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CLAY MINERALOGY OF SOILS FROM LOWER ATRAI BASIN OF BANGLADESH

ABMS Islam, ZH Khan*, AR Mazumder, AZM Moslehuddin[1], MM Uddin and Y Mori[2]

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

Key words: Clay mineralogy, Agroecological zone, Lower Atrai basin, Bangladesh

Abstract

The lower Atrai basin, the study area, lies in the Agroecological Zone-5 (AEZ-5) of Bangladesh. This study reveals the clay mineral composition of top soils of seven different soil series *viz.* Binsara, Taras, Jaonia, Hasnabad, Laskara, Manda and Mainam developed in the basin. X-ray diffraction (XRD) technique was employed to identify and quantify the minerals. Results show that mica (41 to 59%) was the most dominant mineral among all soils except Laskara. In Laskara soils, the interstratified mica-vermiculite-smectite (41%) was the predominant mineral. 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. In contrast, the interstratified mica-vermiculite-smectite (33%) was 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. All the soils have interstratified mica-chlorite minerals (2 to 7%). A tiny amount of smectite (1%) was identified in Taras 1 soil. As far as the clay mineralogical composition is concerned, most studied soils were found at the initial stage of weathering, indicating the high potential to sustain low input subsistence agriculture.

Introduction

In the long past, Bangladesh was strewn with innumerable geosynclines of various sizes and shapes full of 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(1).

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

*Authors for correspondence: <khanzh_du@yahoo.com>. [1]Department of Soil Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh. [2]Department of Agro-environmental Science, Kyushu University, Fukuoka 812-8581, Japan.

Aman rice is grown. The basin falls under AEZ- 5 of Bangladesh. This basin 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 the Rajshahi and Bogra districts. It is located between 24°21′ to 24°51′ N latitudes and between 88°49′ to 89°23′ E longitudes (Fig. 1). 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[1].

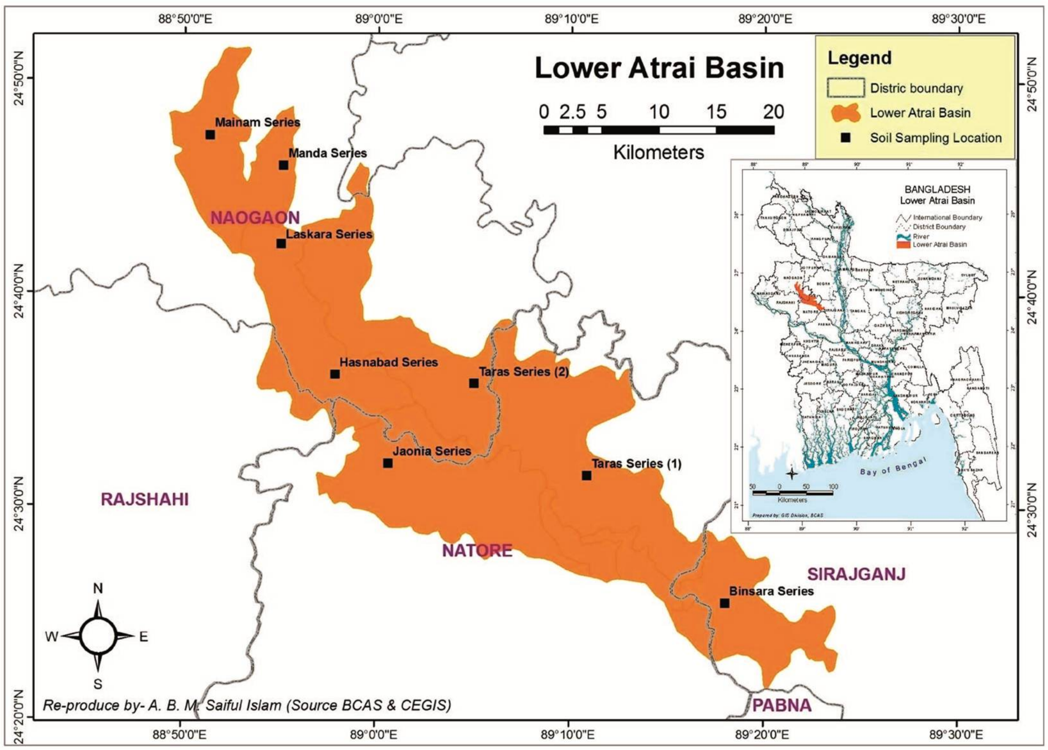


Fig 1. Map of the sampling sites of the lower Atria basin.

