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Pedogenic Characterization of Alluvium-Derived Soils in the Arid Region of Rajasthan, India

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Abstract

South eastern part of the arid region of Rajasthan (India) is an alluvial plain developed from the sediments deposited by the river Luni and its tributaries, arising from the Aravali hill range. Soils of the region are medium to fine textured. Mean annual rainfall ranges between 350-400 mm, the soil temperature regime is hyperthermic, and the moisture regime is aridic, which restricts pedogenic processes. The objective of the study is to characterize the uniformity of the parent material and illuviation process. Extensive field work for the study of morphological characteristics of soil profiles revealed two major types of soils, viz., medium texture non-calcareous and fine texture calcareous. Sand fractionation and related parameters were worked out to ascertain the uniformity of the parent material. In medium texture non-calcareous profiles, medium sand (1-2 Φ) and fine sand (2-3 Φ) are dominant fractions, while in fine texture calcareous alluvium, the major particle sizes are fine sand (Φ 2-3), very fine sand (3-4 Φ), and coarse silt (Φ 4-5). The sorting coefficient in medium texture (1.49 to 1.61) and fine textured (1.41 to 1.81) soils indicated the well-sorted nature of the sediments (values less than 2.5). In both medium and fine texture soils, the depth-wise uniform distribution of all size sand fractions and the sorting coefficient indicated the uniformity of the parent material. Parameters such as clay/sand ratio, HA-carbon/FA-carbon ratio, CEC, and $CaCO_3$, considered together, indicated that in medium texture non-calcareous soils, the clay and humus fractions have moved up to 80 cm depth, whereas in fine texture calcareous soils, the clay, humus fractions, and $CaCO_3$ have moved up to 60 cm depth. These observations suggest that both medium and fine texture soils have undergone the illuviation process, but the process is more pronounced in fine texture calcareous soils.

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Introduction

In the southeastern part of arid Rajasthan, an alluvial plain extends into the southern part of Nagaur, the southeastern part of Jodhpur, and the entire Pali and adjoining parts of Jalor districts. The soils are of medium and fine texture, developed from the sediments deposited by the river *Luni* and its tributaries. The terrain is a vast alluvial plain. Nearly 2.67 million hectares are covered by coarse loamy soils, and 1.44 million hectares are covered by fine loamy soils (Faroda *et al.*, 1999). The soils in the region have been classified as coarse/fine loamy Haplocambids/ Haplocalcids. Coarse/fine loamy Haplocambids (0.96 million hectares) are medium to fine texture sandy loam to loam with a subsoil of sandy loam, clay loam to silty clay loam, and non-calcareous. Coarse/fine loamy Haplocalcids (0.38 million hectares) are similar in characteristics except they are calcareous with a calcic horizon at 70-90 depth. The mean annual rainfall in the region ranges between 350 to 400 mm, the soil temperature regime is hyperthermic, and the moisture regime is aridic. These climatic constraints restrict pedogenic processes. The objective of the study is to characterize the uniformity of the parent material and illuviation process within the soil profile.

Materials and Methods

Several profiles during the course of field work were studied for morphological characteristics in the alluvial soil region spread across Pali, Jodhpur, and Nagaur districts, located in the southeastern and central parts of arid Rajasthan. After collation, eight profiles (four medium texture non-calcareous and four fine texture calcareous), representing typical pedogenic manifestations reflected with respect to soil colour, texture, and formation of argillic and/or calcic horizons, were selected for detailed investigations.

Soil morphological characteristics have been described as per the standard soil survey manual (FAO, 1990). Out of these, three profiles (two medium texture non-calcareous and one fine texture calcareous) have been selected for detailed investigation. Soil samples were analyzed for sand, silt, clay fractions, organic carbon, cation exchange capacity (CEC), $CaCO_3$, and HCl extract following standard methods (Jackson, 1973). The procedures followed for determination of sand fractions and humus composition are presented below.

Sand fractionation: The bulk of the soil was treated with H_2O_2 to make it free of organic matter and with dil. HCl to make it free of $CaCO_3$. The residue soil was stirred to break micro-aggregates. It was decanted and washed till the finer fraction was removed. The residue, termed the sand fraction, was taken for sand fractionation. A sand sample (25 g) was sifted for 10 minutes through a nest of 10 sieves having openings in decreasing sizes from 2 mm to 0.045 mm. Each fraction was weighed and expressed in percentage. Particle sizes were converted from mm to the Φ (phi) scale. The phi value is the negative logarithm to the base 2 of the particle diameter in mm ($\Phi = -\log_2 d$ (mm)). From cumulative frequency curves, the diameter of the sand fraction at quartile 25% (Q1), quartile 75% (Q3), mean diameter (Md at 50% in the curve), P90 grain diameter at 90 percent, and P10 were derived. Parameters of grain size distribution, viz., sorting coefficient (S0), skewness (Sk), and kurtosis (K), were calculated by using the following formulae of Twenhofel and Tyler (1941).

