowest mean is found in Manda series (Fig 41). From the results it may be concluded that the soils of the lower Atrai basin contains medium to low organic matter. Generally, low content of organic matter is a problem of Bangladesh soils, which is presumably caused by rapid decomposition of organic residues owing to the prevalence of high temperature and rainfall, coupled with higher cropping intensity (Huq, 1990; Uddin *et al.,* 2009b; Mazumder *et al.,* 2010; Hossain *et al.*, 2011; khan *et al.*, 2012;

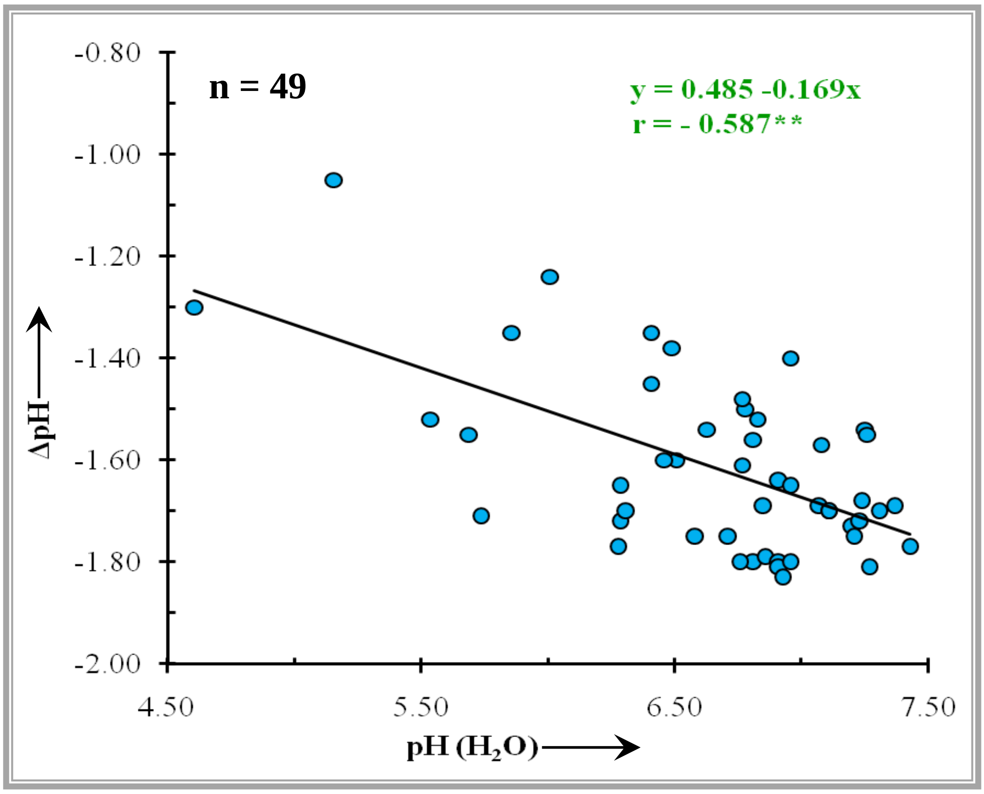

Fig 39. Relationship between pH (H_2O) and ΔpH of the studied soils.

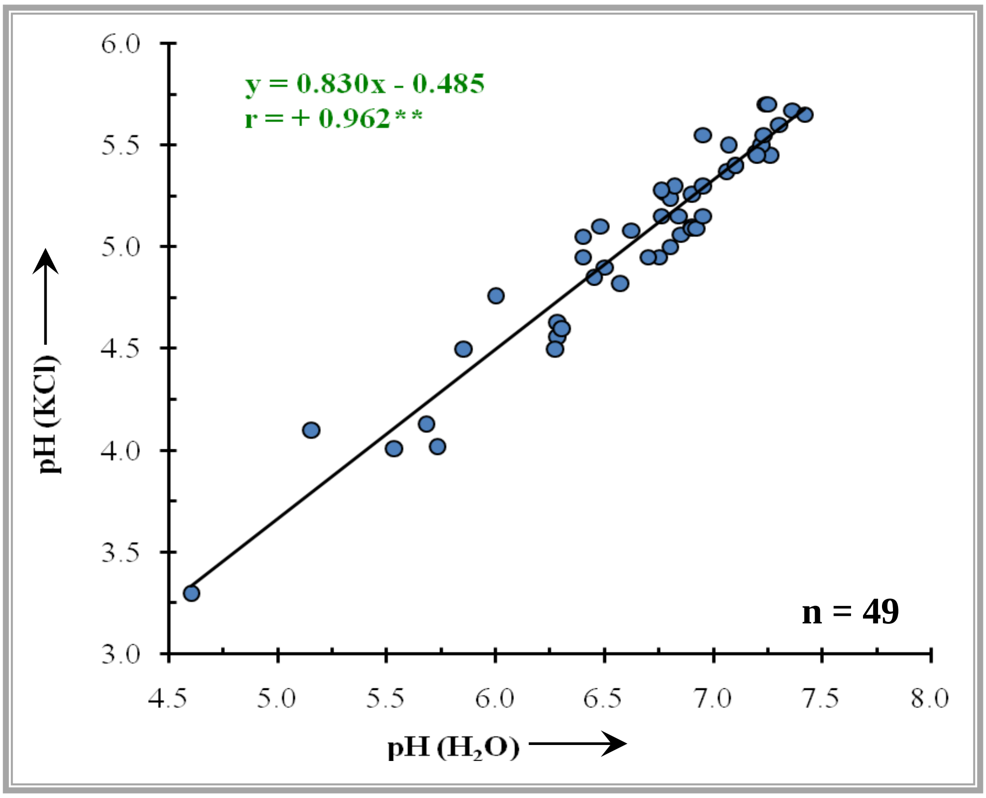

Fig 40. Ralationship between pH (H_2O) and pH (KCl) of the soils under investigation.

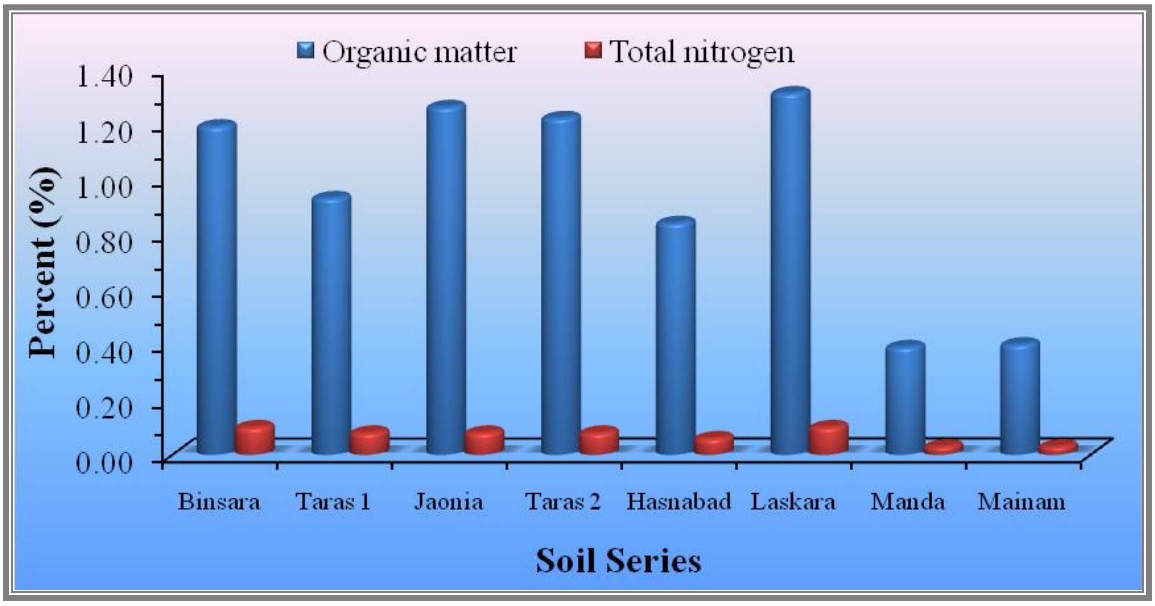

Fig 41. Graph shows the mean value of the percent organic matter and total nitrogen of the soils under investigation.

Islam *et al.*, 2014b). The organic matter contents in the studied soils show the following gradation in the decreasing order:

Laskara > Jaonia > Taras 2 > Binsara > Taras 1 > Hasnabad > Mainam > Manda

The organic matter content in the present soils showed a general tendency of decrease with depth in all the pedons and the decrease is more or less gradual (Figs 42 & 43), which is a sign of their maturity.

All the soil profiles contained higher amount of organic matter in the surface than in the subsoil (Figs 42 & 43). This high amount of organic matter at the surface may be attributed to maximum root activity of growing crops as well as natural and artificial additions of fresh and partly decomposed organic materials in the form of farm yard manures and crop residues (Hussain *et al.*, 1989). Quantity of organic matter in the studied soils appears to be related to length of seasonal flooding and drainage condition. Hussain and Swindale (1970) reported a relationship between organic matter content and drainage impedance in some Gray Hydromorphic soils of Hawaii. The highest content of organic matter is found in the surface soil of Taras 1 profile whereas the lowest content is found in Manda profile.

5.3.3 Total nitrogen and C/N ratio

The total nitrogen content of the lower Atrai basin soils ranges from 0.01 to 0.18 percent with a mean of 0.07 percent (Table 9). As with organic matter, the highest mean value of nitrogen content among the profiles was found in the Laskara and Binsara whereas the lowest amount was found in the Manda and Mainam soils (Fig 41). The total nitrogen contents in the studied soils show the following gradation in the decreasing order:

Laskara > Binsara > Jaonia > Taras 2 > Taras 1 > Hasnabad > Mainam > Manda

The vertical distribution pattern of total nitrogen follows closely the sequence of organic matter (Figs 42 & 43). The total nitrogen content in the present soils showed a general tendency of decrease with depth in all the pedons and the decrease is more or less gradual (Figs 42 & 43) which is a sign of their maturity (Brammer, 1971; Ferdous *et al.*, 2005; Akter *et al.*, 2011; Islam *et al.*, 2014b). Surface soils of the studied pedons contain the higher amount of nitrogen than the underlying horizons. The highest content of total nitrogen is found in the surface soil of Binsara profile whereas the lowest content is found in Manda profile.

A highly significant correlation (r = +0.919**) is found between percent organic matter and percent total nitrogen content in the studied soils (Fig 44).

The quantities of organic matter and total nitrogen are low in the lower Atrai basin soils of Bangladesh. The present results are, however, in accordance with the findings of SRDI Staff (1965-86); (Idris, 1975), who analyzed a large number of soil samples from Bangladesh.

The C/N ratio in the studied soils ranges from 5 to 12 with a mean ratio of 8 (Table 9). This indicates that the organic matter fraction is well oxidized even if these soils remain flooded for 5 to 6 months or more every year.

The highest mean C/N ratio was found in the Joinia soil whereas the lowest value was found in Taras 1 soil. The C/N ratio in the studied soils is generally higher near the surface and gradually narrowed down with depth except in the Jaonia and Hasnabad soils (Table 9). The reason for this feature in the Jaonia and Hasnabad soil profiles is not well understood. Possibly because of heavy texture and compact structure the organic matter decomposition in this profile has been slowed down in the lower horizons (Hoque *et al.*, 2009). The vertical distribution of C/N ratio in the various soil profiles are very irregular trends. The irregular distribution of C/N ratio value in the profiles is due to the different degree of decomposition at various horizons.

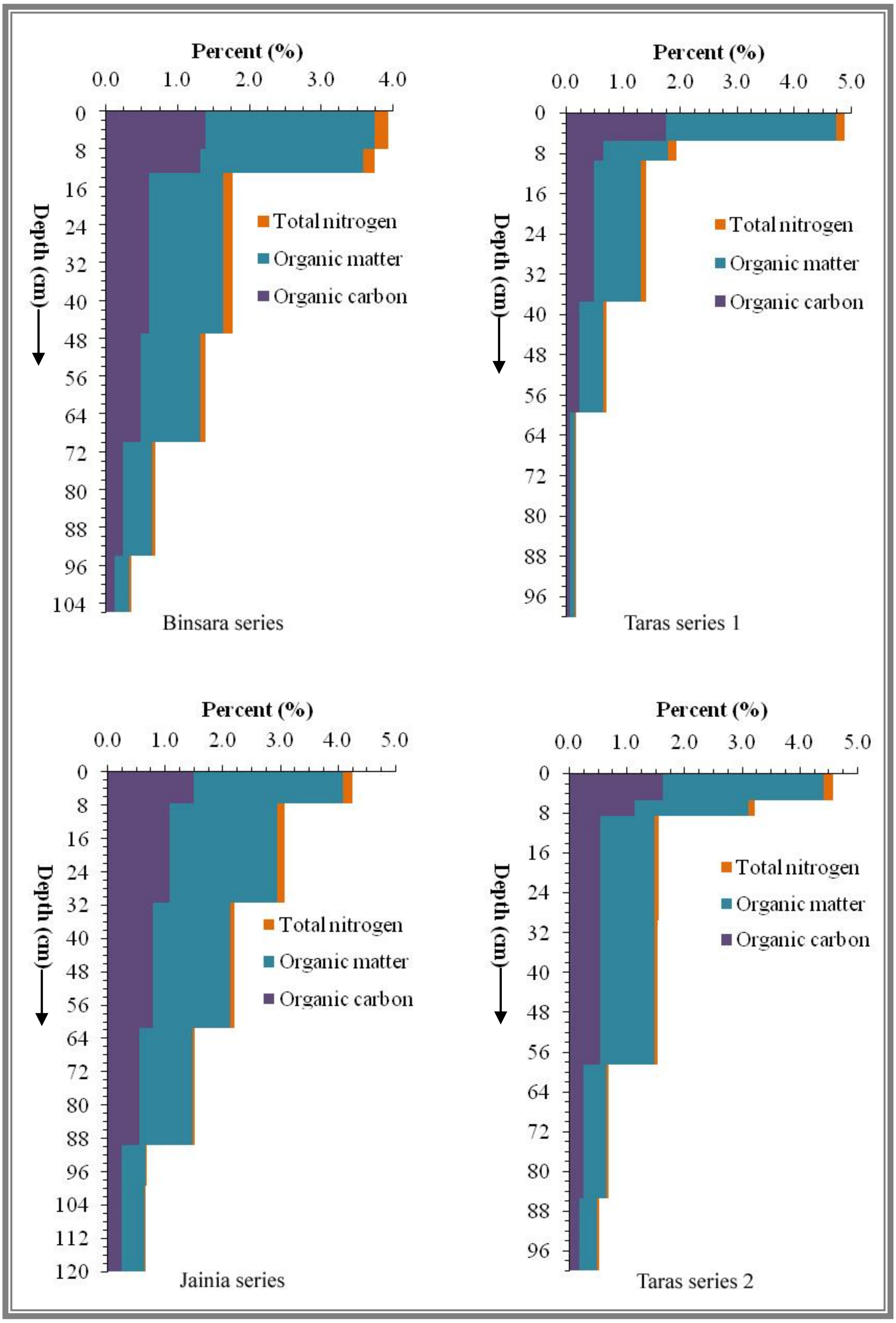

Fig 42. Vertical distribution of organic carbon, organic matter and total nitrogen of Binsara, Taras 1, Jaonia and Taras 2 series.

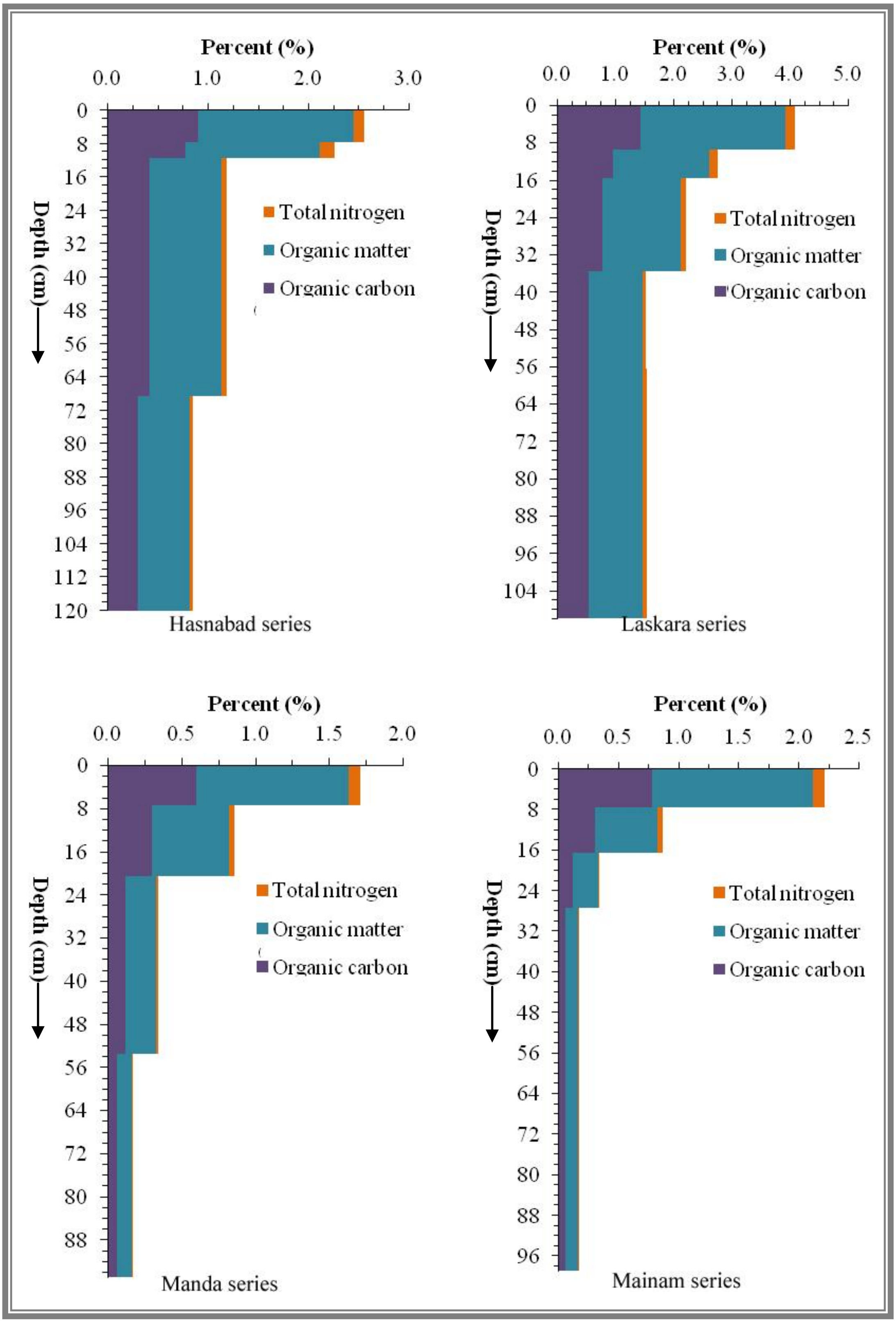

Fig 43. Vertical distribution of organic carbon, organic matter and total nitrogen of Hasnabad, Laskara, Manda and Mainam series.

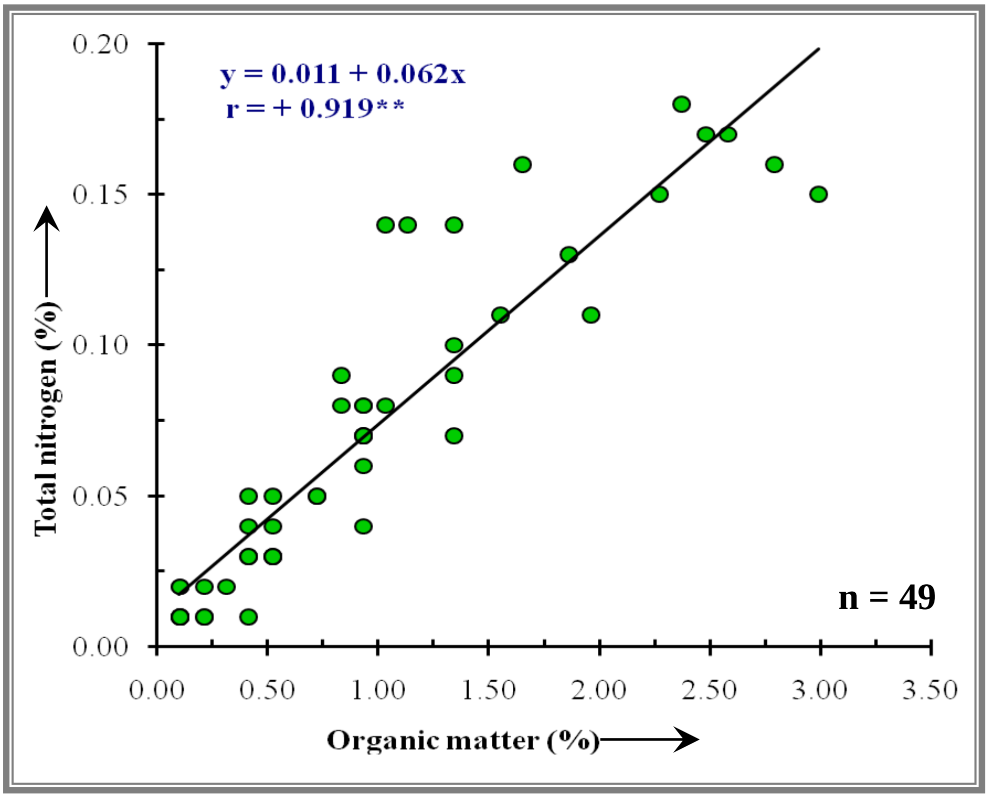

Fig 44. Ralationship between percent organic matter (OM) and total nitrogen (N) contents of the studied soils.

5.4 Physico-chemical properties

5.4.1 Cation exchange capacity (CEC)

The cation exchange capacity of the soils under the present investigation ranges from 9.89 to 23.90 cmol/kg soil with a mean value of 16.84 cmol/kg (Table 10). These results indicate that the fine textured soils contain the higher CEC than the medium textured soils due to their higher clay content. The reason for such low CEC values is due in most cases to their low clay content (Sidhu *et al.*, 1994). Increase in CEC values with increase in clay contents in soils has been reported by many authors (Gupta and Misra, 1970 and Pathak and Patal 1980).

The highest mean value of CEC among the profiles is found in the Jaonia soils and the lowest in the Manda soil (Fig 45). The cation exchange capacity of the Gangetic alluvium soils is much higher than that of the Brahmaputra alluvium (Khan, 1995).

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 cation exchange capacity with depth in the profiles show an irregular trend like those of clay and organic matter (Figs 46 & 47).

Table 10. Cation exchange capacity (CEC) and exchangeable cations of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	Exchangeable cation (cmol/kg)						Ca^{++}/Mg^{++} ratio	CEC/Clay ratio
		Na^+	K^+	Ca^{++}	Mg^{++}	*TEB	*CEC		
Binsara	Ap1g	0.87	0.38	12.75	3.41	17.41	19.50	3.74	0.56
	Ap2g	0.86	0.33	12.70	4.08	17.97	18.60	3.11	0.36
	Bw1g	0.89	0.42	13.00	4.42	18.73	20.80	2.94	0.37
	Bw2g	0.86	0.41	12.70	3.83	17.80	20.85	3.32	0.37
	Bw3g	0.92	0.49	12.60	3.58	17.59	18.20	3.52	0.33
	C1g	0.79	0.33	11.40	3.08	15.60	15.90	3.70	0.35
	Mean	**0.87**	**0.39**	**12.53**	**3.73**	**17.52**	**18.98**	**3.35**	**0.39**
Taras (1)	Ap1g	0.86	0.40	15.50	3.75	20.51	22.80	4.13	0.53
	Ap2g	0.82	0.33	13.10	3.42	17.67	19.80	3.83	0.37
	Bw1g	0.79	0.28	11.75	2.92	15.74	18.60	4.02	0.39
	Bw2g	0.79	0.31	12.40	2.83	16.33	16.60	4.38	0.33
	Bw3g	0.78	0.31	12.75	2.50	16.34	16.80	5.10	0.51
	C1g	0.82	0.42	13.75	3.00	17.99	18.12	4.58	0.31
	Mean	**0.81**	**0.34**	**13.21**	**3.07**	**17.43**	**18.79**	**4.30**	**0.41**
Jaonia	Apg	0.98	0.47	15.65	3.67	20.77	23.90	4.26	0.58
	Bw1g	0.87	0.48	14.55	4.50	20.40	21.50	3.23	0.36
	Bw2g	0.86	0.42	14.20	4.25	19.73	20.13	3.34	0.31
	Bw3g	0.90	0.47	15.65	4.50	21.52	21.72	3.48	0.34
	Bw4g	0.81	0.34	14.55	4.33	20.03	20.10	3.36	1.18
	Cg	0.79	0.32	12.75	3.42	17.28	18.05	3.73	1.20
	Mean	**0.87**	**0.42**	**14.56**	**4.11**	**19.96**	**20.90**	**3.54**	**0.66**
Taras (2)	Ap1g	0.89	0.45	14.85	3.58	19.77	22.90	4.15	0.56
	Ap2g	0.86	0.37	13.30	3.00	17.53	18.40	4.43	0.41
	Bw1g	0.84	0.29	12.40	2.83	16.36	16.48	4.38	0.37
	Bw2g	0.86	0.27	10.50	2.42	14.05	14.48	4.34	0.34
	Bw3g	0.84	0.30	12.05	3.27	16.46	16.60	3.69	0.44
	C1g	0.90	0.37	12.95	4.50	18.72	20.40	2.88	0.35
	Mean	**0.87**	**0.34**	**12.68**	**3.27**	**17.15**	**18.21**	**3.88**	**0.41**

*TEB = Total exchangeable base, *CEC = Cation exchange capacity

Continued next page

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Table 10. Cation exchange capacity (CEC) and exchangeable cations of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	Exchangeable cation (cmol/kg)						Ca^{++}/Mg^{++} ratio	CEC/Clay ratio
		Na^{+}	K^{+}	Ca^{++}	Mg^{++}	*TEB	*CEC		
Hasnabad	Ap1g	0.81	0.38	9.65	3.17	14.01	18.50	3.04	0.62
	Ap2g	0.80	0.28	11.65	2.38	15.11	15.20	4.89	0.35
	Bw1	0.84	0.27	10.10	2.83	14.04	15.40	3.57	0.38
	Bw2	0.84	0.28	14.21	4.75	20.08	22.40	2.99	0.47
	Bw3	0.79	0.22	9.30	3.46	13.77	16.80	2.69	0.48
	Bw4	0.79	0.20	9.65	3.21	13.85	13.95	3.01	0.78
	C1	0.77	0.18	11.65	4.75	17.35	17.80	2.45	0.89
	Mean	**0.81**	**0.26**	**10.89**	**3.51**	**15.46**	**17.15**	**3.10**	**0.57**
Laskara	Ap1g	0.98	0.28	9.15	3.71	14.12	19.40	2.47	0.51
	Ap2g	0.85	0.24	9.88	4.83	15.80	20.80	2.05	0.48
	Bw1g	0.82	0.23	9.15	4.08	14.28	19.20	2.24	0.58
	Bw2	0.82	0.25	8.35	3.50	12.92	18.20	2.39	0.67
	Bw3g	0.86	0.26	11.20	4.17	16.49	16.90	2.69	0.85
	Bw4g	0.87	0.30	13.43	4.20	18.80	19.40	3.20	0.35
	C1g	0.85	0.31	13.95	4.04	19.15	20.30	3.45	0.40
	Mean	**0.86**	**0.27**	**10.73**	**4.08**	**15.94**	**19.17**	**2.63**	**0.55**
Manda	Apg	0.51	0.24	6.18	2.13	9.06	10.20	2.90	0.73
	AC	0.60	0.19	5.28	2.01	8.08	9.95	2.63	0.83
	C1	0.58	0.18	7.28	2.38	10.42	11.40	3.06	1.27
	C2	0.50	0.17	6.75	2.02	9.44	11.40	3.34	1.27
	C3	0.52	0.19	5.93	2.73	9.37	11.60	2.17	1.29
	Mean	**0.54**	**0.19**	**6.28**	**2.25**	**9.27**	**10.91**	**2.79**	**1.08**
Mainam	Ap1g	0.52	0.22	5.30	2.67	8.71	10.00	1.99	0.59
	Ap2g	0.55	0.20	6.08	2.88	9.71	9.89	2.11	0.71
	AC	0.61	0.18	6.53	2.46	9.78	10.20	2.65	1.13
	C1	0.57	0.19	5.63	2.75	9.14	11.00	2.05	0.92
	C2	0.66	0.20	8.78	2.02	11.66	12.40	4.35	1.38
	C3	0.58	0.18	6.31	2.85	9.92	10.10	2.21	1.12
	Mean	**0.58**	**0.20**	**6.44**	**2.61**	**9.82**	**10.60**	**2.46**	**0.98**
Grand Mean		**0.78**	**0.30**	**10.91**	**3.33**	**15.32**	**16.84**	**3.27**	**0.63**

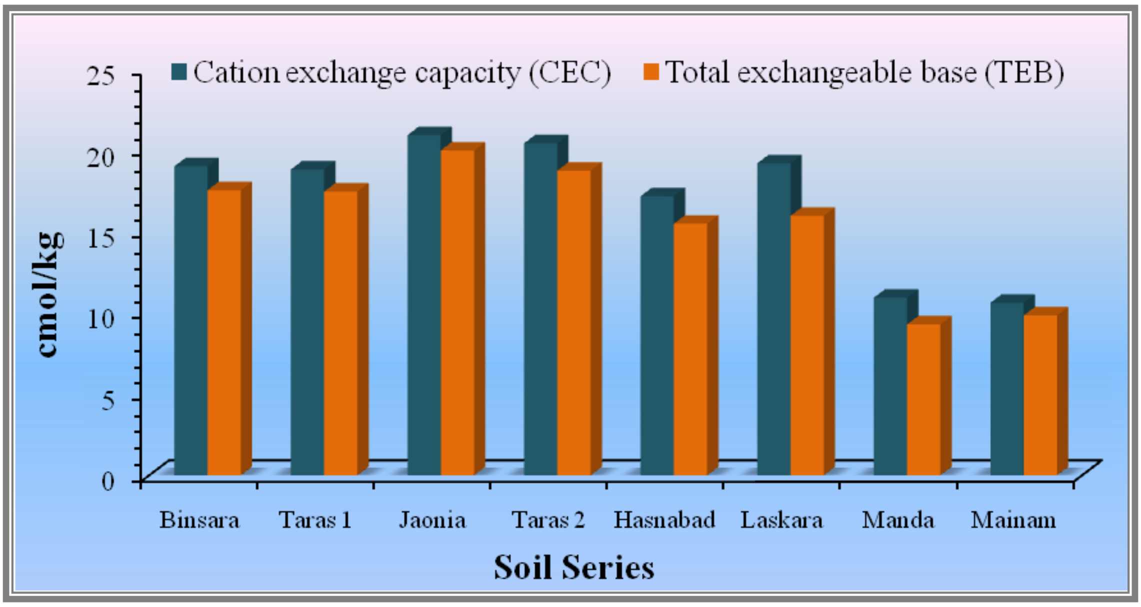

Fig 45. Graph shows the mean value of cation exchange capacity (CEC) and total exchangeable base (TEB) of the soils under investigation.

The index of weathering (IW = CEC/Clay ratio) of these soils is found to vary from 0.31 to 1.38 with a mean index of 0.63 (Table 10). Such a wide range in the above ratio indicates a wide variation in the type of clay minerals present in the clay fraction of these soils.

A highly significant positive correlation (r = +0.747**) is found between CEC and percent clay (Fig 48) and also found a significant positive correlation (r = +0.565**) between CEC and percent organic matter in the present studied soils (Fig 49). However, the degree of correlation coefficient between CEC and clay was 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 noted that the CEC was significantly correlated with clay and organic matter, but clay was the biggest contributor in mineral soils. This is understandable as the quantity of organic matter in the studied soils is low (average organic matter content is 0.96%, while the average clay content in the soils was 36%).

The soils under the present study have relatively lower CEC as compared to the CEC of soils developed under similar climatic condition in the tropics (Dudal and Bramao, 1965). The CEC of mineral soils may range, in accordance with the clay content, from a few to 50 to 60 me per 100g, whereas the CEC of organic soils may exceed 200 coml/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/kg, respectively. This indicates that the silt fraction of Bangladesh soils have cation exchange capacity. This is possibly due to occurrence of considerable quantity of mica which is in different stages of weathering (Jackson, 1965).

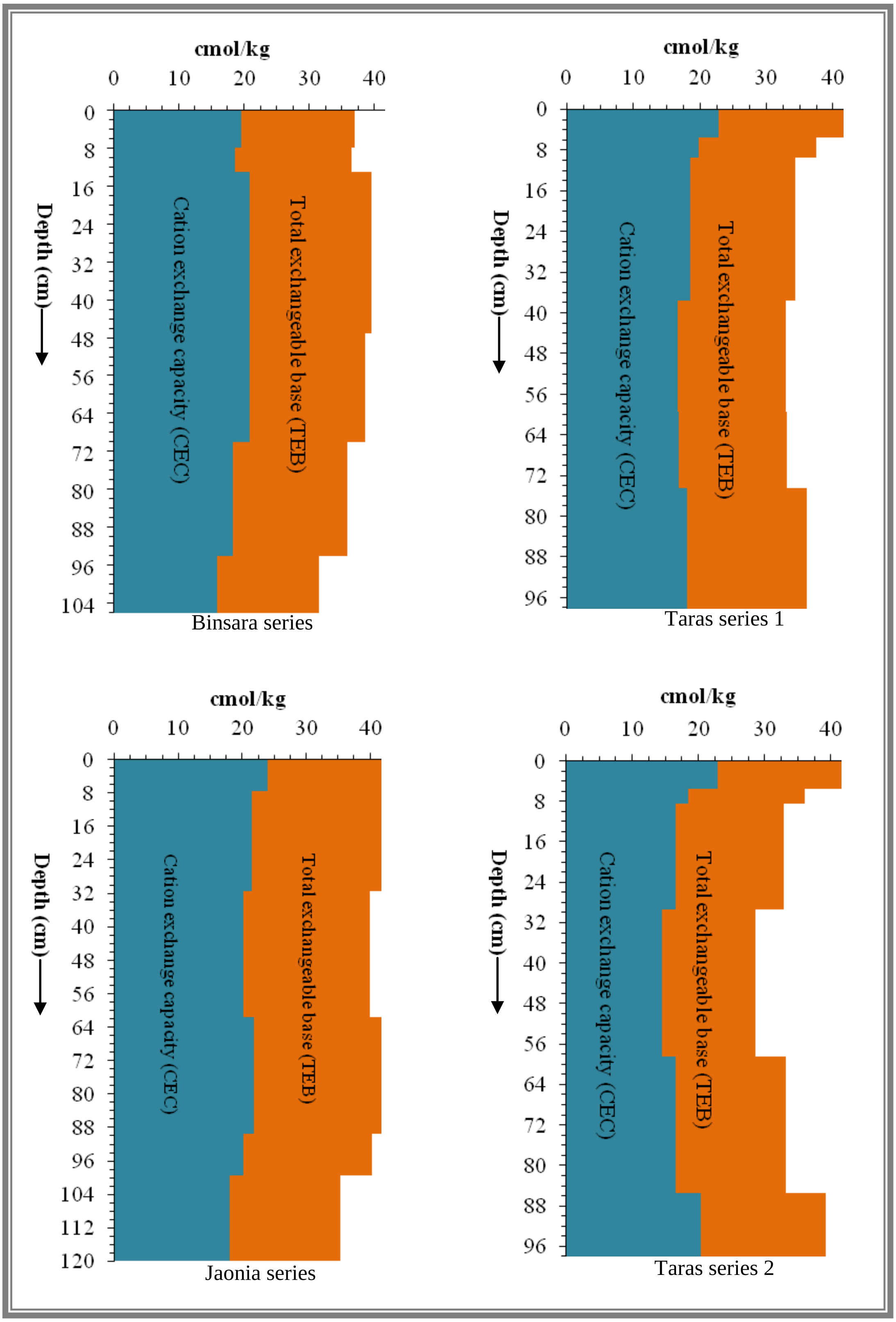

Fig 46. Vertical distribution of cation exchange capacity (CEC) and total exchangeable base (TEB) of Binsara, Taras 1, Jaonia and Taras 2 series.

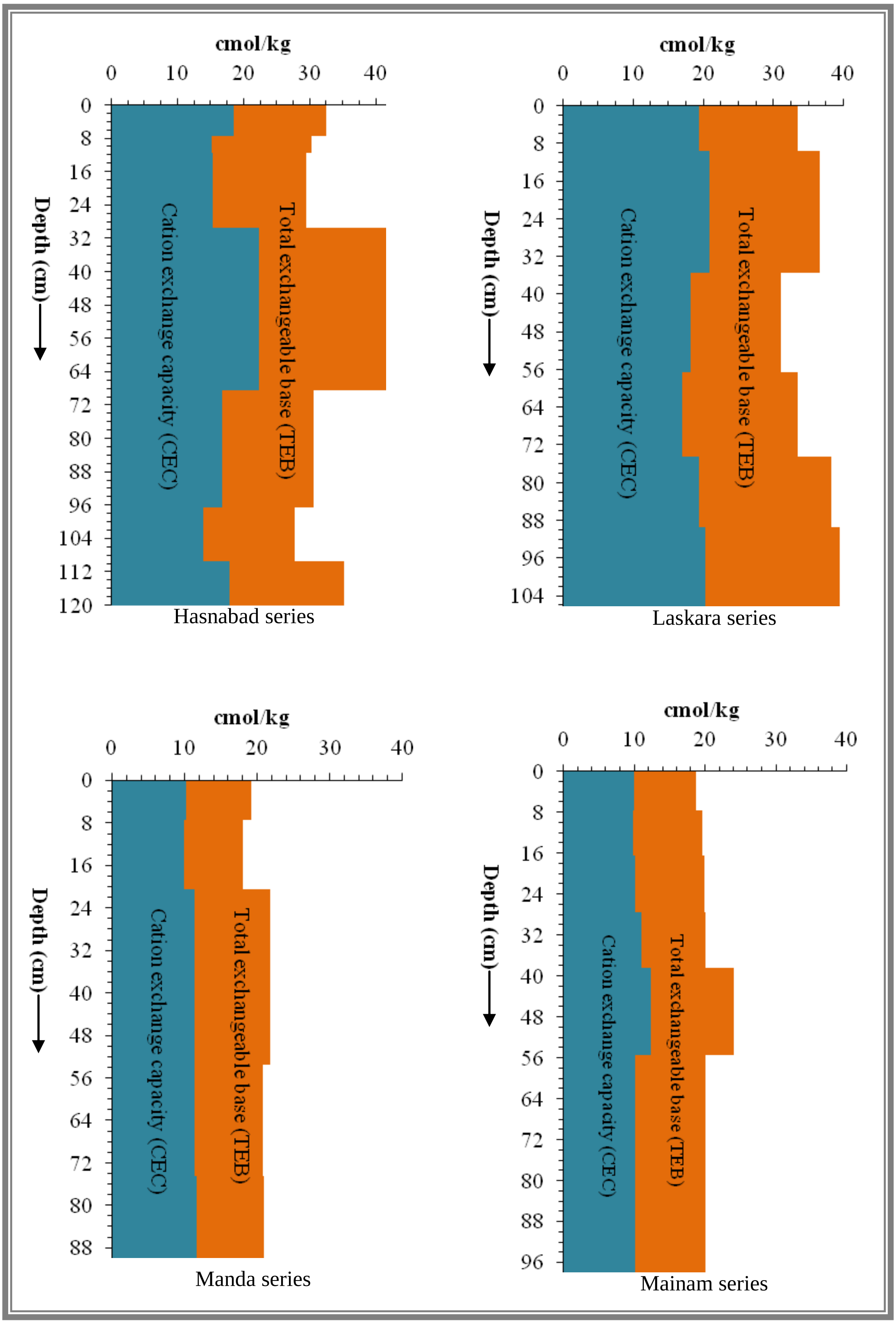

Fig 47. Vertical distribution of cation exchange capacity (CEC) and total exchangeable base (TEB) of Hasnabad, Laskara, Manda and Mainam series.

