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Pedogenesis and Mineralogy of Alluvial Soils from Semi-arid Southeastern Part of Rajasthan in Aravalli Range, India

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ABSTRACT

Three representative alluvial soils were studied from Kothari river basin of Bhilwara district in southeast Rajasthan to assess degree of chemical weathering and pedogenesis. Morphological, geochemical, mineralogical and other analytical investigations were carried out. Soils were classified as Entisols and Inceptisols. These soils are mostly sandy with more than 50% of fine and medium sand fractions, silt to clay ratio more than 0.45 and little textural variation suggesting more uniform weathering. These soils are slight to strongly alkaline with high exchangeable sodium (>15%) and cation exchange capacity less than 10 cmol(+)kg^{-1}. Mineralogical investigations showed the dominance of micas and smectites in Pedon 1 (P1) and Pedon 2 (P2) and increase of smectites and micas in Bw3 horizon of P3 under strong alkalinity and high silica activity with limited lessivage. The low chemical index of alteration (CIA) in soils further indicated an incipient pedogenesis with a relative proportion of mica-smectite composition. The A-CNK-FM diagram shows abundance of CaO + Na_2O + K_2O as against Fe_2O_3+ MgO components under limited leaching environment and chemical weathering. The results of bivariate plot of SiO_2 to (Al_2O_3 + K_2O + Na_2O) indicated the past weathering which influenced by prevailing arid climate in the region.

INTRODUCTION

The soil characteristics in river basins are commonly governed by lithology, climate, topography, transport energy and hydrodynamics of the depositional environment (Kanhaiya, et al., 2018; Verma et al., 2012; Sharma et al., 2013). Under arid climate, carbonate, clay eluviation-illuviation, and salt accumulation are the dominant pedogenic processes (Khresat and Qudah, 2006) that results in translocation and/or accumulation of major or trace elements in soils (Kabata-Pendias and Pendias, 1992). The pedogenic evaluations were done using particle size data for assessing lithological discontinuities in soils of Brahmaputra valley, Assam (Bhaskar et al., 2005) and difference in successive values of sand to silt ratio > 0.8 in alkali soils of Chitravati basin (Raad and Protz, 1971, Bhaskar et al., 2000). Similarly, alkali ratios were used as measures of pedogenic changes and geological uniformity (Muhs et al., 2001) and elemental ratios such as silica to sesquioxides as weathering index (Jackson, 1973). The high silica to sesquioxides in clay fraction of soils of western Rajasthan were reported by Chaudhary and Dhir (1981). Geochemical proxies have been used successfully in the evaluation of chemical weathering and pedogenesis in soils (Yang et al., 2004; Adams et al., 2011).

The Chemical Index of Alteration (CIA) and Chemical Index of Weathering (CIW) in addition to elemental ratios such as K/Na and K/Ca are some of the quantitative methods used in assessing the degree of chemical weathering with respect to their mobility in soil profiles during weathering (Nesbitt and Young, 1982). In India, CIA was used and found as an ideal index for assessing pedogenesis of alluvial soils of Purna valley (Raja et al., 2018). The ternary A-CN-K and A-CNK-FM diagram to define degree of weathering of soils in the Mahi catchment, Gujarat, were constructed and reported that dominance of smectites under water stressed semi-arid conditions (Sharma et al., 2013). Various geochemical proxies were used in assessing weak to moderate weathering of loess paleosol sediments in Karewa basin of Kashmir valley (Chandra et al., 2016). Smectites in arid soils when P/ETº is >~0.4 in Southern Iran (Khormali and Abtahi, 2003) under low-lying topography and poor drainage conditions with high pH, high silica activity and abundance of basic cations (Borchardt, 1989; Aoudjit et al., 1995). An elaborative paleoclimatic studies based on geomorphology, sedimentology and absolute dating of sediments suggested that fluctuating climatic conditions varying between wet and dry phases over the last 100 ka have resulted in the relative dominance of fluvial and aeolian processes in Thar desert of Rajasthan (Ghose et al., 1977; Kar, 1995, 1999; Kar et al., 2004; Moharana and Raja, 2016).

The alluvial soils under Kothari river basin of southeast Rajasthan represent an important modern analog with an impressive record of the pedofeatures that developed over the years in the region. Therefore, the present study is taken up to investigate the pedogenic development of soils in relation to morphological, physico-chemical, elemental and mineralogical composition in Kothari River basin and its significance in sustainable management of natural resources.

MATERIALS AND METHODS

Study Area and Soil Sampling

The Kothari river basin lies between 25°01' and 25°58' N Latitude and 74°01' and 75°28' E Longitude in Bhilwara district of southeast Rajasthan (Fig.1). The rock types are quartzite, conglomerates, shale, slate, phyllites and composite gneisses (Bakliwal and Wadhawan, 2003; Sharma et al., 2010). The area experiences semiarid tropical climate with mean annual rainfall of 699 mm and 32 rainy days during June to September. The mean annual temperature is 25.6°C to 27.1°C with its maximum in May (41.5°C) and minimum in January (7.8°C). The moisture index (Thronthwaite, 1948) is -59.7 to -39.5 indicating semi-arid dry to moist which varied from 95 to 105 days (Singh, 2016) with *ustic* soil moisture regime and hyperthermic soil temperature regime (Soil Survey Staff, 2014).

Three representative profiles were selected based on variations in rainfall and landforms in alluvial tract of Kothari river basin *viz.,* P1-upper pediments (Baniyon Ka Khera) coarse-loamy, mixed, hyperthermic fluventic haplustepts, P2- mid plain (Sarano Ka Kheda) coarse-loamy, mixed, hyperthermic typic ustifluvents, and P3-lower plains (Akola), coarse-loamy, mixed, hyperthermic typic haplustepts.