Sorting coefficients $\left(S_0 = \sqrt{\frac{Q_3}{Q_1}}\right)$; Skewness ($Sk = Q1 x Q3 / Md^2$);

Kurtosis K = Q1 - Q3/2(P90 - P10)

Sorting coefficient. Sediment sorting is the process (aeolian/alluvial) by which sedimentary particles become separated according to size. Sorted sediments have nearly the same particle size. Perfectly sorted sediment has a coefficient of 1.0, values less than 2.5 indicate well-sorted sediments, whereas values above 3 are normal and values greater than 4.5 indicate poorly sorted sediments.

Skewness measures the degree of sorting symmetry to which a cumulative curve approaches symmetry. Two samples may have the same average grain size and sorting but may be quite different in their degrees of sorting symmetry. Symmetrical curves have a skewness equal to 0.00; those with a large proportion of fine material are positively skewed; those with a large proportion of coarse material are negatively skewed.

Kurtosis is a measure of "peakedness" in a curve. If a sample is better sorted in the central part than at the tails, the curve is said to be excessively peaked, or leptokurtic; if the sample curve is better sorted in the tails than the central portion, the curve is flat-peaked or platykurtic. For a normal distribution, the kurtosis is unity. Leptokurtic curves have a value >1.00, and platykurtic curves have a value <1.00.

Humus composition: Humic acid (HA) and fulvic acid (FA) carbon were determined by the method of Kononova and Balchikova (1961) as described by Kononova (1966).

One gm of soil was taken in a 50 ml volumetric flask, 20 ml of NaOH + Sodium pyrophosphate solution (4 gm NaOH + 44.6 g Na_4 P_2O_7. H_2O per liter) was added to the soil, shaken intermittently, and kept overnight in a closed volumetric flask (so that CO_2 is not absorbed). The next morning, the soil was filtered out, and total Humic carbon and Fulvic acid carbon were determined in the extract. Humic acid carbon is calculated as the difference.

***Total humic carbon**:* Take a 2 ml aliquot from the above extract in a conical flask (50 ml), add 2 ml of 0.4N $K_2Cr_2O_7$ and 4 ml of conc. H_2SO_4 (AR quality), and allow to react. The excess of dichromate was titrated against 0.1N Ferrous Ammonium Sulphate using Diphenylamine as an indicator. O-Phosphoric acid and Sodium Fluoride were added before titration to obtain a sharp endpoint. Simultaneously, a blank was also run. Total humic carbon (HA carbon + FA carbon) is calculated as a percent of soil, 1 ml of 0.4 N $K_2Cr_2O_7$ = 1.2 mg of carbon.

***Fulvic acid carbon**:* For FA carbon, a 10 ml aliquot from the initial humus extract was taken, and dil. HCl was added until the precipitate of HA was formed and allowed to stand overnight. The next morning, it was centrifuged to remove the precipitate. The solution was condensed by evaporation. To the condensed solution, 2 ml of 0.4N $K_2Cr_2O_7$ and 4 ml of conc. H_2SO_4 (AR quality) were added, allowed to react. The excess of dichromate was titrated against 0.1N Ferrous Ammonium Sulphate using Diphenylamine as an indicator. O-Phosphoric acid and Sodium Fluoride were added for a sharp endpoint. Simultaneously, a blank was also run. FA carbon is calculated as % of soil.

HA carbon = Total Humic carbon - FA Carbon

***Optical density at wavelength 465 nm and 665 nm (E4/E6ratio**) **of Humic Acid**:* From the extract for determination of humic carbon, a 20 ml aliquot was taken in a centrifuge tube, sufficient dilute HCl was added to precipitate HA. The precipitated HA was washed several times for purification. The HA fraction was dissolved in 0.05N $NaHCO_3$ solution, and with a spectrophotometer, optical density was recorded at the wavelengths 465 nm and 665 nm and termed as the E4/E6 ratio.

Results and Discussion

Morphological characteristics

Medium texture non calcareous soils: Morphological characteristics of four profiles of medium texture non calcareous soils are presented in Table 1. The surface soils are yellowish brown, sandy loam, with moderate subangular blocky structure, and the subsoil is dark brown, sandy loam, with moderate to strongly developed subangular blocky structure and is non-calcareous. These are very deep (more than 100 cm) soils, differentiated into B and C horizons.