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, the Public Works Department (PWD) investigations revealed that siltation from distributaries of the Ganges had reduced the area of the *beel*. Only 8,600 ha of the *beel* remained underwater all year round, and large areas had dried out and were under cultivation. It was estimated that about 4.8 million cubic meters of silt were being deposited in *Chalan beel* each year[1]. Because of siltation *Chalan beel* is gradually shrinking in size, and the future may disappear, and its surface may mix with the surrounding floodplains.

Almost the whole of the basin area has now been scatteredly settled and is under cultivation during the dry season. The *Chalan beel,* geologically known as the lower Atrai basin, is being used by about 5 million people, predominantly through fisheries and agricultural activities(2). Mottles and gleys are the important redoximorphic features in the seasonally flooded soils of the lower Atrai basin. They are reliable indicators of aquic moisture regime(3) in the body of the soils. The fertility level of the *Chalan beel* soils is moderate to optimum, which is believed to be enriched by annual siltation during flooding(4). 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. The soil textural condition of *Chalan beel* is very much appropriate for rice production, which varied from silty clay to clay (4).

The present research has been undertaken to collect clay mineralogical information on the lower Atrai basin soils, 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.

Materials and Methods

Soils used: Eight soil samples from seven different representative soil series of the lower Atrai basin were collected for mineralogical analysis: one each from the Binsara, Jaonia, Hasnabad, Laskara, Manda, and Mainam series, because of the vast floodplain, two soils from the Taras series. The soils used in the present study were collected from the Ap1 horizon (surface soil) in the lower Atrai basin of Bangladesh. The sampling locations have been shown in Fig. 1. The general environmental information of the soils has been given in Table 1. The soil samples were dried at room temperature, crushed, mixed thoroughly, sieved with 2 mm mesh, and preserved in plastic pots for subsequent laboratory analysis. The experiment was carried out in the Pedology laboratory of the Soil, Water and Environment Department, University of Dhaka, Bangladesh, and partly in the laboratory of the Soil Science Department, Bangladesh Agricultural University, Mymensingh. 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, Japan.

Dispersion and separation of clay fraction: To concentrate clay fraction, the soils were thoroughly dispersed. To achieve successful dispersion, the following pretreatments were used for the removal of flocculating and cementing agents.

Table 1. General environmental information of the soils collected from the lower Atrai basin of Bangladesh.

Soil Series	Location	Latitude & Longitude	Land Type	Parent Material	General Soil Type	USDA Soil Taxonomy[8]	Area[9] (ha)
Binsara	Village - Kundoil Union - Saguna Upozila - Taras District - Serajgonj	24º 25′ 310″ N 89º 17′ 598″ E	Very low land	Tista river alluvium	Noncalcareous dark grey floodplains	Typic Endoaquepts	7383
Taras (1)	Village - Borochaugram Union - Chaugram Upozila - Singra District - Natore	24º 31′ 566″ N 89º 10′ 424″ E	Medium low land	Atrai river alluvium	Noncalcareous dark grey floodplains	Typic Endoaquepts	44678
Jaonia	Village - Akdala Union - Khajuria Upozila - Natore Sador District – Natore	24º 32′ 005″ N 89º 00′ 404″ E	Low land	Atrai river alluvium	Noncalcareous dark grey floodplains	Typic Endoaquepts	16228
Taras (2)	Village - Hingolkandi Union - Patisar Upozila - Atrai District – Naogaon	24º 35′ 485″ N 89º 04′ 594″ E	Medium low land	Atrai river alluvium	Noncalcareous dark grey floodplains	Typic Endoaquepts	44678
Hasnabad	Village – Jatamrul Union – Ahsanganj Upozila - Atrai District – Naogaon	24º 36′ 386″ N 88º 58′ 004″ E	Medium low land	Tista river alluvium	Noncalcareous dark grey floodplains	Typic Endoaquepts	4238
Laskara	Village – Ataikula Union – Mirat Upozila - Raninagar District –Naogaon	24º 42′ 191″ N 88º 55′ 009″ E	Low land	Tista river alluvium	Noncalcareous dark grey floodplains	Typic Endoaquepts	19834
Manda	Village - Chakprasad Union – Chakprasad Upozila-Naogaon Sador District – Naogaon	24º 46′ 171″ N 88º 55′ 630″ E	Shallowly flooded	Atrai river alluvium	Noncalcareous dark grey Floodplains	Aeric Endoaquents	5350
Mainam	Village – Jalkorgandi Union – Dubal Hati Upozila-Naogaon Sador District – Naogaon	24º 47′ 250″ N 88º 51′ 180″ E	Shallowly flooded	Atrai river alluvium	Noncalcareous dark grey floodplains	Aeric Endoaquents	11307