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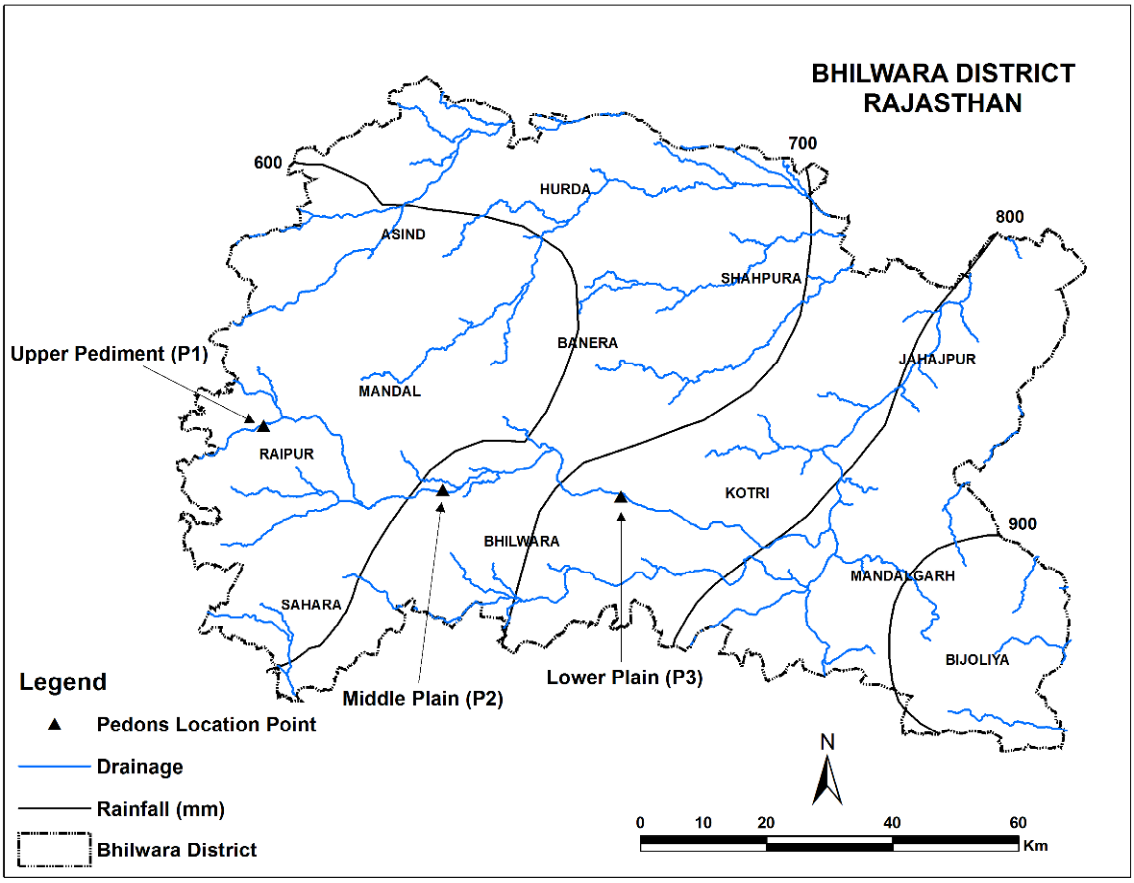

Fig.1. Location map of study area representing soil sampling sites.

The morphology of three profiles were described (Schoeneberger et al., 2012) and classified (Soil Survey Staff, 2014).

Soil Analytical Methods

Horizon wise soil samples were collected and air-dried. The air dried samples were passed through <2mm sieve for fine earth fraction for physical and chemical analyses as per the procedures outlined below:

The particle size distribution (PSD) was determined by the International pipette method with pretreatment of hydrogen peroxide (H_2O_2), citrate-bicarbonate-dithionite (CBD) treatment and dispersed with sodium hexametaphosphate. Silt (50-2mm) and total clay (<2mm) fractions were separated after dispersion according to the size segregation procedure of Jackson (1979).

Among chemical properties, soil pH was determined in 1:2.5 soil-water ratio using pH meter (Hanna instrument) and using electrical conductivity meter (Toshniwal instruments). Wet digestion method was used to determine soil organic carbon (Jackson, 1973). The calcium carbonate equivalent was estimated using acid neutralization method (Rowell, 1994). In neutral normal ammonium acetate extractable Ca, Mg, Na and K were determined using atomic adsorption spectrophotometer (Perkin Elmer-2380). Cation exchange capacity (CEC) was determined by displacing excess ammonia with alcohol and distillation method (Jackson, 1973) and Meyer and Arp (1994). The per cent base saturation was calculated as sum of bases divided by CEC and multiplied by 100.

Elemental Analysis

The 80 mesh size soil sample were used for triacid digestion (few drops of sulphuric acid + 4ml of hydrofluoric acid + 0.5 ml of perchloric acid) of 50 mg (80 mesh size) in platinum crucible (Jackson, 1973). The silica was determined gravimetrically after sodium carbonate fusion. The other elemental oxidex in the study were determined using atomic absorption spectrophotometer except aluminium oxide using inductively coupled plasma spectrophotometer (Jackson, 1973). The molar ratios and weathering indices such as riche's product index (1950), weathering index of parker (WIP, Parker, 1970) and chemical index of alteration (CIA, Nesbitt and Young,1982) and the ratio of bases to R_2O_3 (Birkeland et al., 2003) as leaching index were worked out. The ternary and biplot diagrams were constructed as required for the study. Weighted means for soil profiles were obtained by dividing profile values (horizon values multiplied by horizon thickness and summed for each profile) by the total thickness of the profile.