Table 1. Morphology of medium texture non calcareous soils

Horizon	Depth (cm)	Colour	Texture	Structure	Consistency	Reaction dil. HCl	Roots	boundary
Profile 5. Location: Village Jaitaran								
A_1	0-15	10YR 5/4 d YB	sl	m2sbk	ds	e0	Few fine, few coarse	
B_{21}	15-40	7.5YR4/4 m DB	sl	m3sbk	dsh	e0	Common, fine	as
B_{21}	40- 80	7.5YR4/4 m DB	sl	m3sbk	dh	e0	Common fine, few medium	cs
B_{21}	80- 110	7.5YR4/4 m DB	sl	m3sbk	dh	e0	Few fine	gs
C	110-150	7.5YR4/4 m DB	sl	m3sbk	dh	e0	Few fine	ds
Remarks: coarse sand and gravels distributed throughout the profile. Well drained, uncultivated, no water erosion,								
Profile 8. Location: Village Devli Kalan								
Ap	0-20	7.5YR 4/4 (d), DB	sl	m2sbk	dh	eo	Few coarse, many fine	-
B_{21}	20-45	5YR ¾ (m), DRB	sl+	m2sbk	mfr	eo	Many fine	cs
B_{22}	45- 90	5YR ¾ m, DRB	sl+	m2sbk	mfr	eo	Common fine	ds
C_1	90-120	5YR ¾ m DRB	sl+	m2sbk	mfr	eo	Common fine	ds
C_1ca	120- 150	10YR5/4 d YB	gl	-	-	es	No roots	as
10-20%lime concretions mixed with gravelly soil15-30 mm size frgments of granite								
Profile 16. Location: Village Manda								
Ap	0-15	10YR 5/3d B	ls	gr	ds	eo	Fine common	-
B_1	15-45	7.5YR 4/2 d, DB	sl	m2sbk	mfr	eo	-do-	as
B_1	45- 65	5YR 3/2 m DRB	sl+	m2sbk	mfr	eo	Fine few	cs
C_1	65- 105	5YR 3/2 m DRB	sl+	m2sbk	mfr	eo	Fine few	gs
C_2	105- 150	5YR 3/2 m DRB	sl+	m2sbk	mfr	eo	no	cs
Profile 18. Location: Village Kharchi								
Ap	0-10	10YR5/4dYB	sl	m1sbk	ds	eo	Coarse medium	
B_1	10-35	10YR5.5/3m, B	sl+	m2sbk	dh	eo	Coarse medium	as
C_1	35-50	10YR5/3mB	sl	m2sbk	dh	e	Few fine	cs
C_1	50- 80	10YR6/3mPB	sl	m1sbk	mfirm	e	No roots	as
C_2	80- 100	10YR6/3mPB	ls	-		e	No roots	ds
Remarks: Alluvial gravels cemented with lime. C1 horizons very compact								

Fine texture calcareous soils: Morphological characteristics of four profiles of fine texture calcareous soils are presented in Table 2. The surface soils are brown, loam, moderate subangular blocky, and the subsoil is dark brown and grayish brown, loam and clay loam, with moderate to strongly developed subangular blocky and massive structure. The solum is calcareous. These are moderately deep to deep (60-80 cm) soils, differentiated in B and C horizons. The subsoil has indications of lime streaks, and the C_1ca horizon has invariably lime-coated gravels.

Table 2. Morphology of fine texture calcareous soils

Horizon	Depth (cm)	Colour	Texture	Structure	Consistency	Reaction dil. HCl	Roots	boundary
Profile 6: Location:Village Sanadya								
AP	0-20	10YR4/3m, B	l	m2sbk	mfr	es	Many, medium and fine	-
B_1	20-45	10YR3.5/3, m, DB	l+	m2sbk	mfr	es	Common medium	cs
B_2	45-60	0YR3.5/3, d, DB	si	m3sbk	mfr	es	Common, medium	gs
Lime streaks common indicates leaching of lime								
C1ca	60-100	10YR5/3d, DB	gl	-	massive	ev	Common fine	as
Remarks: C1ca horizon Well-formed concretions, 50% mixed with soil, well distributed, size vary from 5 mm to 20 mm, spherical shape.								
Profile 7. Location: Village Boyal								
A	0-12	10YR5/3 d, B	l	m2sbk	dsh	eo	Many fine, few medium	
B	12- 40	7.5 YR3/2 m LG	cl	m2sbk	mf	es	Many fine, few medium	as
C_1ca	40-80	-	gl	massive	dl	ev	Few fine	as
Remarks: C1ca horizon 50- 70% gravels and rock fragments coated with lime								
Profile 19. Location: Sojat city								
Ap	0-5	10YR6/3dPB	sl	gr	dh	es	Coarse medium	
B_1	5-10	10YR 4/3 m, B	sl+	m2sbk	mfi	es	Few fine	gs
B_1	10-15	10YR 4/3 m, B	gcl	m2sbk	mfi	ev	Few fine	cs
C_1ca	15- 55	10YR6/3d PB		massive	dh	ev	nil	cs
Remarks: In C1ca horizon Gravels cemented with lime mixed with soil								
Prifile 29. Location: Village Denda								
Ap	0-10	10YR5/3d B	i	m2sbk	ds	e	Many fine	
B_1	10- 30	10YR 5/2 d, GB	cl	m2sbk	dvh	es	Many fine	cs
C_1ca	30-50	10YR 5/2 d, GB	gsicl	massive	dl	ev	nil	cs
C_1ca	50-150	10YR7/2d LG		massive	dl	ev	nil	as
Remarks: In C1ca horizon Gravels cemented with lime mixed with soil								

