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Characterization and Classification of Arid Soils of Kachchh district, Gujarat

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Abstract: Six representative pedons (P1, P2, P3, P4, P5, P6) from different landforms of Kachchh district, Gujarat were studied for their morphological, physical and chemical properties. The soils were moderately shallow to deep, well drained, slightly alkaline to strongly alkaline (pH 8.1 to 9.5), non-saline to slightly saline (0.12 to 3.76 dS m^{-1}), low to high in organic carbon (0.39 to 1.78%) $CaCO_3$ (2.1 to 26.1%), and low to medium in CEC [6.4 to 44.5 c mol (p+) kg^{-1}]. Soil texture varied from loamy sand to clay with clay content ranging from 10.9 to 40.4%. Bulk density varied from 1.30 to 1.62 Mg m^{-3} and generally, increased with depth. Saturated hydraulic conductivity, generally, decreased with depth, except in pedon P3. The pedons P1 and P2 with natric horizons, pH >8.5 and ESP >15 were classified as Typic Natrargids. The pedon P3 with an argillic horizon and ESP <15 was classified as Typic Haplargids. The pedons P4, P5, and P6 with cambic horizons and ESP >15 were classified as Sodic Haplocambids. Measures to reduce sub soil sodicity need to be implemented to sustain crop production in these soils.

Keywords : *Aridisols, arid climate, subsoil sodicity, pedogenic carbonate*

Introduction

The arid zone of India covers about 12% of the country's geographical area. A total of 32 million ha is hot arid and is spread over parts of Rajasthan (61%), Gujarat (20%), Andhra Pradesh and Karnataka (10%), and Punjab and Haryana (9%). The remaining 7 million ha is a cold arid zone situated in the Ladakh area of Jammu and Kashmir and the Lahul Spiti area of Himachal Pradesh (Kumar *et al*. 2009). In the arid regions of Rajasthan, Haryana, Punjab and eastern Gujarat, aeolian and alluvium are the major formations. These aeolian and alluvial parent materials are the quaternary formations. During the quaternary period, this region witnessed wide spread alluvial sedimentation (Dhir *et al*. 1994).

The heavy rainfall with storms of short duration results in high run-off and soil erosion in the arid regions. Protective vegetation cover is sparse and there is very little moisture for most parts of the year. Drought stress, high temperatures reaching up to 45°C for 8–10 weeks in a year, coupled with low biomass productivity are common features of dry agro-ecosystems (Dhir 1989). In these regions, cultivation is restricted in limited land, while, a large animal population depends on native vegetation. There are large tracts in north-western India and the interior Peninsula that experience arid conditions. Land degradation is further adding to the problems of the region, and are also responsible for the vulnerability of the communities apart from other factors (Gupta *et al.* 2000; Shyampura *et al.* 2002). Therefore, a detailed study of soil resources is a pre-requisite for developing sustainable management strategies. It is essential to generate sufficient soil data for their

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morphology, physical and chemical properties, to assess the potentials and limitations of arid soils.

Materials and Methods

Kachchh is the largest district of Gujarat, with an area of 45,652 km^2, comprising 23% of the state's total area. It lies in the extreme western part of the state. Kachchh district is situated between north latitudes 22°44'11" and 24°41'25" and east longitudes 68°09'46" and 71°54'47" and is bounded on the north and northwest by the Sindh Province of Pakistan and on the northeast by Rajasthan state. The southern boundary of the district is marked by the Gulf of Kachchh and towards west and southwest by the Arabian Sea (Central Ground Water Board 2013). Physiographically, the district is divided into central highland and upland in the Rann area, central plain in the southern part, little and great Rann areas, and the Banni plains. The geology of the study area in southern coastal plains mainly comprises of Tertiary sediments belonging to Eocene to Miocene and are of marine origin. They are mostly argillaceous and calcareous in nature (Central Ground Water Board 2013). The major field crops grown in the district are pearl millet, green gram, castor, groundnut, cotton, wheat and moth bean. Except wheat, all other crops are grown in *kharif*. Fruit crops including pomegranate and mango are also cultivated.