X-ray Diffraction Analysis

Mineralogical analysis of sand, silt, and clay fractions were performed by X-ray diffraction (XRD) with random powder mounts of the sand and silt specimens. The clay specimens were analyzed after citrate-dithionite-bicarbonate treatment (CDB) as described by Mehra and Jackson (1960); saturation with K mounted on a slide and read at 25 °C and, after heating for 2 h, at temperatures of 350 and 550°C; saturation with Mg and a reading at 25 °C before ethylene glycol solvation. The clay specimens were mounted on oriented slides. A Rigaku Miniflex device equipped with a graphite-monochromated Cu Ká radiation source (30 kV, 15 mA) was used for mineralogy analyses (Ghosh and Dutta, 1974; Jackson, 1979).

RESULTS AND DISCUSSION

Morphological Characteristics

The soils of upper pediments (P1, Baniyon ka khera) have horizon sequence of Ap-Bw1-Bw2-Bw3-C with dark yellowish brown matrix (10YR4/4 to 10YR3/4) and loamy sand texture (Table 1). The soils on mid slopes (P2, Sarano Ka Kheda) have uniformly dark yellowish

Table 1. Morphological* characteristics of representative pedons.

Depth (cm)	Horizon	Soil colour	Texture	Structure	Consistence		Porosity		Roots		Efferv.	pH(2.5:1)
					Moist	Wet	Size	Quantity	Size	Quantity		
P1: Baniyon Ka Khera, 25°23'50" N, 74°03'00" E, altitude- 592 m , - Upper pediments with a mean annual rainfall <600 mm												
0-10	Ap	10YR4/4	ls	m 1 sbk	l	sspo	m,f	c,m	vf, f	c	nil	7.85
10-26	Bw1	10YR3/4	sl	m 1 sbk	fr	sspo	m	m	m	c	nil	7.50
26-46	Bw2	10YR3/4	sl	m 1 sbk	fr	sspo	m	m	vf, f	m	nil	7.08
46-65	Bw3	10YR3/4	sl	f 1 sbk	fr	sspo	m	m	vf	m	nil	7.12
65-80	C1	10YR3/4	ls	m 1 sbk	fr	sspo	m	m	vf	f	nil	7.87
P2: Sarano Ka Kheda, 25°22'00" N, 74°26'30" E, altitude- 455 m, - Mid plain with a mean annual rainfall 600-700 mm												
0-18	Ap	10YR4/4	ls	sg	l	sopo	m,c	m	vf,f	c, f	nil	8.15
18-50	A1	10YR3/4	s	sg	l	sopo	m	m	c	c	nil	8.10
50-100	A2	10YR3/4	ls	f 1 sbk	fr	sopo	m,c	m	c	f	nil	8.06
100-140	A3	10YR3/4	ls	f 1 sbk	fr	sopo	m	m	c	f	nil	8.08
140-175	A4	10YR3/4	ls	f 1 sbk	fr	sopo	m	m	c, f	f	nil	8.12
P3: Akola , 25°21'52" N, 74°43'30" E, altitude- 399 m, - Lower plain with a mean annual rainfall 700-800 mm												
0-19	Ap	10YR5/4	ls	m 1 sbk	l	sspo	m,c	c,m	vf,f	m,c	e	9.31
19-45	A	10YR4/4	sl	m 1 sbk	l	sspo	m,c	c	f	c,f	nil	8.62
45-85	Bw1	10YR4/4	sl	m 2 sbk	fr	spo	m,c	c	f,c	f	e	8.49
85-125	Bw2	10YR4/4	sl	m 2 sbk	fr	spo	m,c	c	f,c	f	e	8.66
125-170	Bw3	10YR4/3	sl	m 1 sbk	fr	spo	m,c	c	f	f	e	8.71

* notations used as per Soil Survey Staff (2017)

brown (10YR4/4 to 10YR3/4) with loamy sand except in sandy C1 horizon. This soils shows gradational increase of structure from single grain to fine, weak, subangular blocky in sub-soils. The soils in lower plains (P3, Akola), have yellowish brown (10YR5/4) with loamy sand surface horizons and dark yellowish brown (10YR4/4) sandy loam sub-surface horizons.

Physical Properties and Sand to Silt Ratio

Irregular vertical distribution of total sand to silt and sub-fractions of sand indicate lithological discontinuities (Table 2). The weighted mean is more than 75% for sand, 5.8% (P2) to 16.3% (P1) for silt and 7.44 (P1) to 10.18% for clay (P3). Among sand fractions, medium sand and fine sand fractions constitute 52% of total sand (P1) to 79% in P2 and 61% in P3. In general, very coarse sand (3 to 16%) and coarse sand (8.5 to 13.1%) shows gradational increase in P1 whereas other fractions of sand show gradational decrease. It is interesting to point out here that P2 & P3 have less than 0.5% of very coarse sand and less than 5% of coarse sand. In P2, the medium sand fraction is 25.6% in Ap horizon but increased to 36.9% in C1 horizon. In P3, the weighted mean for medium sand is 10.64% but drop in its content to 9.3% in Bw2 horizon. This soil (P3) has more than 40% of fine sand in some horizons and of very fine sand of 27.54%. The soils on upper

Table 2. Particle size distribution, bulk density, available water holding capacity (AWC) and sand to silt ratio in soils.

