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Morphology, Genetic Relationships and Classification of Soils of Selected Micro-Watersheds in North-west India

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***Abstract*:** Nine pedons representing the typical landforms of micro-watersheds in Chhachhrauli block of Yamunanagar, Haryana were exposed to determine the interrelationships and variability of soil characteristics. The colour of pedons was yellowish brown with dominant hue of 10YR. Soil structure was weak to strong, fine to medium, sub angular blocky across the pedons. The consistency of different pedons varied from non-sticky non-plastic to sticky plastic and soil texture varied from sand to loam with predominance of sand than clay in all the pedons. Bulk density, particle density and available water content across all the pedons varied from 1.01 to 1.75 Mg m^{-3}, 2.50 to 2.65 Mg m^{-3} and 1.01 to 16.38%, respectively. The pH ranged from 4.20 to 8.30 across all the profiles indicating acidic to alkaline nature of the soils. The soils were low to high in soil organic carbon (SOC). In all soils, SOC varied from 0.06 to 2.54 per cent and was higher in surface horizons than subsurface horizons. The $CaCO_3$ content in pedons 1, 3, 4, 5 and 6 was <1% suggesting nearly complete decalcification in these soils. The exchangeable complex of the soils was dominated by Ca followed by Mg, Na and K. Broadly the physiography and land use considerably influenced the value of total exchangeable bases. Relatively higher content of nutrients was observed in the surface horizons compared to subsurface horizons. The results demonstrated that, in general, varying SOC concentrations are associated with varying slope positions of the pedons, highlighting the significance of landform location in regulating soil water content as well as the SOC concentration. The geomorphic location of each pedon across the watersheds has influenced strongly the movement of solutes and therefore soil development. The soils of the study area were classified as sandy, mixed, hyperthermic, typic Ustipsamments (Pedon 1), fine loamy Ustochrepts (Pedon 2, 3, 5, 6, 7, 8 and 9) and coarse loamy Ustorthents (Pedon 4).

Keywords: Exchangeable bases, Landform, Micro-watershed, Nutrients, Pedon, Soil development

Soil is indispensable natural resource for sustaining life on the earth, therefore, appraisal of soil is imperative for determining productivity and resilience of the ecosystem (Satish et al 2018). The characterization of soil imparts the knowledge about morphological, physical, chemical, microbial and mineralogical characteristics of the soil which are immensely important for crop growth, nourishing forests and grasslands. Contrarily, soil classification aids to organize knowledge, exchange of experience and technology from place to place and helps in comparison of soil characteristics (Devi et al 2015). Soil is a unique natural resource and should be used prudently for sustainable development with minimum environmental risks. On the grounds of meagre knowledge about soil characteristics, soils are easily degraded due to misuse and mismanagement. The pedological assessment and classification of soils of a specific area is imperative for identification of its potential and limitations for increased and sustainable crop production. The purpose of soil characterization is to classify soils and measure physical and chemical characteristics, that could indicate the ability of the soil to function, not readily apparent from field study (Sanchez et al 2003). Therefore, the insight of soil involves marking its geographic location and extent besides discerning morphological, physico-chemical and fertility properties based on its geomorphic-soil relationship (Kharlyngdoh et al 2015).

Watershed is a naturally occurring hydrologic unit defined by natural boundaries, classified on the basis of geographical area, which carries runoff to a common point along a single waterway (Bhardwaj 2020, Sahoo et al 2021). Characterization of watershed can be utilised to determine the limitation and potentials of soil based on detailed information about the soil properties. Knowledge gained through characterization of soils can provide basic information to farmers and indigenous knowledge can be integrated with scientific approaches for the systematic management of watersheds. Based on the profile-wise information, soil management practices specific to that region can be recommended to farmers and other stakeholders for its judicious use. Consequently, this will lead to sustainable agriculture along with environmental protection (Mohammed et al 2017). Information on the type of soil, morphological, physical and chemical attributes of agricultural soils in Haryana, northwest India is essential for strategic decision making and sustenance of land productivity. Therefore, it is important to carry out site-specific soil characterization in order to identify the existing heterogeneity of the soil system and generate adequate information to determine soil potential for proper soil management practices (Gorai et al 2013). Though, considerable work has been done in India and Haryana related to detailed soil survey but much of this information is available in the form of topographic maps and there is dearth of knowledge related to the land use of soils of many districts of Haryana. Moreover, information required for planning management practices for most efficient use of land resources is absent or scant in case of micro-watersheds. Besides, the information about the pedogenesis of soils at watershed scale in Haryana is available for selected areas only (Sahoo et al 2019, Sahoo et al 2021). At watershed scale, the topographic position of soils is considered for soil classification which is not only used to address land use management but also soil erosion and formation (Sadiq et al 2021). Watershed management is essential to agricultural practices because it enables the controlled use of water for irrigation as per the crop needs besides supplying water for a variety of other uses (Mahapatra et al 2019). Therefore, the present investigation was attempted to enhance our understanding about the morphology, genetic relationships and classification of soils of micro-watersheds in Chhachhrauli block of Yamunanagar, Haryana for developing better strategies for agricultural production and resource management.

MATERIAL AND METHODS

Site description: The micro-watersheds in Chhachhrauli block of Yamunanagar lie between 29° 55' 44" N and 30° 28' 34" N latitude and 77° 04' 20"E and 77° 36' 05" E longitude at an altitude of 274 meters with an average elevation of 258 meters above mean sea level. Major part of the Yamunanagar district is formed of alluvium rocks of Pleistocene age. Yamuna is the major river in the study area and Boli is a seasonal river. The soils of this region are sand to loamy sand in texture and has sub-tropical type monsoon climate and Chachhraulli is often termed as "Cherapunjii of Haryana" as it receives highest rainfall in whole Haryana and Punjab. The weather data of the study area is presented in Figure 1. The average rainfall in Haryana is 450mm during monsoon and Chachhraulli receives 1100 mm. The average annual temperature in the study area is 32°C with the highest in June (41°C) and minimum in January (9.1°C) thus qualifying for hyperthermic temperature regime. The district has a favourable climate for the growth of rich vegetation owing to reasonably good rainfall and elevation. Shisham (*Dalbergia sissoo*), kikar (*Acacia nilotica*), mango (*Mangifera indica*), jamun (*Syzgium cumini*), peepal (*Ficus religiosa*), badh (*Ficus bengalensis*), neem (*Azadirachta indica*), safeda (*Eucalyptus* hybrid) etc. are the important tree species grown in the area.

Soil Sampling and Analysis

Field methods: Before exposing soil pedons a reconnaissance survey was carried out in order to explore the representative observation sites. The field areas of villages Dadupur Jattan, Dhakwala, Kot, Fakirmajra, Fatehgarh forest, Yara forest, Arjun Majra, Kot Mushtarka and Mahab Aliwala were traversed thoroughly for field checks and the profile sites were delineated. In the field, based on morphological properties such as texture, roots, cutans, consistency, soil colour, pedon reaction, structure and concretions, different horizons were marked in each pedon. Nine soil profiles were exposed and studied morphologically in field by using FAO 2006 guidelines for soil profile description (FAO 2006). The soil samples of each profile were collected horizon-wise to study their physico-chemical properties in the laboratory.

