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Characterization and Classification of Clay Rich Alluvial Soils to Explore Soil-Landform Relationship in Lower Indo-Gangetic Plains of India

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Abstract: *Characterization and classification of soils divulge its genesis and processes of formation, which is strongly related to geomorphic cycles followed by landform development. The alluvial plains are complex landscape assemblages formed by the overlap of multiple riverine systems. Soils developed under alluvial plains are having wide variations depicting the partial influence of different rivers and the quality and quantity of sediments, spatially and temporally. To investigate the characterization, genesis and classification of alluvial soils with its subsequent spatial occurrence in the Lower Indo-Gangetic Plains of West Bengal, the present study has been carried out in Habibpur block of Maldah district, West Bengal situated within Tangon and Punarbhaba river plains under two contrasting landform situations (old alluvial plains and young alluvial plains) with varying slope classes. Soils of old alluvial plains were very deep, moderately well drained, slight to moderate erosion with having clay enrichment (presence of argillic horizon) in the sub-soil layers and classified as Alfisols. Inceptisols with very deep, well to somewhat poorly drained soils were found under young alluvial plains. In general, the pH, soil organic carbon and cation exchange capacity of the surface horizon ranged from 5.7 to 6.6, 0.3 to 0.9 % and 6.3 to 15.1 cmol (p+) kg^{-1}, respectively. Data on pedogenic indices revealed that, the P1 and P2 pedons of old alluvial plain and P4 pedon of the young alluvial plains had relatively lower sand/silt ratio as compared to the P3 pedon of young alluvial plains (nearly level) in both surface and sub-surface horizons showing the more matured soils with relatively higher profile development in P1, P2 and P4 pedons than P3 pedon. The distance and influence of the river on soil devepoment has been found to be very crucial and could dominate over the other soil forming factors active in alluvial plains.*

Keywords: Earth system; Geogenic process; Geomorphology; Pedogenesis; Sedimentalogy

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Soil resource characterization reveals the imprint of soil forming processes and is intimately related to geomorphic cycles followed by landform development. Landforms are large, contiguous areas of similar geomorphologic history with almost similar chemical and physical properties that distinguish it from other landforms (Easterbrook, 1999). Landform implies the significant effect on soil physical and chemical environment through alteration of soil moisture, drainage, flow pattern, temperature regime, sedimentation and erosion (Bhattacharyya *et al.*, 2010, Vasu *et al.*, 2016, Reza *et al.*, 2022). The balance between morphogenesis-pedogenesis in the same environment and factors such as climate, vegetation, lithology, topography, time, and anthropogenic alteration represents the basic principles of soil geomorphology or geopedology (Birkeland, 1984, Schaetzel and Anderson, 2005; Zinck, 2016). The alluvial plains are complex landscape assemblages composed of active landforms (*e.g.* channels) and stabilized units of various ages and origins (*e.g.* abandoned channels and banks), which are often formed by the overlap of multiple riverine systems in space and time (Gautier *et al.*, 2009, Hoffmann *et al.*, 2010, D'Haen *et al.*, 2012). The formation of alluvial plains mostly depends on tectonic development followed by configuration of landform by flow direction, slope, drainage, erosion and quantity of sediments of a river basin. The agricultural practices and their interactions with the hydrographic networks cause additional changes in the natural soil physical, chemical and biological environments. Many Indian researchers studied the relationship between soil properties developed under various landforms based on the variation in soil forming processes (Vasu *et al.,* 2016, Reza *et al.*, 2022, Gangopadhyay *et al.*, 2022) but in different geological formation. Establishing soil-landform relationship in the alluvial plains is much more difficult and site-specific, because of the high relative interference of riverine flow dynamics. Alluvial soils are dominated in the lower Indo-Gangetic plains, in which Habibpur block of Maldah district, West Bengal is situated within Tangon and Punarbhaba river plains. Some geoscientists commented that this area is evolved due to tectonic upliftment, which under the influence of Ganga and its tributaries resulted alluvial terrace formation and abruptly merged with recent flood plains (Rashid *et al.*, 2015). Limited information is available regarding the soil formation in this area of lower Indo-Gangetic Plains and its subsequent relationship with the landforms. We hypothesized that there is a strong influence of riverine dynamics and geomorphic setting on soil pedogenic processes and properties. Thus, the present study has been conducted to i) evaluate the degree of soil development and maturity using pedogenic indices and ii) characterize and classify the soils developed under various geomorphic settings and their inter-relationship in the alluvial plains of Habibpur block of Maldah district, West Bengal.

Materials and Methods

Study area

The present study has been conducted during 2021 in Habibpur Block of Maldah district, West Bengal, covering an area of 412.7 km^2. The area falls between 24°52′14″ N to 25°07′34″ N latitudes and 88°13′25″ E to 88°27′15″ E longitudes (Fig.1).

The study area is characterized by two major physiographic complexes viz. Barind tract in the central part and narrow floodplain channels bordering the block. The Barind tract of Pleistocene age is actually an alluvial terrace formation slightly elevated to about 20-40 m sloping towards floodplains. The narrow floodplain channels of Holocene age lying within the elevation of 15 m - 20 m are replenished by regular inundation. The rivers Punarbhaba and Tangon are flowing in the eastern and western borders of the block respectively. These rivers are single channel meandering rivers but show