Depth (cm)	Horizon	% sand size fractions (2mm-0.05mm)					Particle size distribution (<2mm, %)			BD (Mgm^{-3})	AWC (%)	TS/TSi
		VCS	CS	MS	FS	VFS	Sand	Silt	Clay			
P1: Baniyon Ka Khera-Ustic Haplocambids												
0-10	Ap	3.0	8.5	20.1	32.5	18.1	82.1	10.7	7.2	1.70	5.10	7.7
10-26	Bw1	6.5	9.2	17.7	22.7	15.9	74.0	18.5	7.4	1.50	6.50	4.0
26-46	Bw2	14.2	12.3	16.8	19.8	12.3	75.3	16.8	7.9	1.42	6.20	4.5
46-65	Bw3	14.7	13.1	16.7	18.0	12.0	74.6	18.0	7.4	1.40	6.60	4.1
65-80	C1	16.0	11.4	20.2	19.5	11.1	78.1	14.8	7.1	1.56	7.30	5.3
Weighted mean		11.7	0.68	18.0	21.5	13.5	76.2	16.2	7.4	1.49	6.42	4.7
P2: Sarano Ka Kheda-Aridic Ustorthents												
0-18	Ap	0.1	3.0	25.6	37.5	16.9	83.1	6.8	10.2	1.67	7.7	12.3
18-50	A1	0.5	4.5	36.9	36.7	12.8	87.3	4.6	8.1	1.63	3.80	18.9
50-100	A2	0.1	4.4	30.7	35.1	14.2	84.5	4.8	10.7	1.64	6.60	17.5
100-140	A3	0.3	4.2	28.4	36.9	13.2	82.9	6.2	10.9	1.59	7.00	13.4
140-175	A4	0.1	3.0	25.3	37.3	16.5	82.2	7.4	10.5	1.56	7.00	11.1
Weighted mean		0.2	0.11	29.7	36.5	14.5	84.0	5.8	10.2	1.61	6.37	15.0
P3: Akola –Sodic Ustic Haplocambids												
0-19	Ap	0.8	2.6	13.0	39.4	25.3	80.1	8.6	10.4	1.37	15.10	4.2
19-45	A	0.4	2.8	12.0	40.6	26.4	82.1	8.1	9.8	1.52	14.40	4.1
45-85	Bw1	0.2	2.2	9.9	33.5	30.6	76.5	13.1	10.5	1.42	16.70	3.3
85-125	Bw2	0.4	2.3	9.3	45.1	26.6	83.7	6.5	9.8	1.21	17.30	3.2
125-170	Bw3	0.2	2.3	10.7	30.9	27.3	71.5	19.2	9.3	1.24	17.30	3.2
Weighted mean		0.3	0.07	10.6	37.1	27.5	77.9	12.1	9.9	1.33	16.49	3.5

Sand (2mm -0.05mm); Silt (0.05mm -0.002mm); Clay (<0.002mm).BD- bulk density; AWC-available water content; TS-total sand; TSi-total silt.VCS-very coarse sand (2mm -1mm); CS-coarse sand (1.0mm –0.5mm); MS-medium sand (0.5 -0.25mm); FS-fine sand (0.25 mm-0.1mm); VFS-very fine sand (0.1mm -0.05mm) pediments (P1) have silt content of 10.7 % to 18.5% with weighted mean of 16.2%. The weighted mean for clay is 7.4% (P1), 10.2% (P2) and 9.9% (P3) showing slight inflections with depth. The bulk density is 1.49 to 1.61 Mgm^{-3} as a growth limiting factor for many agricultural crops in the region (Veihmeyer and Hendrickson, 1948; Daddow and Warrington, 1983). These soils have low water holding capacity (6.4% (P1, P2) to 16.49% (P3)).

Chemical Properties

In accordance with Dellavalle (1992), the slightly alkaline Baniyon ka khera soil (P1) and moderately alkaline Sarano ka kheda (P2) are non-saline but saline in case of strongly alkaline Akola (P3) with EC of 1.2 to 1.6 dSm^{-1} (Table 3). These soils have low organic carbon (OC < 5g/kg), and less than 10g/kg calcium carbonate content in P1and P2. The Baniyon ka khera soil (P1) has low CEC (<5cmol/kg) but medium CEC in P2 and P3 with dominance of Ca on exchangeable complex (<5cmol/kg). These soils have medium content of exchangeable Mg (1.48 to 2.8 cmol/kg), high exchangeable Na (P3, Akola) and low exchangeable K levels (< 0.5 cmol/kg, Moore, 2001). The ratio of Ca^{2+} / K^{+} values exceeding the ideal ratio of 12:18 (Castro and Gomez, 2013) will certainly affect the availability of potassium. On the contrary, the ratio of Mg^{2+}/ Na^{+} is 15.4 in P1 to 5.81 in P2 and then to 1.65 in P3 with increasing pH. Among three soils, the Ca^{2+}/ Mg^{2+} less than 2 (SCCS, 2013) is reported in P2 (Weighted mean of 1.36) and P3 (weighted mean of 1.13) with its negative effect on availability of Ca to vegetables. These soils need Ca fertilization.

Elemental Composition

These soils are rich in SiO_2 (>70%) with slight changes in its content (Table 4) agrees with the earlier reports of Langley- turnbagh et al., (2005). The weighted mean of SiO2 is 71.5% in P1, 75.61 % in P2 and 71.54% in P3. It is observed that SiO_2 content in B horizon is low in P1 and P3 but increase of SiO_2 in soils on mid plains (P2). Next to SiO_2, Al_2O_3 is dominant with weighted mean of 13.1% (for P1) to 10.88% for P2. These soils have more than 3% of Fe_2O_3 with downward increase in B horizons (Table 4). The CaO, MgO and Na_2O contents are more than 1% whereas K_2O is more than 3.3% in P1 and P3 but more than 4% in P2.