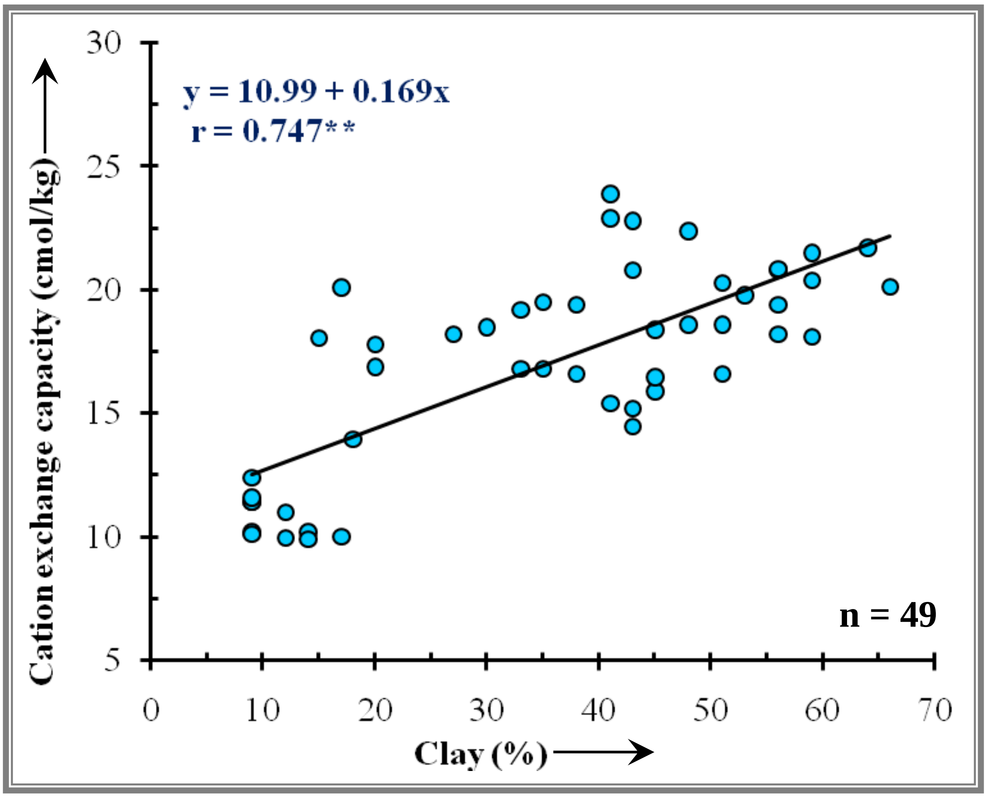

Fig 48. Ralationship between cation exchange capacity (CEC) and clay contents of the studied soils.

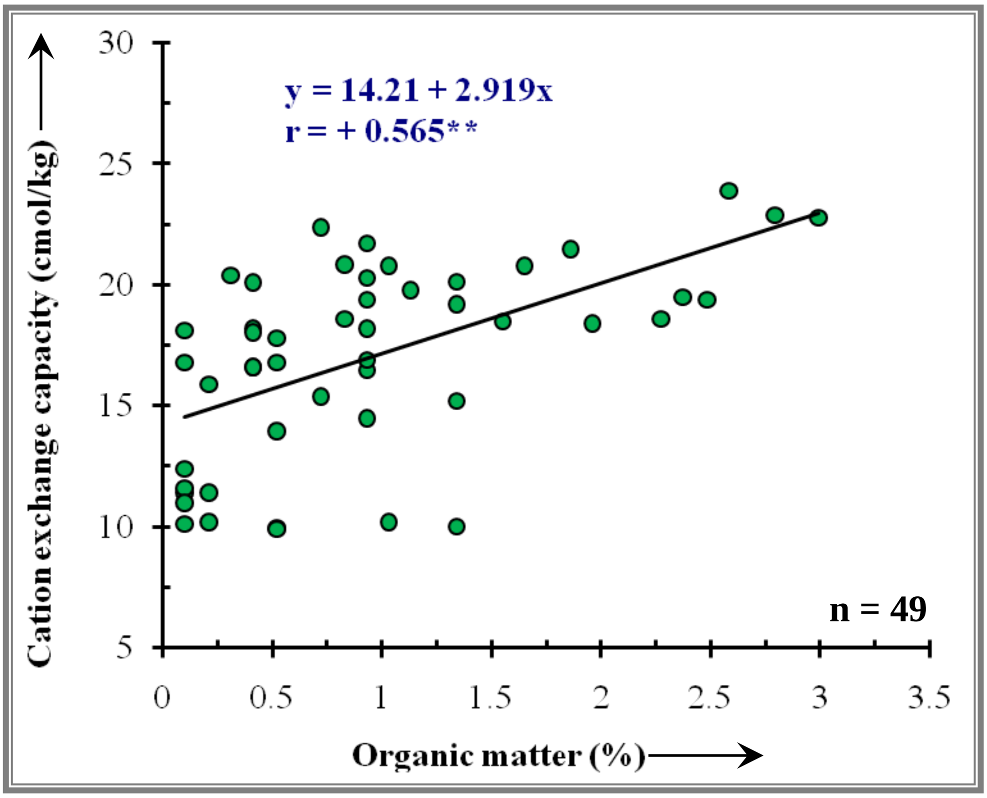

Fig 49. Ralationship between cation exchange capacity (CEC) and organic matter (OM) contents of soils under investigation.

5.4.2 Exchangeable bases

Results of exchangeable bases such as Ca^{++}, Mg^{++}, K^{+} and Na^{+} are presented in Table 10 and percent composition of exchangeable bases are presented in Table 11. The amount of exchangeable Ca^{++} ranges from 5.28 to 15.65 cmol/kg with a mean of 10.91 cmol/kg soil (Table 10). Exchangeable Ca^{++} is the most dominant metal ion in all the soils. It occupies more than 60 percent of the total exchange positions in all the soils (Table 11). The highest exchangeable calcium is found in the soils of the Jaonia series while the lowest value is found in Mainam series (Fig 50). The predominance of Ca^{++} was reported by George *et al*, (1958) in some humic gley soils of Ohio. Similar results have been reported by SRDI Staff (1965-86) in many floodplain soils in Bangladesh.

The vertical distribution of exchangeable Ca^{++} in the profiles showed an irregular trend (Figs 51 & 52). It is observed that Taras 1, Jaonia and Taras 2 profiles contained higher amount of Ca^{++} in their surface due to their seasonal submergence and Binsara, Hasnabad, Laskara, Manda and Mainam profiles contain lower amount of Ca^{++} in their surface due to leaching of Ca^{++} downwards. Consequently, higher values of Ca^{++} content are found in the subsoils due to their leaching from the surface horizons and subsequent accumulation in the lower horizons.

On the quantitative basis, exchangeable Mg^{++} comes after exchangeable Ca^{++}. The exchangeable Mg^{++} in the soils varies from 2.01 to 4.83 cmol/kg with a mean of 3.33 cmol/kg soil (Table 10). The highest mean exchangeable Mg^{++} value among the studied profiles is found in the Jaonia soil and the lowest in the Manda soils (Fig 50). The vertical distribution of exchangeable Mg^{++} shows an irregular pattern with depth (Figs 51 & 52). Exchangeable Mg^{++} increased with increase in depth in Taras 2, Hasnabad and Laskara soils while it was more or less uniform in Binsara, Taras 1, Jaonia, Manda and Mainam series. The soils of the Mainam series contained the highest amount of exchangeable Mg^{++} which was 27 percent of the total exchange positions (Table 11).

The exchangeable Ca^{++}/Mg^{++} ratio of the studied soils varies from 1.99 to 5.10 and the mean ratio was 3.27 (Table 10). Similar results were also reported by many other authors (SRDI Staff, 1965-86). The highest mean Ca^{++}/Mg^{++} ratio among the profiles is found in the Taras 1 soils and the lowest in the Mainam soils. Hussain and Chowdhury (1981) reported an exchangeable Ca^{++}/Mg^{++} ratio of around 2 in some poorly drained floodplain soils from Bangladesh. Buol *et al*. (1980) noted that the Ca^{++}/Mg^{++} ratio in soils decrease with increasing maturity of the soils. The exchangeable Ca^{++}/Mg^{++} raito of agricultural soils of California was 2.49 and of Lanna soil in Sweden was 3.06 (Bohn *et al.* 1979). It appears that the seasonally flooded soils of lower Atrai basin of Bangladesh are similar to those of the other places in respect to Ca^{++}/Mg^{++} ratio.

Table 11. Percent composition of exchangeable bases and base saturation percent (BSP) of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	% Composition				BSP*
		Na^+	K^+	Ca^{++}	Mg^{++}	
Binsara	Ap1g	5.0	2.2	73.2	19.6	89
	Ap2g	4.8	1.8	70.7	22.7	97
	Bw1g	4.8	2.2	69.4	23.6	90
	Bw2g	4.8	2.3	71.4	21.5	85
	Bw3g	5.2	2.8	71.6	20.4	97
	C1g	5.1	2.1	73.1	19.7	98
	Mean	**4.9**	**2.2**	**71.6**	**21.3**	**93**
Taras (1)	Ap1g	4.2	2.0	75.6	18.3	90
	Ap2g	4.6	1.9	74.1	19.4	89
	Bw1g	5.0	1.8	74.7	18.6	85
	Bw2g	4.8	1.9	75.9	17.3	98
	Bw3g	4.8	1.9	78.0	15.3	97
	C1g	4.6	2.3	76.4	16.7	99
	Mean	**4.7**	**2.0**	**75.8**	**17.6**	**93**
Jaonia	Apg	4.7	2.3	75.4	17.7	87
	Bw1g	4.3	2.4	71.3	22.1	95
	Bw2g	4.4	2.1	72.0	21.5	98
	Bw3g	4.2	2.2	72.7	20.9	99
	Bw4g	4.0	1.7	72.6	21.6	99
	Cg	4.6	1.9	73.8	19.8	96
	Mean	**4.4**	**2.1**	**73.0**	**20.6**	**96**
Taras (2)	Ap1g	4.5	2.3	75.1	18.1	86
	Ap2g	4.9	2.1	75.9	17.1	95
	Bw1g	5.1	1.8	75.8	17.3	99
	Bw2g	6.1	1.9	74.7	17.2	97
	Bw3g	5.1	1.8	73.2	19.9	99
	C1g	4.8	2.0	69.2	24.0	92
	Mean	**5.1**	**2.0**	**74.0**	**18.9**	**95**

*Base Saturation Percentage

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Table 11. Percent composition of exchangeable bases and base saturation percent (BSP) of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	% Composition				BSP*
		Na^+	K^+	Ca^{++}	Mg^{++}	
Hasnabad	Ap1g	5.8	2.7	68.9	22.6	76
	Ap2g	5.3	1.9	77.1	15.8	99
	Bw1	6.0	1.9	71.9	20.2	91
	Bw2	4.2	1.4	70.8	23.7	90
	Bw3	5.7	1.6	67.5	25.1	82
	Bw4	5.7	1.4	69.7	23.2	99
	C1	4.4	1.0	67.2	27.4	97
	Mean	**5.3**	**1.7**	**70.4**	**22.6**	**91**
Laskara	Ap1g	6.9	2.0	64.8	26.3	73
	Ap2g	5.4	1.5	62.5	30.6	76
	Bw1g	5.7	1.6	64.1	28.6	74
	Bw2	6.4	1.9	64.6	27.1	71
	Bw3g	5.2	1.6	67.9	25.3	98
	Bw4g	4.6	1.6	71.4	22.3	97
	C1g	4.4	1.6	72.9	21.1	94
	Mean	**5.5**	**1.7**	**66.9**	**25.9**	**83**
Manda	Apg	5.6	2.6	68.2	23.5	89
	AC	7.4	2.4	65.3	24.9	81
	C1	5.6	1.7	69.9	22.8	91
	C2	5.3	1.8	71.5	21.4	83
	C3	5.5	2.0	63.3	29.1	81
	Mean	**5.9**	**2.1**	**67.6**	**24.3**	**85**
Mainam	Ap1g	6.0	2.5	60.8	30.7	87
	Ap2g	5.7	2.1	62.6	29.7	98
	AC	6.2	1.8	66.8	25.2	96
	C1	6.2	2.1	61.6	30.1	83
	C2	5.7	1.7	75.3	17.3	94
	C3	5.8	1.8	63.6	28.7	98
	Mean	**5.9**	**2.0**	**65.1**	**27.0**	**93**
Grand Mean		**5.2**	**2.0**	**70.5**	**22.3**	**91**

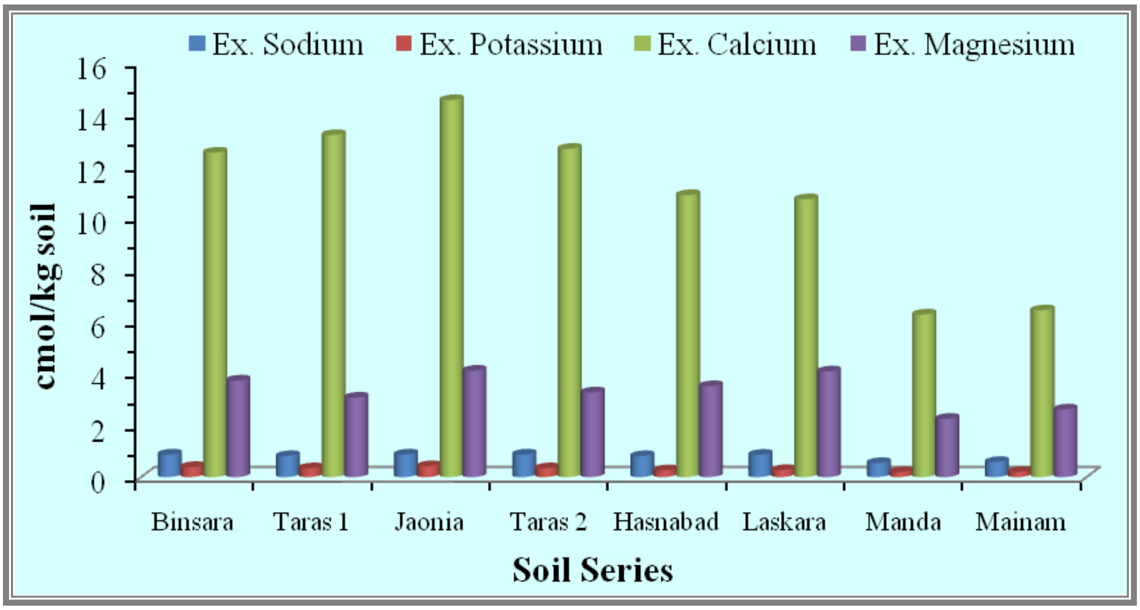


Fig 50. Graph shows mean value of the exchangeable Na^{+}, K^{+}, $Ca^{++}$and Mg^{++} of the studied soils.

The vertical distribution pattern of exchangeable Ca^{++}/Mg^{++} ratio in the profiles showed an irregular decrease with depth in all the studied pedons except the Taras 1 soil (Table 10).

The exchangeable K^{+} in the studied soils ranges from 0.17 to 0.49 cmol/kg with a mean value of 0.30 cmol/kg soil (Table 10). Similar results were also reported for these soils by the SRDI Staff (1965-86) and Ali (1994). The highest mean exchangeable K^{+} among the profiles was found in the Jaonia soils and the lowest in the Manda soils (Fig 50).

The 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 good growth of crops. The vertical distribution of exchangeable K^{+} in the profiles shows no significant variation (Figs 51 & 52). The above results of exchangeable Ca^{++}/Mg^{++} ratio indicate that the lower Atrai basin soils in Bangladesh are immature.

The amount of exchangeable Na^{+} ion varies from 0.50 to 0.98 cmol/kg soil with a mean of 0.78 cmol/kg soil (Table 10). Similar results were also reported by SRDI Staff (1965-86) and Ali (1994) on some profiles from Brahmaputra floodplain. The highest mean exchangeable sodium within the profile was found in Binsara, Jaonia and Taras 2 soils whereas the lowest was found in the Manda soils (Fig 50). The seasonally flooded lawer Atrai basin soils in Bangladesh are so intensely washed, that exchangeable Na^{+} can never be a problem. The vertical distribution pattern of exchangeable Na^{+} in the studied profiles is more or less irregular (Figs 51 & 52). The most common exchangeable cations in soils are Ca^{++}, Mg^{++}, Na^{+}, K^{+}, H^{+} and NH_4^{+}. Ca^{++} generally is the dominant cation.

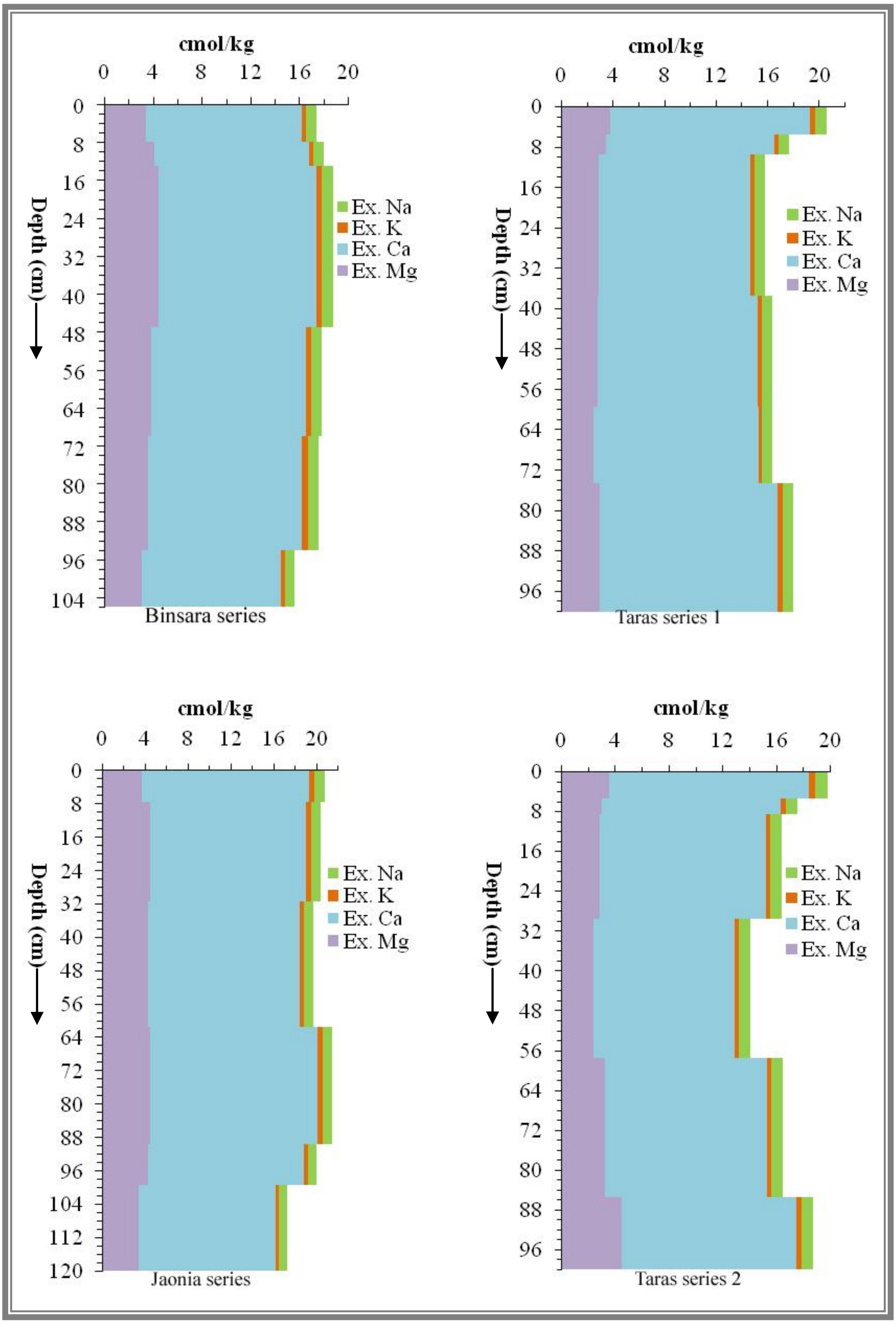


Fig 51. Vertical distribution of exchangeable Na^+, K^+, Ca^{++} and Mg^{++} of Binsara, Taras 1, Jaonia and Taras 2 series.

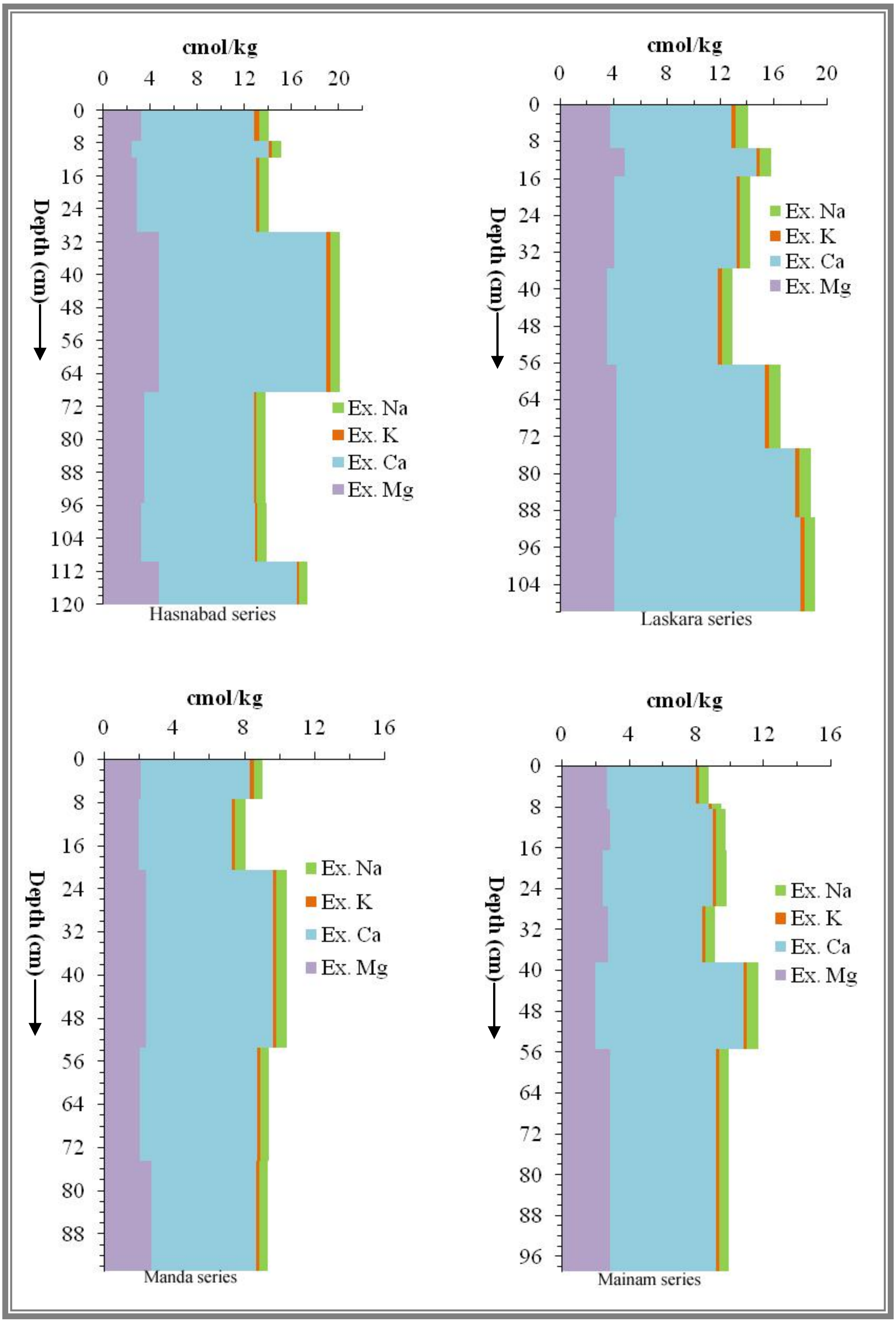


Fig 52. Vertical distribution exchangeable Na^{+}, K^{+}, Ca^{++} and Mg^{++} of Hasnabad, Laskara, Manda and Mainam series.

In an *ideal soil* the cationic composition in the exchange complex was as follows: Ca^{++} 65 percent; Mg^{++} 10 percent; K^{+} 5 percent and H^{+} 20 percent (Toth, 1965). On this basis, the soils under the present study may be considered as very close to the ideal (Table 11).

5.4.3 Total exchangeable bases (TEB)

The total exchangeable bases (Ca^{++}, Mg^{++}, K^{+}, Na^{+}) ranges from 8.08 to 21.52 cmol/kg soil with a mean of 15.32 cmol/kg soil in all the soil profiles (Table 10). The total mean exchangeable bases are the highest in Jaonia soils, and the lowest value was found in Manda soil (Fig 45). The vertical distribution pattern of TEB with depth is irregular in all the soil profiles (Figs 46 & 47).

5.4.4 Base saturation percentage (BSP)

The proportion of the cation exchange capacity occupied by exchangeable bases is called the base saturation percentage (BSP). The BSP of soils are very important for predicting the present genetic processes in soil as well as its stage of development. The BSP have also been used in soils for their classification (Soil Survey Staff, 2014). It is also frequently used as an indicator of soil nutrient status (Landon, 1991).

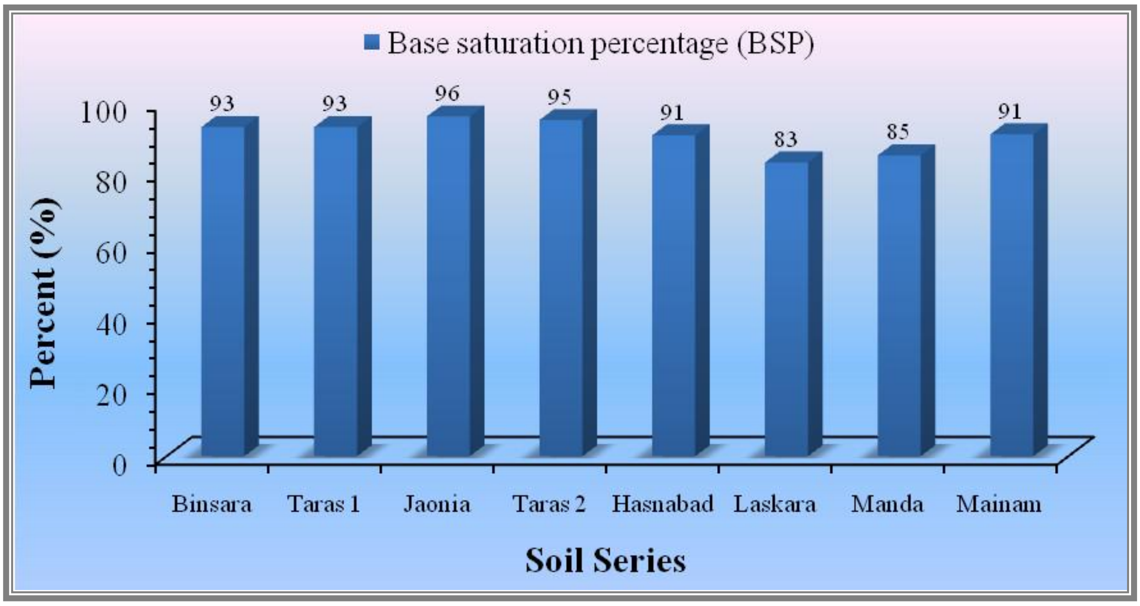


Fig 53. Graph shows mean value of the base saturation percentage (BSP) of the studied soils.

The base saturation percentage of the soils under the present study ranges from 71 to 99 with an average value of 91 (Table 11). This high base saturation may be due to rapid replenishment of bases from the weathering minerals. The highest mean value among the profiles is found in the Jaonia soil series and the lowest in the Laskara soils (Fig 53).

The vertical distribution patterns of BSP indicate that the base saturation percentage, in general, shows an increasing trend with depth except the Manda soils (Table 11). The BSP is found to be lower in the surface horizon of the soils and higher in the underlying subsoils except the Manda and Mainam soils and this is considered to be due to more intense weathering and the subsequent leaching of bases from the surface horizon. Islam *et al.* (2009), Hossen *et al.* (2011), Akter *et al.* (2011) and Hasan *et al.* (2012) were found the similar results in some floodplain soils of Bangladesh.

5.5 Free oxides in soils

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

5.5.1 Dithionate extractable free iron oxide (Fe_2O_3)

Free Fe_2O_3 contents in the present soils vary from 0.12 to 2.58 percent with an average value of 1.23 percent (Table 12). The highest mean value of free iron oxide among the studied profiles is found in Jaonia and the lowest value in the Mainam soil (Fig 54). This low free Fe_2O_3 content is due to 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 substaintial substitution of iron by aluminium in the crystals of lepidochrosite mineral.

The soils under study remain flooded for varying periods during the wet season (Table 2) and are used for cultivation of aus and transplanted aman paddy. During the wet season, some of the dissolved iron move down along with ground water from the surface soil and are deposited in the B horizon in the form of mottles. Mottles, therefore, are prominent in the middle zone of the soil profiles, where oxidation and reduction conditions alternate with season (Saheed and Hussain, 1992).

The pattern of distribution of free Fe_2O_3 with depth in the profiles is irregular (Figs 55 & 56). Similar results were also obtained by Deturck and Somasiri (1992) in the rice soils of Sri Lanka with anthraquic features and also by Fanning *et al.* (1992) in their study of micro-macromorphology of some wetland soils.

Table 12. Dithionate extractable iron and manganese oxides of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	**Horizon**	**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**
Binsara	Ap1g	1.24	0.030	4.70	41	4
	Ap2g	1.30	0.022	4.79	59	4
	Bw1g	1.03	0.013	4.46	79	4
	Bw2g	1.08	0.019	5.03	57	5
	Bw3g	1.46	0.035	5.86	42	4
	C1g	1.13	0.054	4.19	21	4
	Mean	**1.21**	**0.029**	**4.83**	**42**	**4**
Taras (1)	Ap1g	1.19	0.019	5.75	63	5
	Ap2g	1.50	0.022	6.05	68	4
	Bw1g	1.45	0.019	4.98	77	3
	Bw2g	1.93	0.027	4.65	71	2
	Bw3g	2.01	0.089	6.43	23	3
	C1g	1.42	0.057	6.74	25	5
	Mean	**1.58**	**0.039**	**5.76**	**41**	**4**
Jaonia	Apg	1.31	0.021	5.02	62	4
	Bw1g	1.79	0.022	6.08	82	3
	Bw2g	2.58	0.030	6.02	86	2
	Bw3g	2.36	0.092	6.36	26	3
	Bw4g	1.96	0.036	5.16	54	3
	Cg	1.13	0.017	4.58	66	4
	Mean	**1.85**	**0.036**	**5.53**	**52**	**3**
Taras (2)	Ap1g	1.12	0.014	4.12	80	4
	Ap2g	1.54	0.019	4.58	81	3
	Bw1g	1.46	0.024	5.00	61	3
	Bw2g	1.85	0.068	5.86	27	3
	Bw3g	2.23	0.060	6.72	37	3
	C1g	1.31	0.051	5.40	26	4
	Mean	**1.58**	**0.039**	**5.28**	**41**	**3**

Continued next page

Continue…

Table 12. Dithionate extractable iron and manganese oxides of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	Free Fe_2O_3 (%)	Free MnO_2 (%)	Total Fe_2O_3 (%)	$\frac{\text{Free } Fe_2O_3}{\text{Free } MnO_2}$ ratio	$\frac{\text{Total } Fe_2O_3}{\text{Free } Fe_2O_3}$ ratio
Hasnabad	Ap1g	0.96	0.022	4.19	44	4
	Ap2g	1.28	0.038	4.43	34	3
	Bw1	1.17	0.024	4.26	49	4
	Bw2	0.94	0.016	4.79	59	5
	Bw3	1.43	0.021	5.08	68	4
	Bw4	1.84	0.033	6.09	56	3
	C1	1.49	0.028	4.79	53	3
	Mean	**1.30**	**0.026**	**4.80**	**50**	**4**
Laskara	Ap1g	1.16	0.025	5.26	46	5
	Ap2g	1.39	0.024	4.59	58	3
	Bw1g	1.56	0.054	5.91	29	4
	Bw2	1.41	0.038	5.66	37	4
	Bw3g	1.16	0.028	4.13	41	4
	Bw4g	1.58	0.038	5.29	42	3
	C1g	1.48	0.032	5.28	46	4
	Mean	**1.39**	**0.034**	**5.16**	**41**	**4**
Manda	Apg	0.57	0.016	3.56	36	6
	AC	0.73	0.019	4.10	38	6
	C1	0.39	0.009	3.13	44	8
	C2	0.32	0.009	3.19	35	10
	C3	0.43	0.009	3.22	48	7
	Mean	**0.49**	**0.013**	**3.45**	**38**	**7**
Mainam	Ap1g	0.50	0.011	4.57	46	9
	Ap2g	0.51	0.019	4.86	27	10
	AC	0.28	0.014	3.37	20	12
	C1	0.50	0.011	5.65	46	11
	C2	0.48	0.009	5.40	53	11
	C3	0.27	0.006	3.23	46	12
	Mean	**0.42**	**0.011**	**4.52**	**39**	**11**
Grand Mean		**1.23**	**0.028**	**4.82**	**44**	**4**

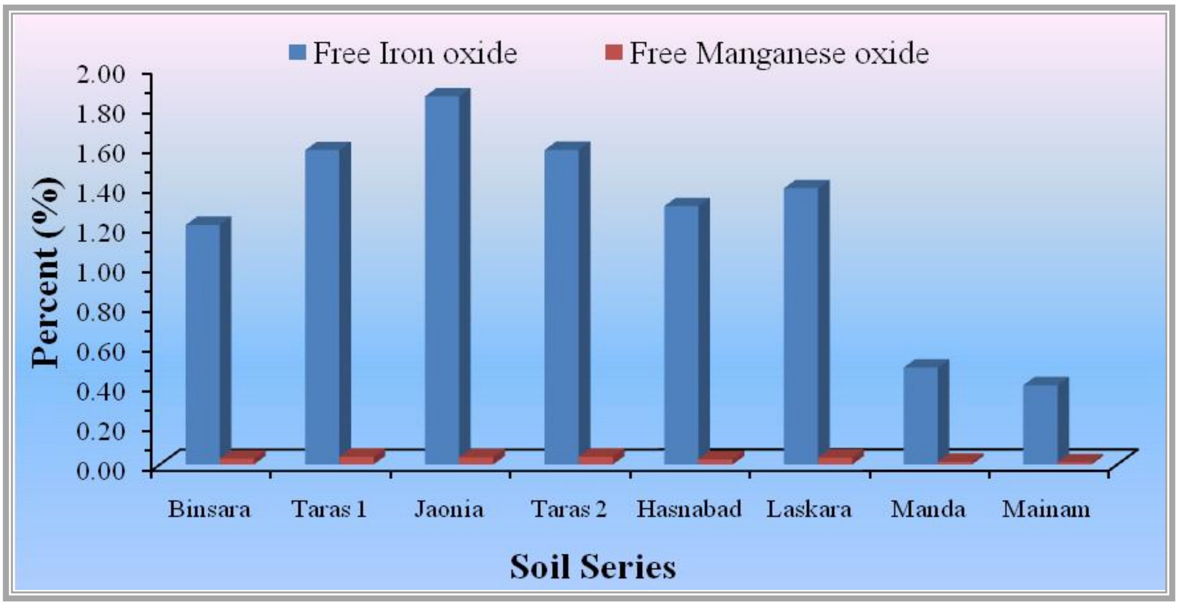


Fig 54. Graph shows mean value of the free iron oxide (Fe_2O_3) and free manganese oxide (MnO_2) of the studied soils.

Joffe (1966) reported that the surface enrichment of free iron oxide in hudromorphic soils is possibly due to the fact that with the receding of the ground water table ferrous iron is oxidized to ferric form near the surface, while in the subsoil the ferrous iron does not change.

A significant positive correlation (r = +0.733**) is found between total and free iron contents of the soils (Fig 57). This indicates that where the free iron oxide contents are high the total iron oxide contents are also high (Jha *et al.* 1984).

5.5.2 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 manganese behaves to some extent like iron (Joffe 1966).

The free MnO_2 contents of the soils vary from 0.003 to 0.092 percent with a mean value of 0.028 percent (Table 12). The highest mean value of free manganese oxide among the studied profiles is found in Taras soils and the lowest value in the Mainam soils (Fig 44). This low free manganese oxide 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) stated that poor drainage condition is probably the important factor that caused the decrease in free MnO_2 content in the soils.

The pattern of distribution of free MnO_2 with depth in the profiles is irregular (Figs 55 & 56). Slightly higher free MnO_2 concentration is noticed in the lower horizons of all the studied profiles except Manda and Mainam profiles.