Abbreviations used in Table 1 and Table 2

- Colour: YB (Yellowish brown), DB (Dark brown), DRB (Dark reddish), B (Brown), LG (Light gray), PB (Pale brown), GB (Grayish brown). d, m refer to dry and moist conditions of soil during recording colour.
- Texture: sl (Sandy loam), ls (Loamy sand), l (Loam), si (Silt loam), gl (Gravely loam), cl (Clay loam), gcl (Gravely clay loam), gsicl (Gravely silty clay loam)
- Structure: m2 sbk (Medium, moderately developed subangular blocky), m3 sbk (Medium strongly developed subangular blocky), gr (Granular).
- Consistency: ds (Dry soft), dsh (Dry slightly hard), dh (Hard), mfr (Moist friable), mfi (Moist firm), dl (Dry loose)
- Reaction with dil. HCl: e0 (No free carbonates), es (Strong, good amount of free carbonates), ev (Violent, high amount

of free carbonates)

- Horizon boundary: as (Abrupt smooth), cs (Clear smooth), gs (Gradual smooth), ds (Diffuse smooth)

Physico-chemical characteristics

Out of eight, three profiles (two medium texture non-calcareous and one fine texture calcareous) have been taken for detailed investigation. The physicochemical characteristics of three profiles are reported in Table 3. Medium texture non-calcareous soils are characterized by a higher proportion of the fine sand fraction (> 40%) followed by the coarse sand fraction (35%). In the A_1 horizon, clay (7.3%) increases in the B horizon, but silt (15.9%) is uniformly distributed. In the A_1 horizon, the cation exchange capacity (CEC) is 6.3 and 11.7 cmol kg^{-1}, which increases with depth. $CaCO_3$ is absent.

Table 3. Physico-chemical characteristics of medium and fine textured soils

Horizon)	Depth (cm)	Clay %	Silt %	Fine sand %	Coarse sand %	$CaCO_3$ %	CEC (c mol kg^{-1})
Pedon 5 Village Jaitaran. Medium texture non-calcareous alluvium							
A_1	0-15	7.3	7.9	46.9	35.8	-	6.3
B_{21}	15-40	8.2	9.6	46.4	36.6	-	8.7
B_{21}	40-80	9.8	11.2	44.4	34.8	-	11.7
B_{21}	80-110	12.3	9.7	43.5	35.0	-	11.7
C	110-150	11.5	8.7	46.1	32.7	-	-
Pedon 18 Village Kharchi. Fine texture non-calcareous alluvium							
Ap	0-10	7.3	15.8	40.2	36.1	-	11.7
B_1	10-35	10.7	14.2	38.9	35.1	-	13.5
C_1	35- 50	9.8	13.3	42.6	32.0	-	15.7
C_1	50-80	14.9	14.9	29.3	38.9	-	16.5
C_2	80-120	7.3	10.8	14.6	65.4	-	-
Pedon 6 Village Sanadaya. Fine texture calcareous alluvium							
Ap	0-20	18.2	21.2	48.1	7.6	4.6	29.3
B_1	20-40	26.5	20.6	28.8	7.0	8.7	39.1
B_2	40- 60	16.2	28.2	32.0	6.0	14.9	39.1
$C_{1}ca$	60-100	21.5	7.9	22.2	6.4	43.8	20.6

In *Fine texture calcareous* pedon, the A1 horizon is characterized by higher clay (18.2 – 26.6%), silt (21.2- 28.2%), and CEC 29.3 cmol kg^{-1}, which increases in the B horizon. Fine sand (48.1%) is slightly and coarse sand very low (6-7%), which decreases in the subsoil. $CaCO_3$ in the A1 and B horizons is respectively 4.6 and 8.7, which increases in the C1ca horizon to 14.9 and 43.8%, qualifying for a calcic horizon. Thus, the fine texture calcareous soil profile has more clay, silt, organic carbon, CEC, and $CaCO_3$ and less coarse sand than the medium texture non-calcareous soil profiles.

Sand fractionation and characterisation

Sand size data in three soil profiles presented in Table 4 reveals that in medium texture non-calcareous profiles, medium sand (1-2 Φ) and fine sand (2-3 Φ) are the dominant sand fractions, which are almost uniformly distributed with depth in P 5 (28.7- 32.7%) and P18 (27.9- 23.8%).

Table 4. Granulometric analysis of the sand fraction

Horizon	Size and percent of sand particles						
mm	2 to 1	1 to 0.50	0.50 to 0.25	0.25 to 0.125	0.125 to 0.05	0.050 to 0.02	0.02 to 0.002
Φ (phi)	-1 to 0	0-1	1-2	2-3	3-4	4-5	5-6
Common name	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Coarse silt	Medium silt
Pedon 5 Medium texture non-calcareous alluvium							
A_1	0.25	16.5	28.7	24.8	10.8	15.9	2.9
B_{21}	0.25	19.3	32.9	24.1	9.0	12.3	2.1
B_{21}	0.52	16.9	30.6	25.6	10.7	12.6	2.1
B_{21}	0.26	14.8	30.9	25.8	10.7	15.4	2.1
C	1.03	18.3	30.7	23.5	9.5	15.7	2.1
Pedon 18 Medium texture non-calcareous alluvium							
Ap	0.87	20.9	27.9	20.4	8.1	18.6	3.2
B_1	1.17	27.2	27.2	18.4	7.1	15.5	3.5
C_1	1.21	16.9	23.6	19.9	8.8	22.7	6.8
C_1	0.96	16.7	23.8	18.6	8.4	23.4	8.4
C_2	2.63	19.4	25.3	19.1	8.2	20.4	4.9
Pedon 6 Fine texture calcareous alluvium							
Ap	0.42	7.5	10.4	15.4	15.4	39.2	11.7
B_1	0.84	7.1	9.2	13.3	14.9	39.6	14.9
B_2	1.04	9.4	9.4	13.0	17.2	40.6	9.4
C_1ca	2.78	16.6	11.4	13.5	10.3	35.9	9.3