A detailed soil survey was carried out to study the soils as per the procedure outlined by AIS & LUS (1970). The horizon-wise morphological properties including depth, colour, structure, texture, gravels, consistence, and occurrence of nodules were described using soil description guidelines (Soil Survey Division Staff 2015). Six typical pedons, covering all the major landforms (Table 1) were selected for characterisation, and soil samples were collected from all the horizons from the selected pedons. Soil samples were air-dried and the fine fraction (2 mm) was used for the analysis of physical and chemical properties using standard procedures (Jackson 1973). The soils were classified as per Keys to Soil Taxonomy (Soil Survey Staff 2014).

Result and Discussion

Morphological characteristics

Pedons P1, P2 and P6 were deep with more than 100 cm depth, and the pedons P3 and P5 were moderately deep, while, P4 was moderately shallow (Table 2). The variation in the depth could be attributed to the variation in elevation of the different landforms, slope, topography and earlier geomorphic processes of arid regions. Soils with similar depth variation occur in various landforms of Kathiawar region of Gujarat (Sharma *et al*. 2001), in the arid regions of Chittorgarh district (Meena *et al*. 2009) and Bhilwara district, Rajasthan (Naitam *et al*. 2016).

The colour of the pedons P3 and P6 were brown (7.5YR4/4, 4/3, 3/3) to dark brown (7.5YR 4/3, 3/3, 3/2). The pedons P1 and P4 have colour varying from very dark gray to very dark grayish brown to dark brown to dark yellowish brown. The pedons P2 and P5 were brown to dark yellowish brown (10YR4/3, 4/4) to very dark grayish brown to dark brown (10YR3/2, 3/3) in colour. The pedons P1, P3 and P5 showed increase in brown colour (10YR 4/3) with depth as the value and chroma increased. The colour variation could be attributed to high iron and oxide content in non-hydrated forms in case of P3 and P6. The variation in the colour of surface and subsurface horizons appears to be the function of chemical and mineralogical composition of soils (Geetha Sireesha and Naidu 2013). The 10YR hue observed in the pedons P1, P2, P4 and P5 could be due to moderate weathering of basaltic parent material (Nayak *et al*. 2000). Similar soils occur in the arid plains of Rajasthan (Meena *et al*. 2009; Kumar *et al*. 2009; Gill *et al*. 2012). It is well established that the red colour of the soils occurring in tropical environments is due to desilication, leaching and illuviation (Bhattacharyya *et al*. 2000).

Soil texture varied from sandy loam (P1, P2, P3 and P4) to sandy clay loam (P5) to loamy sand (P6) in surface horizons and from sandy clay loam to sandy loam to clay (P5) in the sub-surface horizons. As observed in the present study, the coarse and coarse loamy soils are common in the arid region due to wind

Table 1. Site characteristics and land use of studied pedons

Pedon	Location	Landform	Elevation (m)	Slope (%)	Drainage	Run-off	Erosion	Present land use
P1	P1 22°51'28" N 69°22'14" E	Alluvial plain	10	0-1	well	slow	very slight	mango (21 years)
P2		Coastal plain	3	0-1	well	slow	very slight	mango (15 years)
P3		Pediment	45	1-3	well	medium	moderate	sorghum
P4		Upland	56	3-8	well	medium	moderate	cotton
P5		Pediment	17	3-8	well	medium	moderate	sorghum
P6		Coastal plain	10	0-1	well	very slow	very slight	cotton

erosion and aeolian activity (Naitam *et al*. 2016). Similarly, Kumar *et al*. (2009) found fine sand and loamy sand texture dominated soils in the arid plains of Churu District, Rajasthan and Naitam *et al*. (2016) found the occurrence of sandy soils in Bhilwara district. The texture varied widely with depth in P6 which could be due to lithological discontinuity and multiple parent material. Sidhu and Sharma (1990) also observed variation in texture with depth in the arid zone soils of Punjab.