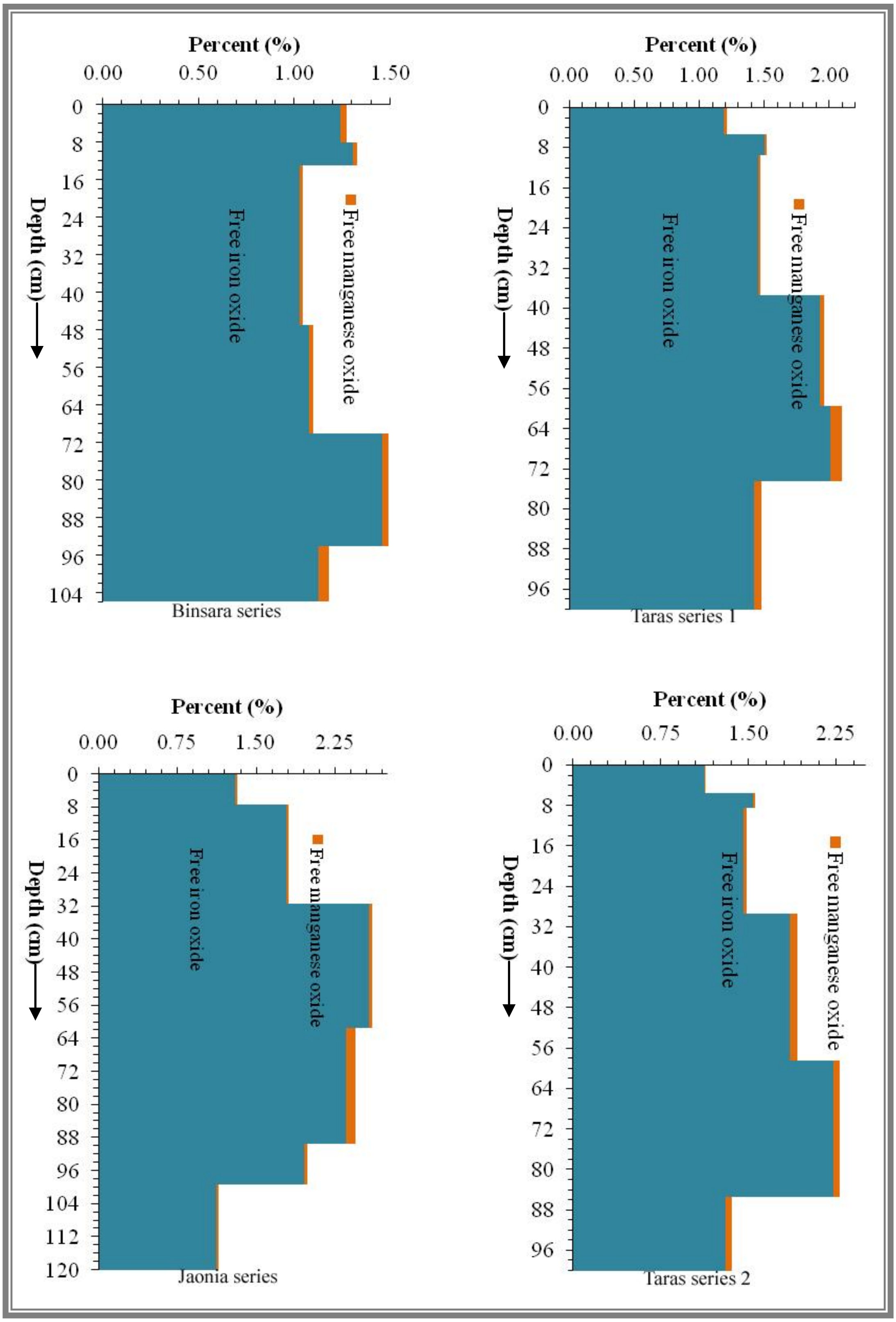


Fig 55. Vertical distribution of free iron (Fe) and free manganese (Mn) of Binsara, Taras 1, Jaonia and Taras 2 series.

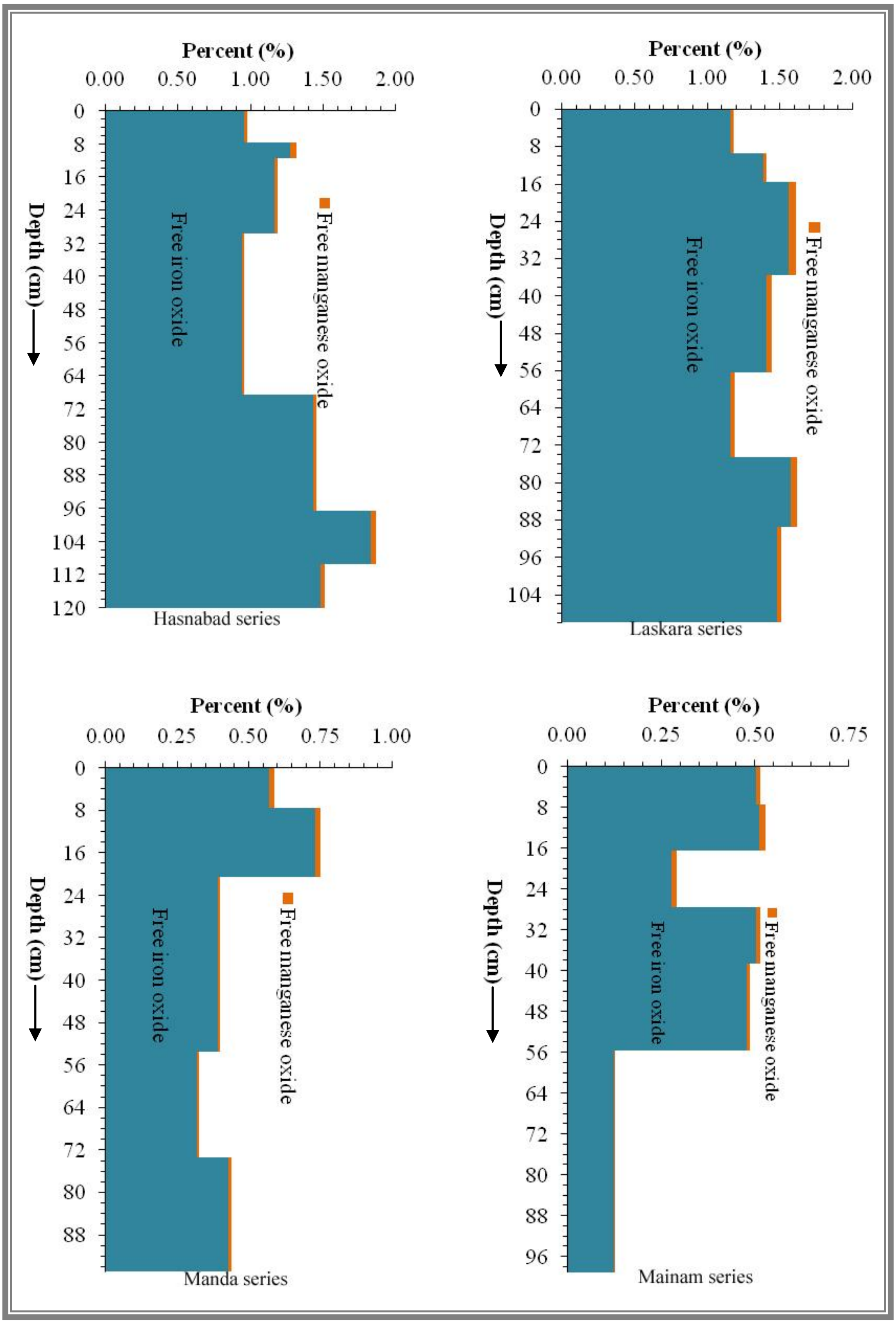


Fig 56. Vertical distribution of free iron (Fe) and free manganese (Mn) of Hasnabad, Laskara, Manda and Mainam series.

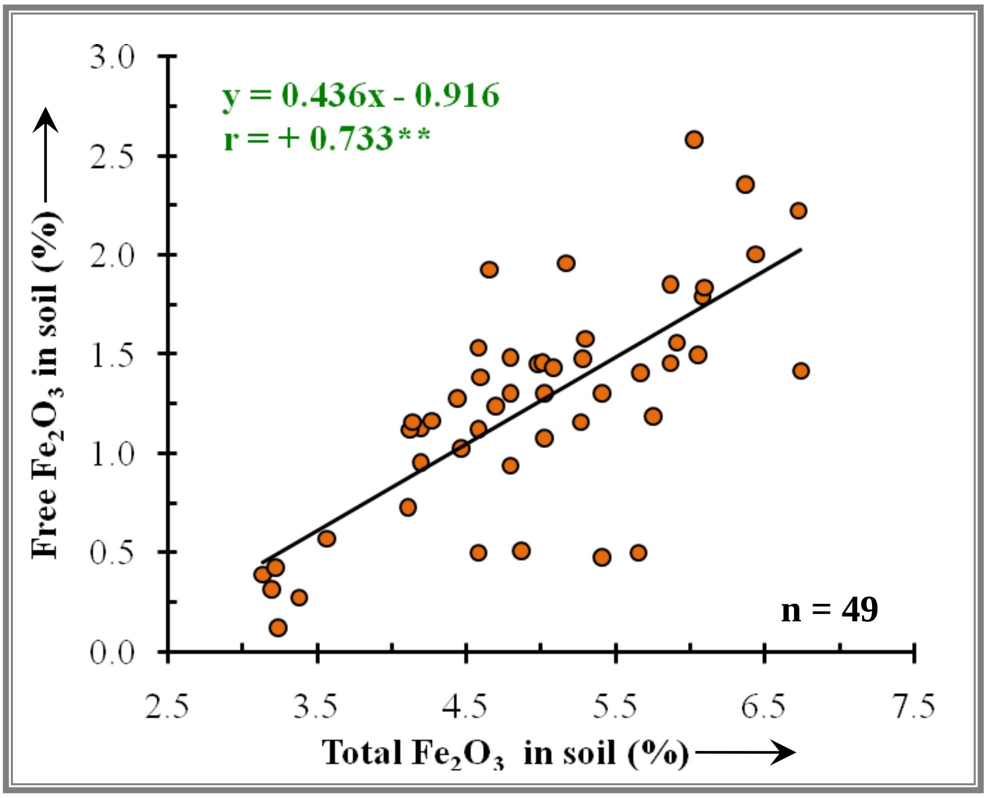


Fig 57. Ralationship between total Fe_2O_3 and free Fe_2O_3 of the studied soils.

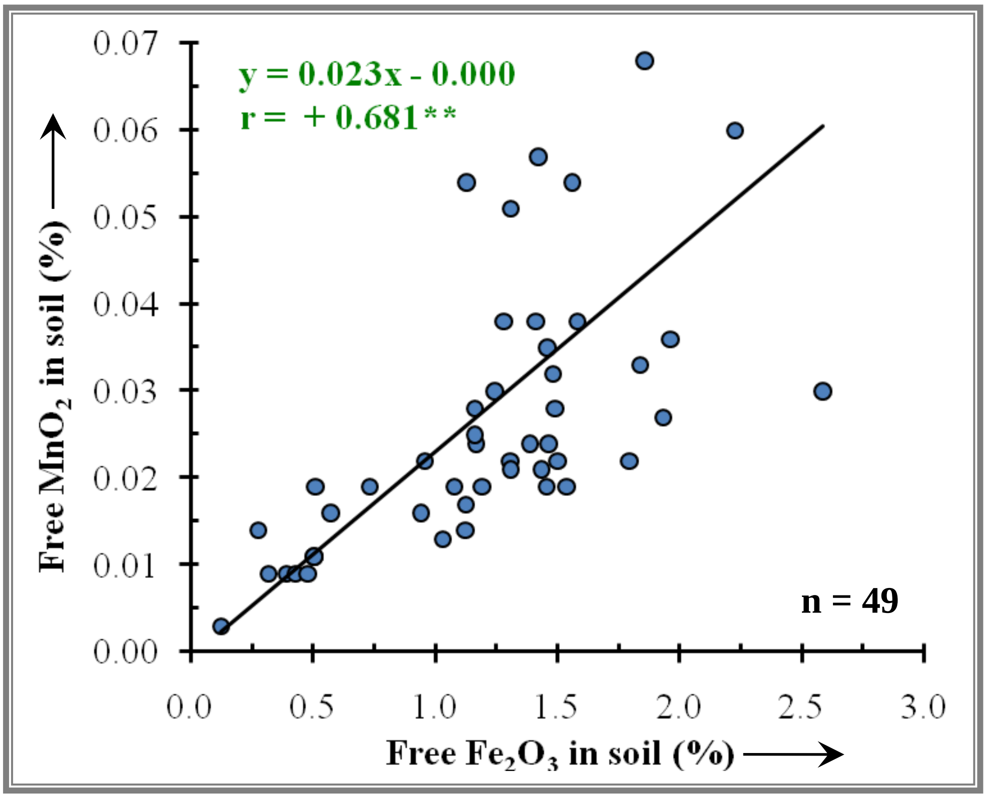


Fig 58. Ralationship between free Fe_2O_3 and free MnO_2 contents of the soils under investigation.

A significant positive correlation (r = +0.681**) is found between free Fe_2O_3 and free MnO_2 contents of the soils under study (Fig 58). This indicates that where the free iron oxide contents are high the free MnO_2 contents are also high and also indicate that the same processes (odation-reduction) are operative in conversion of free Fe/Mn to their oxides.

Manganous ion does not oxidize as easily as iron. Consequently, it moves easily down the profile along with the receding ground water table during the onset of dry season. After a long exposure in the dry period manganous ion get oxidized resulting in an accumulation of free manganese oxide in the subsoils.

The free Fe_2O_3 and free MnO_2 ratio ranges from 20 to 86 with a mean value of 44. The highest mean value was found in Jaonia soil where as the lowest mean value was found in Manda soil. On the other hand total Fe_2O_3 and free Fe_2O_3 ratio ranges from 2 to 12 with a mean value of 4 and the highest mean value was found in Mainam soil where as the lowest mean value was found in Jaonia soil.

5.5.3 Free iron oxide in the soil profiles as indicator of soil development

The distribution of iron oxide in the profile depicts the most important and sometime even the only indicator of what is going in the soil development. The breakdown of Fe-bearing minerals by chemical weathering leads to accumulation of free iron oxide in the form of amorphous, cryptocrystalline 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

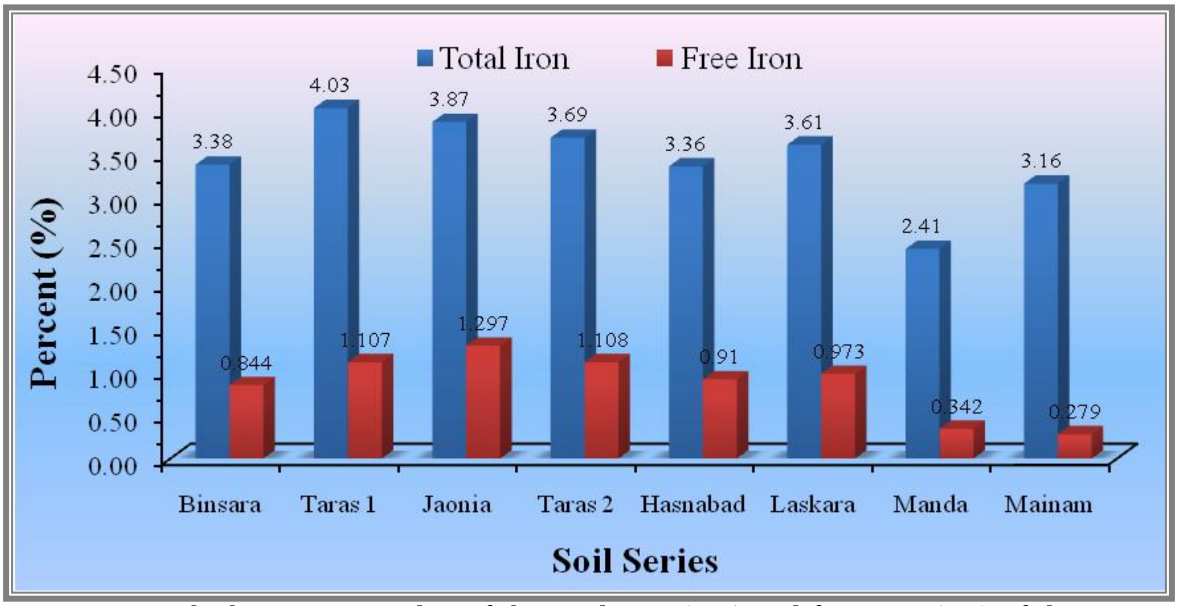


Fig 59. Graph shows mean value of the total iron (Fe_d) and free iron (Fe_t) of the studied soils.

Table 13. Total and extractable iron and manganese of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	Free Fe (%) (*Fe_d)	Total Fe (%) (*Fe_t)	Free Mn (%) (*Mn_d)	Fe_d/Mn_d ratio	$(Fe_d/Fe_t)\times100$
Binsara	Ap1g	0.87	3.28	0.019	46	27
	Ap2g	0.91	3.35	0.014	65	27
	Bw1g	0.72	3.12	0.008	90	23
	Bw2g	0.75	3.51	0.012	63	21
	Bw3g	1.02	4.10	0.022	46	25
	C1g	0.79	2.93	0.034	23	27
	Mean	**0.84**	**3.38**	**0.018**	**56**	**25**
Taras (1)	Ap1g	0.83	4.02	0.012	69	21
	Ap2g	1.05	4.23	0.014	75	25
	Bw1g	1.02	3.48	0.012	85	29
	Bw2g	1.35	3.25	0.017	79	42
	Bw3g	1.40	4.50	0.056	25	31
	C1g	0.99	4.71	0.036	28	21
	Mean	**1.11**	**4.03**	**0.025**	**60**	**28**
Jaonia	Apg	0.91	3.51	0.013	70	26
	Bw1g	1.25	4.25	0.014	90	29
	Bw2g	1.81	4.21	0.019	95	43
	Bw3g	1.65	4.45	0.058	28	37
	Bw4g	1.37	3.61	0.023	60	38
	Cg	0.79	3.20	0.011	72	25
	Mean	**1.30**	**3.87**	**0.023**	**69**	**33**
Taras (2)	Ap1g	0.78	2.88	0.009	87	27
	Ap2g	1.07	3.20	0.012	89	34
	Bw1g	1.02	3.50	0.015	68	29
	Bw2g	1.30	4.10	0.043	30	32
	Bw3g	1.56	4.70	0.038	41	33
	C1g	0.91	3.78	0.032	29	24
	Mean	**1.11**	**3.69**	**0.025**	**57**	**30**

*Fe_d = Dithionate extractable free iron, *Mn_d = Dithionate extractable free manganese, *Fe_t = Total iron

Continued next page

Continue…

Table 13. Total and extractable iron and manganese of the studied soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	Free Fe (%) (*Fe_d)	Total Fe (%) (*Fe_t)	Free Mn (%) (*Mn_d)	Fe_d/Mn_d ratio	$(Fe_d/Fe_t)\times100$
Hasnabad	Ap1g	0.67	2.93	0.014	48	23
	Ap2g	0.90	3.10	0.024	37	29
	Bw1	0.82	2.98	0.015	54	27
	Bw2	0.66	3.35	0.010	66	20
	Bw3	1.00	3.55	0.013	77	28
	Bw4	1.29	4.26	0.021	61	30
	C1	1.04	3.35	0.018	58	31
	Mean	**0.91**	**3.36**	**0.016**	**57**	**27**
Laskara	Ap1g	0.81	3.68	0.016	51	22
	Ap2g	0.97	3.21	0.015	65	30
	Bw1g	1.09	4.13	0.034	32	26
	Bw2	0.99	3.96	0.024	41	25
	Bw3g	0.81	2.89	0.018	45	28
	Bw4g	1.10	3.70	0.024	46	30
	C1g	1.04	3.69	0.020	52	28
	Mean	**0.97**	**3.61**	**0.022**	**47**	**27**
Manda	Apg	0.40	2.49	0.010	40	16
	AC	0.51	2.87	0.012	43	18
	C1	0.27	2.19	0.006	46	12
	C2	0.22	2.23	0.006	37	10
	C3	0.30	2.25	0.006	50	13
	Mean	**0.34**	**2.41**	**0.008**	**43**	**14**
Mainam	Ap1g	0.35	3.20	0.007	50	11
	Ap2g	0.36	3.40	0.012	30	10
	AC	0.19	2.36	0.009	22	8
	C1	0.35	3.95	0.007	50	9
	C2	0.33	3.78	0.006	56	9
	C3	0.09	2.26	0.002	44	4
	Mean	**0.28**	**3.16**	**0.007**	**42**	**9**
Grand Mean		**0.86**	**3.44**	**0.018**	**47**	**25**

terraces. This method has been employed in the present study to examine the degree of chemical weathering that has taken place in the soils. The Fe_d/Fe_t ratio has been calculated and presented in Table 13. It is observed that the Jaonia series contain greater amount of free iron in the profile (Fig 59) which suggested a higher degree of weathering than other soils. The Mainam soils contain lesser amount of free iron and indicate a relatively lower degree of weathering.

The Fe_d/Mn_d ratio is one of the indicators to find out the maturity of the soils. The highest values of Fe_d/Mn_d ratio and the values of Fe_d/Clay are found in the Jaonia soils whereas a lowest Fe_d/Mn_d value is found in Mainam soils (Table 13).

The highest mean value of Fe_d/Fe_t ratio among the soils is found in Jaonia soils and the lowest mean value is found in Mainam soils (Fig 60) its mean that Jaonia soils is more mature than other soils.

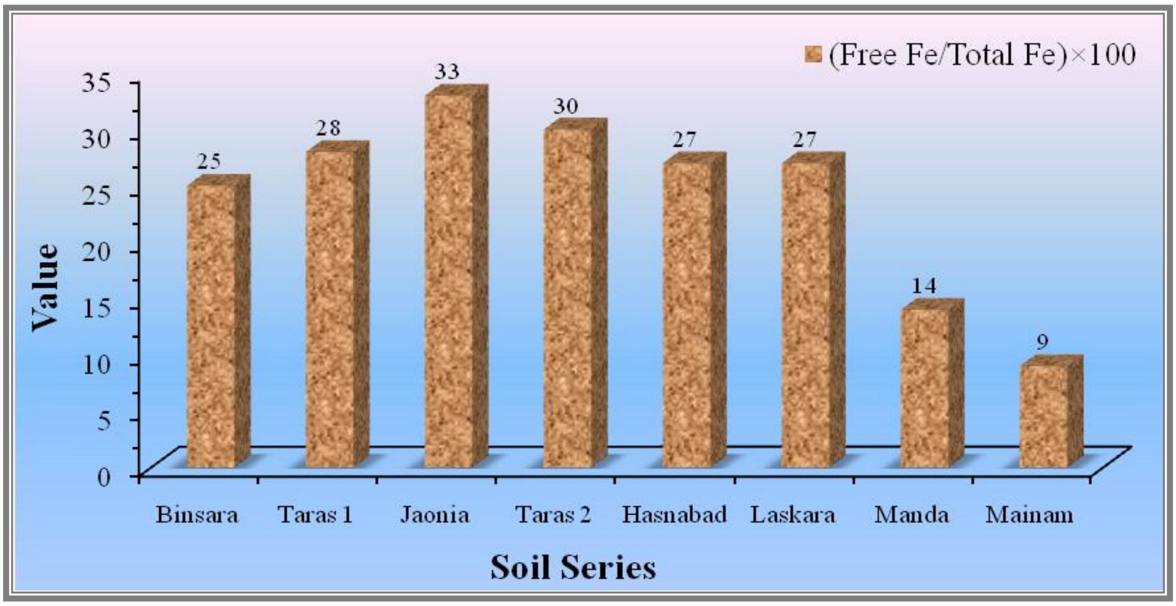


Fig 60. Graph shows mean value of the free iron (Fe_d) and total iron (Fe_t) ratio of the studied soils.

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

Mainam < Manda < Binsara < Hasnabad < Laskara < Taras 1 < Taras 2 < Jaonia

Less developed ⟶ More developed

5.6 Total analysis

5.6.1 Fusion analysis of the soils

To obtain information regarding the chemical nature of the parent materials of the soils under the present investigation, an attempt has been made to determine chemical composition of the soils from the fusion analysis.

The data for fusion analysis of the fine earth fractions of the whole soils (Table 14 & 15) shows that:

- the SiO_2 content varies from 62.5 to 79.1 with a mean of 70.3%,
- the Al_2O_3 content varies from 9.3 to 18.0 with a mean of 13.8%,
- the Fe_2O_3 content varies from 3.1 to 6.7 with a mean of 4.8%,
- the SiO_2/R_2O_3 ratio varies from 5.0 to 11.9 with a mean of 7.4,
- the SiO_2/Al_2O_3 ratio varies from 5.9 to 14.5 with a mean of 9.1,
- the Al_2O_3/Fe_2O_3 ratio varies from 2.6 to 6.2 with a mean of 4.6.

It may be pointed out that the SiO_2 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 silt fraction in the soils. The highest mean value of SiO_2 content has been found in Mainam soil where as the lowest in the Laskara profile (Fig 61).

The vertical distributions of SiO_2 content in the soil profiles are, in general irregular in nature (Figs 62 & 63). This irregular distribution pattern within the soil profile is thought to be due to alluvial nature of the soil parent materials.

Next to silica the most abundant element is aluminium. But the content of Al_2O_3 (mean) is relatively low which may be due to low aluminosilicates content and high quartz contents. The highest Al_2O_3 in the profile has been found in the jaonia profile and the lowest in the Mainam profile (Fig 61).

The vertical distribution of Al_2O_3 content in the soil profile is also irregular in nature (Figs 62 & 63). The irregular distribution pattern of Al_2O_3 within the profile is probably due to the variation is due to alluvial nature of the soil materials. Gotoh and Patrick (1974) also reported that the pattern of the distribution of the total Al_2O_3 with depth closely resembled that of the distribution of clay.

The next abundant element after aluminium is iron. The highest Fe_2O_3 in the profiles were found in Taras 1 soil and the lowest in Manda soil. The variations of the highest and lowest mean value is not wide. The vertical distribution of total Fe_2O_3 content in the soil profiles is irregular in nature (Figs 62 & 63) but except in Manda profile some subsoils of

Table 14. 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
		%						
Binsara	Ap1g	66.4	17.7	4.7	3.6	2.7	2.8	1.1
	Bw2g	67.2	16.1	5.0	4.1	2.8	2.5	1.3
	C1g	71.0	14.9	4.2	3.2	2.1	2.4	1.3
	Mean	**68.2**	**16.2**	**4.6**	**3.6**	**2.5**	**2.6**	**1.2**
Taras (1)	Ap1g	63.6	18.0	5.8	4.6	3.2	2.8	1.1
	Bw2g	69.0	16.4	4.7	3.3	2.0	2.5	1.3
	C1g	69.2	12.5	6.7	3.9	2.8	2.7	1.2
	Mean	**67.3**	**15.6**	**5.7**	**3.9**	**2.7**	**2.6**	**1.2**
Jaonia	Apg	62.5	17.9	5.0	4.5	4.2	3.5	1.4
	Bw2g	63.6	17.2	6.0	3.9	3.1	3.6	1.5
	Cg	70.1	14.4	4.6	3.7	2.6	2.7	1.3
	Mean	**65.4**	**16.5**	**5.2**	**4.0**	**3.3**	**3.3**	**1.4**
Taras (2)	Ap1g	69.0	16.2	4.1	3.6	2.4	2.6	1.1
	Bw2g	71.4	10.4	5.9	5.1	2.1	2.9	1.3
	C1g	72.1	11.0	5.4	4.3	2.7	2.6	1.3
	Mean	**70.8**	**12.5**	**5.1**	**4.3**	**2.4**	**2.7**	**1.2**
Hasnabad	Ap1g	70.7	14.0	4.2	3.2	2.8	2.8	1.3
	Bw2	70.2	12.8	4.8	4.3	3.4	2.7	1.4
	C1	72.6	11.2	4.8	4.0	2.5	2.6	1.4
	Mean	**71.2**	**12.6**	**4.6**	**3.8**	**2.9**	**2.7**	**1.4**
Laskara	Ap1g	67.2	17.3	5.3	3.2	2.2	3.0	1.2
	Bw2	66.1	15.1	5.7	5.1	3.1	2.9	1.3
	C1g	68.0	16.7	5.3	3.3	2.5	2.7	1.1
	Mean	**67.1**	**16.4**	**5.4**	**3.9**	**2.6**	**2.9**	**1.2**
Manda	Apg	72.8	12.3	3.6	4.5	2.6	2.5	0.9
	C1	76.1	10.4	3.1	3.1	2.7	3.0	1.0
	C3	76.4	11.1	3.2	3.0	2.8	2.1	0.8
	Mean	**75.1**	**11.3**	**3.3**	**3.5**	**2.7**	**2.5**	**0.9**
Mainam	Ap1g	76.2	10.4	4.6	3.0	2.3	2.5	0.9
	C1	76.1	9.4	5.7	3.2	2.2	2.6	0.9
	C3	79.1	9.3	3.2	3.1	2.4	2.2	0.7
	Mean	**77.1**	**9.7**	**4.5**	**3.1**	**2.3**	**2.4**	**0.8**
Grand Mean		**70.3**	**13.8**	**4.8**	**3.8**	**2.7**	**2.7**	**1.2**

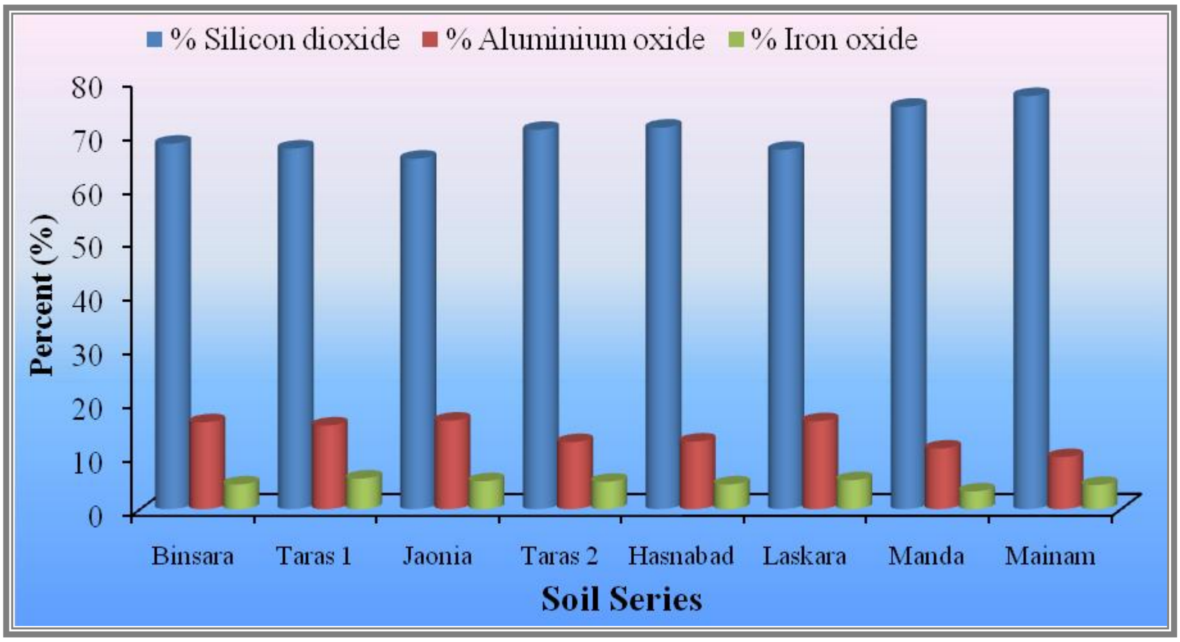


Fig 61. Graph shows mean value of total silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) of the studied whole soils.

all profiles a slight enrichment may be noticed. On the other hand slightly higher Fe_2O_3 is noticed in the topsoils of Manda profiles. Higher Fe_2O_3 content in the subsoils was observed by Mazumder (1996) in some Brahmaputra floodplain soils of Bangladesh.

The SiO_2/R_2O_3 ratio of the studied soils ranges from 5.0 to 11.9 with a mean of 7.4 (Table 15). Higher SiO_2/R_2O_3 ratio in the studied pedons is found in the Mainam profile whereas the lowest value is found in the Jaonia profile. The Distribution of SiO_2/R_2O_3 ratio from the surface downward follows an irregular pattern in all the soil profiles (Table 15). The irregular distribution of SiO_2/R_2O_3 ratio throughout the profile suggested that the parent materials were heterogeneous and were 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/Al_2O_3 ratio in the studied soils ranges from 5.9 to 14.5 with a mean of 9.1. Such a wide range of the above ratio indicates the heterogeneous nature of the soil parent materials. The highest mean of SiO_2/Al_2O_3 ratio in the studied soils is observed in Mainam soils while the lowest value is found in Laskara soils (Table 15). The vertical distribution of SiO_2/Al_2O_3 ratio from the surface downward follows an irregular pattern in all the studied pedons (Table 15). This may indicate the existence of stratification. The highest mean value of Al_2O_3/Fe_2O_3 ratio in the studied pedons is found in the Binsara soils and the lowest in Mainam soils (Table 15). However, the highest and lowest values vary within narrow limits. The vertical distribution of Al_2O_3/Fe_2O_3 ratio from the surface downward follows an irregular pattern in all the soil profiles (Table 15).

Table 15. Total SiO_2, Al_2O_3 and Fe_2O_3 content in the whole studied soils from fusion analysis.

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	→
Binsara	Ap1g	66.4	17.7	4.7	5.4	6.4	5.9
	Bw2g	67.2	16.1	5.0	5.9	7.1	5.0
	C1g	71.0	14.9	4.2	6.9	8.1	5.6
	Mean	**68.2**	**16.2**	**4.6**	**6.1**	**7.2**	**5.5**
Taras (1)	Ap1g	63.6	18.0	5.8	5.0	6.0	4.9
	Bw2g	69.0	16.4	4.7	6.1	7.2	5.5
	C1g	69.2	12.5	6.7	7.0	9.4	2.9
	Mean	**67.3**	**15.6**	**5.7**	**6.0**	**7.5**	**4.4**
Jaonia	Apg	62.5	17.9	5.0	5.0	5.9	5.6
	Bw2g	63.6	17.2	6.0	5.1	6.3	4.5
	Cg	70.1	14.4	4.6	6.9	8.3	4.9
	Mean	**65.4**	**16.5**	**5.2**	**5.7**	**6.8**	**5.0**
Taras (2)	Ap1g	69.0	16.2	4.1	6.2	7.2	6.2
	Bw2g	71.4	10.4	5.9	8.6	11.7	2.8
	C1g	72.1	11.0	5.4	8.5	11.2	3.2
	Mean	**70.8**	**12.5**	**5.1**	**7.8**	**10.0**	**4.0**
Hasnabad	Ap1g	70.7	14.0	4.2	7.2	8.6	5.2
	Bw2	70.2	12.8	4.8	7.5	9.3	4.2
	C1	72.6	11.2	4.8	8.6	11.0	3.7
	Mean	**71.2**	**12.6**	**4.6**	**7.8**	**9.6**	**4.4**
Laskara	Ap1g	67.2	17.3	5.3	5.5	6.6	5.1
	Bw2	66.1	15.1	5.7	6.0	7.4	4.2
	C1g	68.0	16.7	5.3	5.7	6.9	5.0
	Mean	**67.1**	**16.4**	**5.4**	**5.8**	**7.0**	**4.8**
Manda	Apg	72.8	12.3	3.6	8.5	10.1	5.4
	C1	76.1	10.4	3.1	10.4	12.4	5.2
	C3	76.4	11.1	3.2	9.8	11.6	5.4
	Mean	**75.1**	**11.3**	**3.3**	**9.6**	**11.4**	**5.3**
Mainam	Ap1g	76.2	10.4	4.6	9.7	12.4	3.6
	C1	76.1	9.4	5.7	9.9	13.7	2.6
	C3	79.1	9.3	3.2	11.9	14.5	4.5
	Mean	**77.1**	**9.7**	**4.5**	**10.5**	**13.5**	**3.6**
Grand Mean		**70.3**	**13.8**	**4.8**	**7.4**	**9.1**	**4.6**

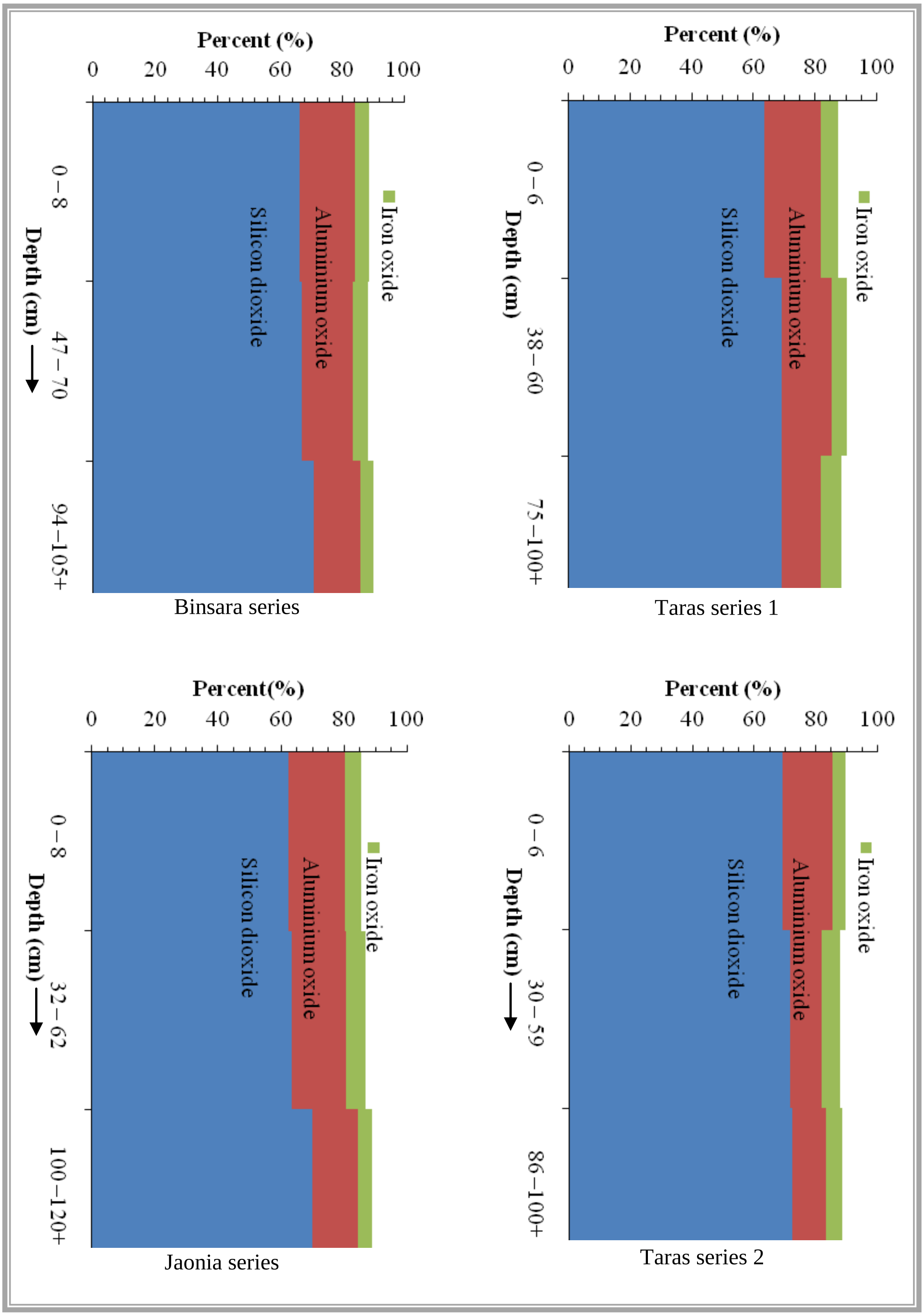


Fig 62. Vertical distribution of total silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) of the whole soils of Binsara, Taras 1, Jaonia and Taras 2 series.