USDA= United States Department of Agriculture.

Removal of carbonates and organic matter: The soil samples were treated with 1*N* NaOAc-acetic acid buffer (pH 5) to destroy the free carbonates, and organic matter was destroyed by 30% H_2O_2 treatment [5].

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 Mehra and Jackson [6].

After removing soluble salts, carbonates, organic matter, MnO_2 and Fe_2O_3, the soils were dispersed with 5% calgon solution[7] and the clay fraction (<2 µm) was separated by repeated stirring-sedimentation-siphoning processes[7].

Preparation of slide and X-ray diffraction analysis: Specimens for XRD of the clay fraction were prepared by taking duplicate clay samples containing 50 mg of clay (<2 µm) in a 10 ml centrifugal tube. Washing by centrifugation and decantation was carried out twice with 8 ml of an equal mixture of 1*M* NaCl and 1*M* $NaCH_3COOH$ (pH 5.0) in order to decrease the pH of the preserved clay samples. Of the duplicate sets, one was saturated with K and the other with Mg by washing three times with 8 ml of 1*M* KCl and 0.5 *M* $MgCl_2$, respectively. Excess salt was removed by washing once with water. Clay in the tube was thoroughly suspended with 1 ml of water. An aliquot of 0.4 ml of the clay suspension was dropped onto a glass slide (28×48 mm), covering two-thirds of its area, air dried, and X-rayed (parallel powder mount). XRD patterns were obtained using a Rigaku X-ray diffractometer (RINT 2100 V, Rigaku) with Ni-filtered CuKα radiation at 40 kV, 20 mA, and a scanning speed of 2^o 2θ per minute over a range of 3 to 30^o 2θ. In addition to the air-dried specimen, the Mg-saturated clay specimen was X-rayed after salvation with glycerol, and the K-saturated clay specimen was X-rayed after heating at 300 and 550°C for two hours.

Identification of clay minerals was made mainly based on their characteristic basal reflections (C-axis length) following the procedure of Jackson[7]. The 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[10]. 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[11]. 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 the application of appropriate values for *Kp.q*[12], 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 <2 µm clay fraction were obtained.

Results and Discussion

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 Figs 3-10. 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. In contrast, sharp peaks (Figs 9-10) 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 small broad bulge around 17.7Å the presence of smectite 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 (Fig. 4). The reflection detected Chlorite 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 (Figs 9-10). The peaks or shoulders suggested the presence of kaolinite 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 was ascertained by the decrease in the peak intensity of the 14.2 Å reflections by heating in the K-saturated specimen. It was positively detected in Hasnabad and Laskara soils. The presence of the interstratified mica-chlorite mineral is suggestive by a peak at 12.1Å in all the treatments. At the same time, 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 indicate the interstratified mica-vermiculite-smectite minerals[13]. All these minerals were detected in Hasnabad and Laskara soils. The reflections of 6.27Å, 4.25Å, 4.18Å and 3.2Å were indicative of the identification of lepidocrocite, quartz, goethite, and feldspar minerals, respectively[7,13].

The approximate mineral composition of the <2 µm 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[10] and is presented in Table 2. The results showed 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 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 interstratified mica-chlorite minerals (2 to 7%). A very little amount of smectite (1%) was identified in Taras 1 soil.

Among other minerals, 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. Feldspar (4%) was identified in Binsara soils, and goethite (3%) was present in Taras 2 soils. These results suggest that the studied soils may derive from parent materials containing fine grained quartz mineral, in the clay fraction. Clay mineralogical composition was hardly influenced by the land type and general soil type[3].