Laboratory methods: Representative soil samples from each genetic horizon of the pedons were collected and dried in shade for laboratory analysis. The air-dried samples were ground with a wooden pestle and mortar and passed through 2 mm sieve to separate the coarse fragments (>2 mm) and through 0.5 mm sieve for chemical properties. Bulk density was determined by core method (Blake and Hartge 1965), moisture retention at 0.03 Mpa and 1.5 Mpa with Richard's pressure plate apparatus (Bruce and Luxmoore 1986), particle density by Pycnometer method (Means and Parcher 1963), mechanical analysis by International pipette method (Piper 1950) and infiltration rate measured in the field by using double ring close top infiltrometer (Reynolds 2002). Soil pH and EC was determined using pH meter and conductivity meter, respectively in 1:2 soil: water suspension (Jackson 1973). Organic carbon content was determined by wet digestion method (Walkley and Black 1934), available

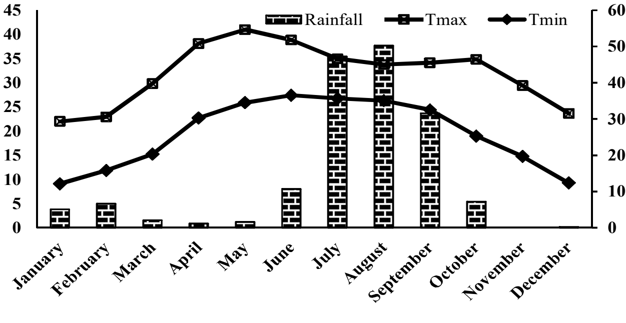

Fig. 1. Mean yearly weather data of the study area

nitrogen (N) by alkaline permanganate method (Subbaiah and Asija 1956), available P content by extracting the soil samples using 0.5M $NaHCO_3$ and analyzed by spectrophotometer (Olsen et al 1954). Available potassium was extracted with neutral normal ammonium acetate (pH 7.0) and the content of potassium in the solution was estimated by flame photometer (Jackson 1973). Calcium carbonate was estimated by rapid titration method (Puri 1949). Cation exchange capacity was determined in the extract obtained by leaching the soil with normal sodium acetate solution (pH 8.2) and sodium in the resultant extract was determined by flame photometer (Jackson 1973). Exchangeable calcium and magnesium were estimated by Versanate titration method (Cheng and Bray 1951) and micronutrients (Fe, Mn, Cu and Zn) by DTPA (Diethylene Triamine Penta Acetic acid) using atomic absorption spectrometer (Lindsay and Norvell 1978). Soils were classified according to Soil Taxonomy (Soil Survey Staff 2014).

Statistical analysis: The Statistical Package for the Social Sciences (SPSS) version 20.0 software (SSPS Inc., Chicago, IL, USA) was used to carry out the correlation of the data.

RESULTS AND DISCUSSION

The detailed characteristics of geomorphic units of micro-watersheds are presented in Table 1. Recent alluvial plain, old alluvial plain, piedmont plain and Shivalik hills were the four different physiographic units in the study area (Fig. 2). Slope, elevation, drainage conditions, location of the site, erosion and physiography control the soil formation process and thus regulate soil physico-chemical properties. Therefore, the study of soils, particularly in relation to landscape, is effective in explaining the natural factors and processes that have direct bearing on soil genesis (Sharma et al 2011). Seibert et al (2007) evinced that topography influences soil formation and different soil types are formed under distinct conditions.

Morphological characteristics: All the pedons were very deep except pedon 9 which was shallow (Table 2). The greater depth of the profile indicates prolonged weathering process which probably began under humid environments and slowed gradually with the present era moderate environmental conditions (Sharma et al. 2011). All the pedons had A-B-C horizons except pedons 5, 6 and 8 which exhibited A-C horizons. The absence of B horizon in pedons 5, 6 and 8 indicates lack of profile development. The B horizon in pedon 4 started at greater depth than B horizon in other pedons due to sola stability in the former. The distinctness of horizon boundary was abrupt to gradual between surface and subsurface horizons in all pedons with smooth topography, except in pedons 2, 5 and 8 where it was clear with wavy topography both in surface and subsurface horizons. The variations in nature of the horizon boundaries are the indications of the variability in the soil forming processes and impacts of anthropogenic activities (Cools and De-Vos 2010). Among the morphological properties, the most obvious feature of soil is colour and it is the most useful

Table 1. General characteristics of geomorphic units of studied area

Pedon No.	Physiography	Drainage	Erosion	Land use	Parent material	Slope (%)	Slope direction
1	Recent alluvial plain	Well drained	Moderate	Cultivated land (Wheat-Sugarcane rotation)	Alluvium	Very gently sloping (1-3%)	N-S
2	Piedmont plain	Well drained	Severe	Forest land (Dek, Bkain, Sheesham, Teak)	Alluvium	Moderately sloping (8-15%)	N-S
3	Old alluvial plain	Well drained	Moderate to nil	Cultivated land (Poplar)	Alluvium	Gently sloping (3-8%)	N-S
4	Recent alluvial plain	Well drained	Moderate	Cultivated land (Poplar)	Alluvium	Gently sloping (3-8%)	N-S
5	Piedmont plain	Imperfectly drained	Severe	Cultivated land (Kikar, Neem, Shrubs)	Alluvium	Moderately sloping (8-15%)	N-S
6	Shivalik hills	Moderately drained	Moderate	Forest land	Alluvium	Gently sloping (3-8%)	N-S
7	Old alluvial plain	Moderately drained	Moderate	Cultivated land (Ratoon Sugarcane)	Alluvium	Gently sloping (3-8%)	N-S
8	Old alluvial plain	Well drained	Low	Cultivated land (Fallow-Wheat in nearby fields	Alluvium	Near to very gently sloping (1-3%)	N-S
9	Old alluvial plain	Moderately drained	Nil	Cultivated land (Wheat)	Alluvium	Near to very gently sloping (1-3%)	N-S

property for identification and classification of soils. The colour of the studied pedons varied form dark yellowish brown to dark greyish brown with predominant hue of 10YR. The values ranged from 3 to 5, whereas chromas varied from 2 to 4. The low chroma is the indication of young nature of the parent material. The variation in the soil colour among different horizons could be due to variation in texture, topographic position, mineralogical, chemical composition, and soil moisture regimes (Dinesh et al 2017a). Broadly, surface horizons are darker in colour than sub-surface layers owing to high organic matter content in the top soil layers. Dinku et al (2014) also observed that the surface horizons are darker in colour than the subsurface horizons.

There was significant difference in the grade and size of the soil structure; however, more or less shape remained the same. By and large, structure of the surface pedons varied from weak medium sub angular blocky to moderate medium sub angular blocky while in the subsurface horizons the structure varied from moderate fine sub angular blocky to strong fine sub angular blocky which could be attributed to higher clay content and sufficient exposure to pedogenic processes in the subsurface horizons than surface horizons. Furthermore, the variation in soil structure is reflection of physiographic position of the pedons (Dinesh et al 2017a). The consistency of different pedons varied from non-sticky non-plastic to sticky plastic. The poor consistency of the studied pedons was due to sandy texture and indicates poor water holding characteristics of the soils. The greater variation in the soil consistency could be attributed to the differences in particle size distribution, predominantly clay content, organic matter and type of the clay particles. Moradi (2013) also evinced that soil consistence varied with soil texture. Mahapatra et al (2019) reported that soils of Buraka micro-watershed in Haryana were non-sticky to slightly sticky and non-plastic to slightly plastic in consistence. The roots in different pedons varied from very fine to coarse (size) and very few to common (quantity). Root biomass decreased with the depth because of reduction in biological activity, aeration and soil management effects. Uwingabire et al (2016) observed fine to coarse roots in the topsoil and few to common, medium to fine roots in subsoils of watershed divide. Coarse fragments were absent in pedons 7, 8 and 9 and formed a considerable volume in the pedons 1, 3, 4 and increased with depth except in pedons 2, 3 and 5 in which calcium carbonate concretions were present. Cutans were absent in all the profiles. The absence of cutans reflect that eluviation and illuviation were not the dominant pedogenic processes. Soil reaction with dilute HCl varied from no effervescence to strong effervescence thereby showing the presence of calcium carbonate which reflects the