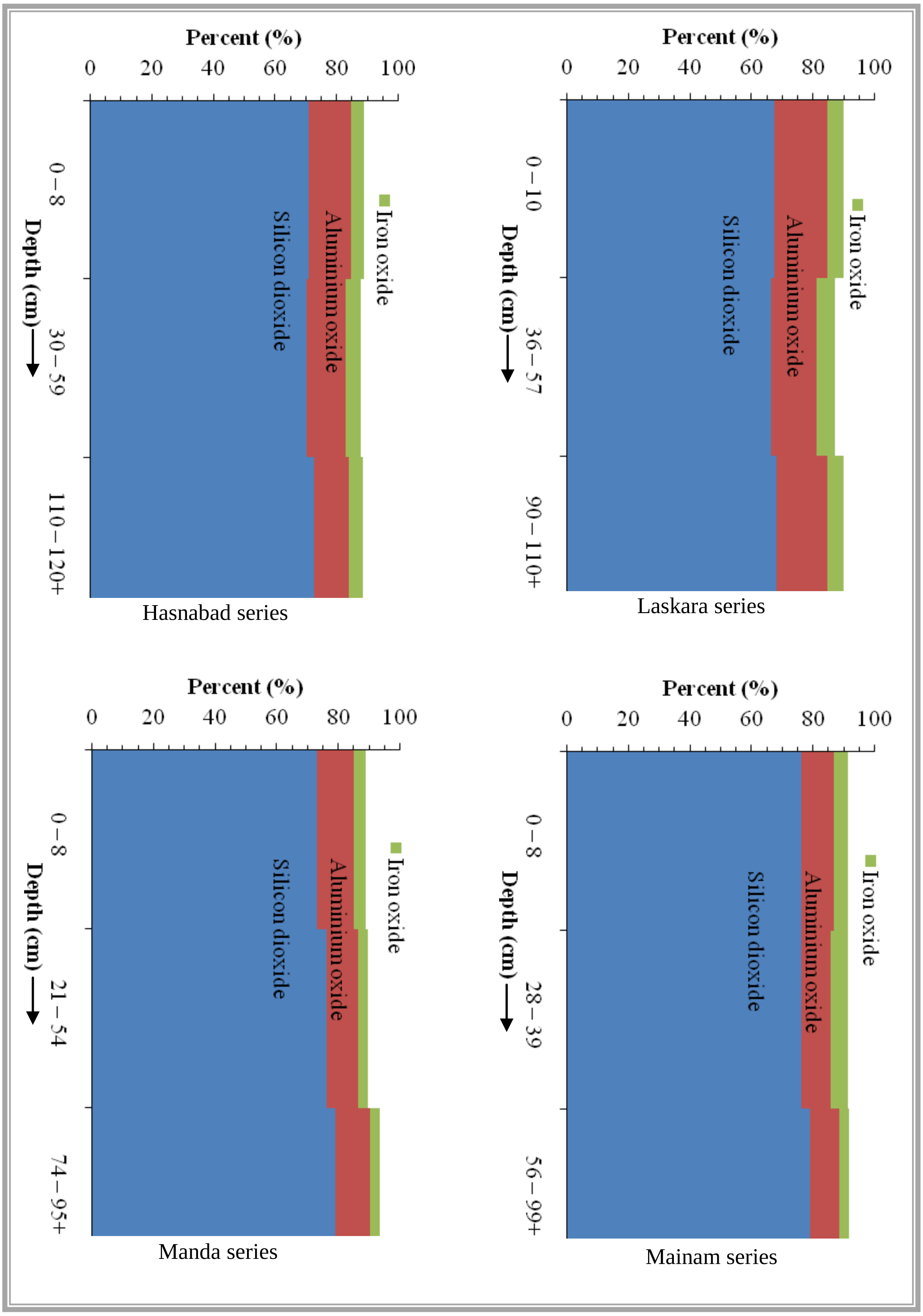


Fig 63. Vertical distribution of total silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) of the whole soils of Hasnabad, Laskara, Manda and Mainam series.

From the vertical distribution pattern of the SiO_2/R_2O_3, SiO_2/Al_2O_3 and Al_2O_3/Fe_2O_3 ratio of these pedons, it may be inferred that the parent materials of the soils are heterogeneous. This finding is in conformity with the previous studies carried out by many authors on Bangladesh soils (Khan, 1995; Mazumder, 1996; Rahman, 2001).

The total CaO content ranges from 3.0 to 5.1 percent with a mean value of 3.8 percent (Table 16). The highest mean value of CaO content occur in the soil of Taras series 2 and the lowest in the Mainam series (Fig 64). The total CaO contents in these soils are rather low. These results are in accord with the findings of Ali (1994), Mazumder (1996). The vertical distribution pattern of CaO content from the surface downward follows an irregular pattern in the studied soils (Figs 65 & 66).

The total MgO content in the soils under investigation ranges from 2.0 to 4.2 with a mean value of 2.7 percent (Table 16). The highest mean value is found in Jaonia soils whereas the lowest mean is found in Mainam soils (Fig 64). The vertical distribution of MgO content in the soil profiles is, in general irregular in nature (Figs 65 & 66) but in some subsoils of Taras 1, Taras 2, Hasnabad, Laskara and Mainam profiles a slight enrichment can be noticed. On the other hand slightly higher MgO is noticed in the top soils of Binsara, Jaonia and Manda profiles. Higher MgO content in the surface horizon was observed by Chatterjee and Dalal (1976) in some alluvial soils of Bihar and West Bengal.

The irregular distribution pattern of calcium and magnesium oxides in the soil profiles may be considered as an indication of the fact that the pedochemical weathering processes have not brought about any significant changes in the distribution pattern of the minerals containing these elements. In other words, ferromagnesian minerals remained in soil as they were when deposited by geological processes. Consequently, the soils may be regarded as still in the youthful stage.

The total MnO_2 content in the soils under investigation ranges from 0.04 to 0.12 with a mean value of 0.07 percent (Table 16). The highest mean value is found in Mainam soils whereas the lowest mean is found in jaonia soils (Fig 64). But the variations of the highest and the lowest mean value is not wide. The vertical distribution of MnO_2 content in the soil profiles is irregular in nature (Figs 65 & 66).

It may be pointed out that the total P_2O_5 contents in the studied soils vary from 0.33 to 0.48 percent with a mean value of 0.41 percent (Table 16). The highest mean value is found in Laskara soils whereas the lowest mean is found in Binsara soils. There is no regular vertical distribution pattern of the P_2O_5 content within the soil profiles (Table 16).

From the above result it seems that the parent materials of these soils are of mixed origin and of non-uniform chemical composition. Nevertheless, the SiO_2 indicate that the parent materials of the soils were derived from acid to intermediate type of rocks.

Table 16. Content of total CaO, MgO, MnO_2 and P_2O_5 present in the whole soils of the lower Atrai basin of Bangladesh.

Soil Series	Horizon	CaO	MgO	(CaO+MgO)	MnO_2	P_2O_5
		←		%		→
Binsara	Ap1g	3.6	2.7	6.3	0.05	0.38
	Bw2g	4.1	2.8	6.9	0.05	0.37
	C1g	3.2	2.1	5.3	0.07	0.35
	Mean	**3.6**	**2.5**	**6.1**	**0.06**	**0.37**
Taras (1)	Ap1g	4.6	3.2	7.8	0.04	0.43
	Bw2g	3.3	2.0	5.3	0.04	0.33
	C1g	3.9	2.8	6.7	0.04	0.46
	Mean	**3.9**	**2.7**	**6.6**	**0.04**	**0.41**
Jaonia	Apg	4.5	4.2	8.7	0.05	0.40
	Bw2g	3.9	3.1	7.0	0.04	0.41
	Cg	3.7	2.6	6.3	0.04	0.33
	Mean	**4.0**	**3.3**	**7.3**	**0.04**	**0.38**
Taras (2)	Ap1g	3.6	2.4	6.0	0.04	0.40
	Bw2g	5.1	2.1	7.2	0.05	0.37
	C1g	4.3	2.7	7.0	0.12	0.37
	Mean	**4.3**	**2.4**	**6.7**	**0.07**	**0.38**
Hasnabad	Ap1g	3.2	2.8	6.0	0.05	0.4
	Bw2	4.3	3.4	7.7	0.06	0.38
	C1	4.0	2.5	6.5	0.05	0.40
	Mean	**3.8**	**2.9**	**6.7**	**0.06**	**0.41**
Laskara	Ap1g	3.2	2.2	5.4	0.08	0.44
	Bw2	5.1	3.1	8.2	0.12	0.46
	C1g	3.3	2.5	5.8	0.09	0.44
	Mean	**3.9**	**2.6**	**6.5**	**0.07**	**0.45**
Manda	Apg	4.5	2.6	7.1	0.07	0.48
	C1	3.1	2.7	5.8	0.07	0.42
	C3	3.0	2.8	5.8	0.11	0.43
	Mean	**3.5**	**2.7**	**6.2**	**0.08**	**0.44**
Mainam	Ap1g	3.0	2.3	5.3	0.10	0.45
	C1	3.2	2.2	5.4	0.10	0.46
	C3	3.1	2.4	5.5	0.06	0.41
	Mean	**3.1**	**2.3**	**5.4**	**0.09**	**0.44**
Grand Mean		**3.8**	**2.7**	**6.5**	**0.07**	**0.41**

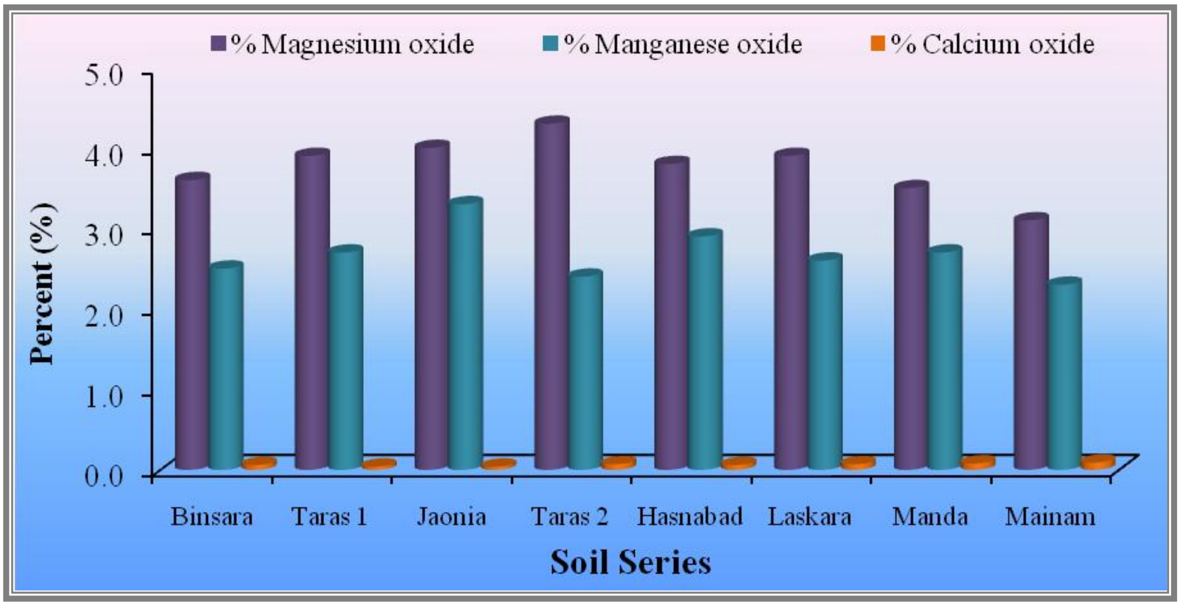


Fig 64. Graph shows mean value of total magnesium oxide (MgO), manganese oxide (MnO_2) and calcium oxide (CaO) of the studied whole soils.

The content of Al_2O_3 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 in soil which may be the result of high content of ferromagnesian minerals in these soils.

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

The clay fraction with a minimum settling velocity of 10^{-4} cm per second were separated from other fractions in all soil samples to carry out fusion analysis on them. Percent SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, MnO_2, K_2O, TiO_2 and loss on ignition were determined.

The SiO_2 contents in the clay fraction of the studied soils vary from 54.1 to 64.6 percent with a mean value of 58.2 percent (Table 17). The highest mean value of total SiO_2 content is found in Manda soils where as the lowest in the Jaonia profile (Fig 67). The variation between the lowest and the highest values of SiO_2 content is very narrow and this indicates that their mineralogical composition is more or less similar. The vertical distributions of SiO_2 content in the clay fraction of soil profiles are more or less uniform (Figs 68 & 69).

The percent Al_2O_3 contents in the clay fraction of the studied soils ranges from 21.9 to 27.5 with a mean value of 24.9 (Table 17). The highest mean value of total Al_2O_3 content is found in Laskara soils where as the lowest in the Taras 2 profile (Fig 67). The variation between the lowest and highest value of Al_2O_3 content is narrow. This may be due to the fact that the minerals in the clay fraction of the studied soils are uniform in composition in their existing pedochemical environment. The vertical distributions of Al_2O_3 content in the clay fraction within the soil profiles of the pedons are more or less identical (Figs 68 & 69).

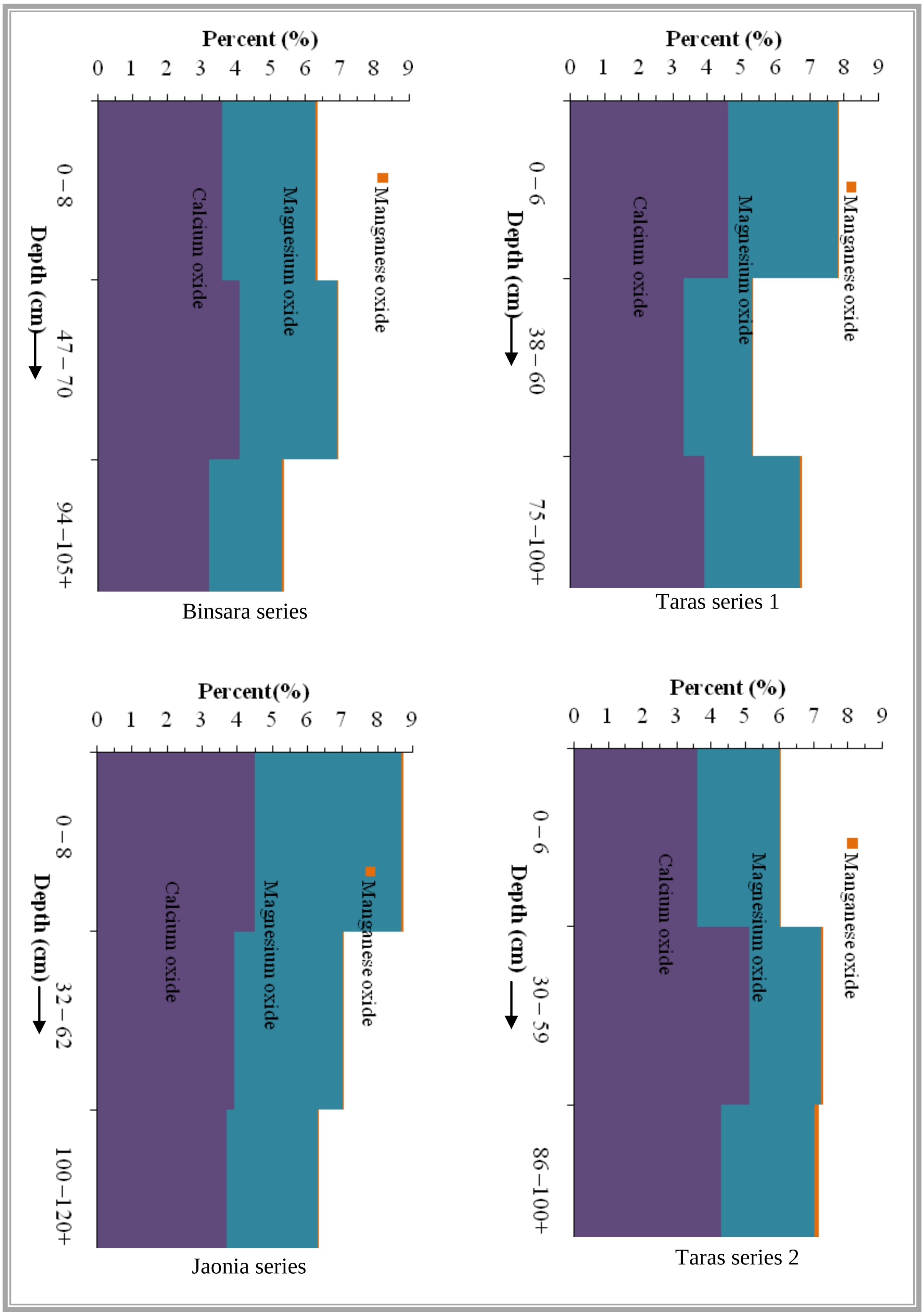


Fig 65. Vertical distribution of total magnesium oxide (MgO), manganese oxide (MnO_2) and calcium oxide (CaO) of the whole soils of Binsara, Taras 1, Jaonia and Taras 2 series.

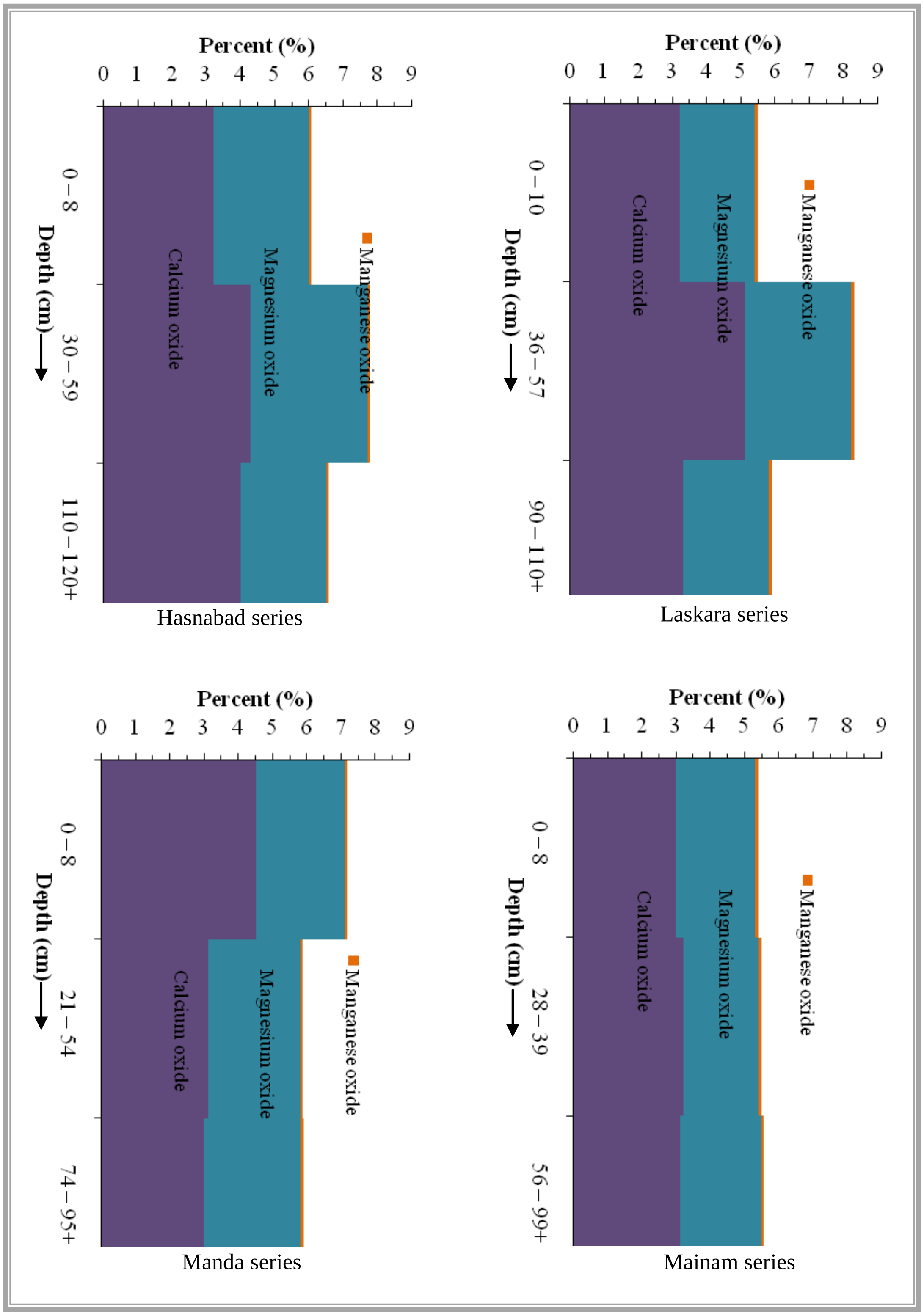


Fig 66. Vertical distribution of total magnesium oxide (MgO), manganese oxide (MnO_2) and calcium oxide (CaO) of the whole soils of Hasnabad, Laskara, Manda and Mainam series.

Table 17. Results of chemical composition of the clay fractions of the studied soils from fusion analysis.

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2
		%						
Binsara	Ap1g	55.1	26.1	7.9	Tr	4.2	4.4	1.8
	Bw2g	56.5	25.7	7.1	0.01	3.7	4.3	1.9
	C1g	58.8	24.7	6.6	Tr	3.5	3.7	1.8
	Mean	**56.8**	**25.5**	**7.2**	**-**	**3.8**	**4.2**	**1.8**
Taras (1)	Ap1g	57.4	23.7	8.1	0.01	4.0	4.3	1.5
	Bw2g	57.3	25.2	8.0	Tr	3.1	3.9	1.7
	C1g	58.8	22.0	9.4	Tr	3.5	3.8	1.7
	Mean	**57.8**	**23.6**	**8.5**	**-**	**3.5**	**4.0**	**1.6**
Jaonia	Apg	55.3	24.1	9.9	0.01	3.4	4.7	1.9
	Bw2g	54.1	25.2	9.6	Tr	3.8	4.2	2.0
	Cg	56.2	26.4	7.2	0.02	3.7	4.0	1.8
	Mean	**55.2**	**25.2**	**8.9**	**-**	**3.6**	**4.3**	**1.9**
Taras (2)	Ap1g	57.8	24.4	7.6	Tr	3.6	4.3	1.5
	Bw2g	60.3	23.9	5.3	0.03	3.5	4.2	1.7
	C1g	64.6	21.9	4.2	Tr	2.7	3.8	1.4
	Mean	**60.9**	**23.4**	**5.7**	**-**	**3.3**	**4.1**	**1.5**
Hasnabad	Ap1g	56.9	27.0	6.3	0.02	3.2	3.6	1.9
	Bw2	55.8	26.8	7.6	0.01	3.5	3.3	1.8
	C1	60.0	24.8	6.5	Tr	3.1	3.2	1.8
	Mean	**57.6**	**26.2**	**6.8**	**-**	**3.3**	**3.4**	**1.8**
Laskara	Ap1g	55.0	27.2	8.1	Tr	3.5	3.6	1.5
	Bw2	56.3	27.5	6.5	0.02	3.2	3.7	1.6
	C1g	59.1	25.7	5.4	0.01	3.5	3.7	1.6
	Mean	**56.8**	**26.8**	**6.7**	**-**	**3.4**	**3.7**	**1.6**
Manda	Apg	61.0	24.9	4.1	Tr	3.6	4.3	1.3
	C1	62.0	23.6	4.1	Tr	3.7	4.2	1.3
	C3	60.0	22.9	8.4	0.01	2.4	3.7	1.0
	Mean	**61.0**	**23.8**	**5.5**	**-**	**3.2**	**4.1**	**1.2**
Mainam	Ap1g	58.9	26.7	4.2	0.01	3.0	4.7	1.1
	C1	60.0	22.9	7.7	Tr	3.1	4.2	1.1
	C3	59.9	24.6	6.2	Tr	3.5	3.7	1.0
	Mean	**59.6**	**24.7**	**6.0**	**-**	**3.2**	**4.2**	**1.1**
Grand Mean		**58.2**	**24.9**	**6.9**	**-**	**3.4**	**4.0**	**1.6**

The total Fe_2O_3 contents in the clay fraction of the soils ranges from 4.1 to 9.9 percent with a mean value of 6.9 (Table 17). The highest mean value of total Fe_2O_3 content is found in Jaonia soils and the lowest in the Manda profile (Fig 67). The variation between the lowest and highest value of Fe_2O_3 content is narrow in these soils. The vertical distributions of Fe_2O_3 content in the clay fraction within the soil pedons are more or less uniform (Figs 68 & 69).

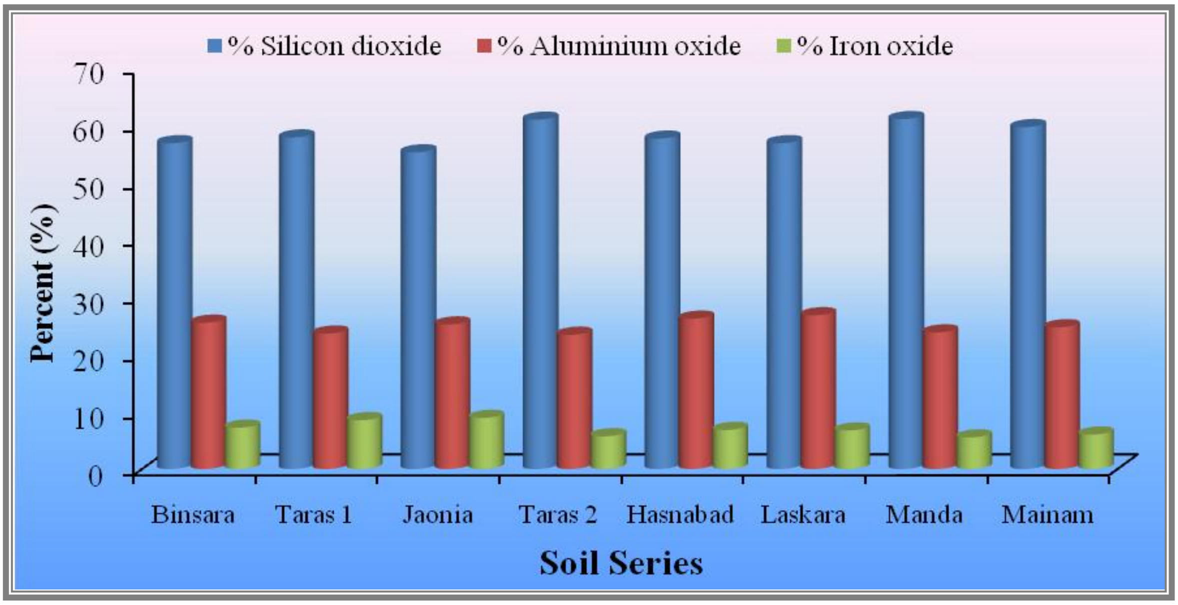


Fig 67. Graph shows mean value of total silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) of the clay fraction of the studied soils.

The silica-sesquioxide (SiO_2/R_2O_3) molar ratio of clay fraction ranges from 2.9 to 4.5 with a mean of 3.4 (Table 18). The highest mean value of SiO_2/R_2O_3 ratio in the studied pedons is found in the Taras 2 profile whereas the lowest value is found in the Laskara profile. The Distribution of SiO_2/R_2O_3 ratio from the surface downward follows an irregular pattern in all the soil profiles (Table 18). This silica-sesquioxide (SiO_2/R_2O_3) ratio may indicate the presence of considerable amount of 2:1 lattice type clay minerals which might be a mixture of variable quantities of mica, montmorillonite, vermiculite and kaolinite minerals. Hussain and Swindale (1974) reported the similar results in some Grey Hydromorphic Soils of Hawaii. The above results are also similar with the results refereed by Karim (1984), Mazumder (1996) and khan (1995).

The SiO_2/Al_2O_3 molar ratio in the clay fraction varies from 3.4 to 5.0 with a mean value of 4.0 (Table 18). The highest mean value of SiO_2/Al_2O_3 ratio is found in the Taras 2 and Manda profile and the lowest value is found in the Laskara profile. The SiO_2/Al_2O_3 ratio does not show any definite trend in the vertical distribution pattern.

Table 18. Total SiO_2, Al_2O_3 and Fe_2O_3 contents in the clay fractions of the studied soils from fusion analysis.

Soil Series	Horizon	SiO_2	Al_2O_3	Fe_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
		←	%	→	←	Molar ratio	→
Binsara	Ap1g	55.1	26.1	7.9	3.0	3.6	5.2
	Bw2g	56.5	25.7	7.1	3.2	3.7	5.7
	C1g	58.8	24.7	6.6	3.4	4.0	5.8
	Mean	**56.8**	**25.5**	**7.2**	**3.2**	**3.8**	**5.6**
Taras (1)	Ap1g	57.4	23.7	8.1	3.4	4.1	4.6
	Bw2g	57.3	25.2	8.0	3.2	3.9	4.9
	C1g	58.8	22.0	9.4	3.6	4.5	3.7
	Mean	**57.8**	**23.6**	**8.5**	**3.4**	**4.2**	**4.4**
Jaonia	Apg	55.3	24.1	9.9	3.1	3.9	3.8
	Bw2g	54.1	25.2	9.6	2.9	3.6	4.1
	Cg	56.2	26.4	7.2	3.1	3.6	5.7
	Mean	**55.2**	**25.2**	**8.9**	**3.0**	**3.7**	**4.6**
Taras (2)	Ap1g	57.8	24.4	7.6	3.4	4.0	5.0
	Bw2g	60.3	23.9	5.3	3.8	4.3	7.1
	C1g	64.6	21.9	4.2	4.5	5.0	8.1
	Mean	**60.9**	**23.4**	**5.7**	**3.9**	**4.4**	**6.7**
Hasnabad	Ap1g	56.9	27.0	6.3	3.1	3.6	6.7
	Bw2	55.8	26.8	7.6	3.0	3.5	5.5
	C1	60.0	24.8	6.5	3.5	4.1	6.0
	Mean	**57.6**	**26.2**	**6.8**	**3.2**	**3.7**	**6.1**
Laskara	Ap1g	55.0	27.2	8.1	2.9	3.4	5.2
	Bw2	56.3	27.5	6.5	3.0	3.5	6.6
	C1g	59.1	25.7	5.4	3.4	3.9	7.4
	Mean	**56.8**	**26.8**	**6.7**	**3.1**	**3.6**	**6.4**
Manda	Apg	61.0	24.9	4.1	3.8	4.2	9.5
	C1	62.0	23.6	4.1	4.0	4.5	8.9
	C3	60.0	22.9	8.4	3.6	4.4	4.3
	Mean	**61.0**	**23.8**	**5.5**	**3.8**	**4.4**	**7.6**
Mainam	Ap1g	58.9	26.7	4.2	3.4	3.7	9.9
	C1	60.0	22.9	7.7	3.7	4.4	4.7
	C3	59.9	24.6	6.2	3.6	4.1	6.2
	Mean	**59.6**	**24.7**	**6.0**	**3.5**	**4.1**	**6.9**
	Grand Mean	**58.2**	**24.9**	**6.9**	**3.4**	**4.0**	**6.0**

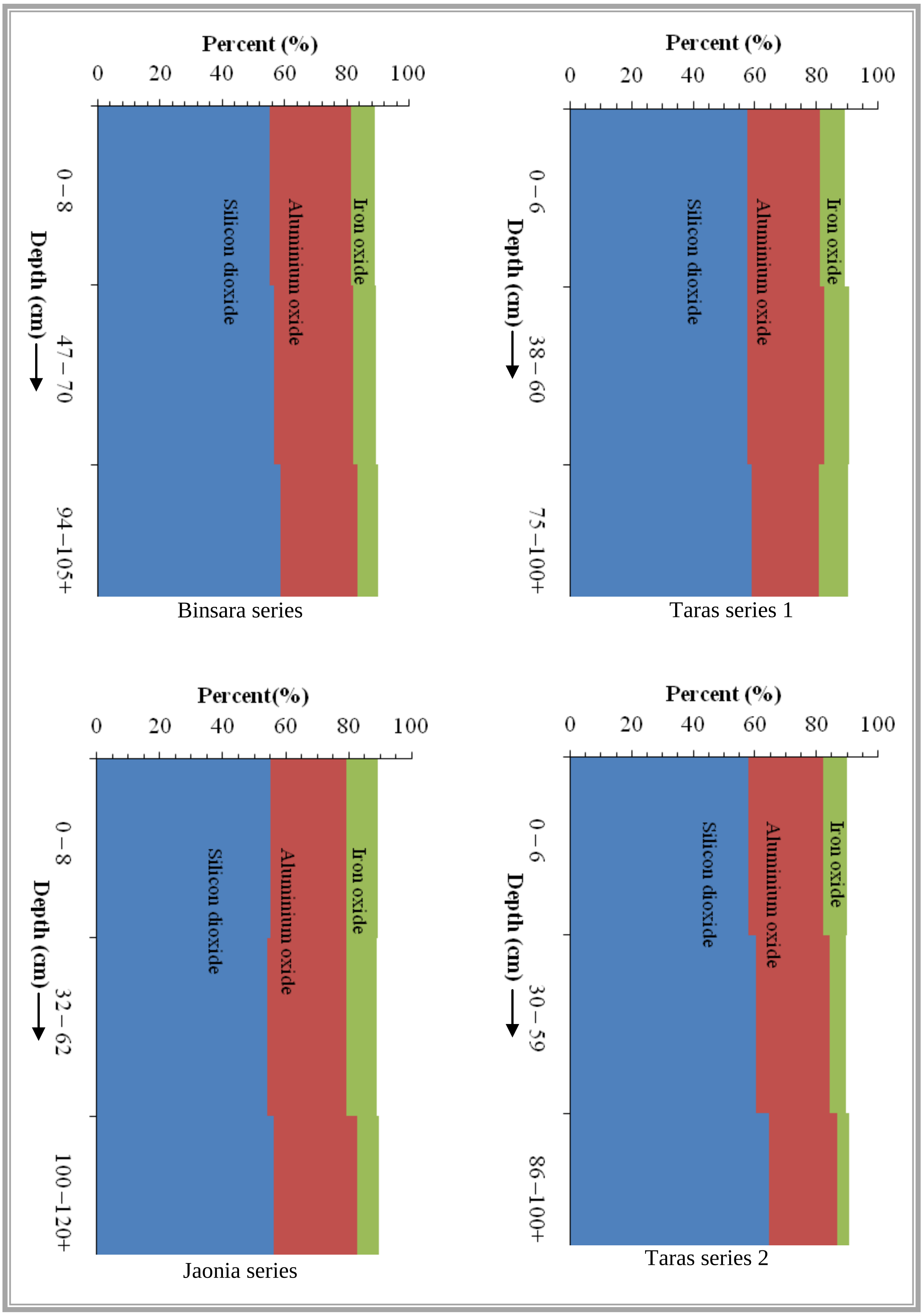


Fig 68. Vertical distribution of total silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) of the clay fraction of Binsara, Taras 1, Jaonia and Taras 2 series.

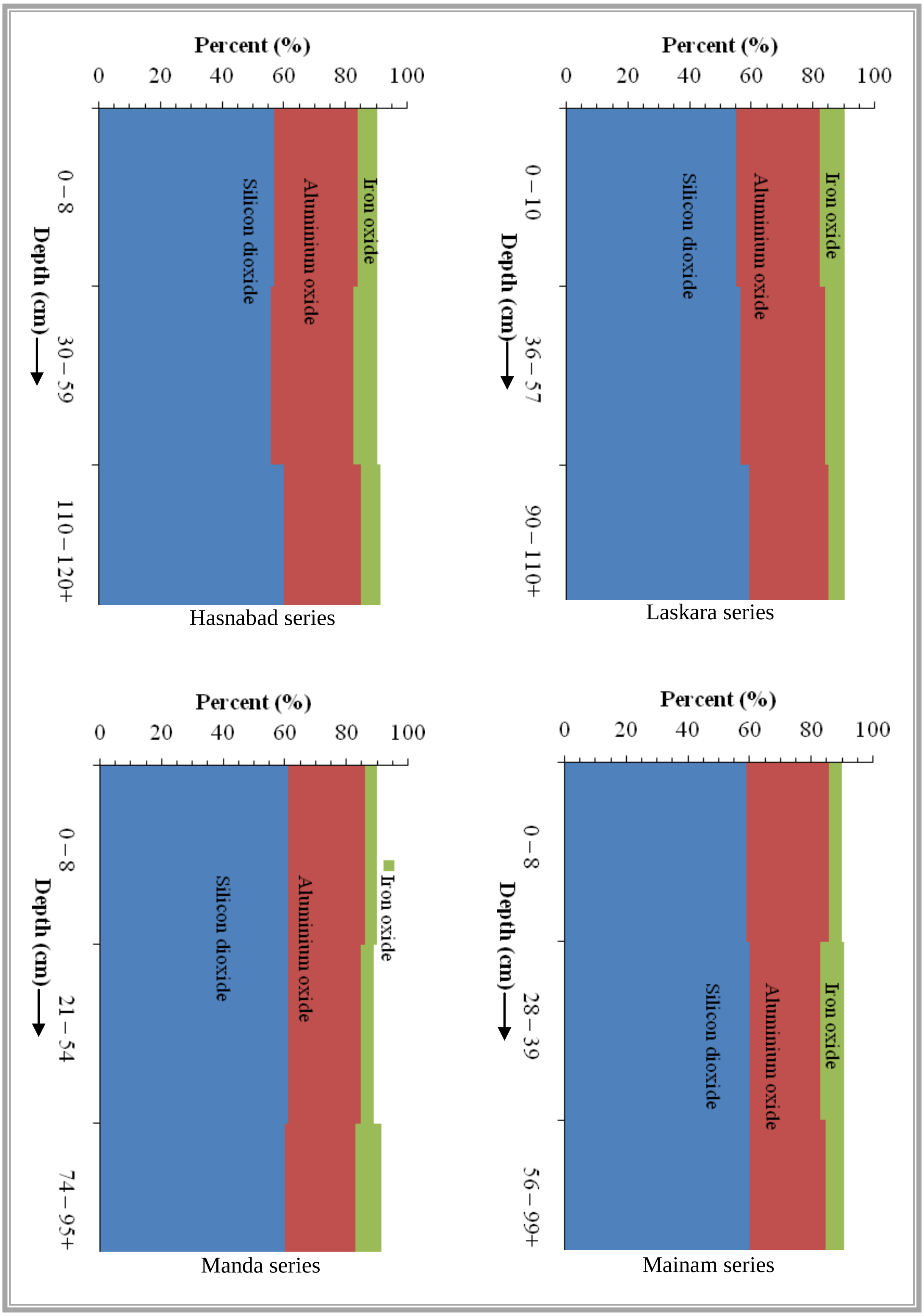


Fig 69. Vertical distribution of total silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) of the clay fraction of Hasnabad, Laskara, Manda and Mainam series.