Discussion on individual minerals: In the clay fraction of the lower Atrai basin soils, mica was the predominant mineral in all soils and ranged from 28 to 59 percent (Fig. 2). Results indicate that a high amount of mica is present in lower Atrai basin soils. Moslehuddin *et al.*[20] found similar results in clay fraction (<2 µm) of the lower Atrai basin soils. Reza *et al.*[14], Khan and Ottner[15], Moslehuddin *et al.*[16], Moslehuddin *et al.*[17], Islam and Hussain[18], Egashira and Yasmin[12] also found that mica was the predominant clay mineral in almost all floodplain soils of Bangladesh. Fanning and Keramidas[19] pointed out that mica in most soils originate mainly from soil parent materials and tend to weather to other minerals with time. They generally are more prevalent in the clay mineralogy of younger and less weathered soils (Entisols, Inceptisols, Alfisols). Also, micas tend to occur more as discrete mica particles in the less weathered soils if such particles are present in the soil parent material, whereas in more weathered materials, the mica is more commonly interstratified with expansible 2:1 minerals that may also be partially chloritized[5].

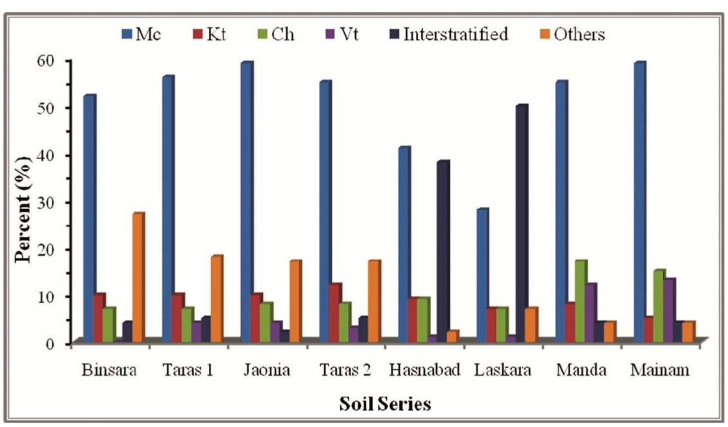


Fig 2. The mineral composition of the clay fraction (<2 µm) of the surface soils of the lower Atrai basin.

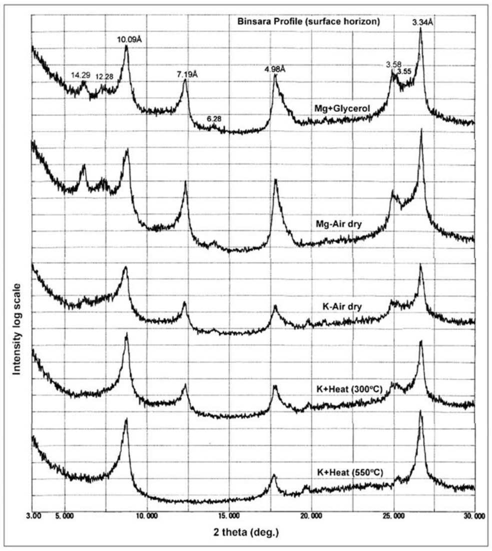


Fig. 3. X-ray diffractograms of clay sample of Binsara soil.

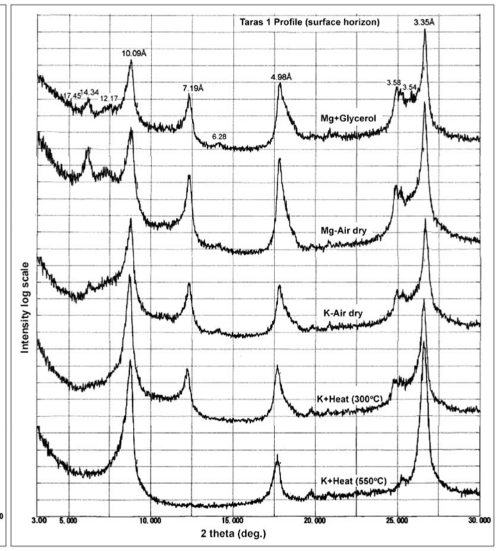


Fig. 4. X-ray diffractograms of clay sample of Taras 1 soil.