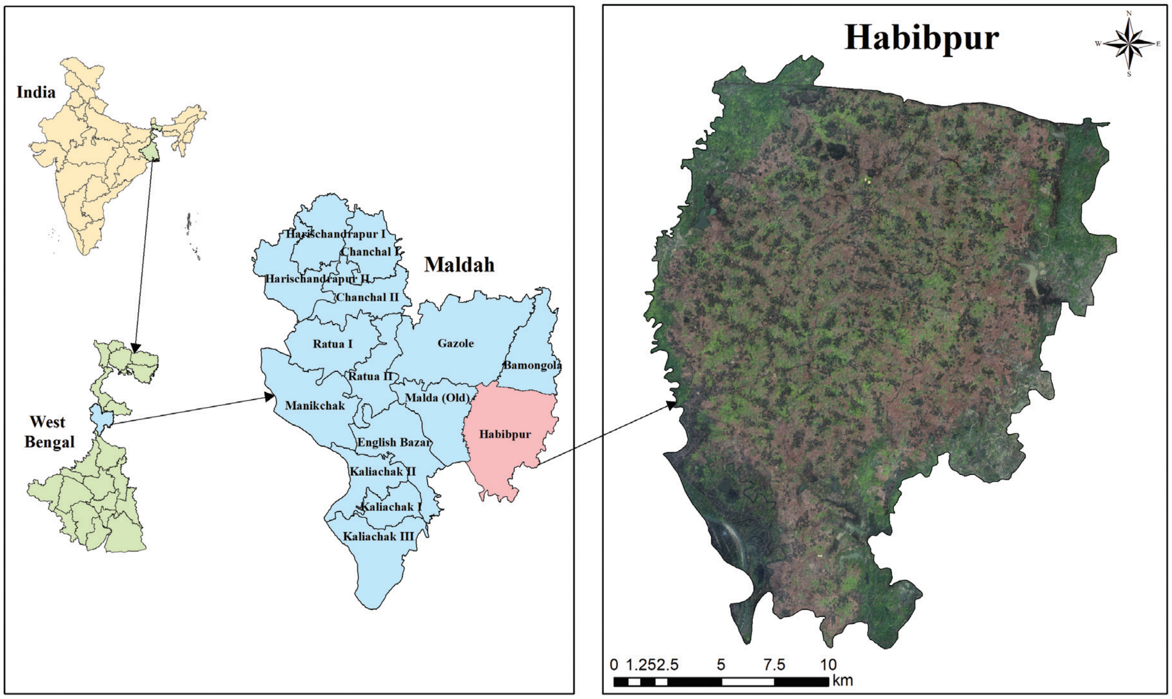

Fig. 1. Location map of the study area (Habibpur block, Maldah district, West Bengal)

their anastomosed character making their beds and banks filled up with soft sediments, sensitive to changes of sediment load resulted to the variation in slopes.

These two physiographic complexes are the result of Neotectonic movements reflected in the small changes in slope (Rashid *et al.*, 2015) and adoption of drainage system with the changes of surface slopes and resultant fluvial anomalies like meander scars, anomalous curve or turn, variation of levees etc are the possible indicators of active tectonic in alluvial plain (DeBlieux, 1951, DeBlieux, 1962, Leopold and Wolman, 1957, Ollier, 1981, Ouchi, 1985, Singh and Ghosh, 1994).

Hot moist sub-humid climate is characterising the climate of the block with an average annual rainfall of 1545 mm, mean summer temperature of 41°C and mean winter temperature of 19.7°C. The relative humidity ranges from 67-83 percent. The area comes under AESR 15.1, hot, moist sub-humid Eco Sub Region (SER) with deep loamy to clayey alluvium derived soils, medium to high AWC and LGP 210-240 days (Mandal *et al.*, 2014). The area is dominated with rice based cropping system. Apart from that, mustard and potato are the other dominant crops in the area under assured irrigation system.

Landform delineation and mapping

The landform was delineated using satellite data (Sentinnel 2 data) with 10 m spatial resolution (Fig. 2), Survey of India Toposheets (at 1:50000 scale), digital elevation model [SRTM (30 m) DEM] (Fig. 3). Sentinel-2 imagery from January shows greater vegetation coverage with high NDVI due to growing *Rabi* crops, while imagery from April shows post-harvest conditions with more bare soil and lower NDVI values in the same year (2021). Different terrain attributes like contours, drainage, slope etc. were treated as input layer for landform delineation (Gupta Choudhury *et al.*, 2019) in GIS environment (ArcGIS 10.5). The landform map was further undergone ground truth checking through field traversing (Fig. 4) and certain transects through