Table 19. Content of total MgO, MnO_2 and Loss on ignition (LOI) of clay fraction of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	MgO	MnO_2	LOI*
		←	%	→
Binsara	Ap1g	4.2	0.01	15.0
	Bw2g	3.7	0.02	14.5
	C1g	3.5	0.01	11.6
	Mean	**3.8**	0.01	13.7
Taras (1)	Ap1g	4.0	0.01	15.7
	Bw2g	3.1	0.02	17.1
	C1g	3.5	0.02	16.1
	Mean	**3.5**	0.02	16.3
Jaonia	Apg	3.4	0.01	10.7
	Bw2g	3.8	0.02	16.9
	Cg	3.7	0.02	8.2
	Mean	**3.6**	0.02	11.9
Taras (2)	Ap1g	3.6	0.01	12.9
	Bw2g	3.5	0.01	13.2
	C1g	2.7	0.01	12.5
	Mean	**3.3**	0.01	12.9
Hasnabad	Ap1g	3.2	0.01	13.3
	Bw2	3.5	0.01	11.5
	C1	3.1	0.01	8.7
	Mean	**3.3**	0.01	11.2
Laskara	Ap1g	3.5	0.01	9.2
	Bw2	3.2	0.02	11.1
	C1g	3.5	0.01	12.8
	Mean	**3.4**	0.01	11.0
Manda	Apg	3.6	0.01	7.9
	C1	3.7	0.01	8.9
	C3	2.4	0.01	14.3
	Mean	**3.2**	0.01	10.4
Mainam	Ap1g	3.0	0.01	15.9
	C1	3.1	0.01	16.7
	C3	3.5	0.01	13.3
	Mean	**3.2**	0.01	15.3
Grand Mean		**3.4**	**0.01**	**12.8**

The Al_2O_3/Fe_2O_3 ratio in the clays of the studied pedons varies from 3.7 to 9.9 with an average value of 6.0 (Table 18). The vertical distribution of the ratio within the profiles shows an irregular trend.

The MgO content of the clay fraction ranges from 2.4 to 4.2 with a mean value of 3.4 percent (Table 19). The highest mean value of MgO content is found in Binsara soils whereas the lowest value is noticed in Manda and Mainam soils. The vertical distribution of MgO shows an irregular trend.

The MnO_2 content in the clay fraction of the studied soils varies from 0.01 to 0.02 percent with an average value of 0.01 percent (Table 19). It shows an irregular distribution pattern in all the profiles.

The loss on ignition (LOI) in the clay fraction of the soils under present study ranges from 7.9 to 17.1 percent with a mean value of 12.8 (Table 19). The loss on ignition of the clay fraction is found to be high. The highest mean value of loss on ignition in the clay fraction is found in Taras 1 soils where as lowest is noticed in the Manda soils. The vertical distribution pattern of loss on ignition shows an irregular trend (Table 19).

5.6.2 Potassium (K_2O) contents in soils and clay

Potassium originates in soils from some primary minerals such as muscovite, biotite, orthoclase and in altered phyllosilicates such as illite. 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 K (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 K (water soluble) 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 K bearing minerals in soil, release of exchangeable K from the inorganic colloidal complexes, the nutrient adsorption capacity and adsorption maxima of the organic colloids present in soil system.

The K_2O content in mineral soils usually ranges from 0.05 to 3.5 percent (Jackson, 1975). The distribution of potassium 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 micas than to the composition of the parent rock themselves (Jackson, 1964).

The analytical data of K_2O content of the soils and clay fractions are presented in Table 20. The K_2O contents in the studied soils vary from 2.12 to 3.6 percent with a mean value of 2.71 percent. Similar results were also reported in Bangladesh soils by Mazumder (1976); Chowdhury *et al. (*1992); Khan (1995); Mazumder (1996) and Rahman (2001).

Table 20. Total potassium (K_2O) contents in the soils and clay fractions of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	K_2O (%)		% Mica in clay fraction	
		Soil	**Clay**	Jackson (1975)*	Karim (1954)**
Binsara	Ap1g	2.82	4.43	44	55
	Bw2g	2.53	4.30	43	54
	C1g	2.38	3.73	37	47
	Mean	**2.58**	**4.15**	**42**	**52**
Taras (1)	Ap1g	2.75	4.30	43	54
	Bw2g	2.48	3.90	39	49
	C1g	2.69	3.80	38	48
	Mean	**2.64**	**4.00**	**40**	**50**
Jaonia	Apg	3.52	4.74	47	59
	Bw2g	3.60	4.20	42	53
	Cg	2.69	4.03	40	50
	Mean	**3.27**	**4.32**	**43**	**54**
Taras (2)	Ap1g	2.58	4.32	43	54
	Bw2g	2.86	4.18	42	52
	C1g	2.58	3.82	38	48
	Mean	**2.67**	**4.11**	**41**	**51**
Hasnabad	Ap1g	2.80	3.64	36	46
	Bw2	2.73	3.32	33	42
	C1	2.60	3.15	32	39
	Mean	**2.71**	**3.37**	**34**	**42**
Laskara	Ap1g	2.97	3.60	36	45
	Bw2	2.90	3.71	37	46
	C1g	2.73	3.67	37	46
	Mean	**2.87**	**3.66**	**37**	**46**
Manda	Apg	2.49	4.30	43	54
	C1	3.02	4.19	42	52
	C3	2.12	3.70	37	46
	Mean	**2.54**	**4.06**	**41**	**51**
Mainam	Ap1g	2.46	4.70	47	59
	C1	2.57	4.21	42	53
	C3	2.16	3.74	37	47
	Mean	**2.40**	**4.22**	**42**	**53**
Grand Mean		**2.71**	**4.00**	**40**	**50**

$$* \text{ \% Mica in clay} = \frac{\text{\% } K_2O \text{ in clay}}{10} \times 100 \qquad ** \text{ \% Mica in clay} = \frac{\text{\% } K_2O \text{ in clay}}{8} \times 100$$

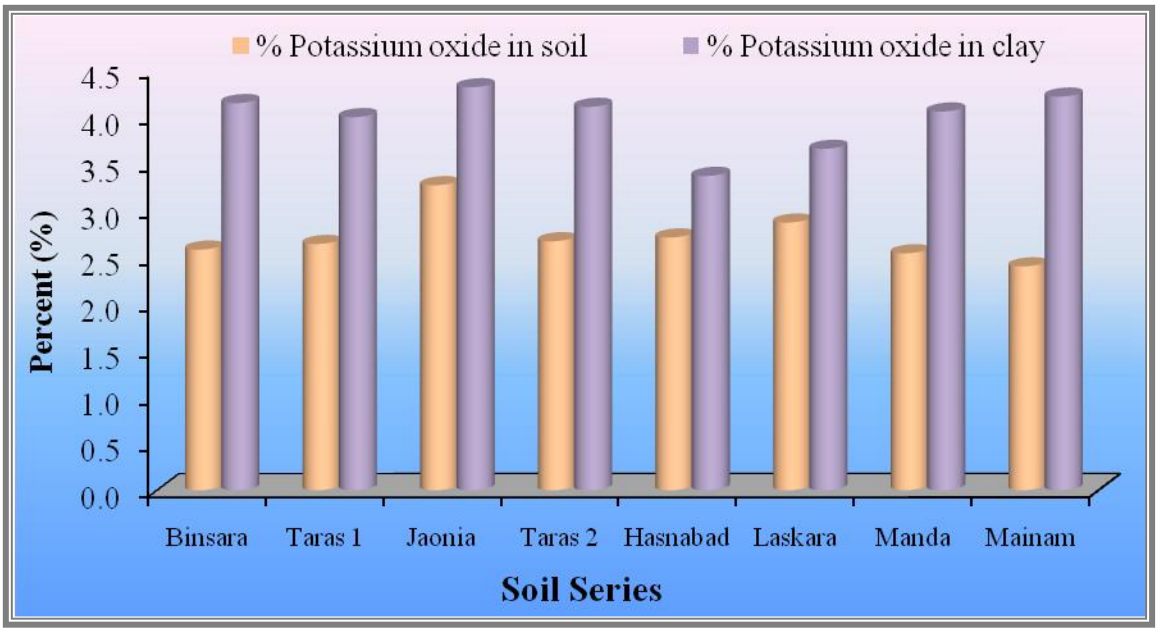


Fig 70. Graph shows mean value of total potassium oxide (K_2O) of the soils and clay fraction of the studied soils.

The above results indicates that the total potassium content is high, which may be due to the presence of abundant potassium bearing minerals like mica in the parent materials of the soils. In fact, mica flakes in some soil samples could be seen even with unaided eyes in the field. Presence of mica flakes in the soil under study also indicates that these soils are relatively young. The slightly higher value of K_2O contents are observed in the soils of the Jaonia profile whereas the lowest K_2O contents are found in the Mainam soils (Fig 70). This variation in K_2O content is due probably to the variation in the K-bearing minerals in their parent materials (Laves, 1978; Mengel and Kirkby, 1982).

The vertical distributions of K_2O content in soils profiles are in general irregular in nature (Figs 71 & 72). However, a little accumulation of K_2O content in the B-horizon of the Jaonia, Taras 2, Manda and Mainam profiles is noticed. In the Binsara, Taras 1, Hasnabad and Laskara profiles there is an increasing tendency of K_2O content in the surface horizons of some profiles (Figs 71 & 72). The impoverishment of K_2O content from the surface horizon of Jaonia, Taras2, Manda and Mainam profiles suggests that the mica present in this horizon are being weathered and potassium is being lost from their interlattice space forming illite/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 studied soils 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.

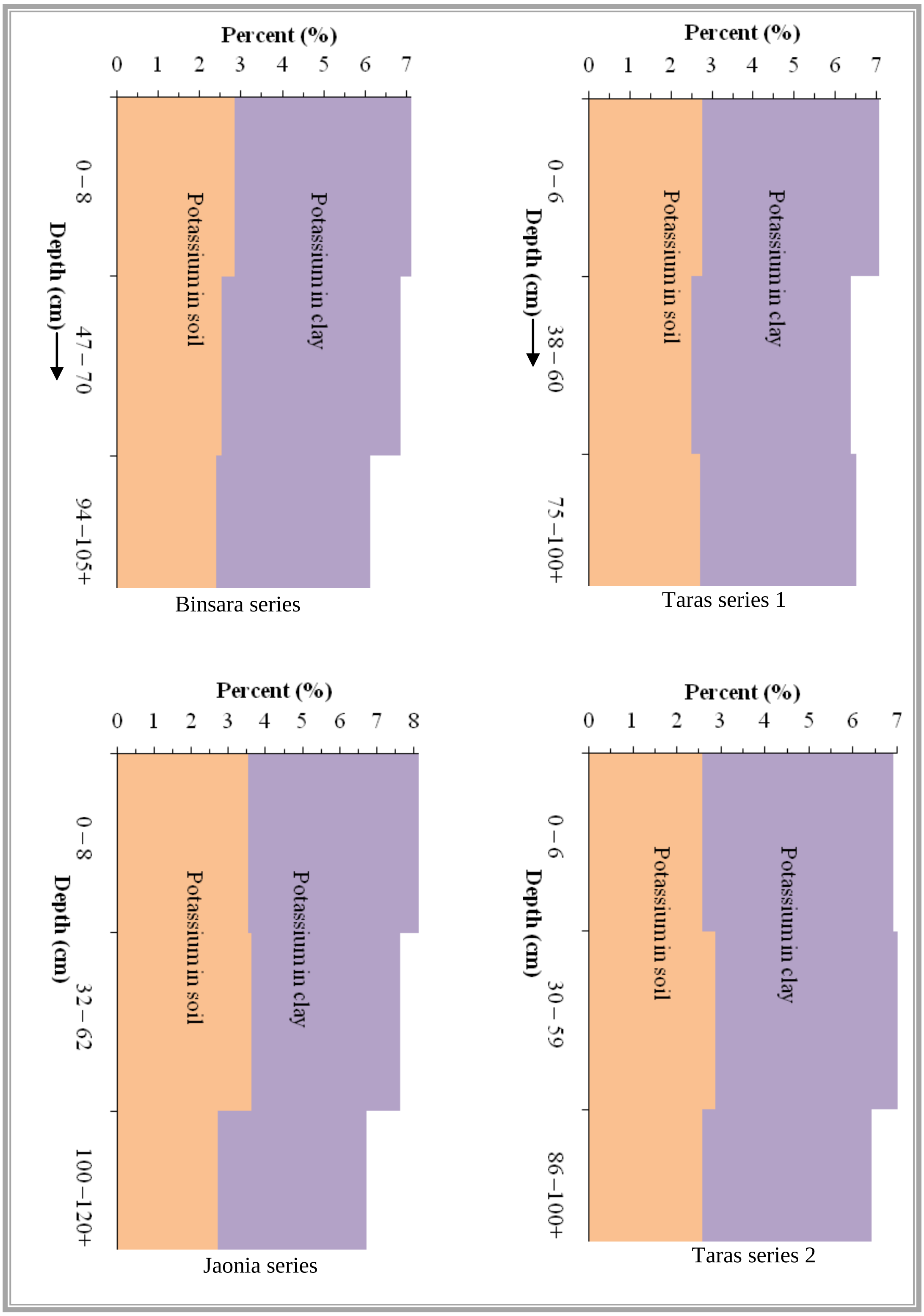


Fig 71. Vertical distribution of total potassium oxide (K_2O) of the whole soils and clay fraction of Binsara, Taras 1, Jaonia and Taras 2 series.

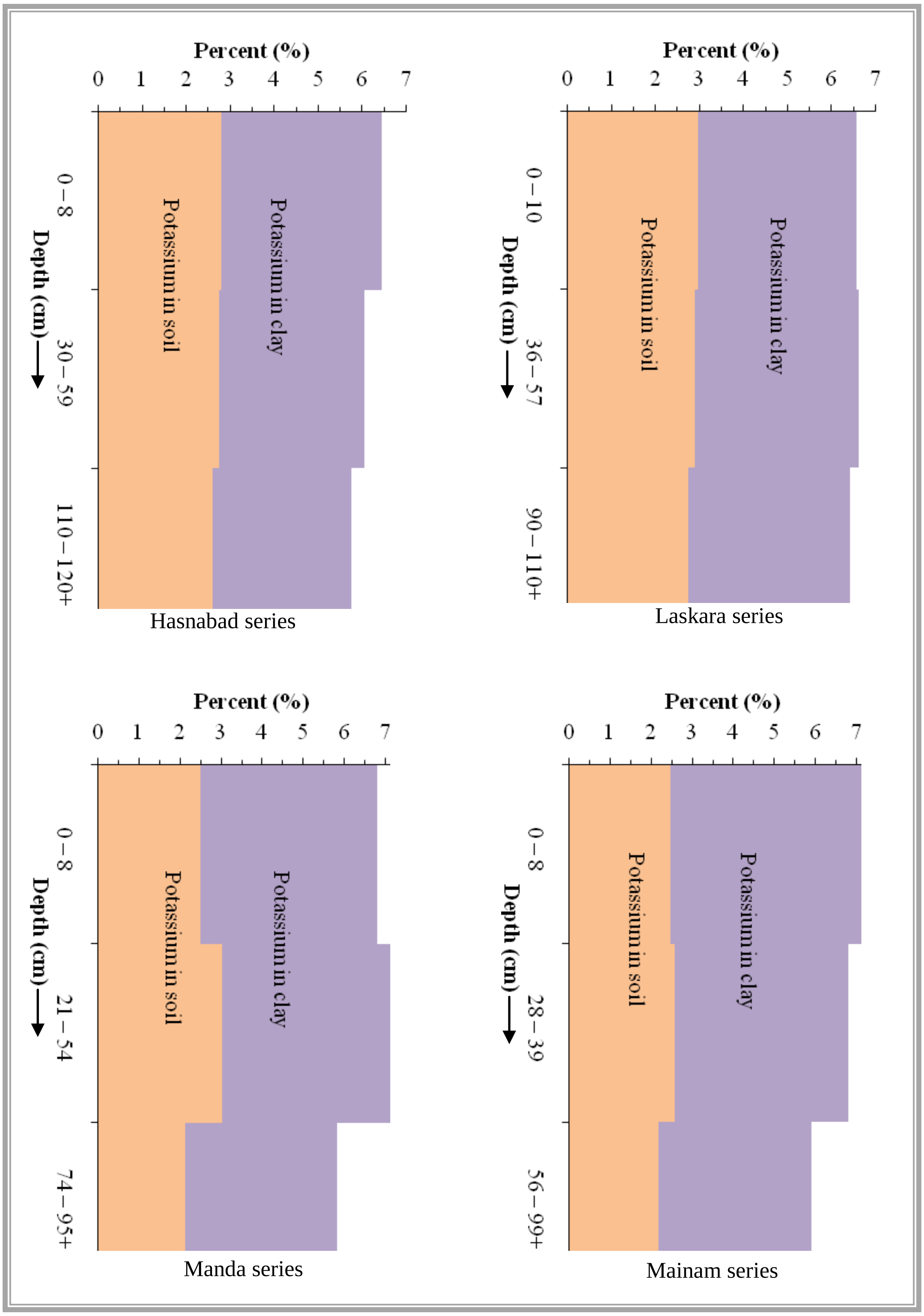


Fig 72. Vertical distribution of total potassium oxide (K_2O) of the whole soils and clay fraction of Hasnabad, Laskara, Manda and Mainam series.

Potassium in the clay fraction

The amount of K_2O in the clay fraction varies from 3.15 to 4.74 percent with a mean value of 4.00 percent (Table 20). The highest amount of K_2O content in the clay fraction is observed in the Jaonia profile while the lowest amount is found in the Hasnabad profiles (Fig 70). This variation of K_2O content in the clay fraction is due to the variation 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 profiles is irregular (Figs 71 & 72). In the Binsara, Taras 1, Jaonia, Hasnabad and Mainam profiles there is a surface enrichment of K_2O content in the clay fraction. However, in the Taras 2, Laskara and Manda profile there is a tendency of K_2O impoverishment in the upper horizons (Figs 71 & 72). A rough estimation of mica minerals in the clay fractions can be made from their K_2O content using Karim's (1954) and Jackson's (1975) method. The former author used 8 percent K_2O and the latter used 10 percent K_2O for 100 percent mica.

In the clay fraction potassium is usually present in mica minerals. The amount of mica minerals can be approximately estimated when it is assumed that there is no other potassium bearing minerals in the clay fraction except mica. It is clear that there is abundant mica minerals present in the clay fraction. The amount varies from 32 to 47 percent (Table 20). The highest mica is present in the Jaonia soil profile while the lowest amount is found in the Hasnabad profiles.

The mean mica content is 40% in the clay fraction of the soils found on the lower Atrai basin by Jackson's (1975) method. But according to Karim's (1954) method, the mean mica content in the clay fraction is 50 percent. If such a high quantity of mica is present in the soils under present investigation which indicates that the supply of potassium for consumption by plants will be adequate and there will be little need for application of potassic fertilizer for optimum crop production.

5.6.2 Titanium (TiO_2) content in soils and clays

The importance of titanium (TiO_2) as an index mineral in pedogenesis was recognized long ago. Dunington in 1891 was the first to come forward with a positive approach to the study of TiO_2 in soils. Since then many authors have worked on the profile distribution of this element in different soils and their respective clay fraction.

The results of titanium oxide (TiO_2) in the soils and clays under the present investigation are shown in Table 21. The titanium (TiO_2) content in the studied soils varies from 0.7 to 1.53 percent and the average titanium content is 1.17 percent. The highest mean value of TiO_2 among the studied profiles was found in the Jaonia soil and the lowest was in the Mainam soil (Fig 73). Similar results were obtained in Combodia, Indonesia, Malaysia, Philipines and Tropical Asia in rice soils (Kyuma, 1978), and in some floodplain soils of Bangladesh (Hussain and Islam, 1979; Khan *et al.*, 1997; Mazumder, 1996 and Rahman, 2001).

The vertical distribution of TiO_2 in soils from the surface downward follows an irregular pattern in all the soil profiles (Figs 74 & 75). Although the distribution pattern is irregular, in all the profiles slight depletion of TiO_2 from the surface horizons may be noticed except Manda profiles (Figs 74 & 75). Immediately below the surface a zone of accumulation of TiO_2 is observed. This zone of accumulation may be important from pedogenic point of view. This irregular distribution pattern indicates that the TiO_2 content has been affected by the present cycle of pedogenic processes and the soils are not sufficientl mature. The above facts also indicate that the titanium minerals in the present soils are allogenic.

As the present soils are seasonally flooded, this seasonal flooding creates an environment of alternate oxidation and reduction conditions throughout the year. Under this situation redistribution of TiO_2 in the soil profiles is very much natural (Sherman, 1952). The reason as to why titanium is not being preferentially accumulated anywhere in the soil profiles is not clear. However, strong alternate oxidation-reduction conditions have been found to cause movement and removal of titanium, in some other soils (Hussain and Islam, 1979).

The TiO_2 content in clay fraction ranges from 0.98 to 1.96 percent and the average value 1.56 percent (Table 21). The TiO_2 content in the clay fraction is 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 Stein Koening (1914); Gileman (1920); Robinson and Holmes (1924).

Table 21. Total titanium (TiO_2) contents in the soils and clay fractions of the lower Atrai basin soils of Bangladesh.

Soil Series	**Horizon**	**%TiO_2**	
		Soil	**Clay**
Binsara	Ap1g	1.14	1.76
	Bw2g	1.31	1.93
	C1g	1.27	1.75
	Mean	**1.24**	**1.81**
Taras (1)	Ap1g	1.10	1.52
	Bw2g	1.29	1.71
	C1g	1.23	1.66
	Mean	**1.21**	**1.63**
Jaonia	Apg	1.41	1.86
	Bw2g	1.53	1.96
	Cg	1.34	1.78
	Mean	**1.43**	**1.87**
Taras (2)	Ap1g	1.11	1.48
	Bw2g	1.31	1.66
	C1g	1.27	1.43
	Mean	**1.23**	**1.52**
Hasnabad	Ap1g	1.32	1.89
	Bw2	1.43	1.83
	C1	1.36	1.78
	Mean	**1.37**	**1.83**
Laskara	Ap1g	1.21	1.53
	Bw2	1.29	1.64
	C1g	1.07	1.55
	Mean	**1.19**	**1.57**
Manda	Apg	0.92	1.32
	C1	0.96	1.27
	C3	0.77	0.99
	Mean	**0.88**	**1.19**
Mainam	Ap1g	0.89	1.08
	C1	0.86	1.12
	C3	0.70	0.98
	Mean	**0.82**	**1.06**
Grand Mean		**1.17**	**1.56**

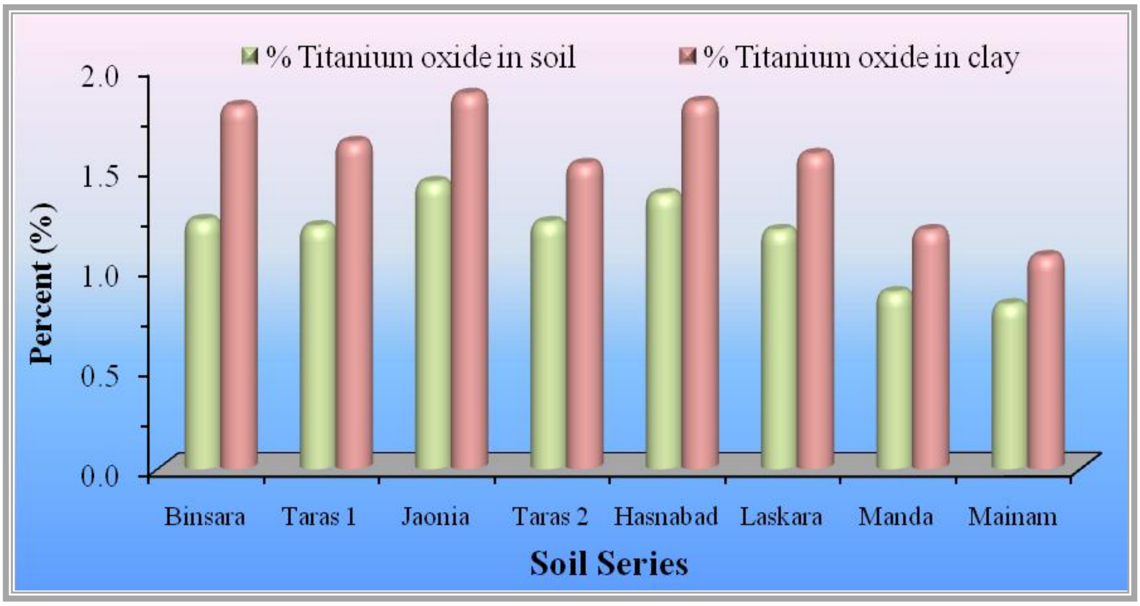


Fig 73. Graph shows mean value of total titanium oxide (TiO_2) of the soils and clay fraction of the studied soils.

The highest mean value of titanium (TiO_2) in clay fraction among the profiles is observed in Jaonia soil and the lowest mean value was in Mainam soil (Fig 73). 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 enter the octahedral layers of clay minerals (Jackson and Sherman, 1953; Brian, 1976 and Hutton 1977), because titanium can isomorphously substitute aluminium in the octahedral layer of clay lattice. The vertical distribution of TiO_2 in clays from the surface downward shows an irregular pattern in all the soil profiles (Figs 74 & 75). The irregular distribution of TiO_2 in the colloidal fraction indicates that the parent material is the possible source of this element in the colloids. The variations in titanium content suggest heterogeneity of parent material in these soils (Smith and Wilding, 1972; Evans and Adams, 1975; Sharma and Dev, 1985).

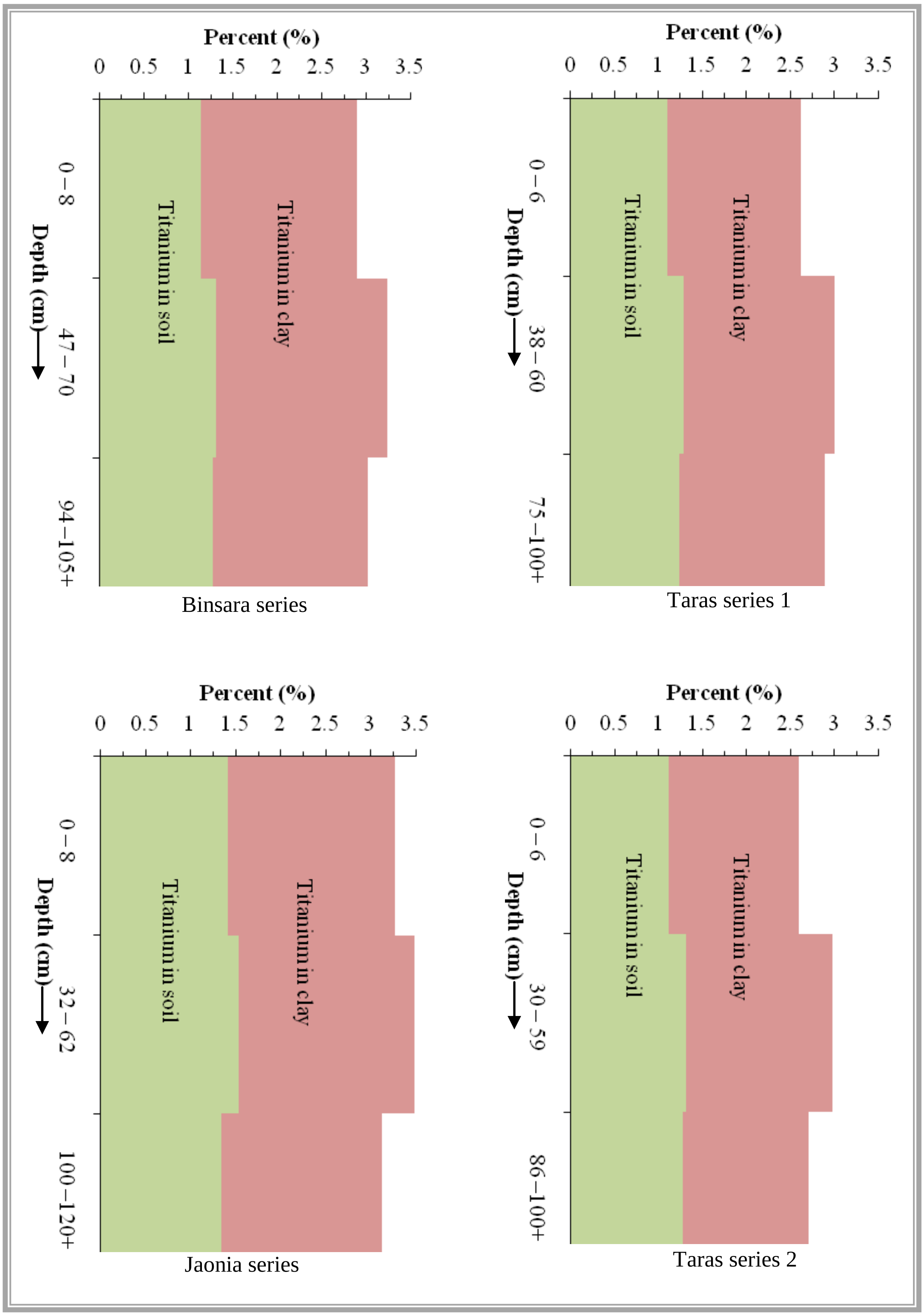


Fig 74. Vertical distribution of total titanium oxide (TiO_2) of the whole soils and clay fraction of Binsara, Taras 1, Jaonia and Taras 2 series.

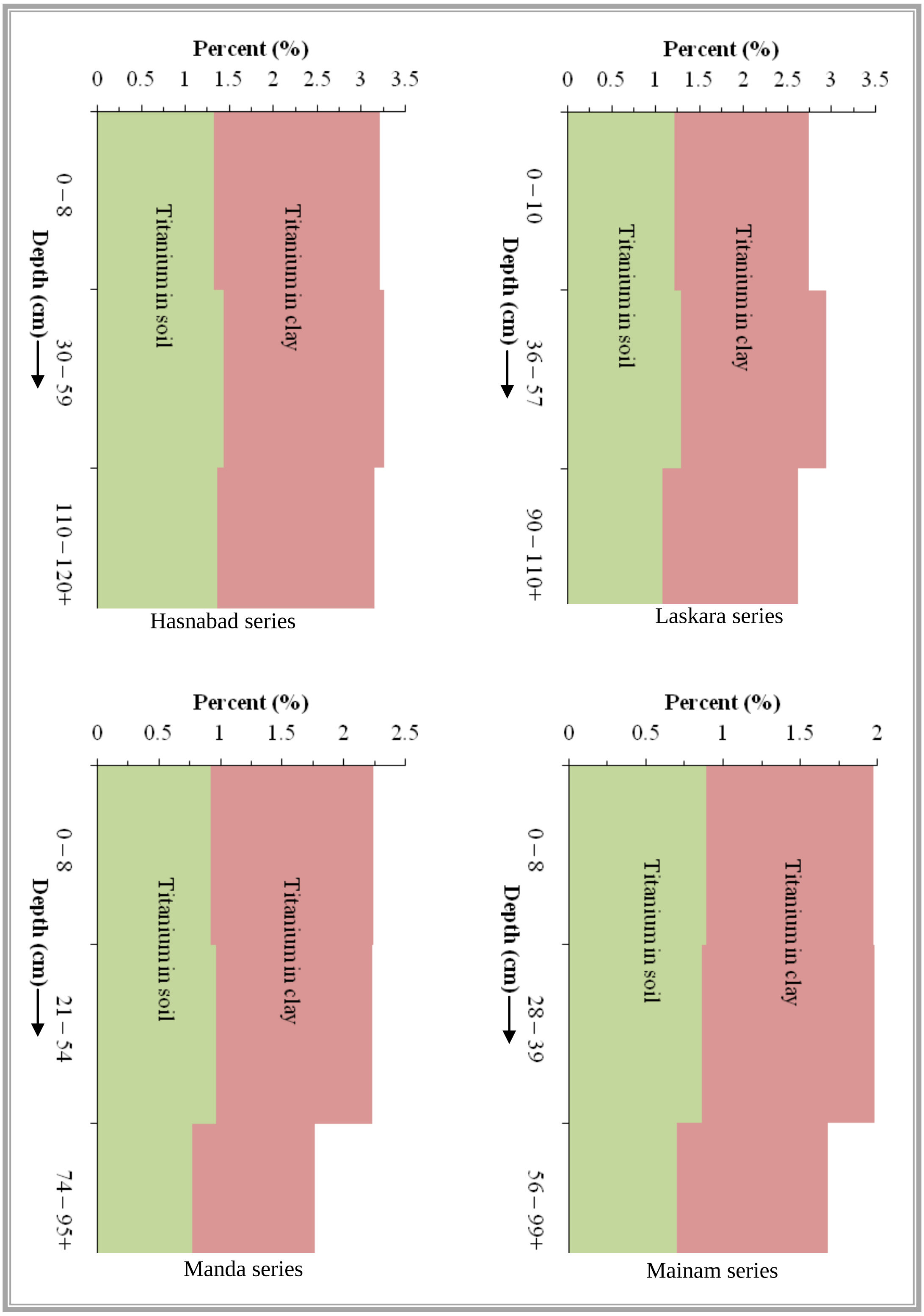


Fig 75. Vertical distribution of total titanium oxide (TiO_2) of the whole soils and clay fraction of Hasnabad, Laskara, Manda and Mainam series.

5.7 Mineralogical analysis of clay fraction (<2µm)

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

Mineral contents in the clay fraction are used as an important criterion for soil classification (Soil Survey Staff, 2014). The most intensive use of clay mineral data in the Comprehensive Soil Classification System was needed for soil characterization at family level. X-ray diffraction technique was used to identify as well as to estimate the quantity of minerals in the clay fraction.

The X-ray diffraction patterns of the clay fraction (<2µm) of the Binsara, Taras 1, Jaonia, Taras 2, Hasnabad, Laskara, Manda and Mainam soils are presented in Figures 77 - 84. Peaks are generally broad, indicating poor crystallinity and/or small crystal size of the minerals in the Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara soils, while sharp peaks are formed in Manda and Mainam soils indicating good crystallinity and/or large crystal size of the minerals. Mica was identified by the presence of the 10Å reflection appearing in all the treatments in all the soils. The presence of smectite is noticed by the small broad bulge around 17.7Å in the Mg-saturated and glycerol-solvated specimen, but it was not identified as a discrete phase in the present soils except Taras 1 soil. Chlorite was detected by the reflection at 14.2Å and its rational orders and by the remaining of the 14.2Å reflection in the K-saturated and 550°C-heated specimen. The presence of kaolinite was suggested by the peaks or shoulders at 7.15Å and 3.57Å in the Mg-saturated specimen. Vermiculite was identified by the decrease in the peak intensity of the 14.2Å reflection with the corresponding increase in the peak intensity of the 10Å reflection by shifting from Mg-saturation to K-saturation followed by air-drying. The presence of vermiculite-chlorite intergrade is ascertained by the decrease in the peak intensity of the 14.2 Å reflection by heating in the k-saturated specimen and it was positively detected in Hasnabad and Laskara soils. The presence of the interstratified mica-chlorite mineral is suggestive by the presence of peak at 12.1Å in all the treatments, while it is considered the interstratified mica-vermiculite mineral when the peak collapses on K-saturation. The poorly defined diffraction effect between 10Å and 20Å in the Mg-saturated and glycerol-solvated specimen and the great increase in the peak intensity of the 10Å reflection after K-saturation is an indication of the interstratified mica-vermiculite-smectite minerals (Egashira, 1988). This three component minerals is detected in Hasnabad and Laskara soils. The reflections of 6.27Å, 4.25Å, 4.18Å and 3.2Å were indicative of identification of lepidocrocite, quartz, goethite and feldspar minerals, respectively.

The approximate mineral composition of the <2µm clay fraction of the present soils was estimated based on the relative peak intensities of the respective minerals in the XRD charts following Moslehuddin and Egashira (1996), as is presented in Table 22. The results indicated that mica (41 to 59%) was the most dominant mineral in all soils except Laskara.

In Laskara soils the interstratified mica-vermiculite-smectite (41%) was the dominant mineral followed by mica (28%). Next to mica, kaolinite (10 to 12%) was found to be present in the Binsara, Taras 1, Jaonia and Taras 2 soils. Chlorite (7 to 17%) was identified in all the soils and was found to be the second dominant mineral in the Manda and Mainam soils followed by vermiculite (12% and 13%), whereas the interstratified mica-vermiculite-smectite (33%) were found to be the second dominant mineral in the Hasnabad soils. Small amounts of vermiculite mineral (1 to 13%) were identified in almost all the soils except Binsara soil. Only Hasnabad and Laskara soils have the interstratified mica-vermiculite-smectite and vermiculite-chlorite minerals. All the soils have the interstratified mica-chlorite minerals (2 to 7%). Very little amount of smectite (1%) was identified in Taras 1 soil.