In fine-textured calcareous soil, the major particle sizes are fine sand (Φ 2-3) (15.5-13.5%), very fine sand (3-4 Φ) (15.4-10.3%), and coarse silt (Φ 4-5) (39.9-35.9%). This is also reflected in Fig. 1. In both medium- and fine-texture soils, uniform depth-wise distribution of all size sand fractions indicates uniformity of parent material.

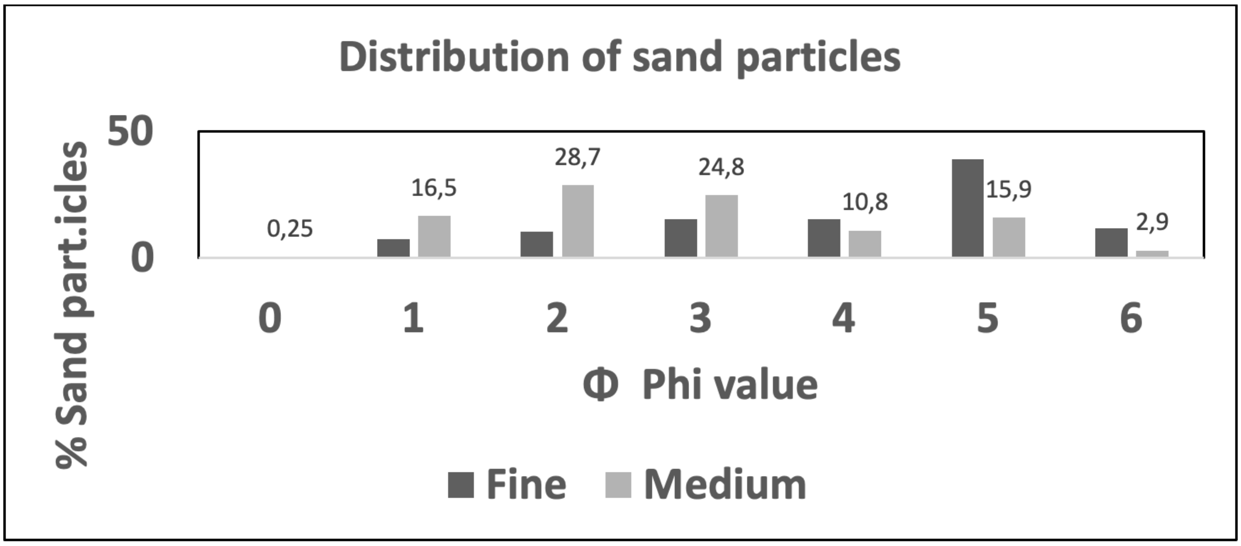

Fig. 1. Distribution of percent sand particles according to size

Gaussian distribution of sand particles

The Gaussian distribution curve (Fig. 2) for the sand fraction of medium-texture soils is skewed towards the coarser side (Φ 2), whereas the sand fraction of fine-texture calcareous soils is skewed towards the finer side (Φ 5), indicating a preponderance of finer particles.