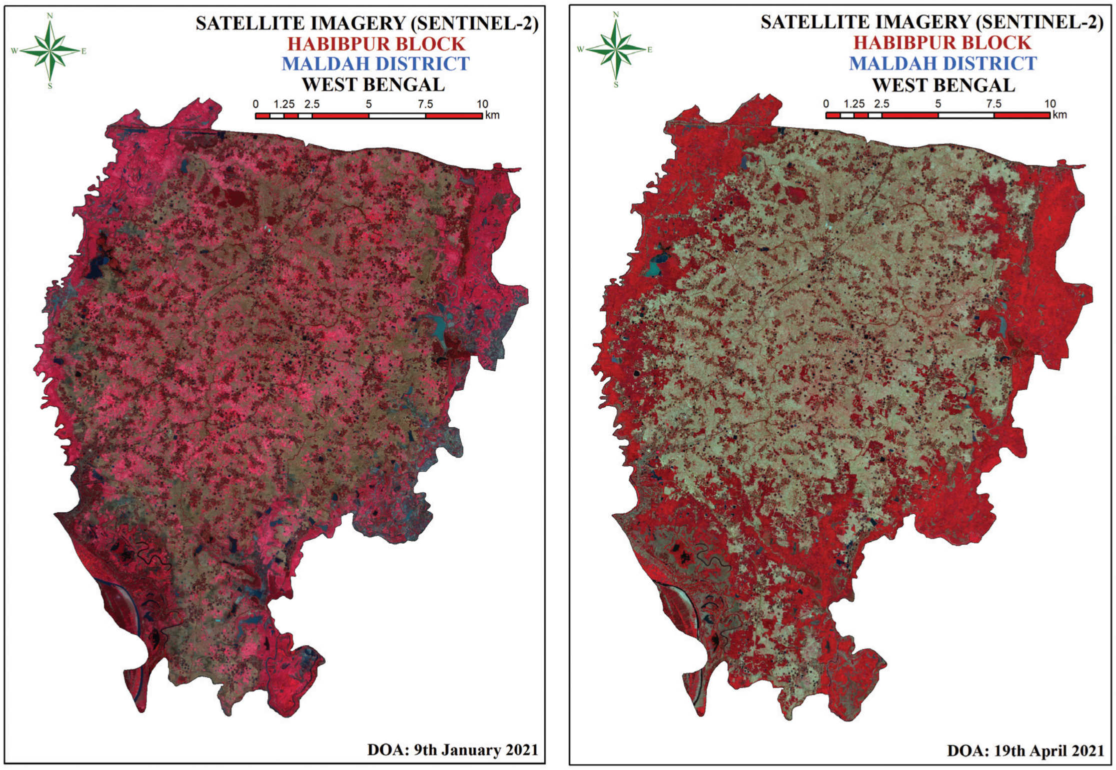

Fig. 2. Satellite imagery of the study area (Habibpur block, Maldah district, West Bengal)

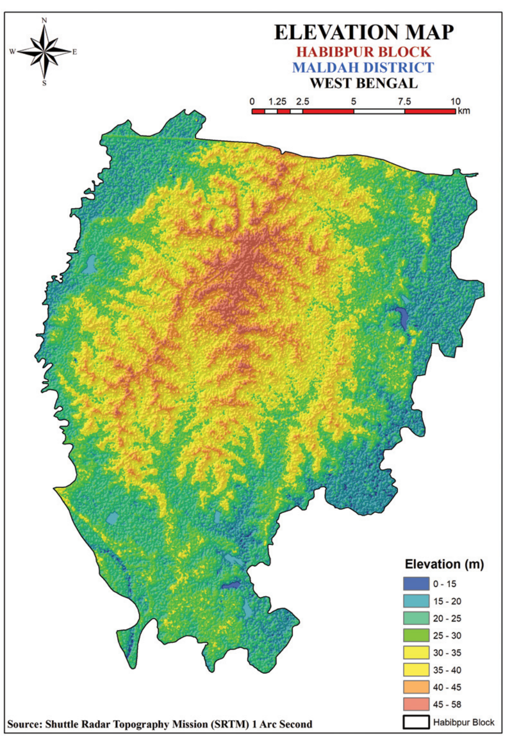

Fig. 3. Elevation map of the study area (Habibpur block, Maldah district, West Bengal)

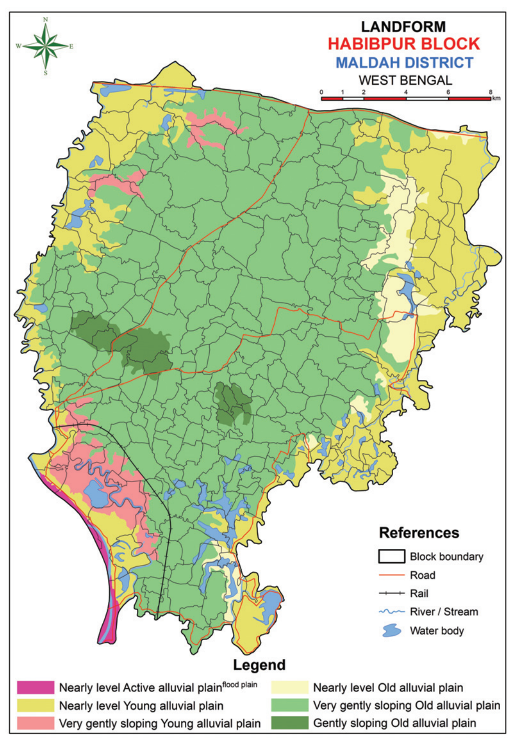

Fig. 4. Landform map of the study area (Habibpur block, Maldah district, West Bengal)

different catena for verification of delineated landform units in detail.

Soil sampling, preparation and analyses

Representative soil profiles (16 nos.) under four specific landforms (nearly level old alluvial plains, very gently sloping old alluvial plains, nearly level young alluvial plains and very gently sloping young alluvial plains of Barind tract and floodplain complexes) have been selected to study the detailed soil characteristics (morphological, physical and chemical), classification, genesis and the relationship of the different soils with the corresponding landforms of its occurrence. The morphological and site characteristics were studied following the guidelines of Soil Survey Staff (1995). The soil site description was noted using the standards proforma developed by ICAR-NBSS & LUP (Sehgal *et al.*, 1987). Horizon wise soil samples were collected, air-dried, processed and sieved (through 2-mm and 0.15 mm sieve) followed by various physico-chemical analyses. Particle size analysis has been carried out through international pipette method as described by Piper (1966). The textural class was determined by USDA textural triangle. Soil reaction and electrical conductivity (soil: water:: 1:2.5) were determined by pH meter (Jackson, 1973) and conductivity meter (Richards, 1954). Oxidizable organic carbon (OC) was determined by wet digestion method proposed by Walkley and Black (1934). Cation exchange capacity (CEC) was estimated by leaching the soil with neutral normal ammonium acetate (Schollenberger and Simon, 1945). The exchangeable cations extracted through neutral normal ammonium acetate were determined by flame photometer (potassium and sodium) and atomic absorption spectrophotometer (calcium and magnesium) following the method of Hesse (1972). The soils from each landform units have been correlated based on their morphological and physico-chemical characteristics and four dominant soil series have been identified. The soils thus obtained were taxonomically classified (Soil Survey Staff, 2022) up to sub-group level.