As minerals other than layer silicates, quartz (2 to 16%) was present in all the soils. Lepidocrocite was found in smaller amounts (2 to 7%) in Binsara, Taras 1 and Jaonia soils. Feldsper (4%) was identified in Binsara soils and goethite (3%) was present in Taras 2 soils. These results suggest that the soils under study are derived from parent materials containing fine grained quartz mineral in the clay fraction. Clay mineralogical composition was hardly influenced by the land type.

The results indicated that mica (41 to 59%) was the most predominant mineral in all soils except Laskara. In Laskara soils the interstratified mica-vermiculite-smectite (41%) was the most predominant mineral followed by mica (28%). Next to mica, kaolinite (10 to 12%) was found to be dominant in the Binsara, Taras 1, Jaonia and Taras 2 soils followed by chlorite. Chlorite (7 to 17%) was identified in all the soils and found to be second dominant mineral in the Manda and Mainam soils followed by vermiculite (12% and 13%), whereas the interstratified mica-vermiculite-smectite (33%) were found to be second dominant mineral in the Hasnabad soils. Small amounts of vermiculite (1 to 13%) were identified in almost all the soils except Binsara soils. Only Hasnabad and Laskara soils had the interstratified mica-vermiculite-smectite and vermiculite-chlorite minerals, while all the soils had the interstratified mica-chloride minerals (2 to 7%). Very little amount of smectite (1%) was identified in Taras 1 soils.

Minerals, other than layer silicates, such as quartz (2 to 16%) was present in all the soils, lepidocrocite was found in smaller amounts (2 to 7%) in Binsara, Taras 1 and Jaonia soils, feldsper (4%) was identified in Binsara soils and goethite (3%) was present in Taras 2 soils. This result suggests that the soils are derived from parent materials containing fine grained quartz mineral in the clay fraction. Clay mineralogical composition was hardly affected by the land type and general soil type.

Table 22. Semi-quantative estimation of minerals in the clay fraction (<2µm) of the lower Atrai basin soils of Bangladesh.

Soil Series	Horizon	Depth (cm)	% Mineral content*												Soil Mineralogy class (USDA)
			Mc	Sm	Vt	Ch	Kt	Vt-Ch	Mc/Vt/St	Mc/Ch	Qr	Gt	Lp	Fd	
Binsara	Surface	0 – 8	52	-	-	7	10	-	-	4	16	-	7	4	Illitic
Taras 1	Surface	0 – 6	56	1	4	7	10	-	-	5	14	-	3	-	Illitic
Jaonia	Surface	0 – 8	59	-	4	8	10	-	-	2	15	-	2	-	Illitic
Taras 2	Surface	0 – 6	55	-	3	8	12	-	-	5	14	3	-	-	Illitic
Hasnabad	Surface	0 – 8	41	-	1	9	9	1	33	4	2	-	-	-	Mixed
Laskara	Surface	0 – 10	28	-	1	7	7	2	41	7	7	-	-	-	Mixed
Manda	Surface	0 – 8	55	-	12	17	8	-	-	4	4	-	-	-	Illitic
Mainam	Surface	0 – 8	59	-	13	15	5	-	-	4	4	-	-	-	Illitic

***According to the methods 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,

Discussion on individual minerals

In the clay fraction of the lower Atrai basin soils, mica was found to be predominant mineral in all soils and ranges from 28 to 59 percent (Fig 76). Results indicate that high amount of mica present in lower Atrai basin soils. Moslehuddin *et al.* (2006) was found the similar results in clay fraction (<2µm) of the lower Atrai basin soils. Akter *et al.* (2015), Reza *et al.* (2013), Khan and Ottner (2010), Uddin *et al.* (2009a), Iftekhar *et al.* (2004), Moslehuddin *et al.* (1999), Moslehuddin *et al.* (2008), Islam and Hussain (2008b), Khan *et al.* (1997), Aramaki (1996), Mazumder (1996), Egashira and Yasmin (1990), Islam *et al.* (1988) also found that mica was the predominant clay minerals in almost all floodplain soils of Bangladesh. 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 clay mineralogy of younger and less weathered soils (Entisols, Inceptisols, Alfisols). 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).

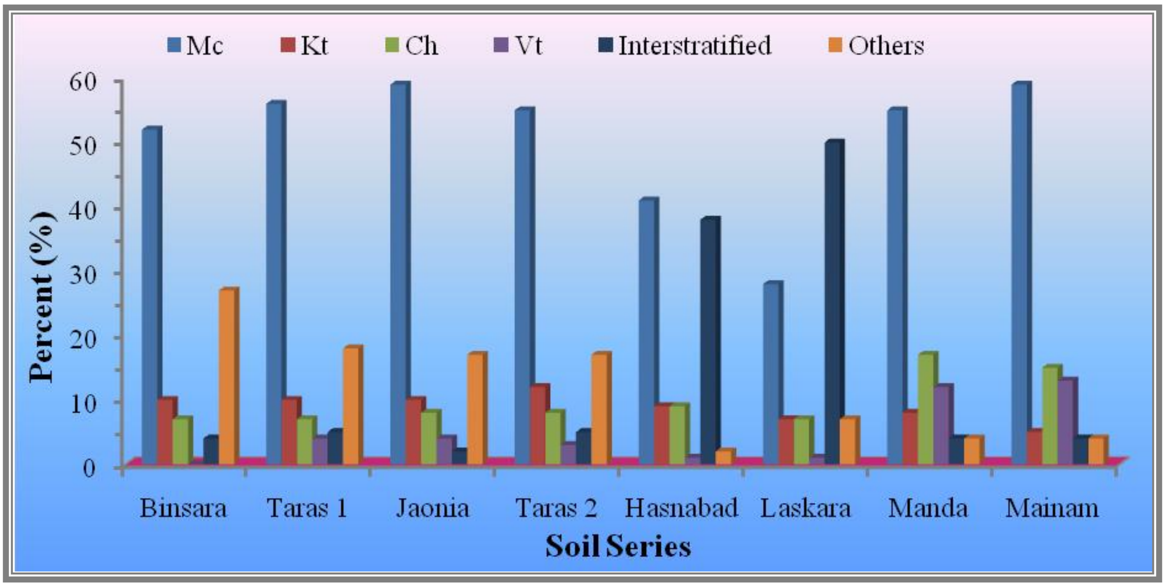


Fig 76. Graph shows the mineral composition of the clay fraction (<2µm) of the surface soils of the lower Atrai basin.

The soils under present study contain 5 to 12 percent kaolinite in the clay fraction (Table 22). Kaolinite was present in all the soils but in small amounts, although this mineral was dominant in four soils. Akter *et al.* (2015), Moslehuddin *et al.* (2008) and Moslehuddin *et al.* (2006) found similar result in their study. Dixon (1977) noted that.

Brady (1994) and Jackson and Sherman (1953) stressed that kaolinite represents a more advanced stage of weathering than does any other major types of silicate clays and formed from the decomposition of silicates under conditions of moderate to strong acid weathering environment which results in the removal of the alkalies and alkaline earth metals. Gupta *et al.* (1984) noted that kaolinite usually forms under well drained condition through the weathering of feldspars. In the floodplain soils of Bangladesh the kaolinite mineral is thought to be allogenic in nature and are believed to be derived from parent material.

The lower Atrai basin contains 7 to 17 precent chlorite (Table 22) in the clay fraction of all the soils. Although this amount was small but chlorite was dominant in Manda and Mainam soils. This findings are in agreement with that of Kader *et al.* (2015), Moslehuddin *et al.* (2006), Shamsuzzoha *et al.* (2003), Moslehuddin and Egashira (1996). Barnhisel (1977) stated that chlorites in soils are largely inherited as primary minerals, found in metamorphic or igneous rocks or occur as alteration products from minerals such as hornblende, biotite and other ferromagnesian minerals. The abundance and frequency of occurrence of chlorites in soils are relatively low and their geographical distribution is related to the parent materials. The low frequency may be due to the low stability of chlorite, or to the difficulty of distinguishing small amount of chlorite in the presence of kaolinite, vermiculite and smectite, especially if the latter minerals contain hydroxyl-Al (or Fe) interlayers.

The occurrence of 1 to 13 percent vermiculite (Table 22) in the clay fraction (<2µm) of all soils except Binsara soils may lead one to conclude that the transformation of mica is considerable. Douglas (1977) stated that soil vermiculites are nearly always reported to accompany; or as an alteration product of muscovite, biotite and chlorite. In soil, dioctahedral vermiculite is more common than trioctahedral vermiculite (Jackson, 1959), probably indicating the relative stability of the muscovite structure, or a stability promoted by the presence of hydroxyl-Al interlayers. Vermiculite can form in many different soil environments, from a variety of parent materials. The transformation of mica to vermiculite during pedogenesis has been reported by Douglas (1977). For vermiculite to persist under intense weathering condition or for long period of time, the normal weathering sequence is: mica > vermiculite > hydroxyl aluminum > interlayered vermiculite.

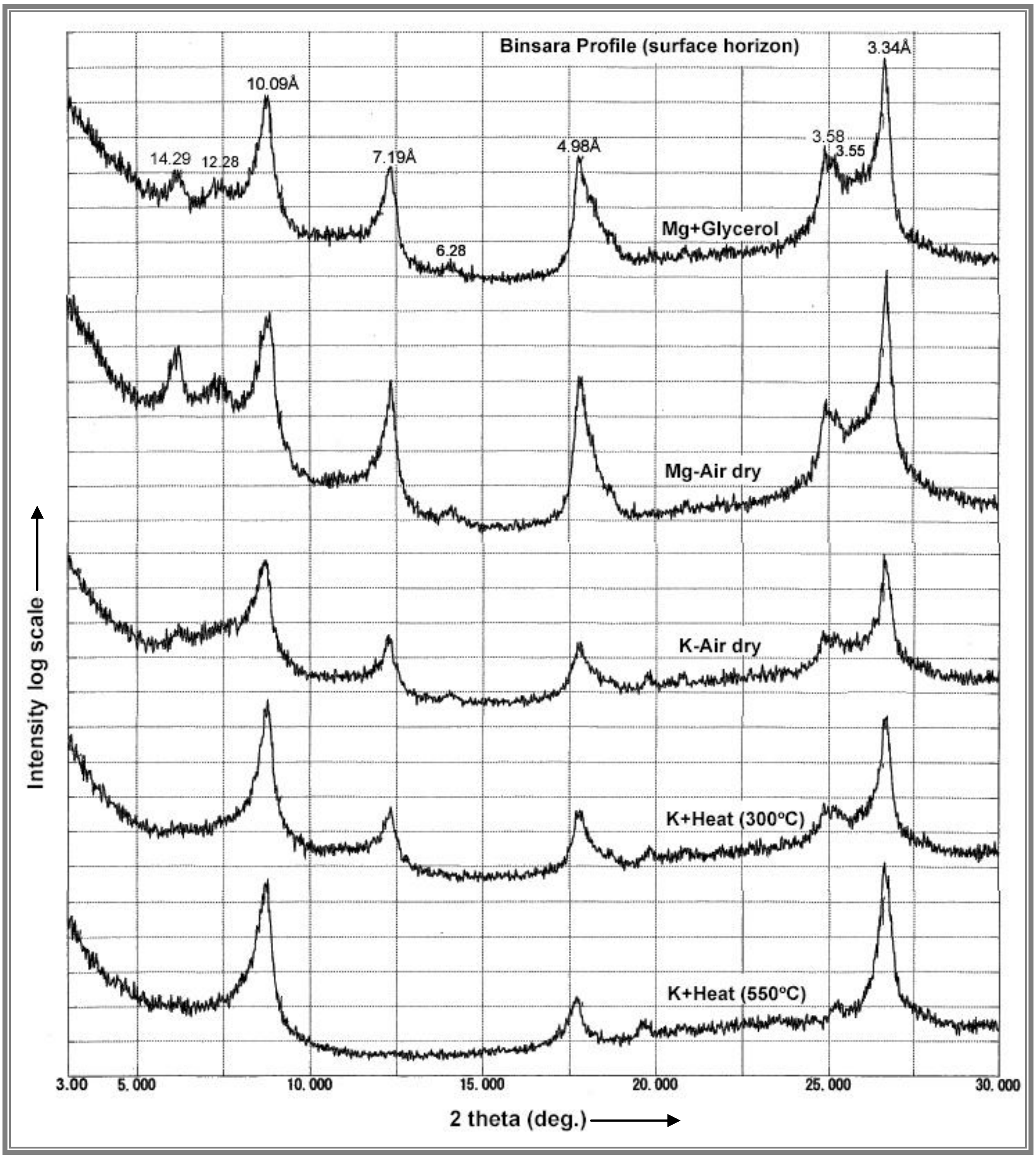


Fig 77. X-ray diffractograms of clay sample from surface horizon of Binsara soil.

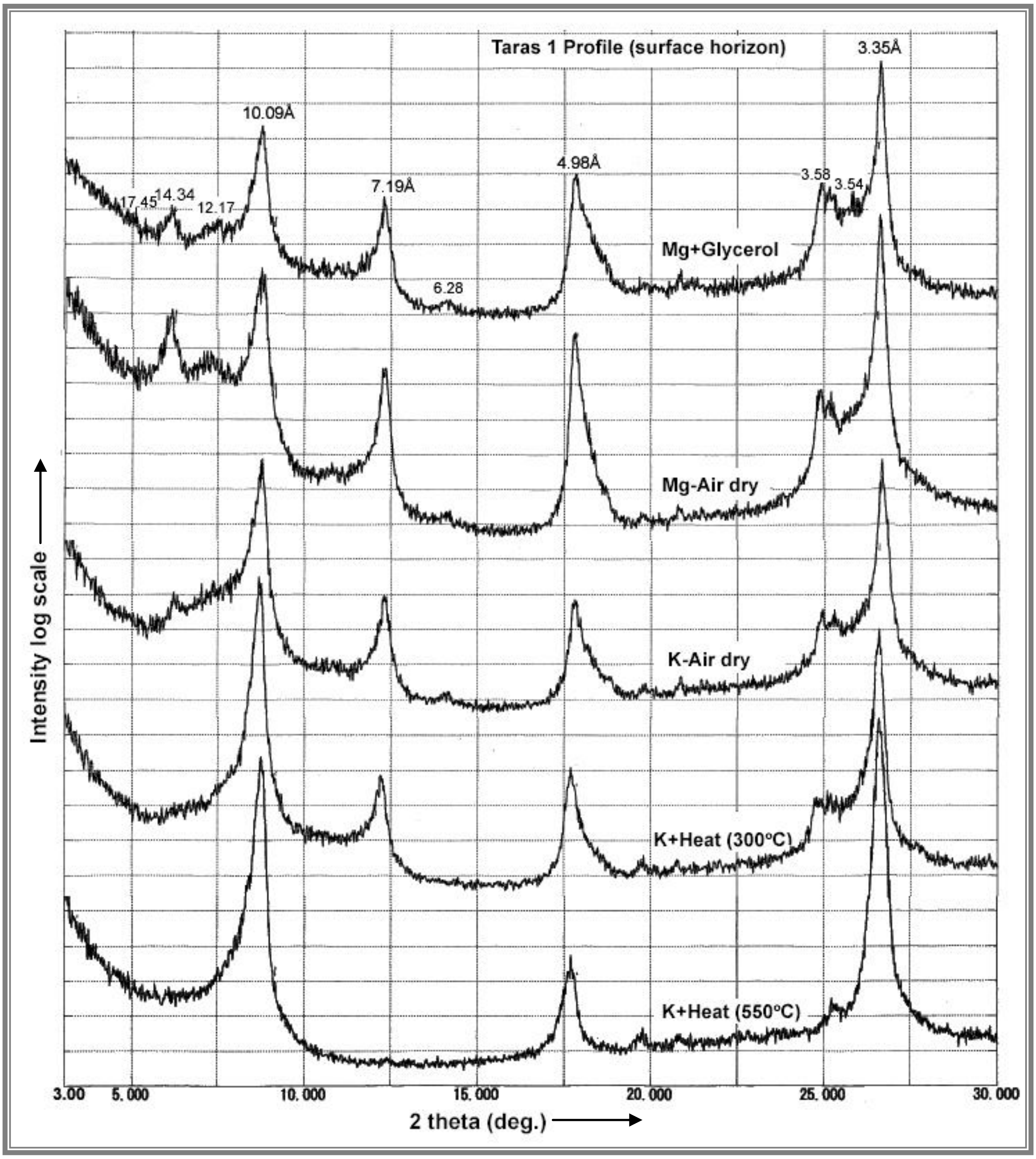


Fig 78. X-ray diffractograms of clay sample from surface horizon of Taras 1 soil.

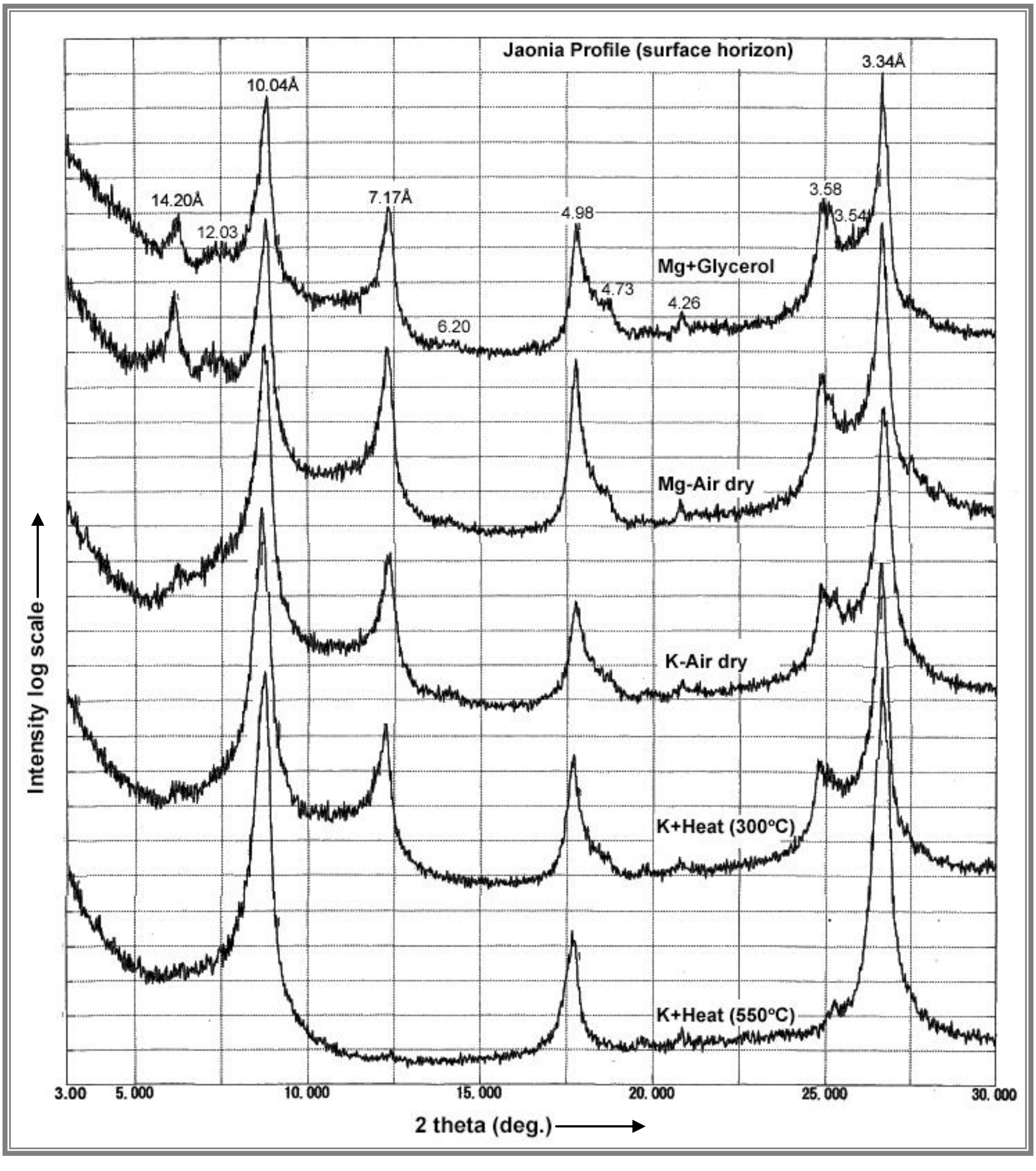


Fig 79. X-ray diffractograms of clay sample from surface horizon of Jaonia soil.

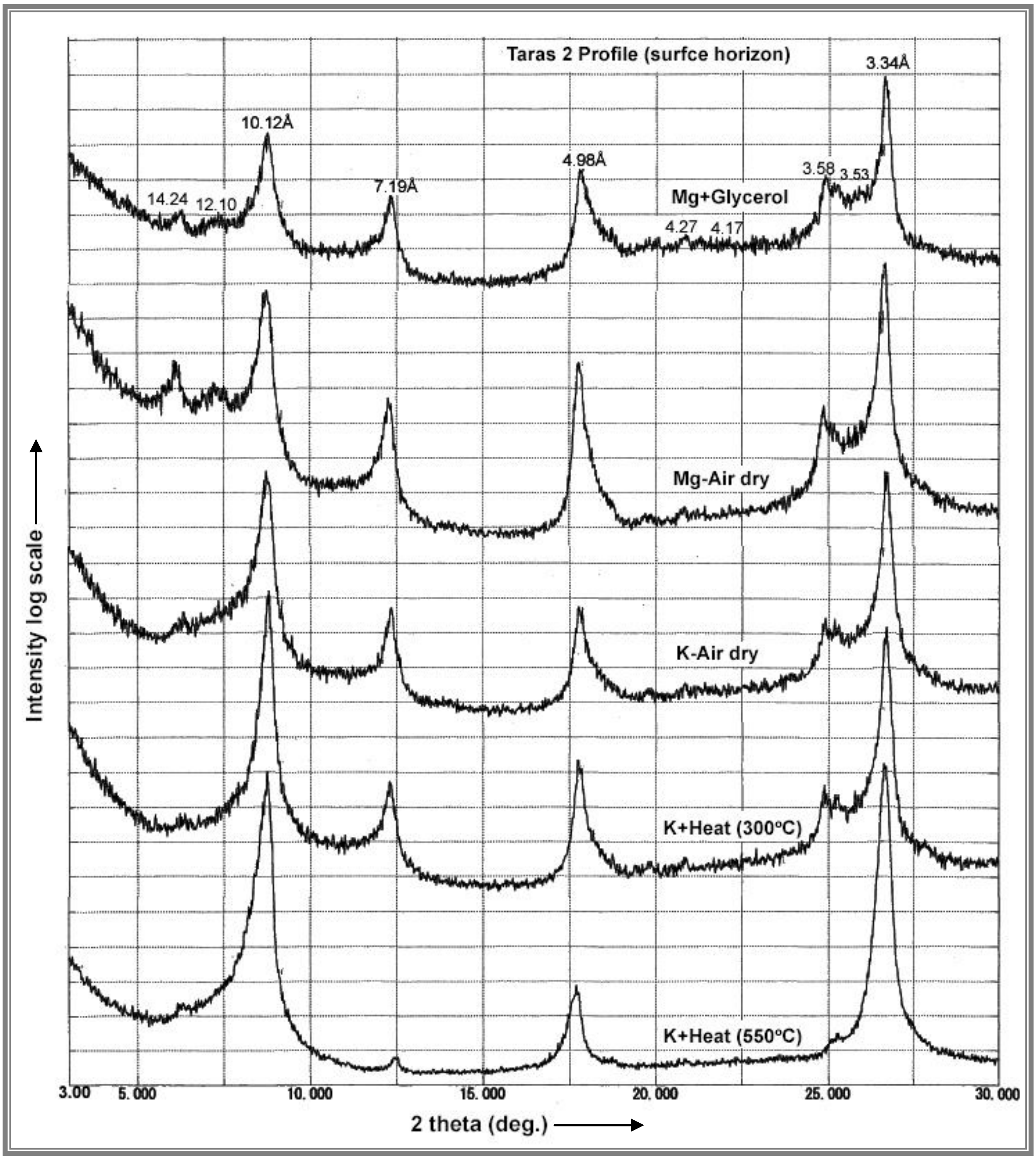


Fig 80. X-ray diffractograms of clay sample from surface horizon of Taras 2 soil.

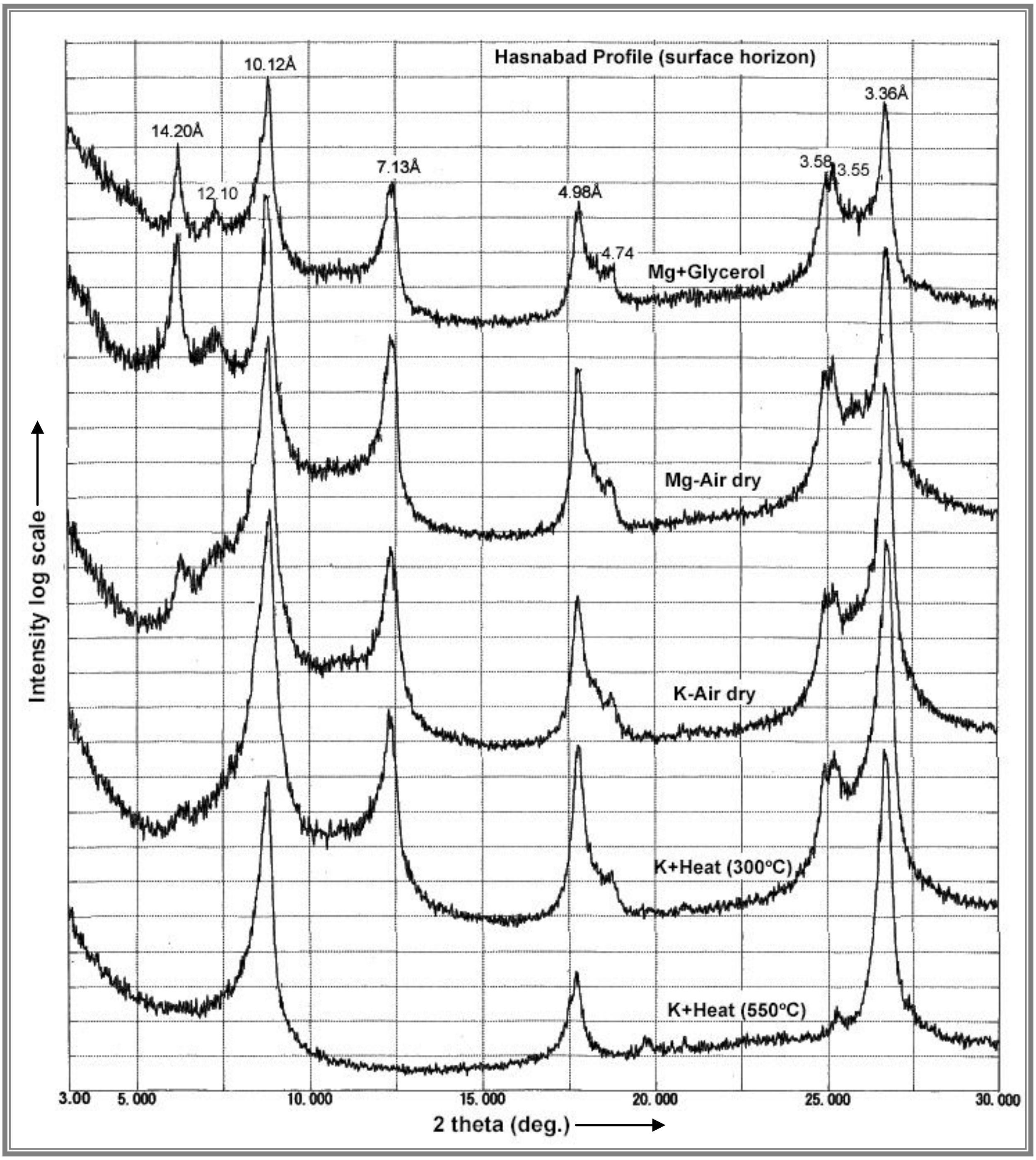


Fig 81. X-ray diffractograms of clay sample from surface horizon of Hasnabad soil.

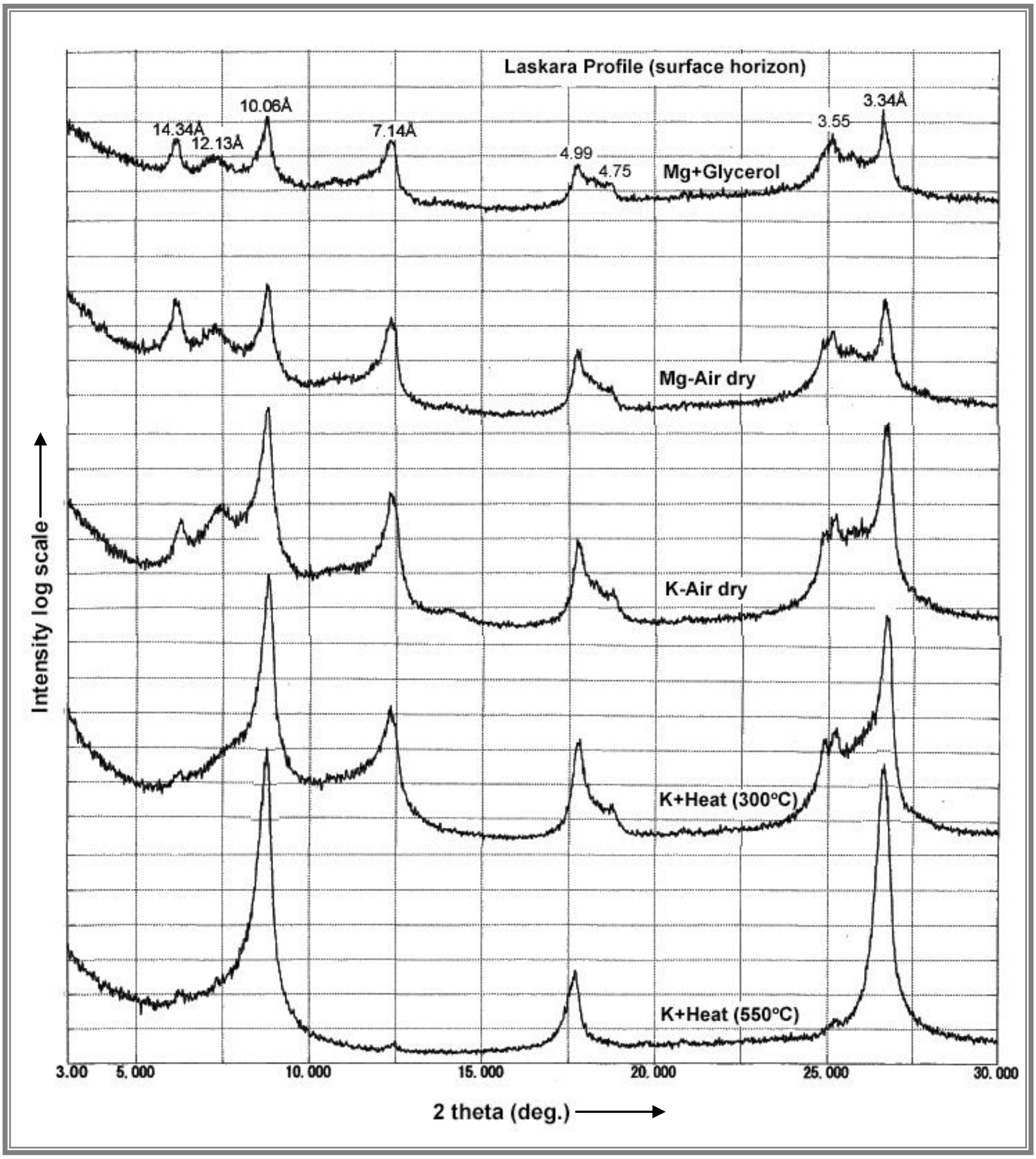


Fig 82. X-ray diffractograms of clay sample from surface horizon of Laskara soil.

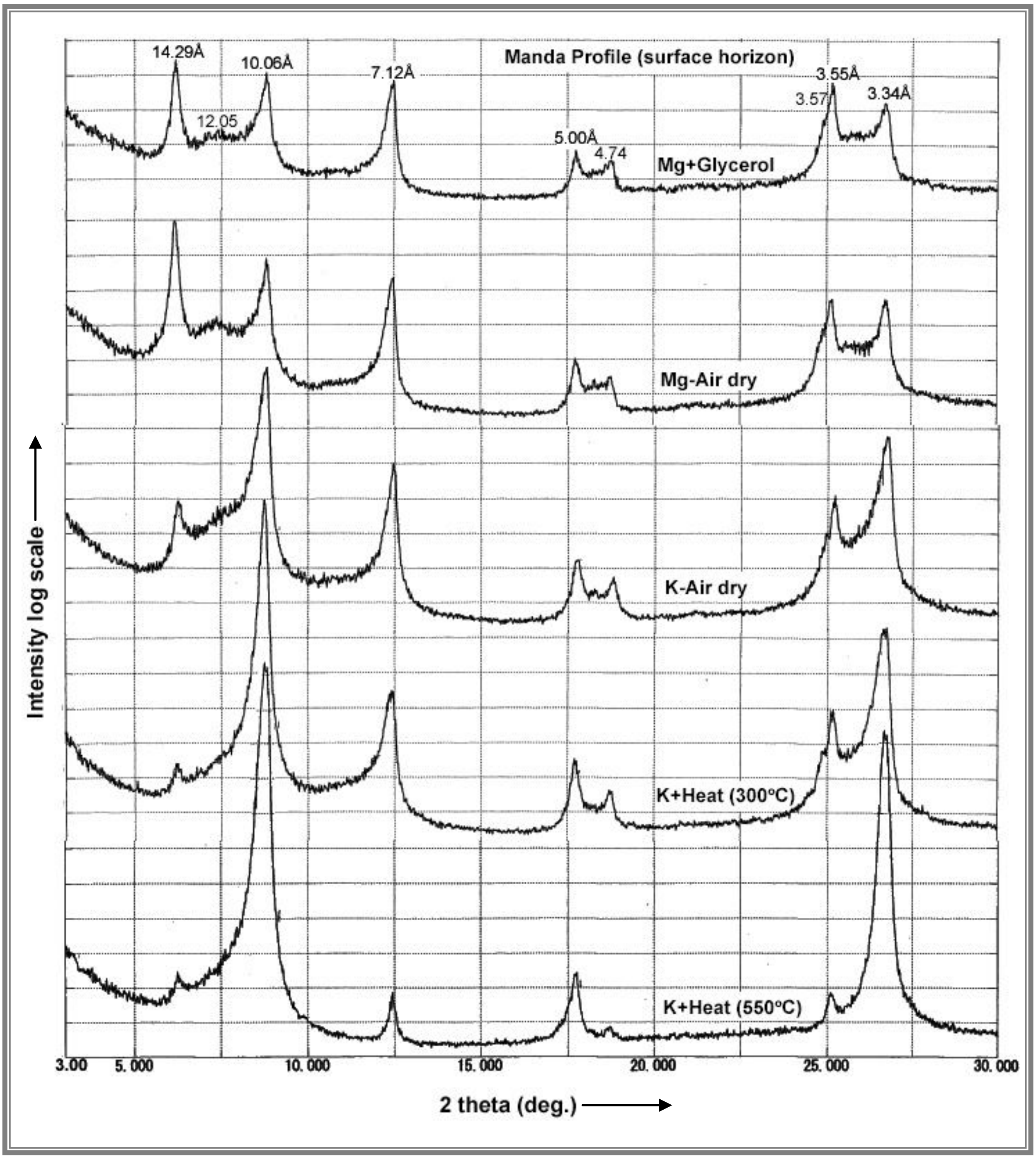


Fig 83. X-ray diffractograms of clay sample from surface horizon of Manda soil.

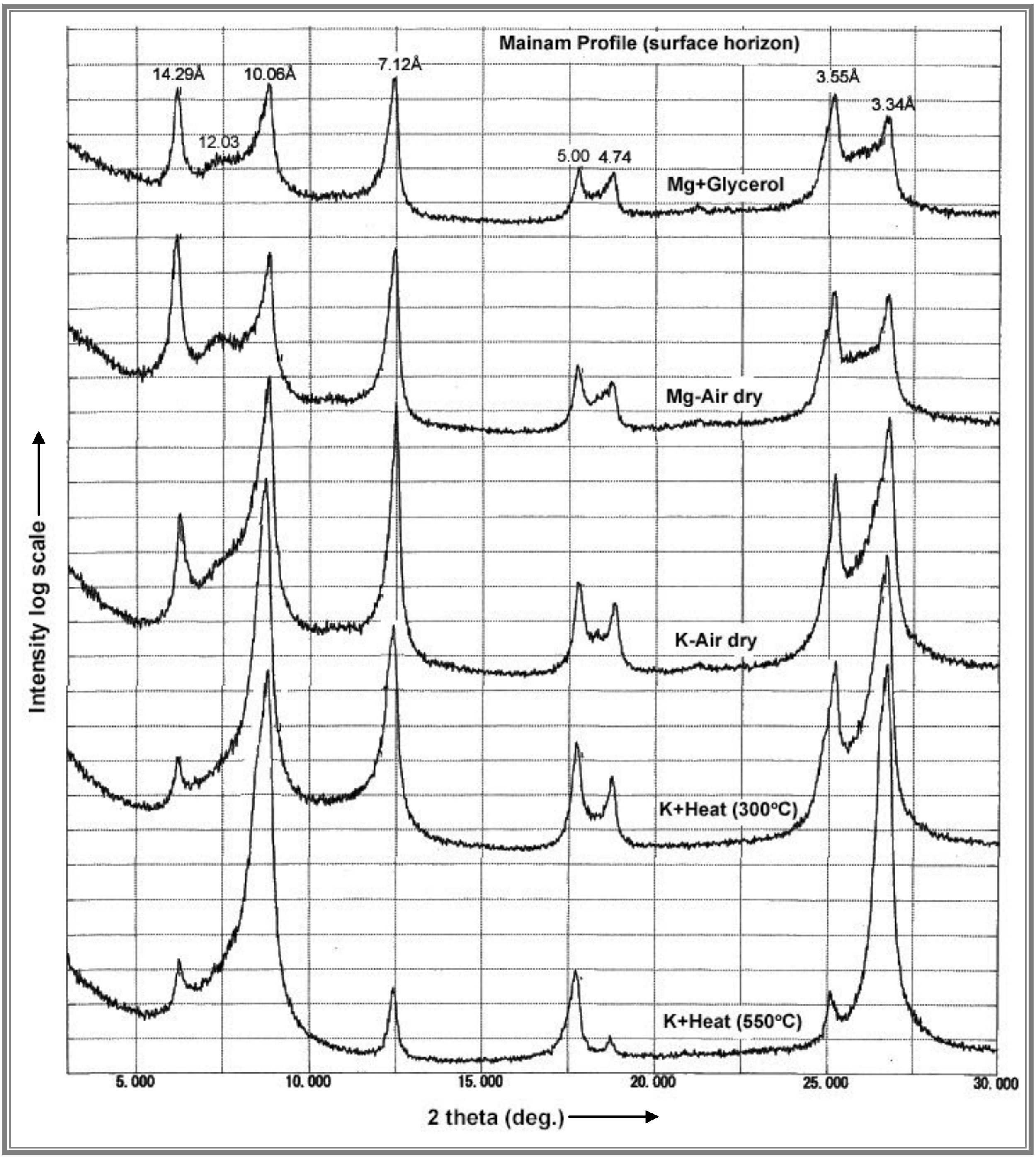
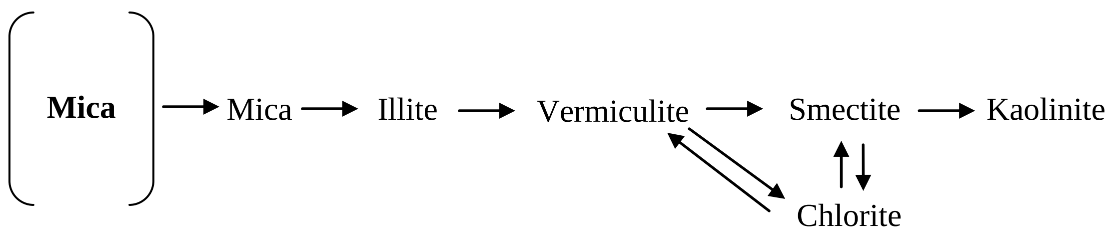


Fig 84. X-ray diffractograms of clay sample from surface horizon of Mainam soil.