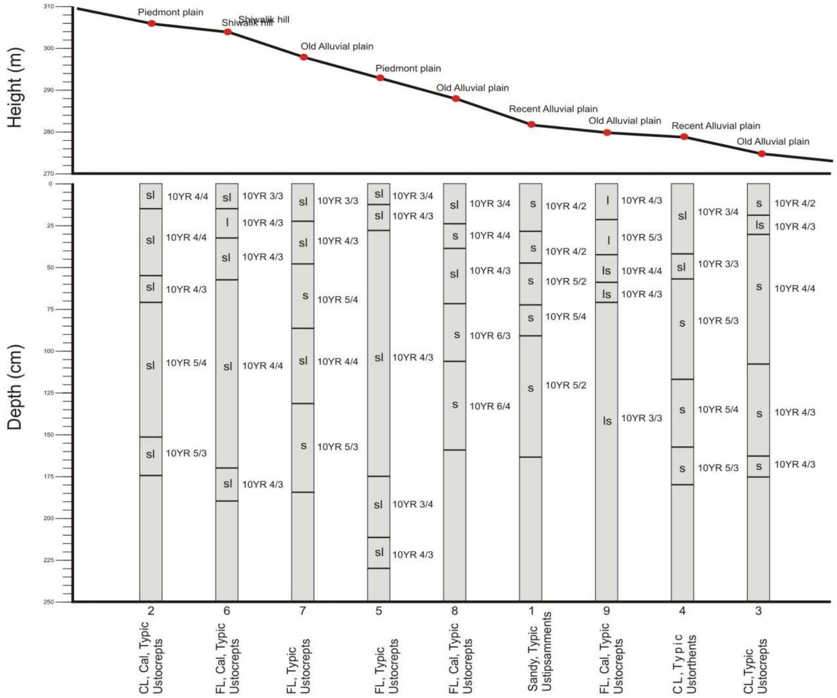

Fig. 2. Landscape-soil relationship of micro-watersheds of Chhachhrauli block of Yamuna Nagar

Table 2. Soil morphological characteristics of the studied pedons

Horizon	Depth (cm)	Horizon boundary	Colour (moist)	Structure	Consistence	Cutans	Roots	Coarse fragment	Reaction
Pedon-1									
Ap	0-28	a-s	10YR 4/2	1md sbk	NSNP	-	ffn	-	-
B1	28-47	c-s	10YR 4/2	1 md sbk	NSSP	-	-	<2%	-
B2	47-73	c-s	10YR 5/2	1 md sbk	NSSP	-	-	<5%	1
C1	73-91	c-s	10YR 5/4	1 md sbk	SSSP	-	-	>10% Pebbles	-
C2	91-164+	c-s	10YR 5/2	1 md sbk	SSNP	-	-	10% Pebbles	-
Pedon-2									
Ap	0-15	c-s	10YR 4/4	2 md sbk	SSSP	-	fc	<2%	-
B	15-55	c-s	10YR 4/4	2 md sbk	SSNP	-	fc	<1%	1
C1	55-71	c-w	10YR 4/3	2 md sbk	SSSP	-	-	<1%	1
C2	71-151	c-s	10YR 5/4	3 fn sbk	SP	-	-	<1%	2
C3	151-175+	c-s	10YR 5/3	2 md sbk	SSSP	-	-	<1%	1
Pedon-3									
Ap	0-19	c-s	10YR 4/2	1 md sbk	SSNP	-	fc	<1% Pebbles	-
B1	19-30	c-s	10YR 4/3	1 md sbk	NSNP	-	fc	<1% Pebbles	-
B2	30-108	c-s	10YR 4/4	1 md sbk	SSSP	-	-	-	-
C1	108-163	c-s	10YR 4/3	2 md sbk	SP	-	-	-	-
C2	163-175+	c-s	10YR 4/3	1 md sbk	SSSP	-	-	-	-
Pedon-4									
Ap	0-38	a-s	10YR 3/4	1 md sbk	SSSP	-	cfn	-	1
B	38-57	c-s	10YR 3/3	1 md sbk	SSSP	-	ffn	<1%	-
C1	57-117	c-s	10YR 5/3	1 md sbk	NSNP	-	-	>5%	-
C2	117-157	c-s	10YR 5/4	1 md sbk	NSNP	-	-	<2%	-
C3	157-180+	g-s	10YR 5/3	1 md sbk	NSNP	-	-	<1%	-
Pedon-5									
Ap	0-13	c-w	10YR 3/4	2 md sbk	SP	-	vffn	<1% concretion	1
C1	13-28	c-w	10YR 4/3	2 md sbk	SSSP	-	vffn	<1% Concretion	-
C2	28-175	g-s	10YR 4/3	1 md sbk	SSSP	-	vffn	-	-
C3	175-212	g-s	10YR 3/4	1 md sbk	SSNP	-	vffn	-	-
C4	212-230+	g-s	10YR 4/3	1 md sbk	SSSP	-	-	-	-
Pedon-6									
Ap	0-14	c-s	10YR 3/3	2 md sbk	SSSP	-	cfn	<1% concretion	-
C1	14-33	c-s	10YR 4/3	3 md sbk	SP	-	cfn	-	3
C2	33-57	g-s	10YR 4/3	2 md sbk	SSSP	-	ffn	-	-
C3	57-170	c-s	10YR 4/4	2 md sbk	SSSP	-	vffn	-	-
C4	170-190+	c-s	10YR 4/3	2 md sbk	SP	-	-	<1% Stones	-
Pedon-7									
Ap	0-22	a-s	10YR 3/3	2 md sbk	SP	-	ffn	-	1
B1	22-48	a-s	10YR 4/3	1 md sbk	SSSP	-	ffn	-	1
C1	48-86	c-s	10YR 5/4	1 md sbk	NSNP	-	ffn	-	-
C2	86-132	c-s	10YR 4/4	1 md sbk	SP	-	-	-	-
C3	132-184+	c-s	10YR 5/3	1 md sbk	SSSP	-	-	-	-
Pedon-8									
Ap	0-24	c-w	10YR ¾	1 md sbk	SP	-	cc	-	1
C1	24-38	c-w	10YR 4/4	2 md sbk	SSSP	-	ffn	-	1
C2	38-72	c-w	10YR 4/3	1 md sbk	SSSP	-	-	-	1
C3	72-106	g-s	10YR 6/3	1 co sbk	NSNP	-	-	-	-
C4	106-159+	g-s	10YR 6/4	1 co sbk	NSNP	-	-	-	-
Pedon-9									
Ap	0-21	a-s	10YR 4/3	1 md sbk	SSSP	-	mfn	-	1
B1	21-43	c-s	10YR 5/3	1 md sbk	SSSP	-	ffn	-	1
B2	43-59	a-s	10YR 4/4	1 md sbk	SSSP	-	-	-	1
C1	59-71	c-s	10YR 4/3	3 md sbk	SP	-	-	-	1
C2	71+	c-s	10YR 3/3	3 md sbk	SP	-	-	-	3

precipitation regime and leaching environment of these soils (Sahoo et al 2019).