Results and Discussion

Morphological characteristics of soils

Soils of the study area were very deep, well to somewhat poorly drained, moderately to slightly eroded with occasional to frequent flooding and loam to silty clay loam surface texture

Table 1. Basic information of pedons in different landforms

Pedon	Series	Landform	Latitude (ºN)	Longitude (ºE)	Slope (%)	Drainage	Erosion	Runoff	Flooding	Present land use
P1	Kismat Daudpur	AaO1	25.03033	88.38033	0–1	Moderately well	Slight	Slow	Occasional	Rice-Fallow
P2	Chhuchail	AaO2	25.00010	88.30946	1-3	Moderately well	Moderate	Medium	Occasional	Rice-Mustard
P3	Mabarakpur	AaY1	24.97639	88.22354	0-1	Well	Slight	Slow	Frequent	Maize-Vegetables
P4	Sadhail	AaY2	25.15676	88.25978	1-3	Somewhat poorly drained	Slight	Slow	Frequent	Rice-Rice

AaO1= Nearly level old alluvial plains; AaO2= Very gently sloping old alluvial plains; AaY1= Nearly level young alluvial plains; AaY2= Very gently sloping young alluvial plains.

developed on Gangetic alluvium. The surface runoff ranged from slow to medium. The area was dominated with rice-fallow/ rice-mustard cropping systems. Some patches were cultivated with maize followed by vegetables.

Surface soil colour of all the pedons were of 2.5Y hue, and the value and chroma both ranged from 4 to 5 and 3 to 4, respectively. The sub-soil colour for all the pedons had hue of 2.5Y and ranged from 3 to 6 in value and 1 to 6 in chroma (Table 2). The soil colour seems to be an impression of combined effect of chemical-minerological composition, texture, topographic position, moisture regime, redoximorphic features and organic matter (Walia and Rao, 1997). The presence of redoximorphic features in all the profiles revealed the alternate wetting and drying conditions within the soil profiles. The mottle colour ranged from 7.5 YR to 10 YR hue with value 4 to 5 and chroma 6 to 8. The soil structure is mostly sub-angular blocky with fine, moderate to coarse in size and moderate in grade. The consistency of the soils varied from loose to hard (dry), friable to slightly firm (moist) and slightly sticky to very sticky (wet). The plasticity varied from slightly plastic to very plastic depending on the soil type. The relative proportion of sand, silt and clay along with the type of organic matter associated with the soil separates might play a major role in soil consistency (Table 2). Most of the cultivated soils showed fine many roots in surface. As the area is dominated by rice and maize (cereal ecology), thus fine to medium, many roots were found in surface soils of the area (Gupta Choudhury *et al*., 2014). The two sub-soil layers were dominated by fine roots with common distribution. The surface soil of pedon 2 and 4 had fine-many pores, whereas, pedon 1 and 3 had medium- many and coarse- many pores space, respectively. In lower soil layers, pedon 1 and 4, the sub-soils were dominated with fine-many pores space and in pedon 2 and 3 there were fine-common pores space in the sub-soil layers. The pores space distribution is also dependent on the structure, texture, organic matter content and root distribution of the particular soil (Gupta Choudhury *et al*., 2019). In P1 and P3 pedons, the top soil horizon was Ap horizon followed by Bw horizons (cambic horizons), but in P2 pedon, the sub-soil horizons were Bt (argillic horizon) depicting the clay illuviation in the lower layers forming Alfisols. The P4 pedon showed gleyed horizon in the lower layer confirming aquic moisture regime in the soil profile. The big cracks with clay/CEC ratio > 0.4 and COLE value ranging from 0.07 to 0.09 indicated the presence of *Vertic* properties of the soils.

Physico-chemical characteristics of soils

Results showed that the surface soils were loam to silty clay loam in texture with total sand, silt and clay content ranging from 0.8% to 39.8%, 45.1% to 83.66% and 14.9 to 39.1%, respectively (Table 3). In general, the surface soils were slightly to moderately acidic in nature with pH ranging from 5.7 to 6.6. Soils were free of salinity (EC ranged from 0.01 to 0.10 dS m^{-1}). The sub-surface soils were non-saline with neutral to slightly alkaline pH ranging from 6.8 to 7.8 (Table 3). The sub-surface soil texture ranged from sandy loam to silty clay with clay content ranged from 8.9 to 54.3%. Among the four pedons distributed in different landforms, P1 and P2 were qualified as Alfisols with clay enrichment along the depth within the soil profile. Presence of Argillic horizon with tiny patchy cutans on the ped faces assured the downward movement of clay particle (Gangopadhyay *et al*., 2012). The higher clay content in the subsoil of P1 and P2 (Table 3) is a result of long-term leaching and deposition of fine particles from the surface layer (illuviation) showing a hallmark of matured soil profiles like Alfisols (Gupta Choudhury *et al.*, 2023). Among all, P3 and P4 soils were classified as Inceptisols. P3 showed sharp clay drop in the lower horizons (from 37 cm onwards) along with absence of true argillic horizon (Soil Survey Staff,