The interstratified mica-chlorite minerals were present in all the soils which ranged from 2 to 7 percent. This small amount of interstratified mica-chlorite minerals implies the presence of the non-terrace-soil origin. The interstratified mica-vermiculite-smectite mineral (33 to 41%) was dominant in Laskara and Hasnabad soils. This result is in agreement with the findings of Moslehuddin *et al.* (2006). It indicates that the major contribution of the Madhupur Clay from surrounding Barind Tract as a parent material. The presence of interstratified mica-vermiculite-smectite mineral as dominant minerals in the clay fraction has been reported to the terrace soils of Bangladesah. (Moslehuddin *et al.*, 2008; Moslehuddin *et al.*, 2005; Moslehuddin and Egashira, 1996; Egashira and Yasmin, 1990; Egashira, 1988).

The lower Atrai basin has high amounts of clay and their mineralogical composition as obtained from the present study is similar to that of the soils from terrace areas (Egashira, 1988; Moslehuddin and Egashira, 1996). The possible explanation is that the lower Atrai basin is situated in a lower topographical position surrounded by the Barind tract. The topsoil having very high amounts of clay was actually obtained as surface run-off from the Barind tract over the long period of time. Thus mineralogy of these soils become similar to that of soils in the Barind tract developed from Madhupur clay. Although the parent material of the soils was written as Tista and Atrai alluvia, the topsoil belonged to the soil derived from Madhupur Clay.

The soils under the present investigations have varying proportions of mica, kaolinite, chlorite and vermiculite minerals (Table 22). The presence of high quantity of mica in these soils is indicative of the micaceous parent material. The kaolinite is allogenic and remains intact. Alteration of mica with the loss of potassium appears to be an important mineral modification in the soils of the lower Atrai basin. A suggested pathway for mineral transformation in the above soils may be as follows:



The reaction of the soils of the lower Atrai basin is slightly acidic to neutral. This indicates that these soils are leached and washed. Under this chemical environment the alteration of minerals is likely to go forward in the direction of the arrows as above.

Since these soils have high content of mica mineral which is believed to be undergoing transformation to expandable minerals, sufficient replenishment of K in the soil solution may be expected. These soils therefore may have little need for potassic fertilizer application as the K content in the soils was high. In such soils if any potassic fertilizer was applied then there was every likelihood of reversing the reaction process. The expanding lattice minerals in that case after fixing K^+ in the inter lattice space may revert to illite. But the probability of this kind of revertion might be remote in the seasonally flooded soils of Bangladesh as there was loss of nutrients in the draining water. Potassium in solution may be washed away by the draining water and is thus lost from the soil system.

Since the soils are young it can be assumed that the minerals present in the studied soils were mainly inherited from their parent materials with little or no *in situ* post-depositional alteration. Ali (1994) noted that some in situ transformation might have taken place under the influence of local soil management practices. However, such change if any was small as the soils are in their incipient stage of development. The clay minerals in the soils are most likely allogenic.

The mineralogy of soils is known to be useful in making predictions about soil behavior and responses to management. Some mineralogy classes occur or are important only in certain taxa or particle-size classes, and others are important in all particle-size classes. If soils have more than 50 percent mica (illite) and commonly 4 percent K_2O then this soil will belong to illitic mineralogy class (Soil Survey Staff, 2014). According to USDA mineralogy classes present mineralogical composition (Table 22) suggested that Binsara, Taras 2, Jaonia, Taras 2, Manda and Mainam soils are characterized as having illitic mineralogy and Hasnabad and Laskara soils are characterized as mixed mineralogy class. With such a combination of clay mineralogical composition, the soils are expected to demonstrate a physical condition quite suitable for the agricultural management of the soils mainly for the production of rice crop. It can be noted that the main crop in the cropping pattern in the lower Atrai basin soils is rice which is the staple food of the people of Bangladesh.

In Bangladesh, agricultural research and technology generation and their transfer, are being done on the AEZ basis. The lower Atrai basin is an agriculturally important region of Bangladesh. Crop production in Bangladesh has many limiting factors of which soil is often a dominant one. The type and amount of clay minerals strongly control the soil-related problems. Therefore, the findings of the present study are useful to highlight the soil related problems, especially in terms of nutrient and water management, selection of crops and so on. In addition, the similarity in the types and amounts of clay minerals in soils of the lower Atrai basin makes easy selection of land use and determination of soil, water and fertilizer management throughout the region.

5.7.2 Scanning electron microscopy (SEM) of clay fraction

5.7.2.1 General statements

With optical microscope, it is possible to increase the magnification range by changing the surface curvature or number of lenses used. Although the magnification can be increased in this way, micrographs zoomed more than 2000-times will loosen their clarity because of long wavelength of light. Electron microscopes are able to obtain much higher powers of magnification than the standard visible light microscopes because electrons have much shorter wavelengths associated with them than the light waves. The highest magnification achievable with light microscopes is about 2,000X (times); modern electron microscopes can achieve magnifications approaching 1,000,000X.

There are two main types of electron microscope, the transmission electron microscope (TEM) and the scanning electron microscope (SEM). The TEM consists of an electron source, a number of lenses, and a system that projects an image onto a fluorescent screen or photographic plate. Modern TEMs are capable of magnifications between 1,000X to about 1,000,000X. The SEM works by scanning a tightly focused electron beam over a sample. SEMs have a range of magnification between 20X to 200,000X.

The scanning electron microscope (SEM) is uniquely suited for studying clay minerals because it gives a magnified, three-dimensional view of the unmodified (natural) clay surface with great depth of focus. The only sample preparation necessary for clays is a thin metallic coating, applied in a vacuum evaporator, which serves to prevent a built-up of electrons on the surfaces by conducting away static electricity. With the conventional transmission electron microscope (TEM), the surface of clay particles cannot be directly observed, and only by an involved and time-consuming procedure of replication can they be viewed at all. That's why we used scanning electron microscope (SEM) in this study.

A scanning electron microscope (SEM) is a type of microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

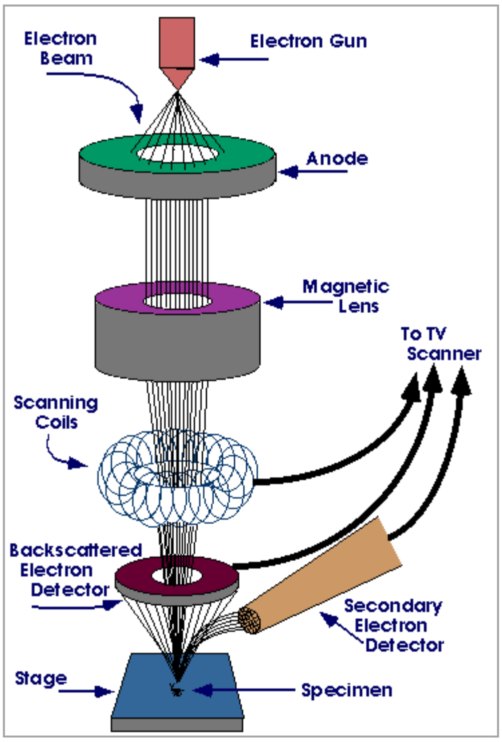


Fig 85. Operational diagram of the SEM

The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam (Fig. 85). The number of secondary electrons that can be detected depends, among other things, on the angle at which beam meets the surface of specimen, i.e. on specimen topography. By scanning the sample and collecting the secondary electrons that are emitted using a special detector, an image displaying the topography of the surface is created. This image is called electron micrograph (McMullan, 2006). In this study, H_2O_2 treated samples were analyzed by scanning electron microscopy (SEM) using a JEOL JSM-6490LA Microscope (Plate 20). This instrument belongs to JEOL limited company of Japan. The SEM was operated at 20 kV and the final aperture was removed to enhance signal collection.

The principle of operation of the SEM is now quite familiar. An electron optical column, containing electromagnetic lenses, demagnefies an electron source in order to focus a fine beam is scanned across the specimen surface in a rectangular raster in synchronism with the spot of a cathode ray tube. The signal resulting from interaction of the beam with the specimen is collected by a suitable electron detector used to modulate the CRT brightness. In most application it is the low-energy secondary electrons which are thus used to form a picture of the specimen on the CRT face (Bohor and Hughes, 1971).

The use of electron microscope has permitted the precise determination of the shape of the particles of various clay minerals and has shed light on the range of particle size of the components of clay and on the degree to which the particle size can be reduced when the clay is worked mechanically with the water. Numerous investigators have published electron micrographs of the clay minerals and discussed electron-microscopic techniques as applied to clay-mineral researches. Particularly worthy of mention are the works of Ardenne *et al.* (1940); Eitel and Radczewski (1940); Middel *et al.* (1940); Humbert and Shaw (1941); Shaw (1942); Marshall *et al.* (1942); Alexander *et al.* (1943); Moore (1947); Bates and Comer (1950); Kerr *et al.* (1950) and their various collaborators.

Plate 20. JEOL JSM-6490LA Microscope

Many papers have been published on the applications of the SEM, but only a few are concerned with clay minerals. Borst and Keller (1969) studied many of the 49 reference clays of the API project. Gillot (1969) and many other authors have included a few SEM micrographs of clays, but the instrument has not been extensively applied in clay mineralogical research. Perhaps this is because of the legacy of fine micrographs produced from replicas on the TEM (Bates and Comer, 1955; Beutelspacher and Van der Marel, 1968).

Certain features of clays and clay minerals are more readily observed on the SEM than by other conventional means. These features include those involving the surface and 3-dimensional aspects of clay minerals, such as the morphology (configuration) of samples, fabric (particle boundary relationships), texture (overall particle arrangements), and growth mechanics of crystals and crystallites. Examples of the latter feature shown here include the variations in layer (packet) thickness, crystal habit, topotaxis (crystallographic control of the development of later diagenetic minerals by preexisting minerals), twinning and spiral growth (helical growth about a central axis). We hope to show, however, that the SEM, because of its unique operation and performance, can bring new dimensions to our understanding of clay minerals of the lower Atrai basin soils.

5.7.2.2 Electron micrographs of clay samples from the soils of lower Atrai basin of Bangladesh

Many scientists have carried out their research on clay minerals by scanning electron microscope (SEM) and published their articles in different journal in many countries. However, no study on electron micrographs of clay minerals in the soils of Bangladesh has been reported as yet. This is the first time we have done SEM micrographs of clay fraction in the soils of Bangladesh. The present research was possible because of acquisition of an electron microscope in the "Centre for Advanced Research in Science (CARS)" at the University of Dhaka, Bangladesh.

In this study whole clay fraction (<2μm) of Ap horizon (surface horizon) of all the profiles were scanned. The SEM have been done for each sample at three different magnification levels like low (2,000x), medium (5,000x) and high (10,000x), so that we find three electron micrographs of each sample at three different magnification levels. The Scanning electron micrographs of the whole clay fraction of Ap horizon of Binsara, Taras 1, Jaonia, Taras 2, Hasnabad, Laskara, Manda and Mainam soil series of the lower Atrai basin are presented in Plates 21 - 28.

The SEMs of the clay fraction of Ap horizon of the Binsara series (Plate 21) revealed small discrete particles scattered among the micro-aggregates. The low magnification (2000x) scanning micrograph in Plate 21a showed the overall appearance of the bulk sample of clay. High resolution (10,000x) SEMs of the same sample (Plate 21c) revealed two types of discrete particles. The first particle types were well-formed six-sided flakes, frequently with a prominent elongation in one direction. Certain edges of the particles are beveled instead of being at right angles to the flake surface. The electron micrographs of Binsara series have shown the dimension of flake surfaces that ranges from 0.3 to 4 microns and thickness from 0.05 to about 2 microns (Plate 21c). These six-sided flake particles are believed to be 1:1 type (well-crystallized) kaolinite mineral and which was further confirmed by the X-ray diffraction analysis. Grim (1953) noted that well-crystallized kaolinite particles show well-formed six-sided flakes and poorly crystallized kaolinite particles show less distinct six-sided flakes. The outline of kaolinite particles is not well defined hexagon because of the mechanical damages done during processing. The second particle type is composed of roughly equal dimensional particles with rounded edges and smooth surfaces. Which are believed to be quartz grains.

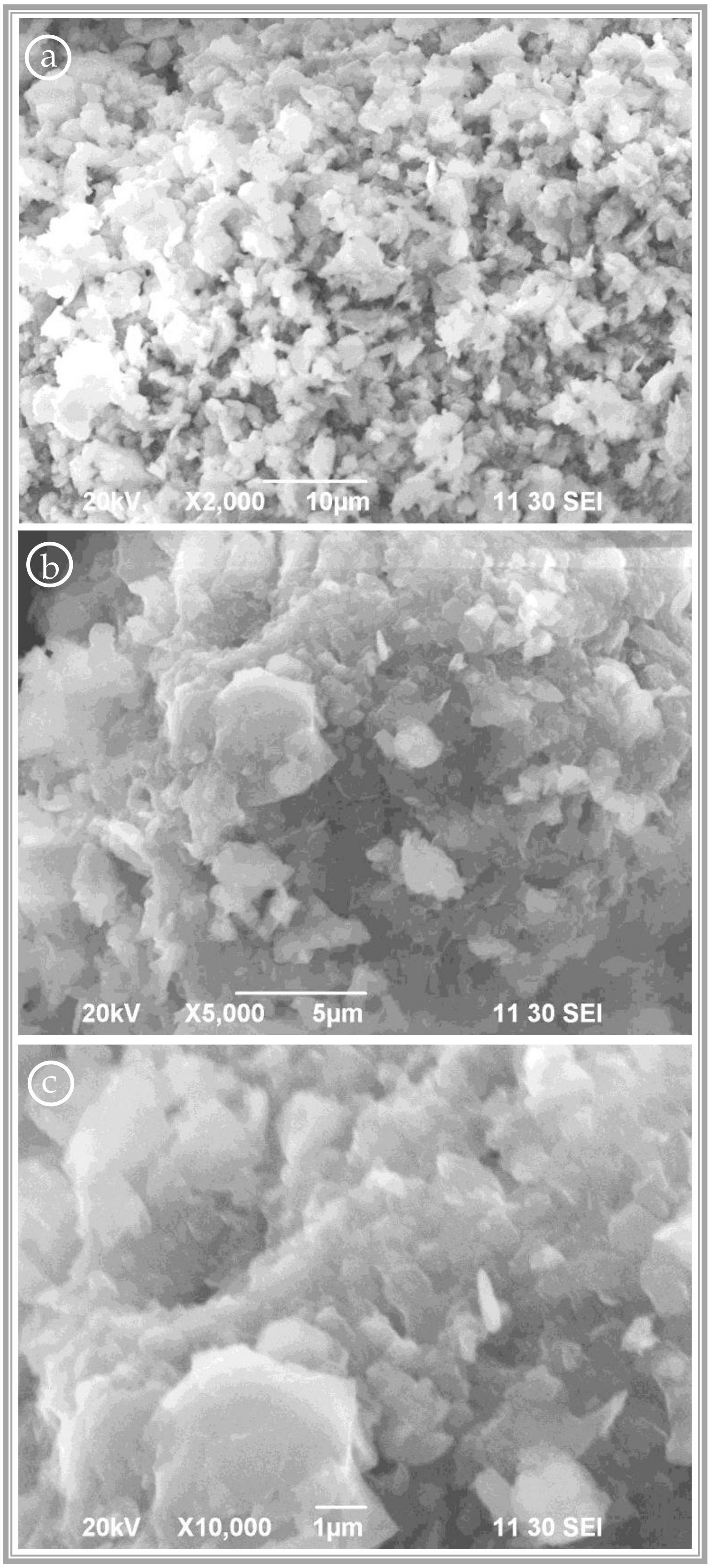


Plate 21. Scanning electron micrographs of the clay fraction of Binsara series from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

The Electron micrograph of the clay fraction from the Ap horizon of the Taras 1, Jaonia, Taras 2, Hasnabad and laskara series (Plates 22-26) revealed numerous small discrete particles scattered among the micro-aggregates. The low magnification (2000x) scanning micrograph (Plates 22a, 23a, 24a, 25a) showed the overall appearance of the bulk samples of clay. High resolution (10,000x) SEMs (Plates 22c, 23c, 24c, 25c) revealed three types of discrete particles. The first particle type were lath-shape, rounded, poorly define flakes, commonly grouped together in irregular aggregates. Some of the flakes have a distinct hexagonal outline and some other flakes show no evidence of hexagonal outlines. Such flakes show somewhat irregular but well-defined outlines and are characterized by an uniform thickness. The thinnest flakes are approximately 30 Å. Many of the flaks have a diameter of 0.1 to 0.3 micron. The above lath-shapes, rounded flakes are suggestive of the well crystallized 2:1 type illite mineral (Bohor and Hughes, 1971; Borst and Keller, 1969 and Grim, 1953) and which was further confirmed by the X-ray diffraction analysis. The second particle type is composed of roughly eqidimensional particles with rounded edges and smooth surfaces. Laird (2001) believed that these small rounded particles may be quartz grains. The third particle type is composed of roughly eqidimensional particles with nodular surfaces. The nature of the nodular particles is not immediately apparent, but the nodular particles are possibly not phyllosilicates, nor are they discrete quartz grains.

The low magnification (2000x) scanning micrograph (Plates 27a & 28a) shows the overall appearance of the bulk sample of clay fraction of Ap horizon of the Manda and Mainam series. The High resolution (10,000x) SEMs of the same sample (Plates 27c & 28c) revealed two types of discrete particles. The first particle type shows irregular fluffy masses, elongate lath-shaped unit, flakes and needles of varying size. The particles appear to show striations parallel to the maximum dimension. The length of the laths is about five times the width dimension. The length of the laths ranges from 1 to 5 microns. Accurate estimations of the areal dimension of the flakes are difficult to obtain because of their irregularity. These road-shaped fluffy masses/flakes indicate that the mineral may be phyllosilicate 2 : 1 type vermiculite (Grim, 1953 and Dixon, 1977) which was further confirmed by the X-ray diffraction analysis. The outline of vermiculite particles is not a well defined flake because of the mechanical damages done during clay processing. The second particle type is composed of roughly eqidimensional particles with rounded edges and smooth surfaces. These rounded particles are believed to be quartz grains (Laird, 2001).

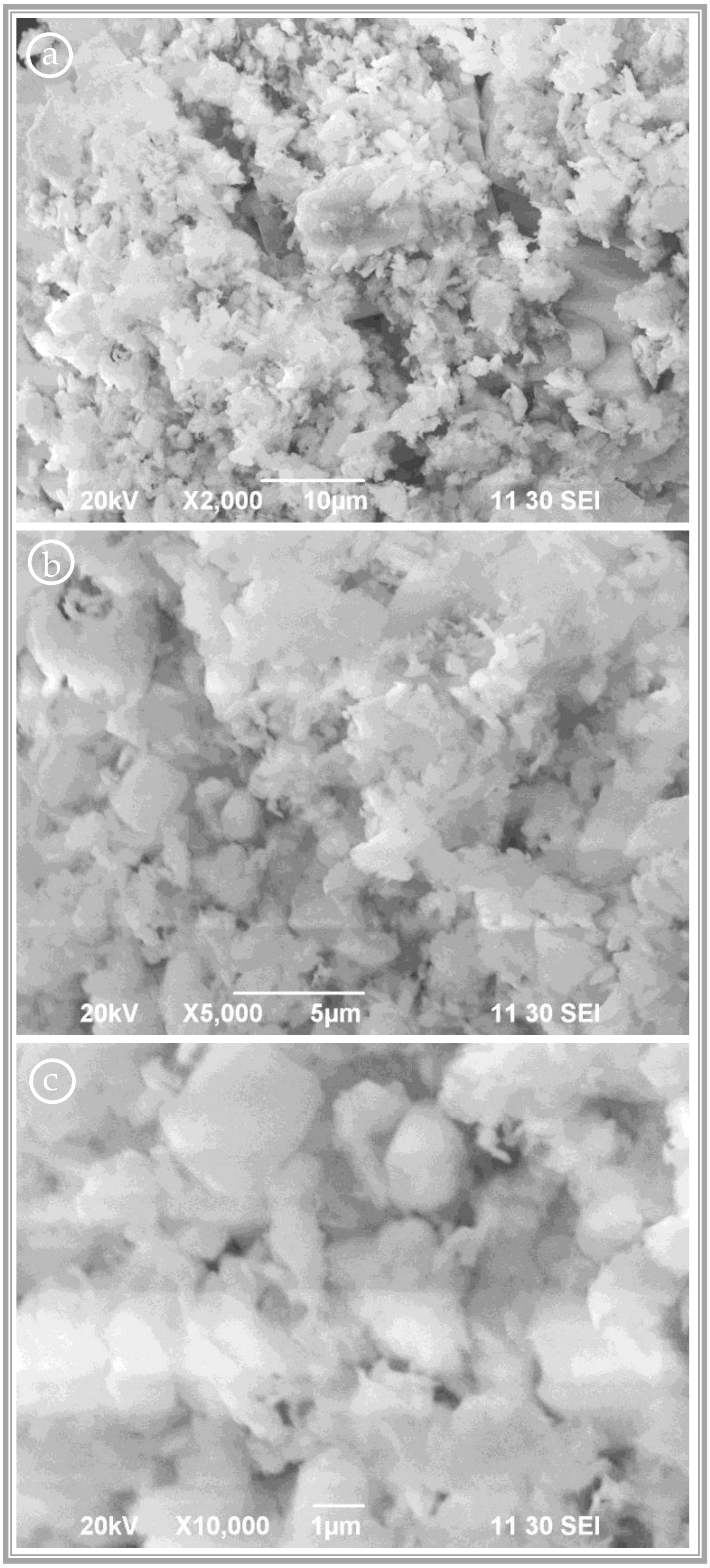


Plate 22. Scanning electron micrographs of the clay fraction of Taras series 1 from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

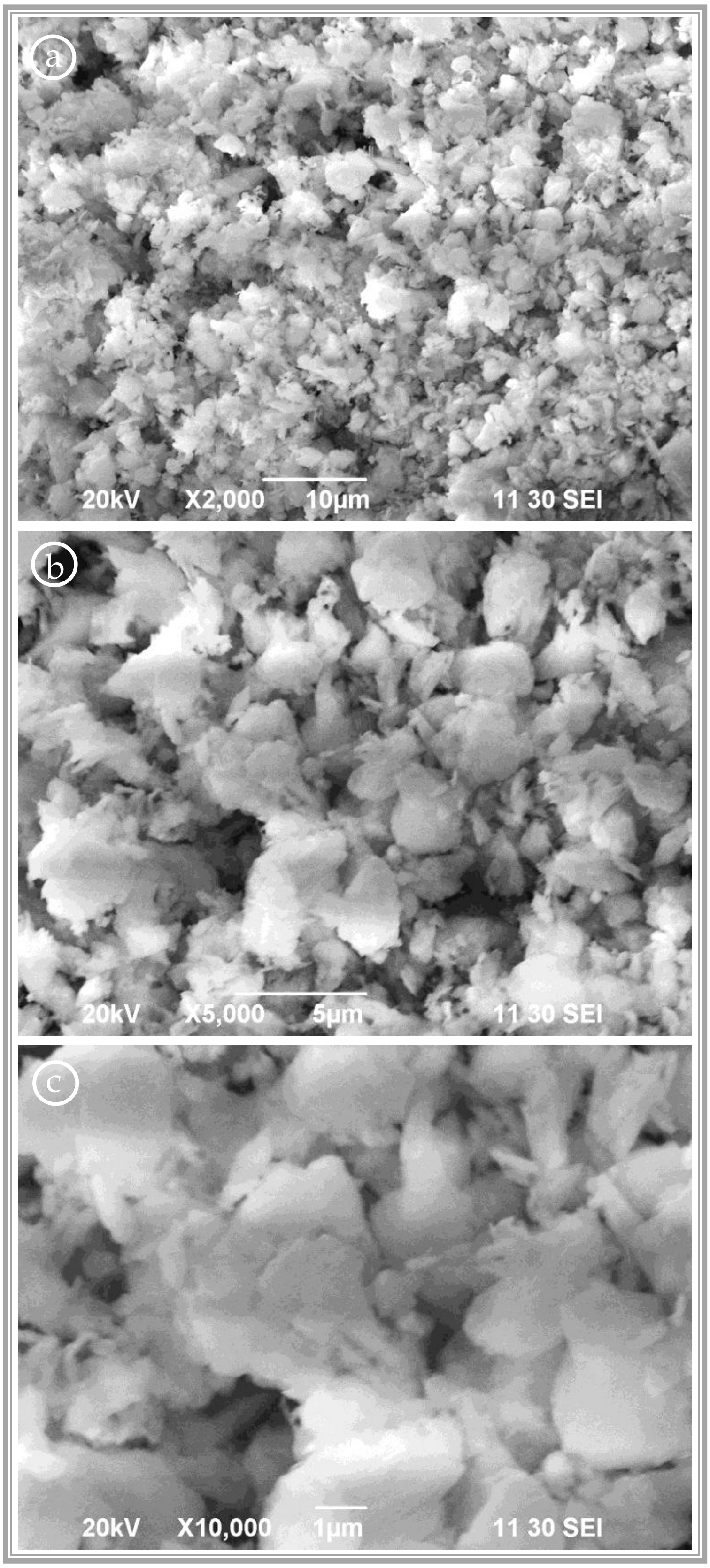


Plate 23. Scanning electron micrographs of the fine fraction of Jaonia series from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

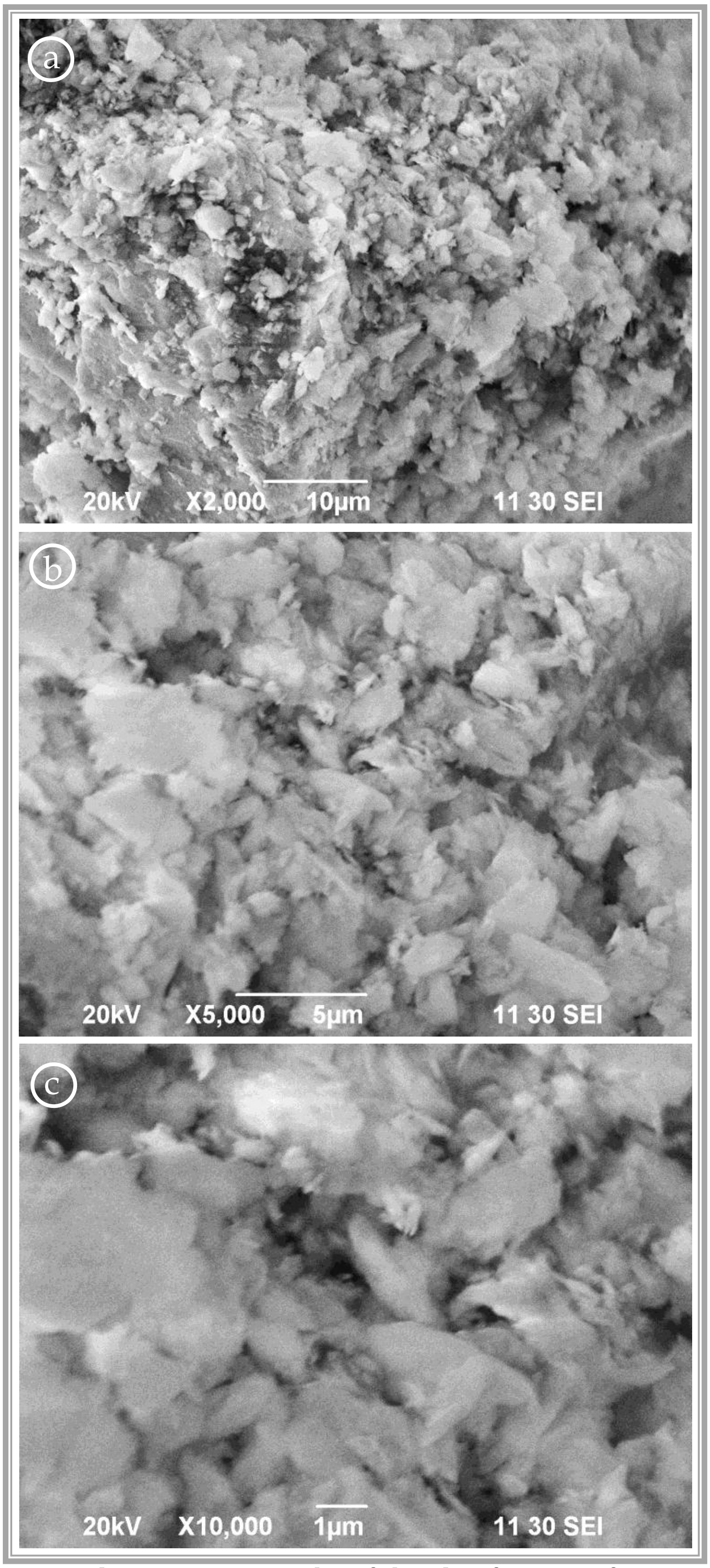


Plate 24. Scanning electron micrographs of the clay fraction of Taras series 2 from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

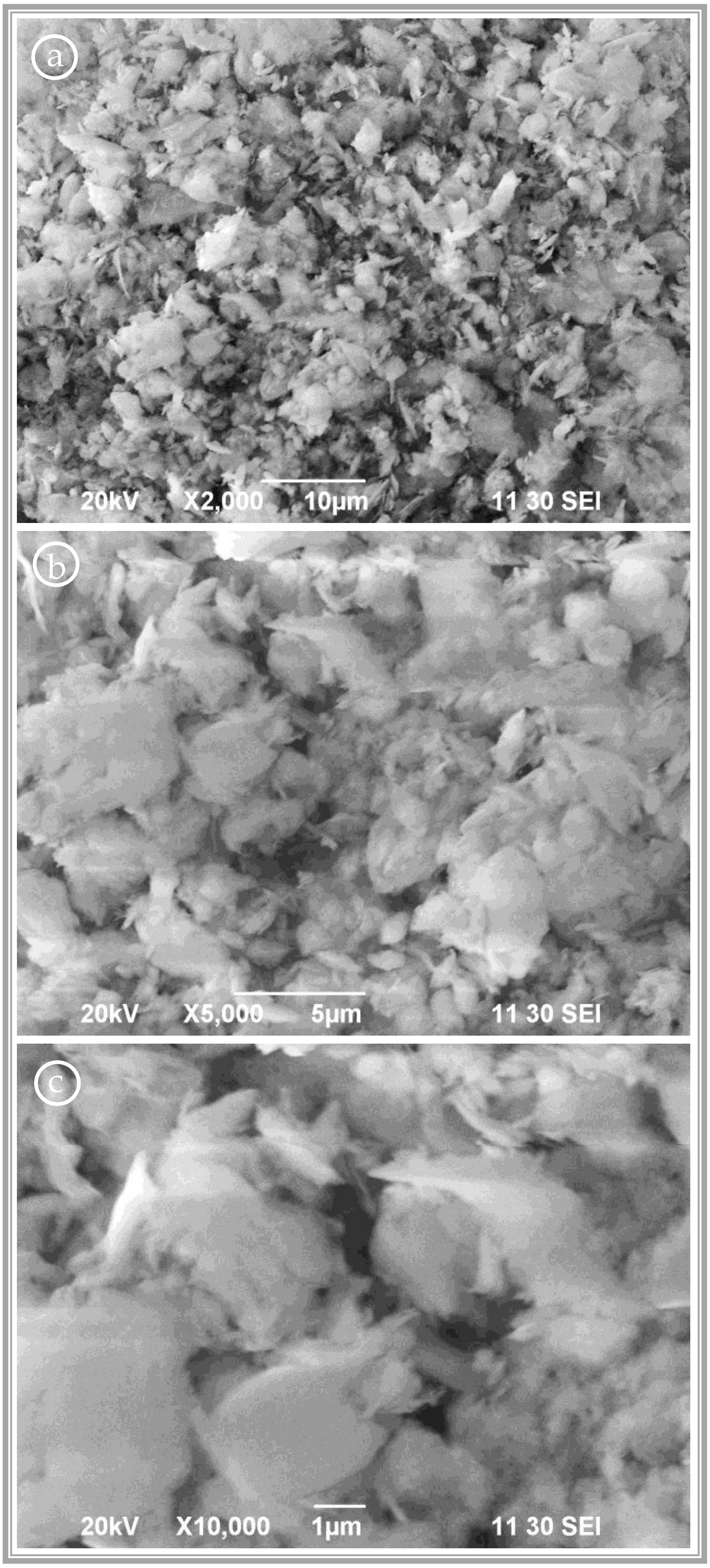


Plate 25. Scanning electron micrographs of the clay fraction of Hasnabad series from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

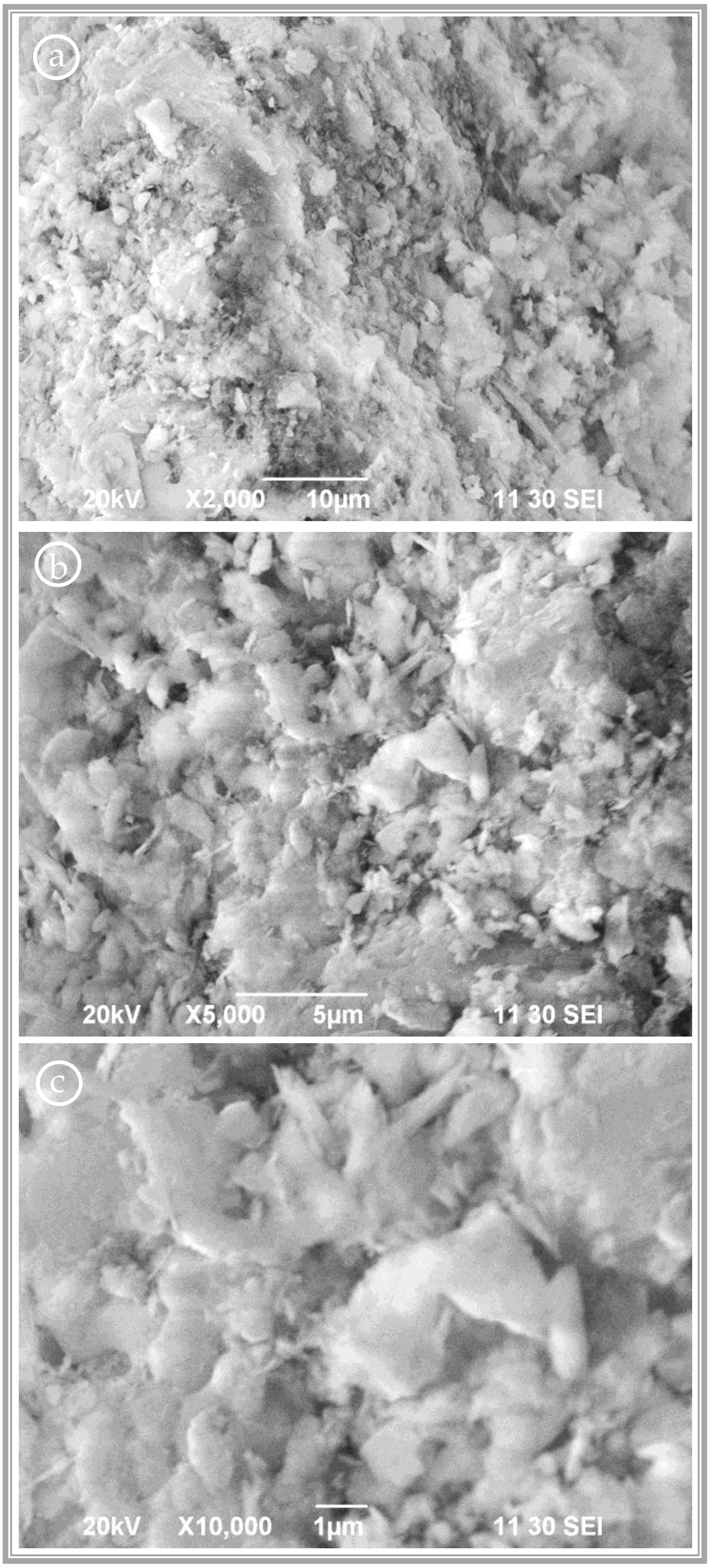


Plate 26. Scanning electron micrographs of the clay fraction of Laskara series from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