Physical characteristics: The physical characteristics of the studied pedons are shown in Table 3. Particle size analysis revealed that sand, silt and clay content across the pedons varied from 50.12-95.53, 1.85-33.25 and 1.6-32.10%, respectively. Sand content, by and large, showed an increasing trend with soil depth and constituted the bulk of the mechanical fractions which may be assigned to siliceous nature of parent material. This kind of particle size distribution reflects slow weathering of the parent material. However, no consistent distribution pattern of silt was observed down the profile. The clay content exhibited an increasing trend with depth up to second horizon and thereafter decreased which could be due to the *in-situ* weathering of parent material or vertical migration of clay (Satish et al 2018). The textural class of soils of pedons 1 and 3 was sand whereas pedons 2, 4, 5, 6, 7, 8 were loam to sandy loam and pedon 9 loam to loamy sand in texture. The abrupt change in soil texture in pedon 8 and 9 indicated lithological discontinuity. Negative and significant correlation (r = 0.82) was observed between sand and clay content indicating that appreciable amount of clay has been formed due to weathering of sand (Sarmah et al 2019).

The particle density varied from 2.50 to 2.65 Mg m^{-3} across all the pedons and did not exhibit any regular trend with depth. Bulk density of all the pedons ranged from 1.01 to 1.75 Mg m^{-3} and increased with depth which may be ascribed to progressive compaction due to filling of pores by eluvial materials, lower organic matter, and less aggregation. It is well recognized that the variation in bulk density is due to differences in soil texture, organic matter content and management practices (Gülser et al 2016). Bulk density was negatively and significantly correlated with clay content (r = -0.60) and organic carbon (r = -0.67) which indicates that bulk density decreases with increasing clay content, partly because of increasing organic matter with the increment in clay content (Keller and Håkansson 2010). The pore space across the pedons ranged from 31.37 to 60.70% and decreased with soil depth which could be attributed to the lower organic matter in the lower depths and restricted penetration of crop roots into subsurface horizons. Moreover, this could be ascribed to high inter- and intra-aggregate voids as a result of high organic matter content and isovolumetric weathering (Chen et al 2001). A significant positive correlation was observed between pore space and clay (r = 0.60) and organic carbon (r = 0.68) but negative relationship with sand (r = -0.71; Table 4) suggesting that clay and organic matter were the principal factors that influenced pore space. Pore space was negatively correlated with bulk density (r = -0.99) but did not show any significant correlation with particle density thereby reflecting the influence of pore space on bulk density.

The variations in moisture retention at all the tensions are mostly linked to variations in soil texture. With increase in fineness of texture, water retention increased significantly which indicated that finer particles had greater effect on retention behaviour of soils as compared to sand content as explicated by the drainage that occurs when suction is increased from 0.03 to 1.5 Mpa. Variation in moisture retention with depth mostly followed the distribution pattern of clay at all the tensions. Water retained at field capacity and permanent wilting point varied from 3.91 to 37.45% and 1.17 to 21.07% across all the pedons, respectively. Water retention was significantly and positively correlated with pore space. The moisture retention at all the tensions was function of mechanical components of the soil which is manifested by highly positive and significant correlation between silt and clay and negative correlation of silt and clay with sand (Table 4). When suction pressure is increased from 0.03 to 1.5 MPa, macropores get emptied at once at lower suction range whereas micropores retain the water even at high suction pressure and predominantly the effect of clay can be seen due to greater number of micropores (Nikam et al 2006, Dinesh et al 2017a). Available water varied from 1.01-16.38% across the pedons and highest value was observed in Pedon 8. Almost 75% values of available water content were lower than 9.5 to 12.5%, values considered by FAO to support adequate plant growth (Sadiq et al 2021). The correlation between clay fraction and available water (r = 0.60) was significantly higher than the correlation of organic carbon (r = 0.57) indicating that increase in clay content increased water retention. However, significantly negative correlation was observed between sand and available water content (r = -0.64). Infiltration rate was very high (>1 cm hr^{-1}) in all the pedons which could be ascribed to sandy texture of the soils and higher organic carbon in the surface horizons. The hydraulic properties of soils, for instance, infiltration is influenced by soil texture; soil structure, especially shape and stability, pore space and size distribution and bulk density (Bhat et al 2022).

Chemical characteristics: Soil pH ranged from 4.2 to 8.3 across all the profiles indicating acidic to alkaline nature of the soils (Table 5). The highest value (8.3) was recorded in C3 horizon of pedon 8 and lowest (4.2) in surface horizon (Ap) of pedon 2. The acidic soil reaction was recorded in pedons 2, 5 and 6 which were under forest land use. The lower pH of some of these soils could be due to high organic matter content as the decomposition of OM releases organic acids thereby lowering the pH of the soil (Nega and Heluf

Table 3. Physical properties of the studied pedons

Pedon and Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density	Particle density	Pore space (%)	Moisture retention		Available water (%)	Infiltration rate (mm hr^{-1})
		0.02-2.0 mm	0.002-0.02 mm	<0.002 mm		Mg m^{-3}			0.03 MPa	0.15 MPa		
Pedon-1												
Ap	0-28	89.26	4.60	5.90	Sand	1.40	2.57	45.52	7.9	3.92	3.98	27
B1	28-47	89.54	4.10	6.20	Sand	1.45	2.60	44.23	8.23	4.11	4.12	
B2	47-73	89.06	5.30	5.50	Sand	1.53	2.64	42.04	8.19	4.3	3.89	
C1	73-91	91.09	3.70	5.10	Sand	1.55	2.63	41.06	8.17	4.56	3.61	
C2	91-164+	92.02	3.6	4.30	Sand	1.59	2.52	36.90	6.5	3.3	3.2	
Pedon-2												
Ap	0-15	54.16	27.2	16.3	Sandy loam	1.07	2.61	59.00	29.1	18.6	10.5	21
B	15-55	54.92	25.5	17.8	Sandy loam	1.10	2.58	57.36	30.2	19.1	11.1	
C1	55-71	53.53	29.8	15.4	Sandy loam	1.14	2.56	55.46	28.7	19.8	8.9	
C2	71-151	54.79	30.4	13.9	Sandy loam	1.19	2.54	53.15	26.2	17.9	8.3	
C3	151-175+	53.33	32.3	12.7	Sandy loam	1.21	2.54	52.36	27.9	19.8	8.1	
Pedon-3												
Ap	0-19	88.41	8.86	2.10	Sand	1.10	2.57	57.19	6.21	3.2	3.01	25
B1	19-30	82.40	7.02	10.11	Loamy sand	1.16	2.61	55.55	7.31	3.87	3.44	
B2	30-108	89.66	5.70	4.40	Sand	1.25	2.56	51.17	7.19	5.14	2.05	
C1	108-163	94.08	3.50	2.20	Sand	1.32	2.54	48.03	6.12	4.16	1.96	
C2	163-175+	95.53	2.80	1.6	Sand	1.41	2.52	44.04	5.34	3.46	1.88	
Pedon-4												
Ap	0-38	52.32	30.83	15.5	Sandy loam	1.27	2.57	50.58	26.27	17.7	8.57	20
B	38-57	50.12	32.2	16.2	Sandy loam	1.29	2.61	50.57	27.29	18.2	9.09	
C1	57-117	87.95	5.70	5.90	Sand	1.42	2.56	44.53	6.12	4.05	2.07	
C2	117-157	91.25	3.70	4.90	Sand	1.44	2.54	43.30	5.71	3.7	2.01	
C3	157-180+	94.10	1.85	3.80	Sand	1.46	2.54	42.51	3.91	2.9	1.01	
Pedon-5												
Ap	0-13	50.61	30.8	16.5	Sandy loam	1.12	2.57	56.42	26.2	14.7	11.5	21
C1	13-28	50.25	30.2	17.3	Sandy loam	1.18	2.61	54.78	27.3	15.1	12.2	
C2	28-175	52.90	29.5	15.8	Sandy loam	1.23	2.56	51.95	24.9	14.2	10.7	
C3	175-212	51.70	32.2	15.0	Sandy loam	1.27	2.63	51.71	23.4	13.3	10.1	
C4	212-230+	54.45	29.8	14.8	Sandy loam	1.32	2.65	50.18	21.9	12.6	9.3	
Pedon-6												
Ap	0-14	50.78	31.25	16.1	Sandy loam	1.10	2.57	57.19	24.6	13.4	11.2	18
C1	14-33	51.28	16.8	30.5	Loam	1.14	2.55	55.29	35	19.1	15.9	
C2	33-57	50.49	30.70	17.80	Sandy loam	1.17	2.56	54.29	10.44	4.1	6.34	
C3	57-170	51.77	32.30	15.10	Sandy loam	1.20	2.52	52.38	17.87	10.3	7.57	
C4	170-190+	54.46	31.52	13.70	Sandy loam	1.24	2.54	51.18	16.73	9.8	6.93	
Pedon-7												
Ap	0-22	53.78	30.10	15.10	Sandy loam	1.01	2.57	60.70	18.93	7.13	11.8	
B1	22-48	50.96	31.80	16.40	Sandy loam	1.09	2.61	58.23	20.11	7.4	12.71	
C1	48-86	88.55	5.70	4.80	Sand	1.26	2.56	50.39	8.53	3.3	5.23	
C2	86-132	51.22	33.25	15.00	Sandy loam	1.29	2.55	49.21	7.81	3.28	4.53	
C3	132-184+	90.82	2.10	6.85	Sand	1.33	2.58	47.84	5.24	1.5	3.74	