Table 2. Morphological properties of the pedons

Pedon Depth (cm)	Horizon	Boundary	Matrix Colour	Texture	Mottle colour	Structure	Consistency			Plasticity	Roots	Pores
							Dry	Moist	Wet			
Pedon 1: Fine-silty, mixed, hyperthermic, Aeric Epiaqualfs												
0-16	Ap	cs	2.5Y5/4	sil	10YR5/8	m2sbk	sh	sfi	ms	mp	mm	mm
16-43	Bt1	cs	2.5Y5/4	sicl	10YR5/6	m3sbk	h	fi	vs	vp	cf	fm
43-70	Bt2	gs	2.5Y5/3	sicl	10YR5/6	m3sbk	sh	fr	ss	sp	–	fm
70-91	Bt3	gs	2.5Y6/2	sicl	7.5YR4/6	m3sbk	h	fi	vs	vp	–	fm
91-150	Bt4	gs	2.5Y5/2	sicl	10YR5/8	m3sbk	h	fi	vs	vp	–	fm
Pedon 2: Fine- silty, mixed, hyperthermic, Typic Haplustalfs												
0-17	Ap	cs	2.5Y5/4	sil	7.5YR5/8	m2sbk	sh	sfi	ms	mp	fm	fm
17-40	Bt1	cs	2.5Y5/4	sicl	7.5YR5/8	m2sbk	h	fi	ms	mp	cf	cf
40-68	Bt2	gs	10YR5/6	sicl	7.5YR5/8	m3sbk	h	fi	vs	vp	mf	cf
68-96	Bt3	cs	10YR5/6	sicl	7.5YR5/8	m3sbk	h	fi	vs	vp	–	cf
96-150	Bt4	cs	10YR5/4	sicl	7.5YR5/8	m2sbk	h	fi	vs	vp	–	cf
Pedon 3: Coarse-loamy, mixed, hyperthermic, Typic Haplustepts												
0-20	Ap	cs	2.5Y5/4	l	–	m1sbk	l	fr	ss	sp	fm	cm
20-37	Bw1	cs	2.5Y4/3	l	10YR5/6	m1sbk	l	fr	ms	mp	cf	fm
37-64	Bw2	cs	2.5Y5/3	l	10YR5/6	m1sbk	l	fr	ss	sp	ff	vcm
64-85	Bw3	cs	2.5Y6/3	sl	–	sg	l	fr	ss	sp	–	vcm
85-150	Bw4	cs	2.5Y4/3	sl	10YR4/6	sg	l	fr	ms	mp	–	cm
Pedon 4: Fine, mixed, hyperthermic, Vertic Endoaquepts												
0-21	Ap	cs	2.5Y4/3	sicl	10YR4/6	m3sbk	sh	sfi	ms	mp	fm	fm
21-44	Bw1g	gs	2.5Y4/2	sic	–	m3sbk	h	fi	vs	vp	–	fm
44-72	Bw2g	gs	2.5Y3/2	sic	–	m3sbk	h	fi	vs	vp	–	fm
72-92	Bw3g	gs	2.5Y4/1	sic	–	m3sbk	h	fi	vs	vp	–	fm
92-150	Bw4g	gs	2.5Y3/1	sic	–	m3sbk	h	fi	vs	vp	–	fm

Boundary: cs= clear smooth, gs= gradual smooth; Soil texture: sl= sandy loam, sil= silty loam, scl= sandy clay loam, l= loam, sicl= silty clay loam, sic=silty clay; Structure: m= medium size, sbk= sub-angular blocky, sg=single grain, 1= weak structure, 2= moderate structure, 3= strong structure; Consistency: l= loose, sh= slightly hard, h=hard; fr=friable, sfi= slightly firm, fi= firm; ss= slightly sticky, ms= moderately sticky, vs= very sticky; sp=slightly plastic, mp=moderately plastic, vp= very plastic; Roots/pores: ff= fine few, fm= fine many, cm= coarse many, cf= coarse few, mm=medium many, mf=medium few, vcm=very coarse many

Table 3. Physico-chemical characteristics of the pedon

Profile	Series	Depth (cm)	Sand	Silt	Clay	pHw	EC (dSm^{-1})	OC (%)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	BS (%)
				(%)							[cmol(p+)kg^{-1}]			
P1	Kismat Daudpur	0-16	1.0	79.3	19.7	5.7	0.06	0.65	3.4	0.8	0.2	0.1	6.8	66
		16-43	2.9	66.2	30.9	7.6	0.08	0.21	6.6	1.4	0.4	0.1	9.9	86
		43-70	3.2	66.4	30.4	7.7	0.10	0.10	6.1	1.3	0.4	0.1	9.1	87
		70-91	3.1	68.3	28.6	7.8	0.10	0.12	8.9	2	0.4	0.1	12.8	89
		91-150	2.4	67.0	30.6	7.8	0.13	0.13	8.5	1.8	0.2	0.1	12.1	88
P2	Chhuchail	0-17	1.5	83.6	14.9	6.3	0.07	0.44	3.9	0.9	0.2	0.1	6.8	75
		17-40	1.8	65.9	32.3	6.8	0.09	0.24	6.5	1.4	0.4	0.2	10.7	79
		40-68	2.6	57.9	39.5	6.8	0.10	0.15	6.8	1.8	0.3	0.2	11.5	79
		68-96	2.1	58.0	39.9	7.1	0.09	0.13	6.9	2.2	0.2	0.2	11.6	82
		96-150	2.9	58.5	38.6	7.1	0.09	0.1	6.5	2	0.3	0.2	11	82
P3	Mabarakpur	0-20	39.8	45.1	15.1	6.6	0.05	0.3	2.9	1.6	0.3	0.1	6.3	77
		20-37	37.2	38.7	24.1	7	0.08	0.24	4.3	1.7	0.3	0.2	8	81
		37-64	50.6	34.5	14.9	7.1	0.06	0.15	3.6	1.8	0.4	0.1	7.3	81
		64-85	65.1	26.0	8.9	7.3	0.04	0.06	2	0.8	0.2	0.1	3.7	84
		85-150	53.1	36.5	10.4	7.4	0.06	0.06	3.6	1.0	0.4	0.3	6.2	85
P4	Sadhail	0-21	0.8	60.1	39.1	5.8	0.14	0.93	8.6	1.3	0.3	0.2	15.1	69
		21-44	1.4	54.2	44.4	6.9	0.1	0.39	10.7	1.7	0.3	0.1	16	80
		44-72	1.4	54.7	43.9	6.9	0.08	0.38	9.3	1.4	0.4	0.1	14	80
		72-92	1.3	46.4	52.3	6.9	0.05	0.38	12.4	2	0.4	0.2	18.3	82
		92-150	1.7	44	54.3	6.9	0.06	0.36	13.1	2.1	0.4	0.2	19.3	82