Molar Ratios and Weathering Indices

The wide molar ratios of SiO_2/R_2O_3 (> 8.0), SiO_2/Al_2O_3 >10 and SiO_2/Fe_2O_3 >55 is in agreement as earlier reported in soils of Rajasthan (Choudhuri and Dhir,1981). Generally, it is observed that the downward decrease of molar ratios is strongly related with leaching index (> 0.7). The gradational increase of WIP in P2 from 29.84 to 33.46 is recorded but with slight variations in Richie product index and low CIA values (Table 4). In P1 and P3, CIA values are above 55 but low in B horizons. The low CIA between 45 to 55 indicates slight weathering (Price and Velbel, 2003) and mostly influenced by texture (Jingqing et al., 2012). The ternary A–CN–K diagram, displays preferential leaching of CaO and Na_2O and then K_2O (Fig.2) as plagioclase is more susceptible to weathering than potassium feldspar (Nesbitt and Young, 1982, 1989). The polynomial relations are worked out between CIA, WIP and PI and developed regression equations as given under:

WIP = $-0.049(CIA)^2 + 1.661(CIA)$ (coefficient of determination (R^2) = 0.684*, significant at 5% level)

The significant positive relation between CIA and product index (PI) shows that high correlation exists between the CIA and mean grain size (Jingqing et al., 2012), seemingly implies that these soils have high values of the PI (being ratio of SiO_2 to SiO_2+ R_2O_3) due to rich in silica.

CIA = $-0.171 (PI)^2 + 26.31(PI) - 955.3$ (R^2 = 0.778**, significant at 1% level)

PI = $0.108 (WIP)^2 - 5.943 (WIP) + 162.3$ (R^2 = 0.323*, significant at 5% level)

Mineralogical Compositions of Silt and Clay Fractions

The high feldspars and quartz in silt fraction with the mica over smectite and kaolinite (Table 5, Fig.3). High mica content was observed in silt fraction of upper pediments (P1, 31 to 47%) over mid plain (P2,

Table 3. Selected chemical properties of soils

Depth (cm)	Horizon	EC (dSm-1)	Organic carbon	$CaCO_3$	CEC	Exchangeable bases Ca	Mg	Na	K	ESP (%)	ExCa/ ExMg	/ExNa ExMg	ExCa/ ExK
			(g/kg)		cmol(p+)kg^{-1}								
P1. BaniyonKaKhera													
0-10	Ap	0.21	4.7	5.7	5.43	3.74	1.25	0.11	0.19	2.09	2.99	11.36	19.68
10-26	Bw1	0.1	3.2	9.5	5.56	3.92	1.31	0.15	0.06	2.7	2.99	8.73	65.33
26-46	Bw2	0.09	2.6	9.5	5.95	3.91	1.78	0.07	0.05	1.14	2.20	25.43	78.20
46-65	Bw3	0.09	3.4	10	5.63	3.65	1.66	0.14	0.06	2.43	2.20	11.86	60.83
65-80	C1	0.17	1.8	9.5	5.11	3.71	1.17	0.07	0.05	1.39	3.17	16.71	74.20
Weighted mean		0.12	3.02	9.14	5.57	3.79	1.48	0.11	0.07	1.92	2.64	15.47	63.44
P2: SaranoKaKheda													
0-18	Ap	0.59	1.5	5.7	7.15	3.72	2.23	0.74	0.11	10.3	1.67	3.01	33.82
18-50	A1	0.89	1.9	3.8	6.19	2.64	2.64	0.56	0.12	9.13	1.00	4.71	22.00
50-100	A2	0.57	1.5	4.3	7.38	4.21	2.1	0.62	0.14	8.4	2.00	3.39	30.07
100-140	A3	0.58	1.4	5.7	7.65	2.78	4.16	0.38	0.04	4.92	0.67	10.95	69.50
140-175	A4	0.53	0.9	6.6	7.29	3.69	2.68	0.46	0.06	6.12	1.38	5.83	61.50
Weighted mean		0.62	1.43	5.13	7.18	3.44	2.80	0.53	0.09	7.48	1.36	5.81	44.28
P3: Akola													
0-19	Ap	0.31	5.3	11.4	4.75	2.24	1.5	0.57	0.07	11.9	1.49	2.63	32.00
19-45	A	1.42	2.1	10	9.07	3.34	2.79	2.24	0.09	24.6	1.20	1.25	37.11
45-85	Bw1	1.56	1.7	12.5	6.94	2.61	2.26	1.5	0.06	21.6	1.15	1.51	43.50
85-125	Bw2	1.41	1.4	14.6	8.46	3.22	2.82	1.97	0.06	23.4	1.14	1.43	53.67
125-170	Bw3	1.21	1.1	12.7	7.01	2.47	2.64	1.5	0.06	21.4	0.94	1.76	41.17
Weighted mean		1.27	1.91	12.55	7.39	2.78	2.49	1.62	0.07	21.4	1.13	1.65	42.96

Note: EC=electrical conductivity, CEC=cation exchange capacity, ESP=exchangeable sodium per cent, ExCa=exchangeable calcium, EXMg= exchangeable Magnesium, EXK= exchangeable potassium, EXNa=exchangeable sodium