Cont...

Table 3. Physical properties of the studied pedons

Pedon and Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density	Particle density	Pore space (%)	Moisture retention		Available water (%)	Infiltration rate (mm hr^{-1})
		0.02-2.0 mm	0.002-0.02 mm	<0.002 mm		Mg m^{-3}			0.03 MPa	0.15 MPa		
Peodn-8												
Ap	0-24	53.34	30.75	15.10	Loam	1.03	2.57	59.92	36.11	20.55	15.56	12
C1	24-38	52.29	16.66	30.5	Loam	1.14	2.61	56.32	37.45	21.07	16.38	
C2	38-72	90.51	4.75	4.4	Sand	1.26	2.56	50.78	7.12	1.17	5.95	
C3	72-106	89.90	7.1	2.90	Sand	1.45	2.54	42.91	7.16	3.82	3.34	
C4	106-159+	90.15	5.3	3.2	Sand	1.75	2.55	31.37	6.04	3.65	2.39	
Pedon-9												
Ap	0-21	58.2	10.24	30.80	Loam	1.18	2.57	54.08	16.67	10.32	6.35	15
B1	21-43	59.9	7.59	32.10	Loam	1.21	2.51	51.79	20.6	13.37	7.23	
B2	43-59	80.76	6.34	12.70	Loamy sand	1.29	2.52	48.80	15.38	11.13	4.25	
C1	59-71	84.82	3.81	11.20	Loamy sand	1.35	2.50	46.00	13.44	10.05	3.39	
C2	71+	86.48	2.91	10.50	Loamy sand	1.41	2.59	45.55	12.71	10.98	1.73	

Table 4. Correlation matrix among physico-chemical properties

Soil property		Sand	Silt	Clay	BD	PD	PS	Moisture retention		Available water	OC	CEC
								0.03 MPa	1.5 MPa			
Sand		1										
Silt		-0.93**	1									
Clay		-0.82**	0.58**	1								
BD		0.70**	-0.63**	-0.60**	1							
PD		-0.21	0.23	0.11	-0.09	1						
PS		-0.71**	0.64**	0.60**	-0.99**	0.21	1					
Moisture retention	0.03 MPa	-0.65**	0.57**	0.62**	-0.57**	0.12	0.57**	1				
	1.5 MPa	-0.60**	0.52**	0.58**	-0.48**	0.07	0.48**	0.96**	1			
Available water		-0.64**	0.57**	0.59**	-0.62**	0.19	0.63**	0.92**	0.78**	1		
OC		-0.69**	0.66**	0.51**	-0.67**	0.25	0.68**	0.55**	0.48**	0.58**	1	
CEC		-0.66**	0.60**	0.60**	-0.48**	0.39**	0.52**	0.49**	0.44**	0.49**	0.686**	1

** Significant at 0.01 probability level; * Significant at 0.05 probability level

2013, Dinesh et al 2020). Moreover, this could be substantiated by negative and highly significant correlation between pH and organic carbon (r = -0.86; Table 6). Generally, it was observed that surface layers have lower pH than sub-surface horizons which can be ascribed to accretion of H^{+} and Al^{3+} ions released from biochemical weathering or it could be due to leaching of exchangeable bases from upper layers under high rainfall (Gogoi et al 2018). Electrical conductivity of all the pedons varied from 0.03 to 0.23 dS m^{-1} indicating non saline nature of the soils. However, EC did not exhibit any trend with the depth. Satish et al (2018) evinced that well drained conditions of soil help in removing excess of salts by the percolating and drainage water thereby resulting in lower EC.

The soils were low to high in organic carbon. Across all the soils, organic carbon varied from 0.06 to 2.54 per cent and was higher in surface horizons than subsurface horizons. The results showed that organic carbon content was less under cultivated land (0.06%) than forest land (2.54%). This variation among the soils could be ascribed to the differences in vegetation cover, land use and human activities among the sites. Moreover, the higher organic carbon in the pedons 1, 8 and 21 might be attributed to the abundance of slow decomposition compounds like lignin of organic matter as these pedons are under forest cover. Organic carbon was positively and significantly correlated with clay (r = 0.51) and silt content (r = 0.66) whereas negatively correlated with sand (r = -0.69;). This relationship could be adduced to higher