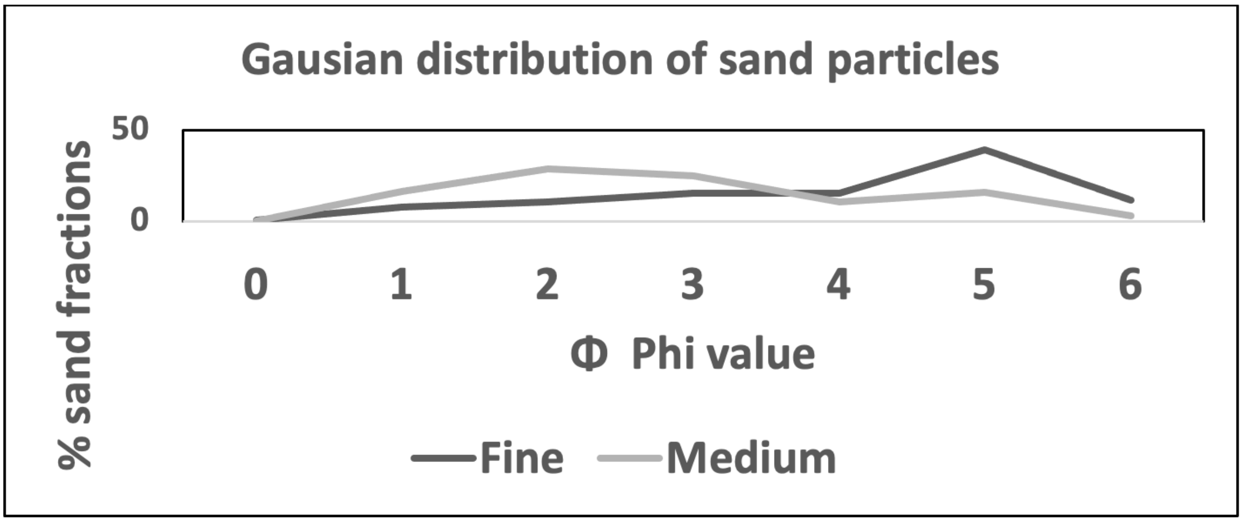

Fig. 2. Gaussian distribution of sand particles according to their size

Cumulative curves for sand particles distribution

Considering all-size sand fractions, cumulative curves were drawn for both medium-texture non-calcareous and fine-texture calcareous soils for all horizons (Fig. 3). From the cumulative curves, the diameter of the sand fraction at quartile 25% (Q1), quartile 75% (Q3), mean diameter (Md at 50% in the curve), P90 grain diameter at 90 percent, and P10 were derived. The parameters of sand size distribution, viz., sorting coefficient (S0), skewness (Sk), and kurtosis (K), calculated, are reported in Table 5.

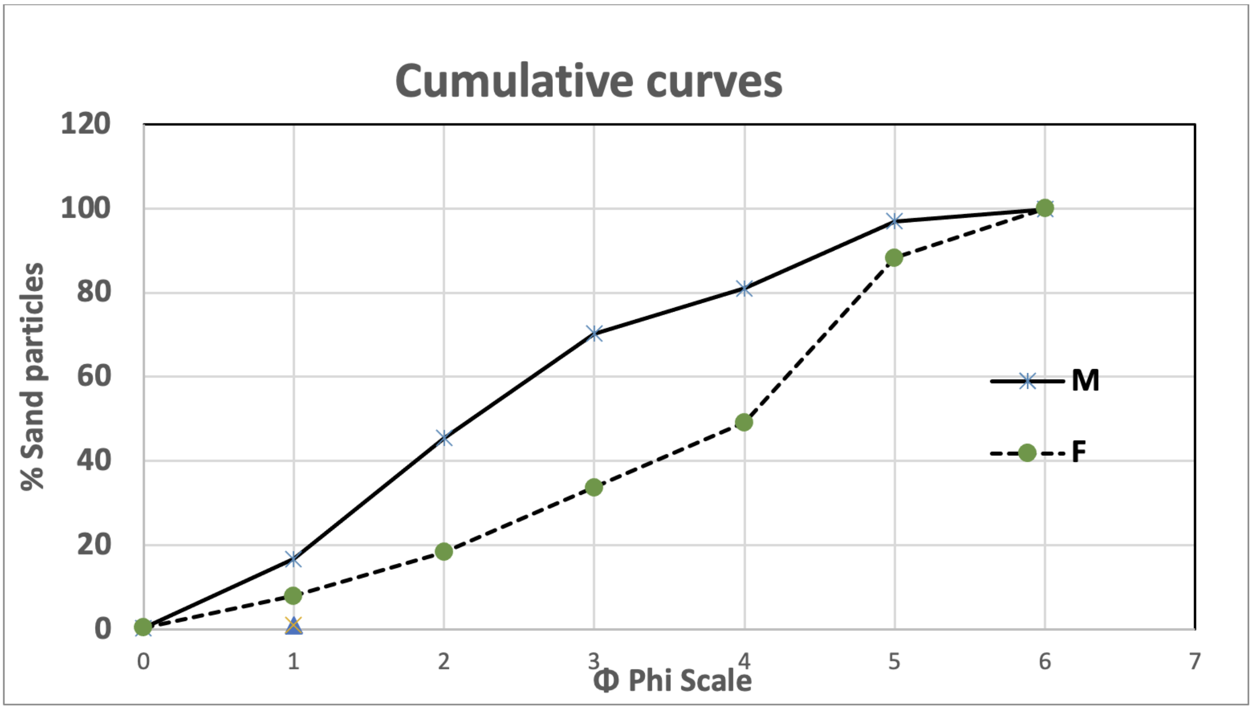

Fig. 3. Cumulative curves for percent sand particles according to their size

Parameters of grain size distribution

A comparison of sand grain size parameters (Table 5) reveals clear differences between the sand sizes in medium and fine texture alluvium. Sand size parameters in medium texture alluvium are coarser (0.6 to 4.4 Φ) than those in the fine texture (1.0 to 5.5 Φ) alluvium. However, in both profiles, sand uniform size parameters distributed with depth indicate uniformity of the parent material. The sand particles show unimodal distribution in both profiles, with 50-70 percent of particles coarser in medium texture (1- 3 Φ) soil and finer in fine texture (4-5 Φ) soil (Fig. 2). The sorting coefficient in medium texture (1.49 to 1.61) and fine-textured (1.41 to 1.81) soils indicates the well-sorted nature of the sediments (values less than 2.5). The coefficient is uniform for the sand fraction at different depths. The skewness values of the sand fraction in medium (0.997- 0.827) and fine texture (0.742 -0.526) soils indicate a large proportion of finer material. The kurtosis values in medium texture soils (0.275- 0.231) indicate a Gaussian distribution better sorted in the central part than in the tails; the curve is leptokurtic. Fine texture soils' kurtosis values (0.267- 0.348) gradually increased with depth, and the curve indicates better sorting in the finer tails than in the central portion; the curve is platykurtic.