The size of the structure varied from 0 to 2 and strength of the structure varied from moderate to fine to weak and the structure of the surface soils varied from sub-angular blocky (P1, P4 and P5) to granular (P2) to crumby (P3) to single grain (P6). The wide variation in the structure of the surface horizons is due to land use, organic matter content, and erosion in the arid regions. Similarly, Nayak *et al*. (2000) observed wide variation in the surface soil structure in the Bhal region of Gujarat.

Physical characteristics

The data of physical properties of the six pedons is presented in table 3. Sand content varied from 57.8 to 82.8% in surface horizons and from 32.9 to 83.9% in the sub-surface horizons. The sand content showed irregular distribution with depth in all the pedons. Silt content varied from 2.8 to 11.9% in surface horizons and from 2.1 to 26.7% in the subsurface horizons. The silt content also showed irregular trend with depth in the pedons, except in P4. Where, it increased with depth. Clay content varied from 10.9 to 30.3% in surface horizons and from 14.0 to 40.4% in the sub-surface horizons. The clay content of the sub-surface horizons was higher than the surface horizons in the pedons, except in P5 , where in, it decreased with depth.

Bulk density (BD) varied from 1.30 to 1.51 Mg m^{-3} in surface horizons and from 1.31 to 1.62 Mg m^{-3} in the sub-surface horizons. The BD, generally, increased with depth which may be due to higher clay content in the sub-surface horizons. The lower BD content of the surface layers of the pedons could be due to the higher OC content than the sub-surface layers. Similar to these findings, Kumar *et al*. (2009) reported an average bulk density of 1.43 Mg m^{-3} and its negative relationship with OC in the arid region soils of Rajasthan.

Saturated hydraulic conductivity (sHC) varied from 0.02 to 2.07 cm hr^{-1} in surface horizons and from 0.01 to 6.44 cm hr^{-1} in the sub-surface horizons. The sHC, generally, decreased with depth, except in P3, where in the surface horizon had lower sHC than the subsurface horizons. The decrease in sHC with depth is due to increase in ESP and clay content (Sharma *et al*. 2016).

Chemical characteristics

Soil reaction (pH) varied from 8.1 to 9.1 in surface horizons and from 8.1 to 9.5 in the sub-surface horizons (Table 4). The pH, generally, increased with depth which is due to higher exchangeable Na^+ in the sub-surface soils. Moreover, the higher pH in the sub-surface soils is due to higher pedogenic $CaCO_3$ content, which forms $NaHCO_3$ and increases the pH (Vasu *et al*. 2018). The pH >8.5 also indicated that, except P3, all the pedons were alkaline in nature (Table 4). This could be due to poor leaching of the Na^+ ions by the limited rainfall and arid climate conditions (Sandhu *et al*. 2017). Similarly, Sidhu and Sharma (1990) reported the occurrence of alkaline soils in the arid regions of Punjab. EC varied from 0.12 to 3.76 dS m^{-1} in surface horizons and from 0.12 to 1.54 dS m^{-1} in the sub-surface horizons. The EC, generally, increased with depth, except in P1 and P3, where in, the surface horizons had higher EC than their sub-surface horizons (Table 4). However, the soils were, generally, non-saline.

$CaCO_3$ varied from 2.8 to 11.5% in surface and from 2.1 to 26.1% in the sub-surface. Except P1, the $CaCO_3$ increased with depth. In P6, the middle horizon had less $CaCO_3$ content than the other horizons. The higher $CaCO_3$ content in the surface horizons of P1 and P6 may be due to precipitation of $CaCO_3$ due to arid climate after being carried upwards by the evapotranspiration process. Organic carbon (OC) varied from 0.39 to 1.35% in surface and from 0.21 to 1.78% in the subsurface. It, generally, decreased with depth, except in P4, where, it was slightly higher (1.15%) in the Bw horizon than the A horizon (1.13%). The highest OC content (1.78%) recorded in the bottom most horizon of