Table 4. Elemental composition, molar ratios and weathering indices of soils

Horizon	Depth	Elemental composition (%)							Molar ratios					Weathering indices		
	(cm)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Bases/ R_2O_3	Bases/ Al_2O_3	WIP	RPI	(CIA)
P1: Baniyon Ka Khera																
Ap	0-10	74.4	12.4	3.2	1.2	1.0	3.1	1.2	8.74	10.18	61.79	0.70	0.81	24.51	82.7	55.25
Bw1	10-26	73.8	12.8	3.1	1.3	1.1	3.2	1.1	8.47	9.78	63.27	0.71	0.81	25.00	82.3	55.12
Bw2	26-46	71.3	13.9	3.6	1.3	1.2	3.5	1.2	7.47	8.70	52.64	0.69	0.80	27.01	80.3	55.46
Bw3	46-65	72.5	13.1	3.5	1.4	1.1	3.6	1.3	8.02	9.39	55.05	0.74	0.87	27.88	81.4	53.55
C1	65-80	74.1	12.8	3.8	1.5	1.2	3.2	1.2	8.26	9.82	51.83	0.84	0.88	26.25	81.7	53.33
Weighted mean		72.99	13.10	3.46	1.35	1.13	3.36	1.20								
P2: Sarano Ka Kheda																
Ap	0-18	75.8	11.1	3.5	1.3	1.3	4.1	1.2	9.65	11.59	57.56	0.90	1.09	29.84	83.9	47.92
A1	18-50	78.2	8.9	3.1	1.2	1.4	4.2	1.3	12.2	14.91	67.06	1.14	1.39	30.74	86.7	41.77
A2	50-100	75.2	11.8	3.2	1.4	1.4	4.2	1.3	9.22	10.81	62.46	0.92	1.08	31.25	83.4	48.02
A3	100-140	75.1	11.2	3.5	1.2	1.2	4.5	1.4	9.49	11.38	57.03	0.92	1.11	31.93	83.6	47.47
A4	140-175+	74.5	10.9	3.5	1.6	1.4	4.6	1.5	9.63	11.60	56.57	1.03	1.24	33.46	83.8	43.95
Weighted mean		75.64	10.88	3.34	1.35	1.34	4.34	1.35								
P3: Akola																
Ap	0-19	74.5	12.8	3.7	1.5	0.9	3.8	1.4	8.34	9.88	53.51	0.75	0.89	28.89	81.8	52.85
A	19-45	72.2	13.4	3.8	1.6	0.8	3.7	1.5	7.74	9.14	50.50	0.72	0.85	28.91	80.7	54.02
Bw1	45-85	71.4	14.0	3.8	1.6	0.8	3.5	1.6	7.38	8.65	49.94	0.69	0.81	28.52	80.0	55.22
Bw2	85-125	70.4	14.2	4.1	1.8	0.9	3.6	1.6	7.10	8.41	45.64	0.72	0.85	29.73	79.3	54.04
Bw3	125-170	71.1	13.8	3.7	1.9	0.8	3.4	1.5	7.47	8.74	51.07	0.72	0.84	28.40	80.2	54.27
Weighted mean		71.54	13.77	3.83	1.72	0.83	3.56	1.53								

20-25%) and least in lower plains (P3, 23 to 25%). In clay fraction, the mica content is more than 30 % in P1 and P2 whereas soils on lower plains (P3) having high amounts of smectite (36 to 39%, (Table 5 and Fig.4). These soils have kaolinite next to mica and smectite with varying amounts of 11 (P1) to 22 % (P3). The talc and chlorites are in traces.

Pedogenic Assessment

The Three representative alluvial soils of Kothari river basin in Rajasthan were studied in relation to climate and topography. These soils display distinct changes in matrix colour from yellowish brown(P1) to dark brown/ gray (P2/P3) with respect to landscape as reported earlier in this region (Raj Kumar et al., 2005). The solum development is more prominent in soils on lower (P3) and middle plains (P2) as against the soils on upper pediments (P1). This observation is in agreement with the earlier reports of alluvial soils in Indo-Gangetic plains with respect to landscape position (Sidhu et al., 2000). The lithological discontinuities as evident from erratic distribution of total sand to silt in soils under study is in agreement and occurrence of such kind of soils in semi-arid tract of Purna valley were documented (Raja et al., 2018). These soils have silt/clay ratio above 0.45 indicating relatively young with high degree of weathering potential. Nwokocha et al., (2003) reported a decreasing silt/clay ratio with depth. It is further evident that high saturations with Na (>10%), and Mg (>30%) on exchangeable complex block the pore and create ionic imbalances (Castro and Gomez, 2013). This is reflected with low Ca^{2+}/Mg^{2+} less than 2 (SCCS, 2013) in P2 (Weighted mean of 1.36) and P3 (weighted mean of 1.13). The low ratio has a negative