2022), whereas, P4 exhibited high clay content (expanding type) throughout the profile with *Vertic* property. Soil organic carbon varied from 0.30% to 0.93 % in the surface horizon, whereas, in the sub-soil layers, it varied from 0.06 % to 0.39 %. The higher soil organic carbon in the top soil might be attributed to the higher organic matter deposition through leaf litter fall, rhizodeposition, root exudates etc. from the crops grown with different management strategies (Gupta Choudhury *et al.*, 2018). The organic carbon content of all the soils decreased with increasing depth in all soil profiles except P1, in which it initially decreased in second and third horizons, and then increased with increasing depth. The cultivation of double crop in the valley fill region (P4) resulted in deposition of higher plant residues in the form of root and shoot biomass, which might increase the SOC content in that region as compared to other landuses (Gupta Choudhury *et al.*, 2014). Among the various exchangeable bases, calcium and magnesium shared the major proportion from 59.0 to 84.0% and from 13.0 to 31.0% of the total exchangeable bases, respectively. The CEC and base saturation of the surface horizon ranged from 6.3 to 15.1 cmol (p^+) kg^{-1} and from 66.0 to 89.0%, respectively. Both the CEC and the base saturation increased in the subsurface horizon as compared to surface horizon. The increased CEC in the sub soil layers, particularly in P1, P2, and P4 profiles, might be attributed to the higher sub-soil clay content, resulting finer particles and higher proportions of weathered secondary clay minerals, which provide more negatively charged exchange sites, thereby enhancing the cation-holding capacity in the soil system (Astera, 2010; Ghimire *et al.*, 2024).

Soil classification

Based on the morphological, physical and chemical characteristics, these four soils of Habibpur block has been taxonomically classified upto family level (Soil Survey Staff, 2010) under two major orders (Alfisols and Inceptisols). Pedon P1, P2 and P4 were classified as Fine-silty, mixed, hyperthermic, Aeric Epiaqualfs and Fine-silty, mixed, hyperthermic, Typic Haplustalfs, and Fine, mixed, hyperthermic Vertic Endoaquepts, respectively; whereas pedons P3 was classified as Coarse loamy, mixed, hyperthermic Typic Haplustepts. Soils under old alluvial plains with a stable older landform development showed clay illuviation (presence of argillic horizon) in the lower layers at more than 1.2 times rate with increasing depth with clear patchy clay cutans and ≥ 35% base saturation, were qualified as Haplustalfs. Similarly, soils with episaturation and comparatively high chroma occurring in the matrix of the peds in the argillic horizon having colour value 3 or more and chroma 2 or more classified as Aeric Epiaqualfs (Soil Survey Staff, 2022). Subsequently, deeply cracked, dark coloured soils saturated with water for more than 200 days in a year with gleying and chroma 1 to 3 revealed P4 soil as Vertic Endoaquepts (Soil Survey Staff, 2022).

Landform-soil relationship

Being situated in the Pleistocene upland locally known as Barind Tract, this part of lower Indo-Gangetic plain (Bengal Basin) subjected to modifications by the thick alluvium deposition of Holocene age. Neotectonic movements are reflected only in those geomorphic features that react to smallest changes of slope while merging into Recent Floodplain of Tangon and Punarbhaba Rivers (Rashid *et al*., 2015) and adoption of drainage system with the changes of surface slopes resulted in the anomalous fluvial geomorphic features like meander scars, anomalous curve or turn, variation of levees etc which are all possible indicators of active tectonic process in alluvial plain (DeBlieux, 1951, DeBlieux, 1962; Leopold and Wolman, 1957, Ollier, 1981, Ouchi, 1985, Singh and Ghosh, 1994). The presence of fault like Maldah-Kishanganj fault, Jamuna fault restricted the water flow to the uplifted Barind Tract from the adjacent channels of Punarbhaba and Tangon rivers. Therefore, this tract is now dominated by older alluvium while the floodplain channels are covered with younger alluvium. The impact of young alluvium cannot be ignored due to juxtaposition of narrow floodplain channels on both eastern and western boundaries of the block. Hence, the study area is having four typical landforms viz. nearly level old alluvial plains, very gently sloping old alluvial plains over Barind formation, nearly level young alluvial plains and very gently sloping young alluvial plains along the floodplains (Table 1, Fig. 5).

Soils of old alluvial plains were very deep, fine-silty with moderately well-drained and slight erosion (P1 and P2). On the contrary, based on the type of alluvium deposition, soils of young alluvial plains were characterized by very deep, coarse loamy to fine, well to somewhat poorly drained and slight erosion hazard (P3 and P4). In the Indo-Gangetic plains, finding the soil-landform relationship was very difficult, as there