Table 5. Parameters of sand size distribution

Horizon	Q1particle size Φ at 25%	Q3 particle size Φ at 75%	P10 particle size Φ at 10%	P90 particle size Φ at 90	Md particle size Φ at 50%	Sorting coefficient	Skewness	Kurtosis
Pedon 5 Medium texture non-calcareous alluvium								
Ap	1.2	3.4	0.6	4.6	2.2	1.49	0.827	0.275
B_{21}	1.2	3.0	0.5	4.4	1.9	1.58	0.997	0.231
B_{21}	1.2	3.0	0.6	4.4	2.1	1.58	0.816	0.237
B_{21}	1.3	3.2	0.6	4.5	2.1	1.57	0.943	0.244
C	1.2	3.1	0.5	4.4	2.0	1.61	0.93	0.243
Pedon 6 Fine texture calcareous alluvium								
Ap	2.2	4.5	1.2	5.5	4.0	1.42	0.619	0.267
B_1	2.6	4.8	1.2	5.3	4.1	1.21	0.742	0.268
B_{22}	2.3	4.6	1.0	5.0	4.0	1.41	0.661	0.288
C	1.4	4.6	0.4	5.0	3.5	1.81	0.526	0.348

In the sand fraction of medium texture soils, Joshi and Sharma (1987) observed a primary mode at 3.8 to 5.6 Φ and a secondary mode at 2.5 to 3.5 Φ. In fine-textured soils, the sand fraction was finer and better sorted (1.92) than medium-textured soils (1 to 2.46). However, the narrow range in the skewness (0.17 to 0.84) and kurtosis (0.13 to 0.23) indicated the dominance of finer particles in the sand fraction of soils.

Humus composition

Medium texture non calcareous: Organic carbon in surface soils is 0.21% and 0.45% of the soil decreases with depth. Carbon associated with humus ranges from 0.099 to 0.113% of the soil and from 36.8 to 53% of organic carbon, both of which decrease with depth. The humus fraction was more prevalent in the surface horizon, while the non-humus fraction dominated the lower horizons. In the surface horizons of the P5 and P18 profiles, slightly higher HA-carbon (36.8% and 53.0% of organic carbon) and slightly low FA-carbon (12.4% and 11.9% of organic carbon) and narrow values of the HA-carbon/FA-carbon ratio (2.96 and 4.51) indicated the dominance of HA carbon. The wider ratio in surface soils narrowed down with depth, indicating the dominance of fulvic acid in the lower horizons. The ratio of optical densities at 465 nm and 665 nm (E4/E6 ratio) is used for the characterization of humic acid. The E4/E6 ratio is related to the aromaticity and degree of condensation of the chain of aromatic carbons of humic acid. E4/E6 ratios of humic acid of fine-texture soils (<1 to 2) than medium-texture soils (2 to 3) indicate more condensed aromatic nuclei in the humic acid of fine-texture soils.

Table 6. Humus composition and E4/E6 ratio of Humic acids

(Horizon)	Organic carbon	Humus carbon	HA- carbon	FA- carbon	HA- carbon / FA- carbon	E4/E6 ratio of Humic acid
	(% o soil)		(% of organic carbon)			
Pedon 5	**Medium texture non-calcareous alluvium**					
A_1	0.21	0.099	36.8	12.4	2.96	3.08
B_{21}	0.19	0.076	24.3	16.6	1.46	3.06
B_{21}	0.21	0.056	13.0	12.8	1.01	3.35
B_{21}	0.15	0.056	22.1	14.2	1.56	2.21
C	-	-	-	-	-	-
Pedon 18	**Medium texture non-calcareous alluvium**					
Ap	0.45	0.113	53.0	11.9	4.51	1.91
B_1	0.37	0.113	20.9	10.2	2.05	2.28
C_1	0.31	0.085	17.9	9.5	1.89	1.86
C_1	0.23	0.076	15.3	18.1	0.85	2.84
Pedon 6 Fine texture calcareoualluvium						
Ap	0.49	0.250	40.1	5.8	6.9	1.21
B_1	0.57	0.261	41.0	4.6	8.9	1.07
B_{22}	0.53	0.134	19.1	6.4	2.9	0.76
C_1ca	0.35	0.268	63.8	11.5	5.5	1.89