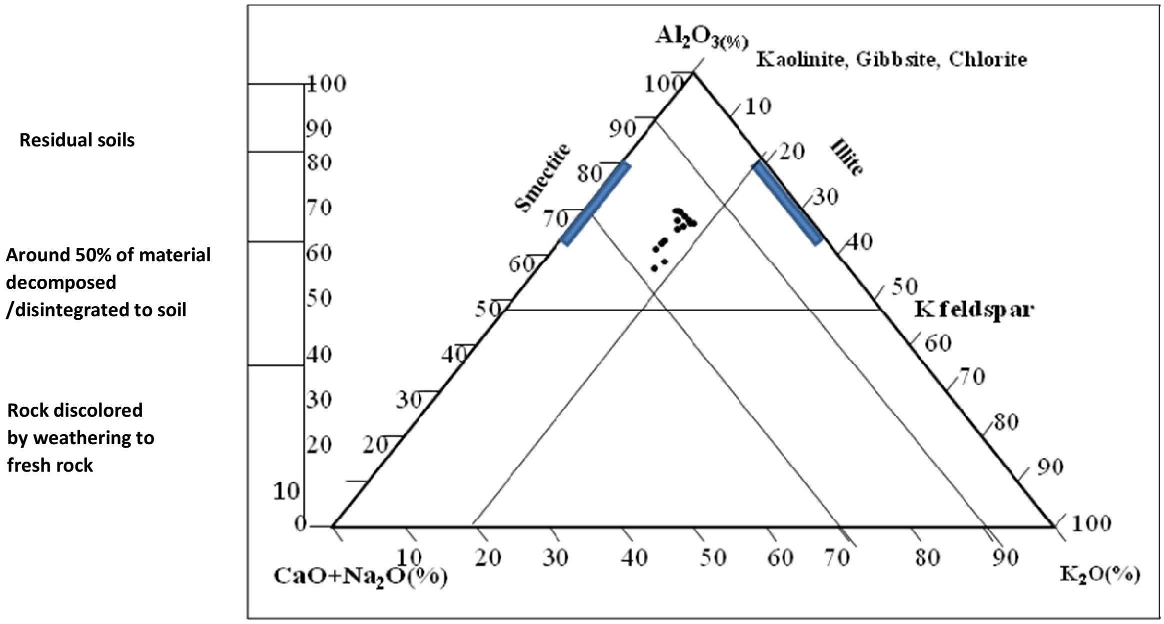

Fig. 2. A-CN-K diagram with chemical index of alteration and plagioclase K feldspar line.

Table 5. Semi-quantitative estimation of minerals in silt and clay fractions

Pedon	Silt fraction								Clay fraction							
	Minerals (%)															
	Smec-tite	Mica	Talc	Kaoli-nite	Quartz	Feld-spar	Chlo-rite	Vermi-culite	Smec-tite	Mica	Talc	Kaoli-nite	Quartz	Feld-spar	Chlo-rite	Vermi-culite
Baniyonka Khera (P1): Upper pediments (rainfall <600mm)																
Ap	9	47	tr	19	5	13	5	tr	14	32	10	20	tr	11	6	tr
Bw2	21	31	tr	21	5	8	tr	14	15	43	5	11	tr	8	tr	12
Sarano Ke Kheda (P2): Mid plain (rainfall of 600 to 700mm)																
Ap	18	25	-	24	9	18	5	tr	16	47	tr	20	8	-	5	tr
A3	20	20	-	15	15	21	8	nil	20	37	tr	15	6	7	8	6
Akola (P3)- Lower plain (mean annual rainfall of 700 - 800 mm)																
Ap	17	25	-	12	18	23	tr	tr	36	17	-	22	7	7	tr	8
Bw3	18	23	-	11	11	23	5	9	39	23	-	20	5	-	tr	9

effect on availability of Ca to vegetables crops. The ratios of sesquioxides are generally more than 3 (Sombroek and Zonneveld, 1971) and CIA values of 45 to 55 indicate slight weathering (Price and Velbel, 2003, McLennan, 2001; Abdou et al., 2007) with the relative proportion of mica-smectite suggests a dry and cold climate during deposition (Nesbitt and Young, 1982; Cai et al., 2008) and influence of texture in decreasing CIA values (Jingqing, *et al*., 2012). The A–CN–K diagram (Fig.2), shows a partial removal of the Ca- and Na-bearing silicate minerals and the K-bearing minerals remain less attacked with weak to moderate weathering under semi-arid sub-tropical climate with moisture index of -59.7 to -39.5. The bivariate plot between SiO_2 and Al_2O_3+K_2O+Na_2O (Fig.6a, Sutter and Dutta, 1986) for paleoclimatic inference during deposition is well recognized and used for constraining the climatic condition as semi-arid. Hence these soils are quartz rich to intermediate in bivariate plot of K_2O and Na_2O (Fig. 6b).

The presence of mica and smectite in P1 and P2 suggests a juvenile stage of weathering but in P3 increase of smectite and mica in Bw3 horizons was noticed. Mica (Table 5) in P1 and P2 is largely due to parent rocks and limited mechanical erosion (Fanning et al., 1989; Wilson, 1999). It is reported that the decrease of illite (P2) is due to an aeolian deposition (McFadden et al., 1986), and of physical weathering of biotite grains due to wide daily and seasonal fluctuations in temperature and moisture under semiarid climate (Boettinger & Southard, 1995). The large amounts of smectite in three soils is inherited or transformed from the parent material / mica during translocation and indicated that the minerals were not formed during the post-deposition period of the soil formation. Partly the smectite is originated by a process of neoformation under slightly (P1) to strongly alkaline conditions (Table 1) with high concentrations of Si, Mg and Al in Kothari basin (Table 4). The pedo-environment having high Mg^{++} and high Si mobility is congenial for the formation of smectite through transformation of illite under semiarid conditions (Pal and Deshpande 1987, Khomali and Abtahi, 2003, Emadi et al., 2008). The presence of kaolinite next to smectite in these soils indicates the existence of tropical climate in the region long years ago as stated by Brite and Armin (2007). The clay mineral formation and weathering patterns are in conformity with ternary diagram of A-CNK-FM (Fig.5). Clay minerals that plot closest to the residual field are smectites and illites with values of representing 75 to 85 but have poor Mg/Fe rich phyllosilicates under alkaline conditions of semi-arid climate.