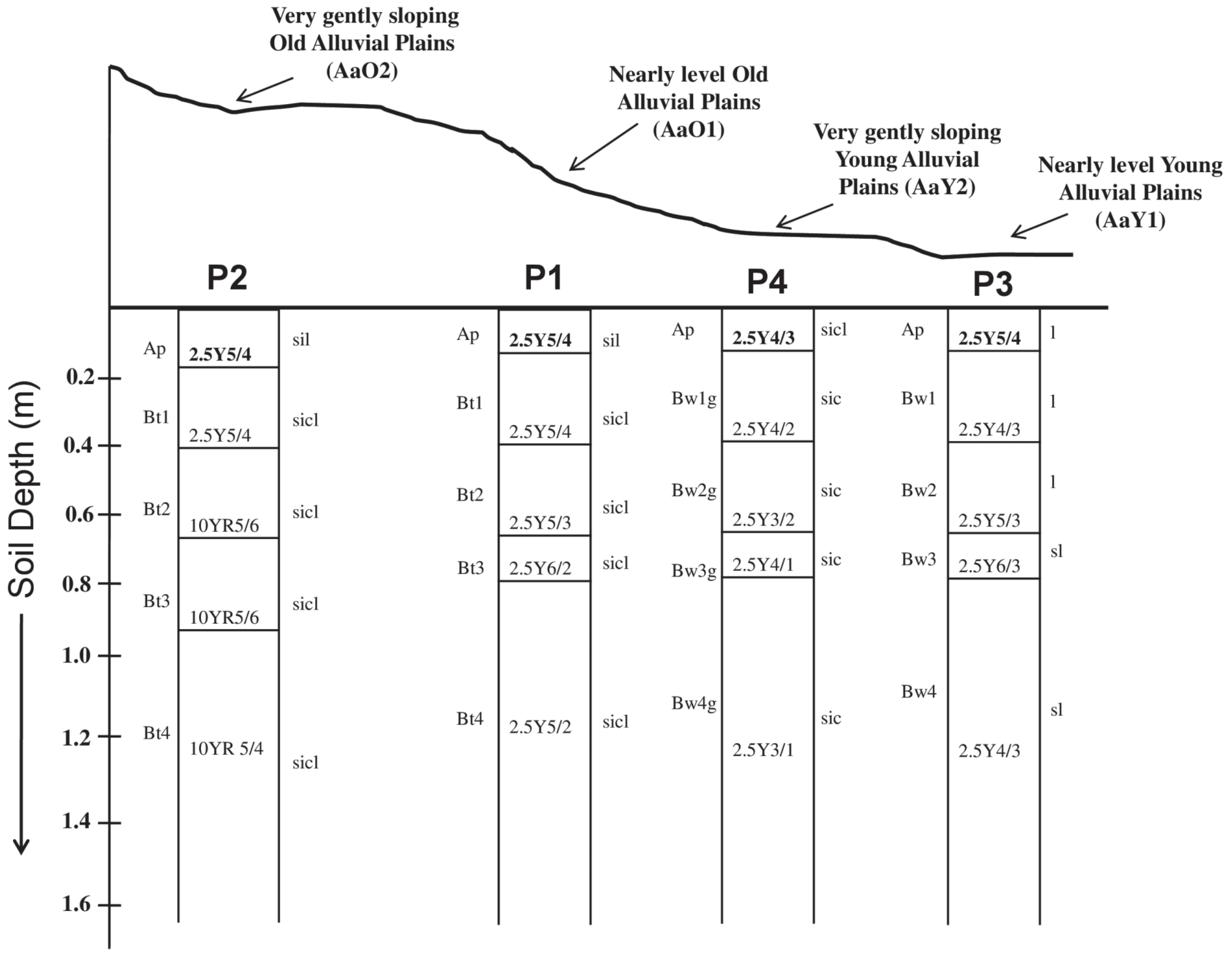

Fig. 5. Landform-soil relationship of Habibpur Block, Maldah District, West Bengal

was less influence of landform on soil formation as compared to type of alluvium carried by various rivers and time of deposition. The varying range of characteristics in alluvial soils was due to the partial influence of different rivers and the quality and quantity of sediments they deposit, which in turn influences the formation of soils. Different pedogenic indices showed the level of maturity and soil development under both the landforms. The P1 and P2 pedons of old alluvial plain and P4 pedon of the young alluvial plains had relatively lower sand/silt ratio as compared to the P3 pedon of nearly level young alluvial plains in both surface and sub-surface horizons showing the more matured soils with relatively higher profile development in P1, P2 and P4 pedons than P3 pedon (Fig. 6). The silt/clay ratio was also in decreasing pattern from surface to sub-surface layers in P1, P2 and P3 soils. This same ratio did not follow a regular pattern in P3 pedon (Fig. 6), which signified that there is an irregularity in the distribution showing relatively immature soils in nearly level young alluvial plains, which was quite obvious because of the affinity of these soils to the Tangon river floated through the adjacent area. All the four soils (P1, P2, P3 and P4) contained average 69.4%, 64.8%, 36.2% and 51.9% silt, respectively. The Fine silt and total silt ratio was the highest in P4 pedon followed by P1>P2 >P3 pedons showing the preponderance of fine silts within total silt content resulting fine (P4) to fine-silty (P1 and P2) soils followed by coarse silty (P3) soils in this block under different landform situations. The average