Fig. 5. X-ray diffractograms of clay sample of Jaonia soil.

Fig. 6. X-ray diffractograms of clay sample of Taras 2 soil.

The soils under the present study contain 5 to 12 percent kaolinite in the clay fraction (Table 2). Kaolinite was present in all the soils but in small amounts, although this mineral was dominant in four soils. Moslehuddin *et al.*(17) and Moslehuddin *et al.*(20) found a similar result in their study. Brady(21) and Jackson and Sherman(22) 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. Dixon [23] noted that kaolinite usually forms under well drained conditions through the weathering of feldspars. In the floodplain soils of Bangladesh, the kaolinite mineral is thought to be allogenic in nature and is believed to be derived from parent material [3,12].

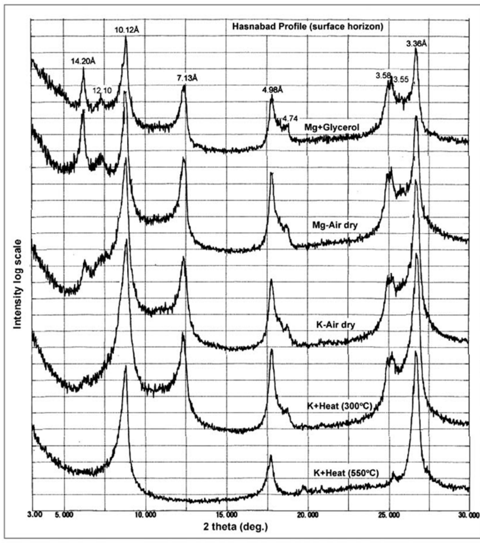


Fig. 7. X-ray diffractograms of clay sample of Hasnabad soil.

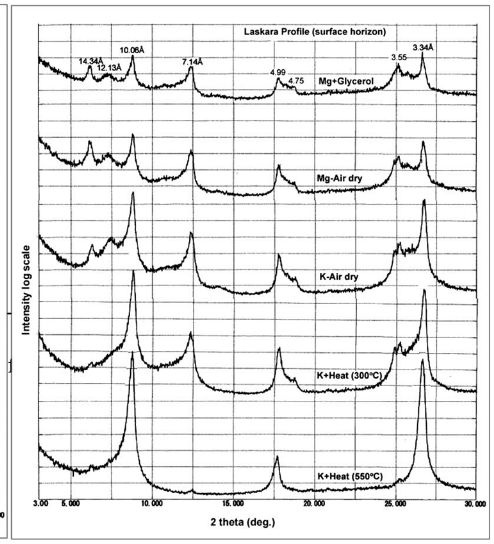


Fig. 8. X-ray diffractograms of clay sample of Laskara soil.

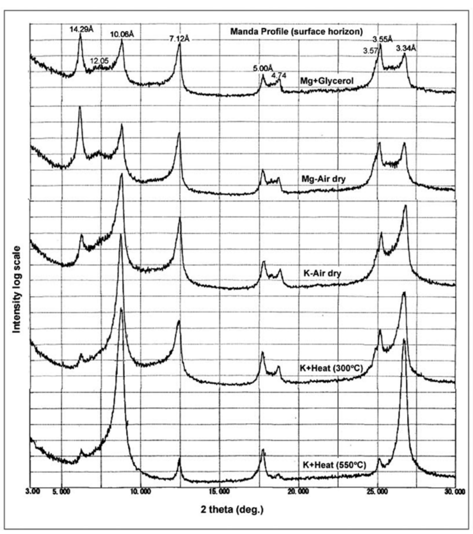


Fig. 9. X-ray diffractograms of clay sample of Manda soil.