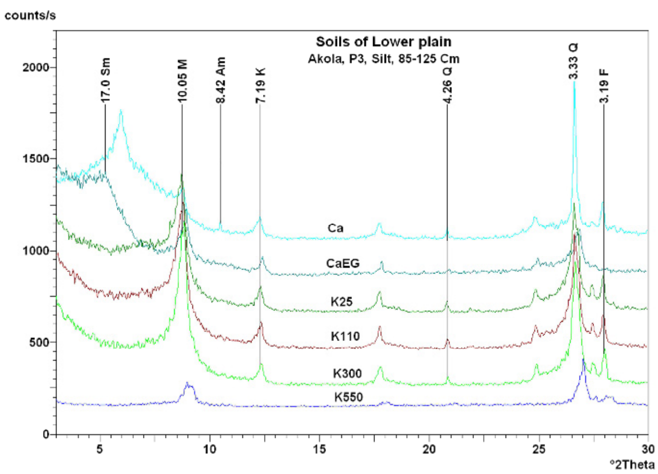

Fig.3. Representative XRD patterns of 2-50 mm silt fraction of the sub-surface horizon of Akola, soils of lower plain: Ca = Ca-saturated, K-25/110/ 300/550 = K saturation and room temperature (250C), K-saturation and heated to 110 0C, 300 0C and 550 0C; Sm = smectite, Ch = chlorite, V= vermiculite, M = mica, K= kaolin, Q = quartz, F = feldspar, Am = amphibole.

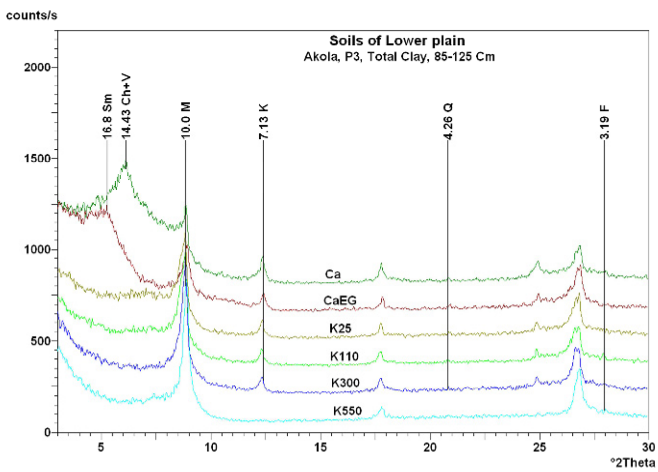

Fig. 4. Representative XRD patterns of <2mm clay fraction of the sub-surface horizon of Akola, soils of lower plain: Ca = Ca-saturated, K-25/110/ 300/550 = K saturation and room temperature (25 ^{0}C), K-saturation and heated to 110 ^{0}C, 300 ^{0}C and 550 ^{0}C; Sm = smectite, Ch = chlorite, V= vermiculite, M = mica, K= kaolin, Q = quartz, F = feldspar.

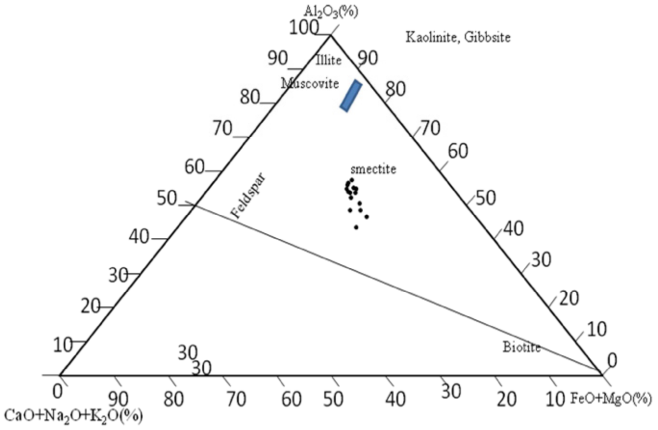

Fig.5. A-CNK-FM diagram to identify clay mineral association.

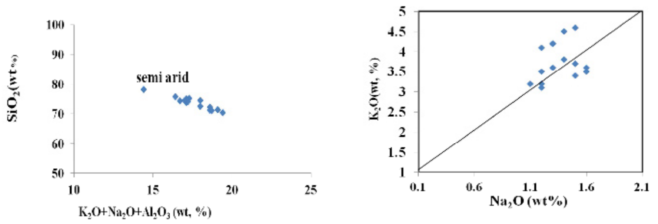

Fig.6. **(a)** Plot of SiO_2 (reflective of quartz content) versus $K_2O+Na_2O+Al_2O_3$ (reflective of feldspar content). **(b)** Plot of Na_2O versus K_2O of soils

CONCLUSIONS

The present study concludes that the alluvial soils of Kothari basin has distinct lithological discontinuities which is indicated by the variation in total sand and silt ratios. The silt to clay ratio, SiO_2 to sesiquioxide ratio, CIA, and weathering product index values of these soils suggest low to moderate weathering with limited lessivage under semi-arid conditions. Moreover, the ternary plot A-CN-K and A-CNK-FM diagram showed partial removal of Ca and Na bearing minerals and least attacked on K bearing minerals. It also suggests moderate weathering status in these soils. The study revealed that river alluvium is deposited under semi-arid conditions as reflected through bivariate plot of SiO_2 against total Al_2O_3+K_2O+Na_2O. However, clay mineralogical evidence showed the presence the mixture of kaolinite with smectite which indicates existence of tropical humid climate in the past.

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