Table 5. Chemical characteristics of the studied pedons

Pedon and Horizon	Depth (cm)	pH (1:2)	EC (dS m^{-1})	OC %	$CaCO_3$	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	ESP	BSP	N	P	K	Zn	Fe	Cu	Mn
						cmol (+)kg^{-1}							kg ha^{-1}			mg kg^{-1}			
Pedon-1																			
Ap	0-28	8.0	0.07	0.24	Nil	2.50	1.00	0.47	0.21	5.82	8.07	71.82	173	19	227	0.41	4.01	0.17	0.84
B1	28-47	7.9	0.07	0.16	Nil	2.00	0.50	0.26	0.17	6.56	3.96	44.66	157	14	198	0.34	3.77	0.13	0.55
B2	47-73	8.0	0.12	0.14	0.50	1.70	0.50	0.26	0.15	5.78	4.49	45.15	125	11	177	0.28	3.20	0.07	0.48
C1	73-91	8.1	0.08	0.11	Nil	1.00	0.50	0.34	0.20	4.84	7.02	42.14	94	9	163	0.27	2.95	0.05	0.32
C2	91-164+	8.0	0.05	0.08	0.63	1.00	0.50	0.17	0.25	2.97	5.72	64.64	78	5	152	0.25	1.78	0.02	0.11
Pedon-2																			
Ap	0-15	4.2	0.07	2.34	Nil	4.70	2.30	0.56	0.38	8.92	6.28	89.01	188	20	431	0.48	4.63	1.60	5.27
B	15-55	5.1	0.07	1.78	0.62	3.00	1.50	0.61	0.64	7.11	8.58	80.87	157	16	312	0.46	4.56	1.22	4.05
C1	55-71	5.1	0.10	1.27	1.00	3.50	0.50	0.69	0.35	6.50	10.62	77.54	125	13	170	0.42	3.61	1.01	3.87
C2	71-151	5.5	0.13	0.91	4.05	3.00	0.50	0.75	0.38	5.56	13.49	83.27	94	19	143	0.39	3.05	0.80	3.48
C3	151-175+	5.9	0.10	0.67	0.87	1.50	1.00	0.62	0.35	4.44	13.96	78.15	78	5	124	0.34	2.93	0.50	2.71
Pedon-3																			
Ap	0-19	7.6	0.05	0.63	Nil	1.00	0.50	0.56	0.15	5.14	10.89	43.00	204	18	275	0.94	4.59	0.20	0.84
B1	19-30	7.5	0.03	0.47	Nil	4.50	1.50	0.47	0.12	6.98	6.73	94.41	173	15	141	0.88	4.35	0.17	0.67
B2	30-108	7.4	0.08	0.24	Nil	0.70	0.30	0.30	0.85	4.71	6.37	45.65	125	11	124	0.81	3.32	0.11	0.25
C1	108-163	7.5	0.04	0.22	Nil	1.75	0.65	0.49	0.46	3.55	13.80	94.37	86	8	105	0.75	2.19	0.07	0.14
C2	163-175+	7.9	0.09	0.07	Nil	0.55	0.23	0.37	0.21	2.79	13.26	48.75	70	5	88	0.63	0.12	0.03	0.06
Pedon-4																			
Ap	0-38	7.6	0.14	1.48	0.50	5.00	2.00	0.61	0.30	10.04	6.08	78.78	212	19	170	0.95	8.11	0.48	1.96
B	38-57	7.3	0.09	1.38	Nil	5.50	2.00	0.68	0.53	10.23	6.65	85.14	204	17	133	0.89	6.58	0.33	1.08
C1	57-117	7.3	0.03	0.45	Nil	0.34	0.16	0.17	0.17	1.20	14.17	70.00	173	12	105	0.81	5.29	0.21	0.42
C2	117-157	7.2	0.11	0.15	Nil	0.14	0.23	0.25	0.30	1.89	13.23	48.68	141	10	57	0.72	4.17	0.18	0.11
C3	157-180+	7.8	0.14	0.30	Nil	1.50	0.50	0.35	0.33	3.89	9.00	68.89	110	6	19	0.65	3.87	0.11	0.91
Pedon-5																			
Ap	0-13	4.3	0.09	2.25	0.50	5.00	2.50	1.08	0.53	10.54	10.25	86.43	236	18	275	0.91	9.86	0.47	4.97
C1	13-28	4.4	0.05	2.09	Nil	6.00	1.60	0.53	0.56	15.01	3.53	87.21	204	15	190	0.88	9.32	0.41	4.94
C2	28-175	4.7	0.03	1.80	Nil	4.00	1.50	0.39	0.79	7.48	5.21	89.30	169	13	135	0.79	9.06	0.35	4.92
C3	175-212	5.3	0.04	1.10	Nil	3.00	2.00	0.26	0.84	7.10	3.66	85.92	110	10	111	0.71	8.26	0.26	4.17
C4	212-230+	5.9	0.04	0.95	Nil	2.70	1.50	0.26	0.84	6.10	4.26	86.89	78	8	95	0.68	5.23	0.21	3.80
Pedon-6																			
Ap	0-14	5.9	0.05	1.87	Nil	3.50	0.80	0.95	0.51	9.40	10.11	61.28	243	17	181	0.88	8.09	0.55	5.38
C1	14-33	6.1	0.11	1.42	4.50	4.30	1.10	0.91	0.23	10.10	9.01	64.75	220	15	170	0.76	6.78	0.48	5.17
C2	33-57	6.4	0.07	1.01	Nil	3.10	0.50	0.69	0.51	7.60	9.08	63.16	196	12	162	0.70	6.26	0.36	5.01
C3	57-170	6.7	0.08	0.83	Nil	2.40	1.10	0.71	0.30	7.30	9.73	61.78	153	10	157	0.65	6.15	0.24	4.34
C4	170-190+	7.0	0.07	0.32	Nil	2.40	1.10	0.17	0.35	6.70	2.54	60.00	94	7	67	0.56	4.92	0.12	4.07
Pedon-7																			
Ap	0-22	6.3	0.23	1.02	0.35	2.00	0.20	0.66	0.35	4.56	14.47	70.39	195	19	227	0.90	8.33	0.45	4.42
B1	22-48	6.0	0.19	0.84	0.50	3.03	1.13	0.73	0.38	6.58	11.09	80.09	173	15	200	0.86	7.14	0.38	4.14
C1	48-86	6.2	0.10	0.69	Nil	1.00	0.50	0.47	0.38	3.41	13.78	68.91	157	13	143	0.74	5.17	0.32	3.49
C2	86-132	7.3	0.23	0.52	Nil	1.50	0.30	0.68	0.69	4.67	14.56	67.88	70	10	133	0.66	3.61	0.29	3.46
C3	132-184+	7.1	0.20	0.23	Nil	1.70	0.80	0.57	0.51	4.01	14.21	89.28	62	8	68	0.61	1.84	0.16	3.28

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Table 5. Chemical characteristics of the studied pedons

Pedon and Horizon	Depth (cm)	pH (1:2)	EC (dS m^{-1})	OC %	$CaCO_3$	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	ESP	BSP	N	P	K	Zn	Fe	Cu	Mn
						Cmol (+)kg^{-1}							kg ha^{-1}			mg kg^{-1}			
Pedon-8																			
Ap	0-24	7.6	0.16	0.81	0.50	0.60	1.40	0.54	0.38	4.33	12.47	67.44	212	18	300	0.52	4.53	0.19	1.11
C1	24-38	8.0	0.12	0.55	0.75	3.00	2.00	0.56	0.30	6.86	8.16	85.42	188	13	252	0.47	4.15	0.14	0.96
C2	38-72	7.9	0.12	0.34	1.25	1.50	0.50	0.61	0.30	4.23	14.42	68.79	141	10	161	0.31	3.93	0.12	0.75
C3	72-106	8.3	0.06	0.10	Nil	2.00	1.50	0.39	0.12	4.56	8.55	87.94	110	6	145	0.22	3.53	0.05	0.62
C4	106-159+	8.2	0.07	0.06	Nil	1.00	0.50	0.34	0.12	2.46	13.82	79.67	78	4	105	0.14	2.41	0.08	0.22
Pedon-9																			
Ap	0-21	7.6	0.1	0.8	0.1	2.5	0.5	0.4	0.2	4.1	9.5	87.9	212	18	259	0.63	5.28	0.91	1.78
B1	21-43	7.8	0.1	0.4	0.2	3.2	1.7	0.5	0.3	6.9	7.5	83.0	188	12	212	0.54	4.66	0.89	0.80
B2	43-59	7.8	0.1	0.2	0.5	1.9	0.5	0.6	0.4	4.3	14.1	78.8	125	11	190	0.26	3.55	0.78	0.46
C1	59-71	7.6	0.2	0.2	0.8	1.5	0.4	0.5	0.4	4.2	12.4	67.0	110	9	165	0.19	2.65	0.41	0.26
C2	71+	7.8	0.2	0.1	4.5	1.1	0.5	0.4	0.2	3.6	10.8	60.8	78	7	143	0.05	1.12	0.20	0.25