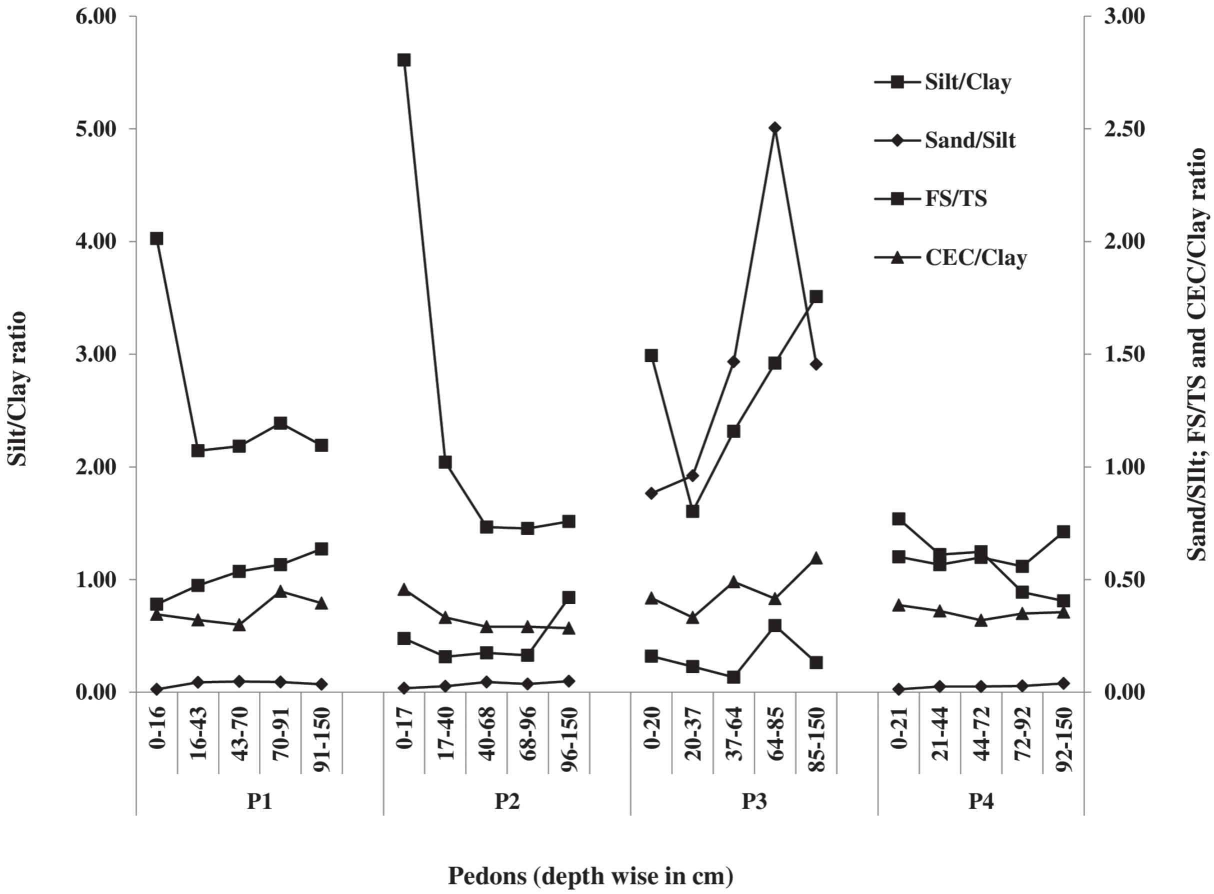

Fig. 6. Different pedogenic indices in soils of Habibpur Block, Maldah District, West Bengal

CEC/clay ratio of all the soils were more than 0.20 depicting mixed mineralogy in the study area (Reza *et al.*, 2022). The higher values of average CEC/clay ratio (0.41-0.60) in soils might be attributed to the presence of hydroxyl interlayered vermiculite (Bhattacharyya *et al.*, 1997) clay minerals.

The above study on pedogenic indices showed that the particle size, different chemical and exchange ratios did not follow any trend in the alluvial plain as compared to the other stable landforms (Martini, 1970, Bandyopadhyay *et al.*, 2017, Reza *et al.*, 2022). This might be due to shifting of river and their tributaries and also the quality and quantity of sedimentation deposited by the river. The soils under nearly level and very gently sloping old alluvial plains and very gently sloping young alluvial plains had more matured soils as compared to nearly level young alluvial plains, which had recent alluvium deposition for being spatially distributed near the Tangon river as compared to others for being distributed away from the river flowpath. Hence, the soil-landform relationship could be established for the study area under Indo-Gangetic alluvial plains.

Conclusions

The variation in soil type and profile development depicted the combined influence of landform and river tributaries responsible for alluvium deposition in the Indo-Gangetic plains. The characterization and classification of existing soils revealed the presence of Alfisols and Inceptisols in the study area. The present study for the first time identified and is reporting the occurance of Alfisols in this zone of lower Gangeic plains. Soils were very deep, fine to fine silty, well to somewhat poorly drained with slight erosion. Presence of Alfisols with more matured soil developmental state were found to be situated in comparatively stable landform distributed away from the river flowpath, whereas Inceptisols of recent origin were found near the river with current alluvium deposition. The different pedogenic indices showed the maturity as well as genesis of the soils in different landform situations in the study area. The distance and influence of the river on soil devepoment has been found to be very crucial and could dominate over the other soil forming factors active in alluvial plains. Thus, while establishment of soil-landform relationship in alluvial track, the fluvial influence, distance from the river coarse and the periodic alluvium deposition would be the important components to consider. The information on soil characteristics, classification, genesis and its relationship with underlying landforms would further be used to develop diversified crop planning in Habibpur block of Maldah district, West Bengal.

Conflict of interest

Authors declare that they have no potential conflicts of interest, whether financial or non-financial, direct or indirect, related to this work, and this statement is applicable across all fields of science for the publication of this manuscript.

Authors Contribution

Shreyasi Gupta Choudhury: Conceptualization; Field and laboratory investigation; Data curation; Supervision; Formal analysis; Original draft preparation, review, and final editing.

Tapati Banerjee: Conceptualization; satellite data curation; review of literature and editing.

Subrata Mukhopadhyay: Satellite data analysis and land use study.

Birendra Nath Ghosh: Laboratory data analysis and interpretation.

Nirmalendu Basak: Data curation; Review and editing.

Chandrakala M: Data analysis and interpretation, and review.

Jayjayanti Mukhopadhyay: Satellite data analysis and map preparation

Udayan Rudra Bhowmick: Data analysis, review and editing

Masjuda Khatun: Satellite data analysis and DEM preparation

Feroze Hasan Rahman: Review and editing

Nitin G. Patil: Review and editing

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