Table 2. Morphological characteristics of the studied pedons

Pedon	Depth (cm)	Horizon	Boundary	Munsell Colour (Moist)	Structure	Gravel (%)	Cutans	Plasticity	Roots	Effervescence
P1	0-9	Ap	g s	10YR 3/3	m 1 sbk	-	-	sp		violent
	9-23	Bw	g s	10YR 3/2	m 2 sbk	-	-	sp	f f	violent
	23-68	Bt1	c s	10YR 3/2	m 2 sbk	2.5	-	mp	-	strong
	68-105	Bt2	g s	10YR 3/2	m 2 sbk	2.5	-	mp	m c	strong
	105-122	Bt3		10YR 3/4	m 2 sbk	15	-	mp	m f	strong
P2										
	0-8	Ap	c s	10YR 4/3	f 0 gr	5		sp	f f	slight
	8-23	Bw	g s	10YR 3/3	m 1 cr	5		sp	-	slight
	23-57	Bt1	g s	10YR 3/2	m 2 sbk	-	tk p	mp	m c	strong
	57-89	Bt2	c w	10YR 3/2	m 2 sbk	-	tk p	mp	m c	violent
	89-123	Bt3		10YR 4/4	m 2 sbk	25		np	m f	violent
P3										
	0-12	Ap	c s	7.5YR 3/3	f 1 cr	-	-	sp	f m	slight
	12-34	Bw1	g s	7.5YR 3/2	m 1 sbk	-	-	sp	f c	slight
	34-57	Bt	c w	7.5YR 3/3	m 1 sbk	-	tn p	mp	vf f	violent
	57-95	Bw2		7.5YR 4/3	m 1 sbk	-		sp	-	violent
P4										
	0-17	Ap	c s	10YR 3/1	m 1 sbk	-	-	sp	f c	slight
	17-48	Bw1	a b	10YR 3/2	m 2 sbk	-	-	mp	f c	slight
	48-70	Bw2		10YR 3/3	m 2 sbk	5	-	mp	f f	violent
P5										
	0-16	Ap	c s	10YR 3/3	m 2 sbk		-	mp	f f	slight
	16-42	Bw1	g s	10YR 3/2	m 2 sbk		-	mp	vf f	strong
	42-78	Bw2	c w	10YR 3/2	m 2 sbk		-	mp	-	violent
	78-90	Bw3		10YR 4/4	massive		-	p	-	violent
P6										
	0-17	Ap	c s	7.5YR 4/3	f 0 sg	-	-	np	f f	violent
	17-44	Bw1	g s	7.5YR 3/3	m 2 sbk	-	-	sp	f c	violent
	44-73	Bw2	g s	7.5YR 3/3	m 2 sbk	-	-	sp	vf f	strong
	73-117	Bw3	c w	7.5YR 3/3	m 2 abk	-	-	mp	-	violent
	117-130	Bw4		7.5YR 4/4	f 1 cr	-	-	np	-	violent

Table 3. Physical characteristics of the studied pedons

Pedon	Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	Texture	BD (Mg m^{-3})	sHC (cm hr^{-1})
P1	0-9	Ap	78.2	7.5	14.3	Sandy loam	1.30	0.10
	9-23	Bw	83.1	2.8	14.2	Sandy loam	1.32	0.23
	23-68	Bt1	68.2	2.5	29.3	Sandy clay loam	1.38	0.06
	68-105	Bt2	73.1	2.8	24.1	Sandy clay loam	1.41	0.05
	105-122	Bt3	73.2	2.6	24.2	Sandy clay loam	1.42	0.05
P2	0-8	Ap	82.7	2.8	14.5	Sandy loam	1.35	1.28
	8-23	Bw	83.9	2.1	14.0	Sandy loam	1.39	0.43
	23-57	Bt1	68.2	2.8	29.0	Sandy clay loam	1.41	0.02
	57-89	Bt2	62.5	8.1	29.4	Sandy clay loam	1.42	0.02
	89-123	Bt3	77.8	2.8	19.4	Sandy loam	1.45	0.01
P3	0-12	Ap	77.6	3.0	19.4	Sandy loam	1.40	2.07
	12-34	Bw1	78.1	2.8	19.1	Sandy loam	1.52	6.44
	34-57	Bt	72.5	3.1	24.4	Sandy clay loam	1.54	3.4
	57-95	Bw2	72.8	7.5	19.7	Sandy loam	1.55	2.8
P4	0-17	Ap	77.8	3.2	19.0	Sandy loam	1.32	0.02
	17-48	Bw1	67.8	11.3	20.9	Sandy clay loam	1.31	0.01
	48-70	Bw2	68.1	11.8	20.1	Sandy clay loam	1.45	0.01
P5	0-16	Ap	57.8	11.9	30.3	Sandy clay loam	1.51	0.51
	16-42	Bw1	57.9	16.4	25.7	Sandy clay loam	1.53	0.18
	42-78	Bw2	60.2	11.8	28.0	Sandy clay loam	1.55	0.05
	78-90	Bw3	32.9	26.7	40.4	Clay	1.55	0.05
P6	0-17	Ap	82.8	6.1	10.9	Loamy sand	1.45	1.71
	17-44	Bw1	77.0	6.8	16.2	Sandy loam	1.47	0.15
	44-73	Bw2	72.5	12.1	15.4	Sandy loam	1.5	0.03
	73-117	Bw3	74.2	4.6	21.2	Sandy clay loam	1.55	0.03
	117-130	Bw4	79.2	4.3	16.5	Sandy loam	1.62	0.09