Table 6. Correlation matrix among physico-chemical properties

Soil property	pH	EC	OC	$CaCO_3$	CEC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	ESP	BSP	Sand	Silt	Clay
pH	1													
EC	0.37*	1												
OC	-0.86**	-0.17	1											
$CaCO_3$	-0.33*	0.32*	0.08	1										
CEC	-0.61**	-0.18	0.69**	0.05	1									
Ca^{2+}	-0.60**	-0.19	0.65**	0.03	0.92**	1								
Mg^{2+}	-0.45**	-0.20	0.48**	-0.05	0.62**	0.55**	1							
Na^{+}	0.22	0.27	0.29	0.13	0.31*	0.20	0.25	1						
K^{+}	-0.50**	-0.12	0.45**	-0.17	0.30*	0.25	0.26	0.09	1					
ESP	0.16	0.37*	-0.19	0.04	-0.38*	-0.35*	-0.30*	0.60**	-0.09	1				
BSP	-0.33*	0.04	0.31*	-0.01	0.19	0.39**	0.50**	0.43**	0.26	0.32*	1			
Sand	0.59**	-0.03	-0.69**	-0.16	-0.66**	-0.58**	-0.55**	-0.37*	-0.44**	0.14	-0.36*	1		
Silt	-0.61**	0.10	0.66**	0.04	0.60**	0.51**	0.48**	0.41**	0.50**	-0.06	0.31*	-0.93**	1	
Clay	-0.39**	0.10	0.51**	0.33*	0.60**	0.52**	0.54**	0.23	0.25	-0.20	0.28	-0.82**	0.58**	1

surface area of fine silt and clay fractions that results in the formation of organo-mineral complexes which protect carbon form microbial oxidation. Moreover, organic matter decomposes more rapidly in sandy soil as compared to clayey soil (Zhang and Liu 2010). In addition, the findings demonstrated that varying SOC concentrations are associated with varying slope positions of the pedons, highlighting the significance of landform location in regulating soil water content was well as the SOC concentration. Calcium carbonate ($CaCO_3$) content across all pedons but pedon 3 ranged from 0.12 to 4.50% showing an increase with increasing soil depth. The relatively higher concentration of $CaCO_3$ in the subsurface than the surface horizons can be attributed to the leaching effect and calcitic parent material. The $CaCO_3$ content in pedons 1, 3, 4, 5 and 6 was <1% suggesting nearly complete decalcification in these soils. Satish et al (2018) adduced that the downward movement of calcium and its subsequent precipitation as carbonate and/ or decomposition of calcium carbonate is responsible for higher $CaCO_3$ at lower depths. Negative correlation was observed between $CaCO_3$ and P ($r = -0.12$) which can be due to fixation of P as calcium phosphate and $CaCO_3$ and pH ($r = 0.13$) because higher pH causes the saturation of calcium carbonate (Bhat et al 2017).

The exchangeable bases exhibited non-uniform trends as a result of variations in soil depth and topographic position (Table 5). The exchangeable complex of the soils was dominated by Ca followed by Mg, Na and K which is in agreement with the findings of Sadiq et al (2021). Exchangeable Ca with values ranging between 1.00 to 2.50 cmol (p$^+$) kg^{-1} dominated other cations sites which could be adduced to its affinity for exchange sites or as a result of calcium bearing parent material (Nahusenya et al 2014). Exchangeable Mg was medium to high (Landon 1991) and overall exhibited an increasing trend with depth up to second horizon and thereafter decreased with depth which could be ascribed to higher clay content in these horizons which contributes easily to the retention of Mg^{2+}. The significant and positive correlation between clay and Ca^{2+} (r = 0.52; Table 6) and Mg^{2+} (r = 0.54) reveals that clay contributed to the retention of divalent cations. Exchangeable Na and K varied between 0.17 to 1.08 cmol (p$^+$) kg^{-1} and 0.12 to 0.85 cmol (p$^+$) kg^{-1}, respectively across the pedons and exhibited irregular distribution with soil depth. The variation in exchangeable cations across the pedons might also be due to the preferential adsorption of divalent cations over monovalent cations on the variable negative charges on soil organic matter surfaces as well as limited development of the charge sites in the sandy soil (Yusoff et al 2017).

The CEC, by and large, was low and varied from 1.20 to 15.01 cmol (p$^+$) kg^{-1} in all the pedons and decreased with increase in depth due to decrease in organic matter and lower clay content in underlying horizons with an increase in sand proportion (Mandal 2014). Dinesh et al (2017b) evinced that low CEC of the soils could be due to the dominance of illite or low charge minerals besides low organic matter. Cation exchange capacity was higher in pedons 2, 5, 6 because these soils were under forests having high organic matter. A significant positive correlation was observed between CEC and clay (r = 0.60), CEC and OC (r = 0.69) whereas negative correlation was observed between CEC with sand (r = -0.66) which suggest that colloidal fractions were key factors that influenced CEC. Bhat et al (2017) also reported positive relationship between colloidal fractions and CEC of the soils of Gohana Haryana. Broadly the physiography and land use considerably influenced the value of total exchangeable bases. The exchangeable sodium percentage varied from 2.54 to 14.56% indicating the non-sodic nature of the soils and followed irregular pattern with the increase in depth. The lower ESP in soils could be adduced to masking effect of Ca and Mg *vis a vis* Na on exchange complex whereas the higher ESP in some horizons could be attributed to precipitation of Ca by carbonates, bicarbonates and hydroxide ion concentrations in the soil. These results are affirmed by the significant and positive relationship between ESP and Na ions (r = 0.60) while a negative correlation of ESP with Ca (r = -0.35) and Mg (r = -0.30). The base saturation percentage was medium to high (Landon 1991) and ranged from 42.14 to 94.41% across all the pedons. Base saturation percentage exhibited an irregular distribution pattern with soil depth. Calcium, Mg, Na and pH significantly influenced the base saturation percentage of the soil. The differences in CEC, base saturation and water retention properties among the soils could be attributed largely to the type and content of the soil colloids and soil pH values (Sharma et al 2011). The geomorphic location of each pedon across the watersheds has influenced strongly the movement of solutes and therefore soil development.