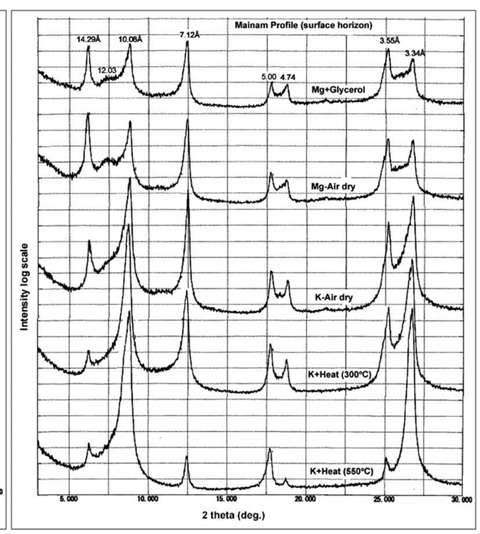


Fig. 10. X-ray diffractograms of clay sample of Mainam soil.

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

Soil Series	Horizon	Depth (cm)	% Mineral Content(10,11)												Soil Mineralogy Class(8)
			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

Mc = Mica, Sm = Smectite, Vt = Vermiculite, Ch = Chlorite, Kt = Kaolinite, Qr = Quartz, Gt = Goethite, Lp = Lepodocrocite, Fd = Feldspar.

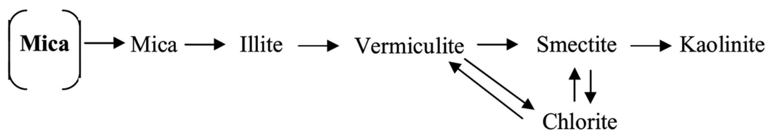
The lower Atrai basin contains 7 to 17 percent chlorite (Table 2) in the clay fraction of all the soils. Although this amount was small, chlorite was dominant in Manda and Mainam soils. These findings are in agreement with that of Kader *et al.* [24], Moslehuddin *et al.* [20], Shamsuzzoha *et al.* [25], Moslehuddin and Egashira[10]. Barnhisel[26] 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 a 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 2) in the clay fraction (<2µm) of all soils except Binsara soils implies that the transformation of mica is considerable. Douglas [27] stated that soil vermiculites are nearly always reported to occur as an alteration product of muscovite, biotite and chlorite. In soil, dioctahedral vermiculite is more common than trioctahedral vermiculite [22], probably indicating the relative stability of the muscovite structure or 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 was reported by Douglas [27]. Vermiculite persists under extreme weathering condition for a long period of time; the normal weathering sequence is: mica > vermiculite > hydroxyl aluminum > interlayered vermiculite [27].

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 signifies 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.*[20]. This gives the impression that the major contribution of parent material might be from the Madhupur clay of adjacent Barind Tract. The presence of interstratified mica-vermiculite-smectite minerals as dominant minerals in the clay fraction has been reported from the terrace soils of Bangladesh [10,12,13,17,28].

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 [10,13]. The possible explanation is that the lower Atrai basin is situated in a lower topographical position surrounded by the Barind tract. The topsoil with very high amounts of clay was probably formed due to surface run-off from the Barind tract spanning over a long time. Thus mineralogy of these soils has become similar to soils in the Barind tract developed from Madhupur clay. Although the parent material of the soils has been designated as Tista and Atrai alluvium, 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 2). The presence of a 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 potassium loss appears to be a vital 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 a high mica mineral content, which is believed to be transforming expandable minerals, sufficient replenishment of K in the soil solution may be expected. The soils, therefore, may have little need for potash fertilizer application as the K content in the soils was high. If any potash fertilizer was applied in such soils then there are likelihood of reversing the reaction processes. In that case the expanding lattice minerals, after fixing K^+ in the inter lattice space, may revert to illite. But the probability of this kind of reversal might be remote in the seasonally flooded soils of Bangladesh as there was the loss of nutrients in the draining water. Potassium in the 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. Saheed and Hussain(3) noted that some *in situ* transformation might have taken place under the influence of local soil management practices. However, if any, such change is as 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 helps make predictions about soil behavior and responses to management. Some mineralogy classes are essential only in specific 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, this soil will belong to the *illitic* mineralogy class(8). According to USDA mineralogy classes, the obtained mineralogical composition (Table 2) shows that Binsara, Taras 2, Jaonia, Taras 1, Manda, and Mainam soils fall under *illitic* mineralogy, Hasnabad and Laskara soils are characterized as *mixed* mineralogy classes. 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 crops. 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, technological innovation and their transfer are being done based on AEZ. 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 present study's findings 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 the easy selection of land use and determination of soil, water, and fertilizer management throughout the region.

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