Fine texture calcareous soil: Compared to medium texture soils, fine texture soils in the surface horizon are higher in organic carbon (0.49% of soil) and humus carbon (0.250% of soil), which increases in the B1 horizon. Higher HA acid carbon (40.1% of organic carbon) and lower FA acid carbon (5.8 % of organic carbon), and a wider humic acid-C/fulvic acid-C ratio (6.9) indicated the dominance of humic acid in the A and B horizons. In the B_1 horizon, the HA-carbon slightly increases, FA-carbon decreases, and the HA-carbon/FA-carbon ratio widens, indicating a higher content of HA in the lower horizon. The narrow E4/E6 ratio of humic acid (<2) indicated a well-aromatic nucleus of HA. A wider E4/E6 ratio is indicative of less condensation of aromatic constituents and a preponderance of aliphatic structure. The E4/E6 ratio of HA varied from 3 to 5 for alluvial, 3.5 to 6.4 for dunes, interdune and sandy plain soils, and between 2.8 to 5.3 for medium-textured soils (Joshi 1990). For FA, the ratio varied between 9 to 12 (Joshi, 1981).

HCl extract analysis

The HCl extract of the soil samples analysed for the content of Fe, Mn, Zn, Cu, K, and Na (Table 7) was uniform with depth in medium and fine texture calcareous soils. This indicated uniform parent material within the profile.

Table 7. The HCl extract analysis of soil

Horizon)	Potassium %	Sodium %	Mn ppm	Zn ppm	Cu ppm	Free Mn Ppm
Pedon 5Medium texture non-calcareous alluvium						
A_1	1.19	0.53	121	24	10	79
B_{21}	1.56	0.44	146	23	10	80
B_{21}	1.50	0.44	146	27	11	80
B_{21}	2.13	0.56	141	30	12	81
C	0.94	0.31	135	23	9	81
Pedon 18 Medium texture non-calcareous alluvium						
Ap	1.38	0.34	135	27	10	96
B_1	1.50	0.34	138	28	10	96
C_1	2.00	0.41	129	33	14	97
C_1	2.00	0.59	129	30	13	97
C_2	1.25	0.56	127	28	11	97
Pedon 6 Fine texture calcareous alluvium						
Ap	1.50	0.31	155	39	18	82
B_1	2.06	0.56	152	41	20	83
B_2	2.25	0.72	146	46	21	84
C_1ca	2.00	0.47	152	36	15	85

Uniformity of parent alluvium

Sand size parameters in medium texture alluvium are coarser (0.6 to 4.4 Φ) than the fine texture (1.0 to 5.5 Φ) alluvium. However, in both the profiles, sand size parameters are uniformly distributed with depth, indicating uniformity of parent material. The sand particles show unimodal distribution in both the profiles, with 50-70 percent of particles coarser in medium texture (1- 3 Φ) and finer in fine texture (4-5 Φ) alluvium.

Translocation within the profile

The profile distribution of clay to sand ratio, HA-carbon to FA-carbon ratio, CaCO3, and CEC in two profiles (Table 8) shows that the clay/sand ratio is wider in fine texture calcareous (0.327- 0.746) than in medium texture non-calcareous soils (0.088 – 0.218), and an increase in the B horizon in both profiles indicates the illuviation of the clay fraction. A decrease in HA-carbon/FA-carbon ratio in medium and fine texture soils with depth indicates the translocation of FA-carbon in the B horizon.

Table 8. Mobile constituents in the soil profiles

Horizon	Depth (cm)	Clay/sand ratio	HA carbon/ FA carbon ratio	CaCO3 %	CEC (c mol kg^{-1})
Pedon 5 Village Jaitaran. Medium texture non-calcareous alluvium					
A_1	0-15	0.088	2.96	nil	6.3
B_{21}	15-40	0.099	1.46	nil	8.7
B_{21}	40-80	0.124	1.01	nil	11.7
B_{21}	80-110	0.157	1.56	nil	11.7
C	110-150	0.146	-	nil	-
Pedon 18. Village Kharchia Fine texture non-calcareous alluvium					
Ap	0-10	0.096	4.51	nil	11.7
B_1	10-35	0.145	2.05	nil	13.5
C_1	35- 50	0.132	1.89	nil	15.7
C_1	50-80	0.218	0.85	nil	16.5
Ap	80-120	0.091	-	nil	-
Pedon 6. Village Sanadia Fine texture calcareous alluvium					
Ap	0-20	0.327	6.9	4.6	29.3
B_1	20-40	0.740	8.9	8.7	39.1
B_{22}	40- 60	0.426	2.9	14.9	39.1
C_1ca	60-100	0.752	5.5	43.8	20.6

The CEC also follows the pattern of clay illuviation. In fine-texture calcareous soils, a gradual increase in CaCO3 is evidence of its leaching and the formation of a calcic horizon. Considering all these parameters, in medium-texture soils, the constituents have moved to a depth of 80 cm, whereas in fine-texture soils, they have moved to a depth of 60 cm. These observations suggest that both medium- and fine-texture soils have undergone an illuviation process, but the process is more pronounced in fine-texture calcareous soils.

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