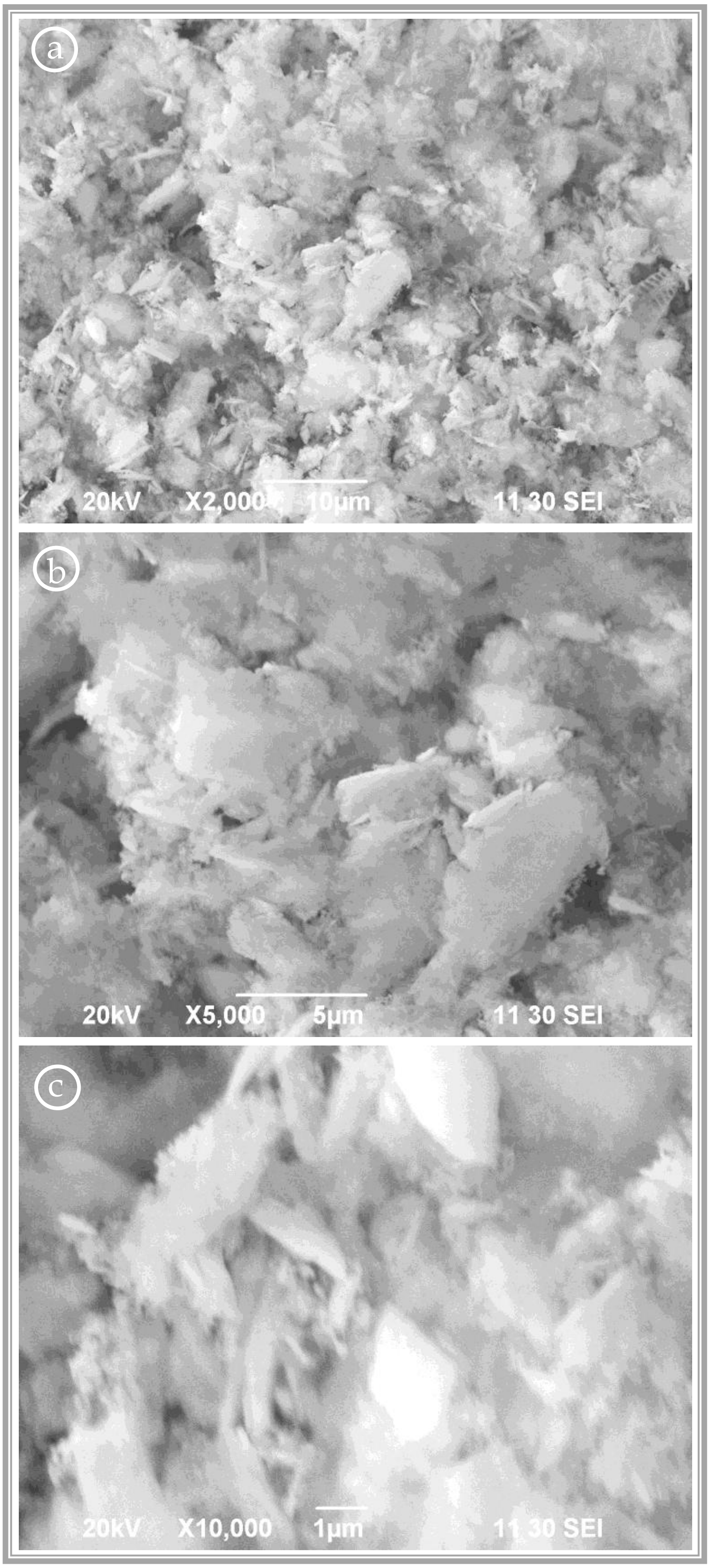


Plate 27. Scanning electron micrographs of the clay fraction of Manda series from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

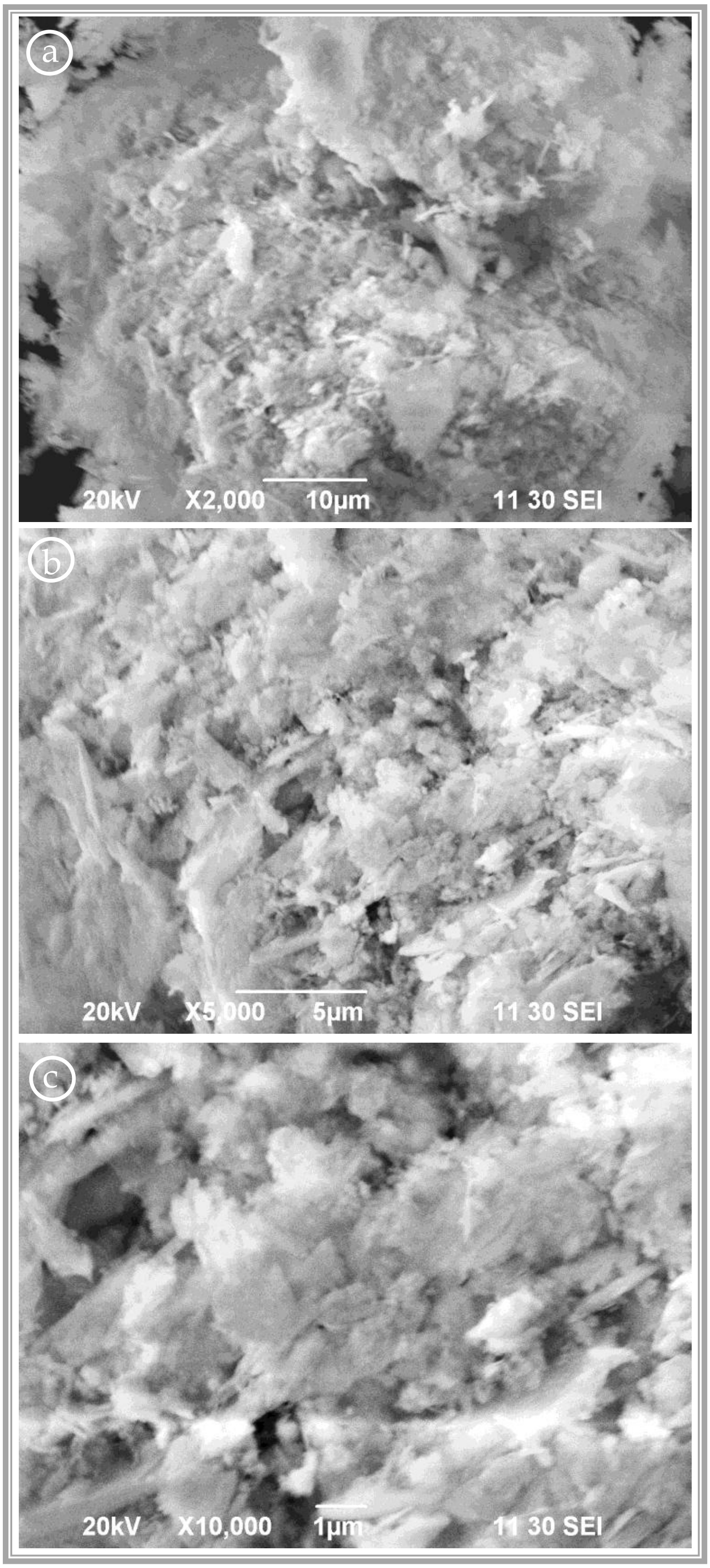


Plate 28. Scanning electron micrographs of the clay fraction of Mainam series from the lower Atrai basin soils; (a) low (2,000x) magnification scanning electron microscopy (SEM) (b) medium (5,000x) magnification SEM and (c) high (10,000x) magnification SEM.

These SEMs of surface horizons of eight soils have been very useful in examining the shape and size of clay minerals from lower Atrai basin of Bangladesh. The speed and ease of operation, high magnification, and great depth of focus of SEMs make it uniquely suited to the study of very fine-grained materials and surfaces. It is concluded that the SEM is almost indispensable for the study of clay mineral configuration (size and shape), fabric (interpenetration), texture (intergrowth), and growth mechanics in the lower Atrai basin soils. In the latter category, such growth-related phenomena as layering, crystal habit, topotaxis, twinning, and spiral growth can be clearly visible in samples of many of the larger, well crystallized clay minerals, such as authigenic kaolinites. Advances in technology have made possible the use of SEM for studying clay minerals of the soils of lower Atrai basin which is first of its used in Bangladesh.

Chapter Six

GENESIS AND CLASSIFICATOIN

CHAPTER - 6

GENESIS AND CLASSIFICATION OF THE STUDIED SOILS

6.1 Genesis of the soils under investigation

On the basis of the information obtained from the field and laboratory studies, an attempt has been made to shed light on the pedogenic processes that are in operation in the soils under the present investigation and also to classify them according to the USDA Soil Taxonomy (Soil Survey Staff, 2014), the FAO-UNESCO legend (FAO-UNESCO, 1990) and WRB (IUSS Working Group WRB, 2015).

In consideration of the geological history, the area wherefrom the soils have been collected, may be considered to be of recent (Holocene) origin. The environmental, morphological, physical, chemical and mineralogical properties (Tables 2-22) of these soils indicate clearly that the parent materials of these soils were alluvial deposits of mixed origin.

Profile characteristics of these soils showed that their development did not proceed too far. All the soils under investigation appear to be incompletely developed which means that they are still immature. 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 its incipient stage of development.

The parent materials and the conditions like the poor drainage and the aquic moisture regime due to regular submergence during the rainy season are probably the factors affecting the profile characteristics of the soils. The soils are at their youthful stage and presumably at this stage the parent materials will play a key role in exhibiting the properties of the soils. The direct consequence of poor drainage is the retardation of leaching and negligible alteration of soil materials. Apart from that, the soils have been under cultivation for a long time which disturbed the normal pedological processes. There is mechanical translocation of finer fractions downward through cracks forming flood coatings. A plough pan was also formed. The finer fraction blocked the pore space and restricted to some extent the movement of the product of weathering.

Seasonal submergence and drying set the conditions of alternate reduction and oxidation 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 reaction (pH) of the soils closely follows the course of oxidation-reduction condition because the soils contain considerable amount of Fe and Mn which are subjected to change. The grey tinges of the top soils are probably due to the presence of organic matter.

Another interesting feature of these soils is the presence of mottling of yellow or brown colours usually along the old root channels and sometimes along the ped faces. The horizons containing mottles of various shapes, size and colour have been formed due to alternation of oxidation-reduction conditions. Their presence may also be attributed to evidences of a weak type of gleization process in the studied soils.

In most of the soils, alternate wet and dry conditions produce vertical cracks leading to 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 fine materials from the top through the cracks along with the first floodwater made the structural aggregate more conspicuous. In Jaonia soil, the structural development is pronounced due to its congenial environment whereas in Manda and Mainam soils it is the initial stage indicating youthfulness.

The development of coating along the ped faces, fissures and pores in the subsoil are typical characteristics of these soils. These coatings are not clay skins but are flood coatings or gleyan as was named by Brammer (1971). They appear to have developed rapidly from the materials that were taken down from the surface under flooded condition.

Ploughpan is a soil layer compected by tillage and occurs below 5 to 10 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. Ploughpan was developed 3 to 6 cm thick in Binsara, Taras 1, Taras 2, Hasnabad and Laskara soils. The ploughpan prevent vertical water percolation, restricts aeration as well as root penetration (Brammer, 1971)

The vertical distribution pattern of sand, silt and clay of these soils (Table 7) support the preceeding statement that the parent materials of the soils were of mixed origin. The annual deposition of silts by flooding affects the existing pedogenic processes. The soil profile with weak to moderate angular blocky structures suggests the formation of altered B (cambic) horizon in all the soils except Manda and Mainam. However, the soils in the surface horizon have mostly massive structure.

Vertical distribution of clay in all the soil profiles except Manda and Mainam indicates an impoverishment of clay in the surface horizon. This lower content clay near the surface may be for two reasons: Firstly it may be due to stratification and secondly there may be destruction of clay in the surface horizons by ferrolysis process (Brinkman, 1977).

In each soil profile, there is a trend of increasing pH with depth (Table 9). 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 (Table 10). The base saturation increases gradually with depth and Ca^{++} and Mg^{++} dominate the exchange complex (Table 11). Exchangeable Ca^{++}/Mg^{++} ration is, in general, around 3.48 (mean value). 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 Taras 1, Taras 2 and Jaonia soils have vertic soil properties because these soils showed vertical cracking during dry seasons.

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 illite. Alteration of mica to vermiculite may be a common pedochemical weathering process in the soils under investigation. But this process is not strong enough and as a result amount of vermiculite is small. Depotassication may be thus a common weathering process. The marked similarities in the clay mineralogy of these soils suggest that mineral weathering and/or synthesis have been quite limited and uniform.

From the characteristics discussed in the above paragraphs, it appears that the soils under the present investigation are likely to be generally designated as hydromorphic in nature. However, the absence of well developed gley horizons and the higher Ca^{++}/Mg^{++} ratio in these soils may lead one to cast doubt about the true hydromorphic nature of these soils. Nevertheless, it may be worthwhile to mention that the weak gleying represented by the occurrence of mottles which is due to the seasonal wetting and drying of the soils. Finally, weak type of gleization seems to be the dominant process of soil formation in these soils.

In conclusion, it may be said that the studied pedons developed on the lower Atrai basin area shows marks of hydromorphism in their body. Gleization, therefore is thought to be the major process of soil formation in them. It is worth noting that some other factors like parent materials of mixed origin and incipient age as well as annual siltation during long flooding have played dominant roles in the functions of pedogenetic processes that have been in operation in the soils under discussion.

6.2 Classification of the soils under investigation

An endeavor has been made in this section to classify the studied 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, 2014). As evident from the result of morphological, physical, chemical and mineralogical properties of the studied soils presented in chapter 4 and 5, there were variations in the surface and subsurface colours, textures, structures, pH, base saturation and clay mineralogical composition. The variation in the above properties in the studied soil profiles was very important in differentiating the soils into the various orders, suborders, great groups, subgroups and families.

These soils are not bestowed with well developed structures in the top soils as has been pointed out in the pervious chapters. However, the presence of moderately to strongly developed coarse to medium prismatic and angular blocky structures distinctly coated with clay, silt and humus on ped faces in the subsoils of all these profiles except Manda and Mainam indicates the destruction of alluvial stratification and aeration. Occurrence of variously coloured mottles along root channels and pores was another persisting feature in all the soil series. In addition, these subsoils are devoid of any rocky structure.

In soil taxonomy (Soil Survey Staff, 2014) a cambic horizon has been defined as having soil structure development and absence of any rock structure in conjunction with the occurrence of mottling. Consequently, the structural B horizon in the subsoils of these profiles except Manda and Mainam along with the redox concentration and the regular decrease of organic matter may be designated as a cambic horizon.

As has been noted in the previous section the coatings that were found on the ped faces in the subsoil horizons are not true clay skins, but apparently represents the mechanically down washed materials from surface soil through cracks. There is no indication of eluviation of clay from the top soil and their illuviation in the subsoil, as in the case of true clay skins or cutans which occur in the argillic horizon. These coatings formed by mechanically down washed materials and have been designated as flood coatings or gleyans in the floodplain soils of Bangladesh (Brammer, 1971).

The characteristics of the top soils are often altered by mechanical manipulation during cultivation when the soil is wet. Most of these soils have been used for rice cultivation for centuries. As a result, structure formation in the surface soil has been disturbed and consequently it was weakly developed. These soils are seasonally gleyed and often show mottles and iron stains along root channels and at the base of ploughpan.

Although typical gley horizons are absent all the soils have aquic moisture regime. It has to be recognized that lack of strong horizon differentiation in the soils and the variable

SiO_2 : R_2O_3 ratios throughout the profiles are the characteristics of soils at the incipient stage of soil formation.

The epipedon (diagnostic horizon) of the soils, studied were identified as ochric epipedon in Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara profiles. In Manda and Mainam profiles no diagnostic horizon were found.

The presence of "structural B" (Cambic B) horizons and ochric epipedon suggests that Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara soil profiles may qualify to be classed in the **"Inceptisols order"**. The Manda and Mainam soils is very young soils, lacking horizons because their parent material has only recently accumulated and in which stratified layers occur within 50 cm of the surface and thereby may qualify for the **“Entisols order”**.

The n-value has been used as a criterion for separation of the soils of Inceptisol and Entisols. The soil of Entisol should have, between 20-50 cm below the mineral soil surface and n-value of 0.7 or more in one or more sub-horizon. On the other hand, Inceptisols have n-value of <0.7 to a depth of at least 50 cm. The n-value of Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara soils is <0.7 and this value is more than 0.7 in Manda and Mainam soils (Table 23). Thus, Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara series can be placed in the **“Inceptisols”** and the Manda and Mainam series in the **“Entisols order”**.

Soils belonging to the Inceptisol and Entisol order are subdivided into suborders on the basis of difference in soil moisture regime, and some other extreme physical and chemical properties. As excessive moisture (flooding) at certain season is the most important factor in the genesis of these soils. The soils studied on the basis of their relevant properties can be placed into two suborders **Aquepts** and **Aquents** (Table 24). The soil series namely Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara fall in the Aquept suborder due to their reduced colour (Chroma ≤ 2), distinct mottling.

The soils belonging to Aquept suborder may be placed into the **Endoaquepts** great groups because of its wetting from below by the ground water (endo saturation). Manda and Mainam soils may be placed under **Endoaquents** great groups because these soils also endo saturation.

At the subgroups level the soils of Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara series may be fit into the **Typic Endoaquepts** as they have 50% or more matrix colour chroma ≤ 2 with in 75 cm depth. The soils of Manda and Mainam series may be classed in the **Aeric Endoaquents** subgroups because of Chroma ≥ 2 within 75 cm and there are no redox concentrations in the control section.

Table 23. Properties of soils for their classification in the lower Atrai basin.

Soil Series	Surface soil colour (moist)	Subsoil colour (moist)	Subsoil Texture	Subsoil Structure	pH range upto 50 cm depth	Organic matter (decreased from upto substratum)	BSP upto 75 cm depth	n-value upto 50cm depth	Mineralogy class
Binsara	5Y4/1 Dark grey	5Y4/1 Dark grey	C	ST,ME,PR	5.6 - 6.5	2.37 - 0.83	89 - 85	0.25 - 0.43	Illitic
Taras (1)	5Y4/1 Dark grey	5Y4/1 Dark grey	SiC	ST,ME,AB	6.5 - 6.8	2.99 - 0.41	90 - 97	0.24 - 0.30	Illitic
Jaonia	5Y4/1 Dark grey	5Y3/1 Very dark grey	C	ST,CO,PR	6.0 - 7.2	2.58 - 0.93	87 - 99	0.29 - 0.31	Illitic
Taras (2)	5Y4/1 Dark grey	5Y5/1 Grey	SiC	ST,ME,AB	6.4 - 7.3	1.62 - 0.54	86 - 99	0.47 - 0.34	Illitic
Hasnabad	5Y5/2 Olive grey	5Y4/1 Dark grey	SiC	MO,ME,AB	5.6 - 6.5	1.55 - 0.72	76 - 82	0.14 - 0.31	Mixed
Laskara	5Y4/1 Dark grey	5Y6/1 Grey	SiCL	ST,CO,PR	5.9 - 6.9	2.48 - 0.93	73 - 98	0.49 - 0.52	Mixed
Manda	5Y5/2 Olive grey	5Y5/2 Olive grey	SiL	MA	6.3 - 6.8	1.03 - 0.10	96 - 70	0.74 - 0.72	Illitic
Mainam	5Y5/2 Olive grey	5Y6/2 Light olive grey	SL	MA	6.4 - 7.2	1.34 - 0.21	98 - 99	0.73 - 0.75	Illitic

Moisture regime – Aquic, **Temperature regime** – Hyperthermic

Table 24: Classification of studied soils from Lower Atrai Basin.

<table>
<tr><th colspan="5">USDA Soil Taxonomy*</th><th rowspan="2">Soil Series</th><th rowspan="2">General Soil Type (GST)**</th><th rowspan="2">World Reference Base (WRB)***</th></tr>
<tr><th>Order</th><th>Suborder</th><th>Great group</th><th>Subgroup</th><th>Family</th></tr>
<tr><td rowspan="6">Inceptisols</td><td rowspan="6">Aquepts</td><td rowspan="6">Endoaquepts</td><td rowspan="6">Typic Endoaquepts</td><td rowspan="3">Clayey, illitic, nonacid, hyperthermic, Typic Endoaquepts</td><td>Binsara</td><td rowspan="8">Noncalcareous Dark Grey Floodplain Soil</td><td rowspan="6">Gleysols</td></tr>
<tr><td>Taras 1</td></tr>
<tr><td>Taras 2</td></tr>
<tr><td>Clayey over loamy, Illitic, nonacid, hyperthermic, Typic Endoaquepts</td><td>Jaonia</td></tr>
<tr><td rowspan="2">Clayey over loamy, mixed, nonacid, hyperthermic, Typic Endoaquepts</td><td>Hasnabad</td></tr>
<tr><td>Laskara</td></tr>
<tr><td rowspan="2">Entisols</td><td rowspan="2">Aquents</td><td rowspan="2">Endoaquents</td><td rowspan="2">Aeric Endoaquents</td><td>Loamy over sandy, illitic, nonacid, hyperthermic, Aeric Endoaquents</td><td>Manda</td><td rowspan="2">Fluvisols</td></tr>
<tr><td>Loamy, illitic, nonacid, hyperthermic, Aeric Endoaquents</td><td>Mainam</td></tr>
</table>

*(Soil Survey Staff, 1999 and 2014) **(FAO-UNDP, 1988) ***(IUSS Working Group, 2015)

It should be noted here that all the above soils have "***Hyperthermic"*** temperature regime (Table 23) (Soil Survey Staff, 2014).

On the basis of soil reaction, all the studied soils can be placed under the "***nonacid***" class (Soil Survey Staff, 2014).

Mineralogical studies indicates that Binsara, Taras 1, Jaonia, Taras 2, Manda and Mainam soils have illitic mineralogy class because mica is the dominant clay minerals, which constitute more than 50%. On the other hand Hasnabad and Laskara soils have mixed mineralogy class as they do not have any particular clay minerals, which constitute more than 50%. In fact none of the clay minerals are dominant in Hasnabad and Laskara soils.

On the basis of particle size distribution in the profile the Binsara, Taras 1 and Taras 2 soil series are classed as clayey. The Jaonia, Hasnabad and Laskara soil series are classed as clayey over loamy. The Manda soil series are classed as loamy over sandy and Mainam soil series are classed as loamy.

Therefore, according to the US Soil Taxonomy the studied soils have been characterized into the Entisols and Inceptisols order, two suborders (Aquents and Aquepts) two great groups (Endoaquents and Endoaquepts) they are classed at the two subgroups level as Aeric Endoaquents and Typic Endoaquepts. As indicated in the above discussion the soils have been placed into five soil families (Table 24).

According to General soil type system (GST) of classification of Bangladesh (FAO-UNDP, 1988) all the studied soils are **"*Noncalcareous Dark Grey Floodplain"*** (Table 24)**.** These soils are seasonally flooded and top soil colour is grey to dark grey. The subsoil colour ranges from grey to dark grey with many fine yellow to brown mottles throughout (Table 23). These soils have strongly developed coarse prismatic structure and continuous, thick, dark grey flood coatings on structural faces.

The World Reference Base for Soil Resources (WRB) is the international standard taxonomic soil classification system endorsed by the International Union of Soil Sciences (IUSS). It was developed by an international collaboration coordinated by the International Soil Reference and Information Centre (ISRIC) and sponsored by the IUSS and the FAO.

According to WRB system 2014 the soil series namely Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara may be classed into **Gleysols** groups because these soils having gleyic properties within 50 cm of surface. The Manda and Mainam soil series may fit into the **Fluvisols** groups of WRB (Table 24) because the soils developed on flood plains sediments and A horizon is commonly directly above C horizon (IUSS Working Group WRB, 2015).

Chapter Seven

SUMMARY AND CONCLUSION

CHAPTER - 7

SUMMARY AND CONCLUSION

The present investigation was undertaken to study the pedogenic characteristics of soils from the lower Atrai basin of Bangladesh. The first step in this investigation was to examine the environmental settings of the soils and then to undertake field investigation and to record morphological characteristics of the pedons in the field. The next step was to determine the physical, chemical, physico-chemical and mineralogical properties and elemental composition of the selected soils in the laboratory. On the basis of the above information, the fourth stage was to throw light on the probable genetic processes that have been in operation for the formation of these soil profiles. Finally, an attempt has been made to characterize these soils in the USDA Soil Taxonomic system, the FAO-UNESCO legend and WRB classification system.

Eight soil pedons from the lower Atrai basin of Bangladesh, each representing a typical soil series, was selected and studied in the field as well as in the laboratory. Soil samples were collected from the genetic horizons from each of the profiles.

A. The soils were studied morphologically in the field and their detailed profile descriptions were recorded according to the guidelines of FAO (FAO, 2006) and Soil Survey Manual (Soil Survey Staff, 1993). The prominent morphogenetic features are as follows:

- The top soils were generally olive grey to dark grey in colour when moist, with silt loam to clayey texture.
- The subsoil colours were usually light olive grey to grey or very dark grey when moist, with silty clay to silty clay loam texture.
- All the soils under the present study developed flood coatings and variously coloured mottles along the old root channels and pores.
- Prismatic, angular to subangular blocky structure has been developed in the subsurface horizons of all the profiles except Manda and Mainam, whereas massive structure was found in the surface horizons. In Manda and Mainam series massive structure was found all over the profiles.
- Soil reaction was moderately acidic to neutral in the surface and showed a tendency of increasing pH with depth.
- All the soils have poor drainage condition and remain flooded for various periods during the monsoon season.

B. The physical investigations of the collected soil samples were carried out and the results obtained there from might be summarized as follows:

- Silt was by far the dominant fraction in the soils and played a significant role in moulding the textural character of these soils.
- The irregular vertical distribution pattern of sand/silt ratio as well as the clay content in all the studied profiles indicated the heterogeneous nature of the parent materials from whish these soils have developed.
- The hygroscopic moisture content in the present soils, in general, is rather low. The highest value recorded in the Laskara series where as the lowest is found in Mainam series. Such a variation possibly due to the difference in their clay and organic matter contents.
- The highest mean of oven dry/air dry ratio among the profiles are found in Manda and Mainam series and the ratio of the other series are same except Hasnabad series.
- The n-value of Manda and Mainam series is more than 0.7 and the other soils n- value is less than 0.7.

C. Results of chemical analysis may be summarized as follows:

- All ΔpH values were negative and ranged from -1.05 to -1.83 with a mean of -1.62 pH unit. The ΔpH values showed a significant positive relationship with the pH with water.
- The organic matter content of the soils was generally medium to low and showed a gradual decrease with depth and ranged from 0.10 to 2.99 percent. The C/N ratio of the soils varied from 5 to 12 with an irregular vertical distribution pattern.
- The total nitrogen content of the soils ranged from 0.01 to 0.18 percent and showed a gradual decrease with depth.
- The cation exchange capacity (CEC) of the soils ranged from 2.10 to 23.9 cmol/kg soil. The Jaonia soils have higher cation exchange capacity than the other soil series. Significant positive correlations were found between CEC and percent clay content and also with the organic matter, but the CEC is more strongly correlated with clay.
- The base saturation was high and showed a tendency to increase with depth in the profiles. Exchangeable Ca^{++} and Mg^{++} were the dominant bases in all the soils. Calcium occupies more than 60% of the exchange position. Base saturation had a positive relationship with pH (H_2O).
- Free oxides of iron and manganese in the soils studied were low. Free Fe_2O_3 content had a significant positive correlation with the free MnO_2 content.

- From the fusion analysis of the whole soils, it was clear that the distribution pattern of SiO_2/R_2O_3 (silicon-sesquioxide) ratios throughout the profiles was non-uniform. This suggested that the parent materials were heterogeneous and were of mixed origin.
- From the fusion analysis of the clay, the distribution of SiO_2/R_2O_3 ratio from the surface downward follows an irregular pattern in all the soil profiles. This silicon-sesquioxide (SiO_2/R_2O_3) ratio may indicate the presence of considerable amount of 2:1 lattice type clay minerals which might be a mixture of a variable amount of mica and vermiculite minerals with a small amount of kaolinite, chlorite.
- The higher K_2O content of the soils and clay suggested that the soils were rich in illitic (mica) type of clay minerals.
- The TiO_2 content of the colloidal fraction of the soils was around 1.56 percent. The distribution pattern of TiO_2 content from the surface downward was irregular in nature.

D. Mineralogical composition may be summarized as follows:

- Mineralogical composition of the clay fraction of the surface soils from each profiles were determined. All the soils have high amount of mica. Other clay minerals are kaolinite, vermiculite, chlorite, considerable amount of interstratified mica-vermiculite-smectite, vermiculite-chlorite, mica-chlorite minerals and other than layer silicates quartz, feldspar, lepidocrocite, goethite minerals were also presents. The above minerals are considered allogenic.
- The presence of vermiculite in the soils indicated that mica was possibly being gradually transformed to vermiculite.
- Mineralogical composition as obtained from the present study was somehow similar to terrace areas. The possible explanation is the lower Atrai basin situated in a lower topographical position surrounded by the Barind Tract. The topsoil having very high amounts of clay was actually obtained as surface run-off from the Barind Tract over the long period of time. Thus mineralogy of these soils become similar to that of soils in the Barind Tract developed from Madhupur Clay.

E. Since the soils remains seasonally inundated for few months every year, the moisture regime of the studied is '***aquic'***. All these soils have therefore been characterized as ***hydromorphic*** where ***gleization*** is the dominant process of soil formation. The thermal regime of lower Atrai basin may, therefore, be characterized as ***hyperthermic***.

F. The soils of lower Atrai basin of Bangladesh have been classified according to the US Soil Taxonomy. All the soils under the present investigation meets the requirements of the ***Inceptisol*** order except Manda and Mainam soils they meets the requirements of the ***Entisol*** order of the above system.

H. At the subgroup level all the soils belong to Typic Endoaquepts except Manda and Mainam series which are Aeric Endoaquents.

I. According to General soil type system (GST) of classification of Bangladesh all the soils under present investigation meets the requirements of the **“*Noncalcareous Dark Grey Floodplain soils”.***

J. According to the latest World Reference Base (WRB) classification system Binsara, Taras 1, Jaonia, Taras 2, Hasnabad and Laskara soils meets the requirements of the ***Gleysol*** groups and Manda and Mainam soils meets the requirements of the ***Fluvisol*** group.

Finally, on the basis of the morphological, physical, chemical and mineralogical properties of the soils under the present investigation, the following conclusions are hereby drawn:

- Of the soils studied, only two pedons were found to fit in the Entisol order and the rests six pedons in the Inceptisol order.
- Gleization appear to be the dominant pedogenic process.
- All the studied soils are presently used for production of Boro rice and are likely to have seasonally high productive potentiality under improved management practices.
- The soils have been characterized at the family category level according to the US Soil Taxonomic system as follows (Table 25):
- This family level classification will be useful for better management of the studied soils.

Table 25. Characterization of the studied soils at the family category according to US Soil Taxonomy.

Soil Series	Family name*
Binsara **Taras 1** **Taras 2**	Clayey, illitic, nonacid, hyperthermic Typic Endoaquepts
Jaonia	Clayey over loamy, illitic, nonacid, hyperthermic Typic Endoaquepts
Hasnabad **Laskara**	Clayey over loamy, mixed, nonacid, hyperthermic Typic Endoaquepts
Manda	Loamy over sandy, illitic, nonacid, hyperthermic Aeric Endoaquents
Mainam	Loamy, illitic, nonacid, hyperthermic Aeric Endoaquents

*According to USDA Soil Taxonomy (Soil Survey Staff, 2014)

Chapter Eight

REFERENCES

CHAPTER – 8

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APPENDICES

APPENDICES

APPENDIX – 1

Values used for classification of soil acidity and alkalinity (BARC, 2012).

Class	Ranges
Extremely acid	Below 4.5
Strongly acid	4.5 - 5.5
Moderately acid	5.6 - 6.5
Neutral	6.6 - 7.3
Moderately alkaline	7.4 - 8.4
Strongly alkaline	8.5 - 9.0

APPENDIX – 2

Values used for classify organic matter content and Cation Exchange Capacity (BARC, 2012).

Class	Organic matter (%)	Cation Exchange Capacity cmol/kg
Very high	>5.5	>30
High	3.4 - 5.5	15 – 30
Medium	1.7 – 3.4	7.5 – 15
Low	1.0 – 1.7	3 – 7.5
Very low	<1.0	<3

APPENDIX – 3

Correlation coefficient value between different parameters.

Parameters	Clay (%)	HM (%)	OD/AD	LOI	OM	n-value	pH (H_2O)	pH (KCl)	ΔpH	Total N	CEC	Free Fe_2O_3	Free MnO_2	Total Fe_2O_3
Clay (%)	1.000													
HM (%)	0.862**	1.000												
OD/AD	-0.817**	-0.957**	1.000											
LOI	0.704**	0.838**	-0.813**	1.000										
OM	0.351*	0.420**	-0.439**	0.682**	1.000									
n-value	-0.542**	-0.684**	0.666**	-0.610**	-0.298*	1.000								
pH (H_2O)	-0.113 NS	-0.072 NS	0.084 NS	-0.296*	-0.585**	0.169 NS	1.000							
pH (KCl)	-0.145 NS	-0.081 NS	0.077 NS	-0.265 NS	-0.472**	0.129 NS	0.962**	1.000						
ΔpH	-0.041 NS	0.007 NS	-0.060 NS	0.232 NS	0.614**	-0.202 NS	-0.587**	-0.346*	1.000					
Total N	0.419**	0.449**	-0.445**	0.698**	0.919**	-0.288*	-0.702**	-0.618**	0.584**	1.000				
CEC	0.747**	0.918**	-0.907**	0.887**	0.565**	-0.741**	-0.188 NS	-0.185 NS	0.097 NS	0.537**	1.000			
Free Fe_2O_3	0.658**	0.772**	-0.745**	0.659**	0.185 NS	-0.681**	0.178 NS	0.203 NS	-0.010 NS	0.169 NS	0.716**	1.000		
Free MnO_2	0.415**	0.472**	-0.465**	0.266 NS	-0.124 NS	-0.317*	0.246 NS	0.256 NS	-0.085 NS	-0.134 NS	0.379*	0.681**	1.000	
Total Fe_2O_3	0.532**	0.623**	-0.654**	0.460**	0.081 NS	-0.448**	0.264 NS	0.282 *	-0.070 NS	0.069 NS	0.538**	0.733**	0.635**	1.000

** 1% level of Significance, * 5% level of Significance, NS = Not Significant

HM = Hygroscopic moisture, OD/AD = Oven dry/Air dry, LOI = Loss on ignition, OM = Organic matter N = Nitrogen, CEC = Cation exchange capacity,

APPENDIX – 4

Correlation coefficient between different parameters of the studied soils.

Parameters	**Calculated Correlation Coefficient (r)**	**Level of Significance (%)**
Clay content Vs Hygroscopic moisture	+0.862**	1
Clay content Vs Oven dry/Air dry (OD/AD)	-0.817**	1
Clay content Vs Loss on ignition (LOI)	+0.704**	1
Organic matter (OM) Vs Loss on ignition (LOI)	+0.682**	1
Clay content Vs n-Value	-0.542**	1
pH (H_2O) Vs ΔpH	-0.587**	1
pH (H_2O) and pH (KCL)	+0.962**	1
Organic matter (OM) Vs Total nitrogen (N)	+0.919**	1
Cation exchange capacity (CEC) Vs Clay content	+0.747**	1
Cation exchange capacity (CEC) Vs Organic matter	+0.565**	1
Total Fe_2O_3 Vs free Fe_2O_3	+0.733**	1
Free Fe_2O_3 Vs free MnO_2	+0.681**	1

APPENDIX – 5

Classification of land types in Bangladesh (BARC, 2012).

High land	Land above normal flood level
Very shallowly flooded	Flooded to a depth of a few cm to 30 cm in the monsoon season
Shallowly flooded	Flooded to a depth of 30 cm to 90 cm in the monsoon season
Medium low land	Flooded to a depth of 90 cm to 180 cm in the monsoon season
Low land	Flooded to a depth of 180 cm to 270 cm in the monsoon season
Very low land	Flooded to a depth of more than 270 cm in the monsoon season
Bottom land	Land remains flooded or wet for more than 8 months in a year.

APPENDIX – 6

Types of drainage condition (BARC, 2012).

Class	Description
Well drained	i) Water is removed from the soil readily but not rapidly. ii) Soil may be mottled in the G horizon.
Moderately well drained	i) Water is removed from the soil somewhat slowly. ii) Profile remains wet for a significant period of the time.
Imperfectly drained	i) Water is removed from the soil slowly. ii) Have slowly permeable layer with the profile.
Poorly drained	i) Water is removed so slowly that the soil remains wet for large period of time. ii) Water table near the surface of soil.
Very poorly drained	i) Water table near the surface of soil for a greater period of time. ii) Gleying is evident.

APPENDIX – 7

Molar ratio calculation

Ratio	**Calculation**
$\%SiO_2$	$= \frac{(10{,}000 \times \%\ SiO_2)}{At.\ Wt.\ of\ SiO_2} = m\ Mol/L\ \ SiO_2$ Or $\frac{ppm\ of\ SiO_2}{At.\ Wt.\ of\ SiO_2 \times 1000} = Mol/L\ \ SiO_2$
$\%Al_2O_3$	$= \frac{(10{,}000 \times \%\ Al_2O_3)}{At.\ Wt.\ of\ Al_2O_3} = m\ Mol/L\ Al_2O_3$ Or $\frac{ppm\ of\ Al_2O_3}{At.\ Wt.\ of\ Al_2O_3 \times 1000} = Mol/L\ \ Al_2O_3$
$\%Fe_2O_3$	$= \frac{(10{,}000 \times \%\ Fe_2O_3)}{At.\ Wt.\ of\ Fe_2O_3} = m\ Mol/L\ \ Fe_2O_3$ Or $\frac{ppm\ of\ Fe_2O_3}{At.\ Wt.\ of\ Fe_2O_3 \times 1000} = Mol/L\ \ Fe_2O_3$
SiO_2/Al_2O_3	$= \frac{Mol/L\ \ SiO_2}{Mol/L\ \ Al_2O_3}$
Al_2O_3/Fe_2O_3	$= \frac{Mol/L\ Al_2O_3}{Mol/L\ \ Fe_2O_3\ )}$
$\%R_2O_3$ (Sesquioxide)	$= \%Al_2O_3 + \%Fe_2O_3$
SiO_2/R_2O_3 ratio	$= \frac{Mol/L\ \ SiO_2}{(Mol/L\ \ Al_2O_3 + Mol/L\ \ Fe_2O_3\ )}$

APPENDIX – 8

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 – 9

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 – 10

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		
3.57 Å/3.54 Å = 1/P		

*2. Values for the coefficient **Kp.q** was 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. *Peak 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
I plotted this formula in excel sheet to find out the individual minerals and by addition of individual minerals I got total minerals, then I calculate the percentage of each mineral

Source: Aramaki (1996)