Amongst the available macronutrients, nitrogen was low and varied from 62 to 243 kg ha^{-1}. The availability of nitrogen was high in surface horizons and decreased with increase in

Table 7. Correlation matrix among nutrients and physico-chemical properties

Soil property	N	P	K	Zn	Cu	Mn	Fe	OC	$CaCO_3$	pH	Sand	Silt	Clay
N	1												
P	0.75**	1											
K	0.60**	0.61**	1										
Zn	0.67**	0.63**	0.52**	1									
Fe	0.40**	0.34*	0.57**	0.16	1								
Mn	0.56**	0.26	0.31*	0.44**	0.45**	1							
Cu	0.73**	0.53**	0.42**	0.33*	0.47**	0.64**	1						
OC	0.54**	0.29*	0.53**	0.55**	0.22*	0.55**	0.39**	1					
$CaCO_3$	-0.03	-0.22*	0.06	-0.01	-0.09	0.07	-0.05	0.08	1				
pH	-0.26	-0.03	-0.28	-0.41**	-0.10	-0.41**	-0.12	-0.86**	-0.33*	1			
Sand	-0.46**	-0.17	-0.36*	-0.27	-0.17	-0.62**	-0.55**	-0.69**	-0.16	0.59**	1		
Silt	0.32*	0.13	0.25	0.22	0.02	0.53**	0.42**	0.66**	0.04	-0.61**	-0.93**	1	
Clay	0.47**	0.11	0.36*	0.23	0.27	0.56**	0.50**	0.51**	0.33*	-0.39**	-0.82**	0.58**	1

depth which might be due to decreased organic carbon content with increasing depth and prevailing high temperature. Nitrogen showed significant and positive correlation with organic carbon (r = 0.54) indicating that N is closely linked with organic matter. The positively significant relationship between nitrogen and clay (r = 0.47) and negatively significant correlation with sand content (r = -0.45) indicated that the finer fractions influence the availability of nitrogen than coarser fractions. A positive and significant correlation was observed among N, P and K which suggests the synergistic effect. The significant relation of N with OC, N, P and K is similar to the findings reported by Dinesh et al (2020). Available phosphorous was low to medium and varied from 4 to 20 kg ha^{-1}. The pedons under forested land use had higher available P as compared to agriculture land use. Available phosphorous decreased with the increase in depth which might be due to the external application of phosphatic fertilizers in soils under cultivation and higher organic matter in the surface horizons of the pedons under forest land use. The results agree with those of Sahoo et al (2020) who reported higher available P content in the surface horizons of different pedons. Positively significant correlation between P and OC (r = 0.29) indicates that organic matter serves as reservoir of available P. This could be adduced to the synthesis of easily accessible organophosphate complexes, acidulation effect of organic matter, phosphorus release from organic complexes and reduced phosphorus fixation by humus through formation of iron and aluminium oxide coatings (Sadiq et al 2021). Available potassium varied from 19 to 431 kg ha^{-1} and showed decreasing trend with the soil depth. Available K was medium to high across all the pedons. The higher content of K in surface horizons could be due to greater exposure of surface soil to weathering agencies at surface than subsurface thereby resulting in higher release of potassium in surface soils. The correlation analysis showed that available K exhibited positive and significant correlation with organic carbon (r = 0.53) and clay (r = 0.36) due to the availability of enough exchange sites and high specific surface area while sand and available K were negatively correlated (r = -0.36). The results agree with those of Dinesh et al (2020) who reported positive and significant correlation between available K and OC and clay. Reza et al (2014) reported that available potassium increases with increase in clay and silt due to presence of potassium bearing minerals like feldspars, illite, mica in clay and silt fractions. However, available K was negatively correlated with sand which may be due to presence of quartz which is the dominant mineral in the sand fraction and does not retain K.

The DTPA extractable Zn content varied from 0.05 to 0.95 mg kg^{-1} across the pedons. Considering 0.6 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Zn for normal plant growth, it was observed that surface horizons of all the pedons except pedon 8 were sufficient in zinc content. Zinc exhibited a decreasing distribution pattern down the profile which could result from biomining and turnover by plant residues (Dinesh et al 2020). The distribution pattern of DTPA extractable Zn in these profiles suggests that during the early stages of soil development the pedochemical weathering of soils released zinc from soil minerals. Portion of the released Zn combined with clay by strong adsorption on the surface and some part got complexed with organic matter. However, complex formation with organic matter was more dominant as evinced by significant and positive correlation (r = 0.55). The DTPA extractable Fe content ranged from 0.12 to 9.86 mg kg^{-1} across all the pedons. Considering 4.5 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Fe for normal plant growth, it can be inferred that soils of the study area were sufficient in Fe except pedon 1 and lower horizons of few pedons. Relatively higher content of available iron was observed in the surface horizons compared to subsurface horizons which could be adduced to mobility of Fe in the soil. The mobility of Fe is governed by its redox potential and several soil characteristics such as pH, organic matter and moisture regimes (Sharma and Jassal 2013). The DTPA extractable Cu content varied from 0.02 to 1.60 mg kg^{-1} across all the pedons. Considering 0.2 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Cu for normal plant growth, it can be adduced that all pedons were high in Cu content except pedons 1 and 7. Relatively higher content of available Cu was observed in the surface horizons compared to subsurface horizons which could be ascribed to higher OC in surface horizons as Cu is strongly complexed with organic matter even to a greater extent than other micronutrients (Sharma et al 2015). The DTPA extractable Mn content varied from 0.06 to 5.38 mg kg^{-1} across all the pedons. Considering 2.5 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Mn for normal plant growth, it is observed that all surface horizons were high in Mn content except pedons 1, 3, 4, 8 and 9. It was high in the surface horizons and gradually decreased with depth which might be due to higher biological activity and organic carbon in the surface horizons. Manganese was positively and significantly correlated with clay (r = 0.56) indicating that fine textured soils had higher Mn compared to coarse textured soils which may be due to higher adsorption and retention of Mn by finer fractions (Dinesh et al 2020).

Soil classification: The soils under study were classified in accordance with USDA Soil Taxonomy (Soil Survey Staff 2014). Based on climate variation, geomorphic position, morphology, physico-chemical characteristics, the soils of the study area were classified into different orders. Soil moisture regime is a function of climate, soil and landform and it is important for not only understanding pedogenesis and nutrient availability, but also in the classification of soil at different categoric levels, such as Soil Family and Suborder. There are two dominant kinds of soil moisture regimes based on rainfall, evaporation and geomorphic position. The soils of the watershed were grouped into two moisture regimes *i.e.*, Ustic (rainfall 300-1000mm) and Udic (rainfall >1000 mm). Based on soil temperature and mixed minerals the soils were placed under hyperthermic (22° to < 28°) and mixed mineralogy family, respectively.

The soils of pedons 2, 3, 5, 6, 7 and 9 were placed under the order Inceptisols whereas pedons 1, 4 and 8 were classified as Entisols. The soils under Entisols were immature, lacked pedogenic development and horizon differentiation. The soils of the pedon 1, 4 under the order Entisols were formed from recent alluvial parent material. Pedon 1 was placed under great groups of Ustipsamments due to presence of ustic soil moisture regime in this area. Entisols that are coarse-textured, have excessive drainage, low available water-holding capacity and would need frequent and lighter irrigation are placed under suborder Psamments. Pedon 4 was placed under suborder Orthents because this pedon was better drained and show regular decrease of organic matter with depth. The soils of the pedon 2, 3, 5, 6, 7, 8 and 9 were placed under the order Inceptisol formed from old alluvial parent material and suborder Ustochrepts because they have ustic soil moisture regime. Dinesh et al (2017a) classified soils of north-eastern Haryana into Entisols and Inceptisols as the former lacked pedogenic development and latter had cambic subsurface horizons.

CONCLUSION

The different landscape positions alongside variation in land use substantially determine differences in morphological, physical, and chemical properties of soils in the selected micro-watersheds of Chhachhrauli block of Yamuna Nagar, Haryana. The geomorphic location of each pedon across the watersheds has influenced strongly the movement of solutes and therefore soil development. By and large, the morphological, physical and chemical characteristics of the soils indicate a moderate stage of soil development, which is characteristic of Inceptisols. The soils were classified into two soil orders that is Entisols and Inceptisols on the basis of soil properties. The study reveals the significance of soil characterization and classification for understanding similarities and relationship among soil attributes for better agronomical evaluation within the region.

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