P2 may be due to marine deposits with high organic matter in the coastal plain region during the earlier climate and also, partly, due to active roots of mango plantations. The low to medium OC content of the pedons may be due to rapid OM decomposition under arid conditions and less biomass addition (Sidhu and Sharma 1990; Bhattacharyya *et al*. 2000).

The exchangeable cations were in the order of $Na^{+}> Ca^{2+}> Mg^{2+} >K^{+}$. Similar observations were made by Gill *et al*. (2012) in the soils of Udaipur district. Exchangeable Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} varied from 1.01 to 1.92, 0.38 to 1.24, 0.50 to 17.75 and 0.32 to 0.97 cmol p+ kg^{-1}, respectively, in surface horizons. In the sub-surface horizons, the bases varied from 0.89 to 2.38, 0.33 to 1.52, 0.77 to 19.06 and 0.18 to 0.83 cmol p+ kg^{-1} in the same order.

Base saturation (BS) varied from 17.8 to 100% in surface and from 15.6 to 100% in the sub-surface. BS of P1 was high in the surface and low to moderate in the sub-surface horizons. It was low in the surface and increased with depth in P2. In P3, it was very low and did not vary much with depth. It was high in P4 and moderate in P5 and P6 with irregular depth distribution. The low to moderate BS of the pedons could be attributed to the development of these soils from granite, sandstone and limestone dominated parent materials and pre-dominantly coarse soil texture as sandy loam and sandy clay loam were the common texture of the pedons.

The cation exchange capacity (CEC) varied from 7.2 to 37.2 cmol (p^{+}) kg^{-1} in surface and from 6.4 to 44.5 cmol (p^{+}) kg^{-1} in the sub-surface. The low to moderate CEC of the pedons may be due to the coarse texture, sandy nature of the parent material, and low activity clay (Yadav *et al*. 2005; Meena *et al*. 2009). The significant positive relationship between CEC and clay content (r=0.707; p=0. 5) confirms the above fact. Further, surface soil texture may influence the CEC of the surface horizons due to aeolian activity in the arid regions. In this study also, the CEC of the surface layers is significantly influenced by the clay content (r=0.995; p=0. 1). The ESP varied from 4.1 to 95.4 and from 3.5 to 99.7 in surface and sub-surface horizons, respectively. Except P3, all the pedons had high ESP, indicating alkalinity. Many earlier studies in the western arid region recorded high ESP in the subsurface soils (Naitam *et al*. 2016; Sandhu *et al*. 2017).

Soil classification

The study area belongs to aridic soil moisture regime, and the soils have an ochric or anthropic surface horizons, and cambic, argillic, and natric horizons in the subsurface. Therefore, the soils were classified as Aridisols at order level. The pedons P1 and P2 have natric horizons with pH >8.5 and ESP >15, and they were classified as Fine-loamy, mixed, hyperthermic typic natrargids and coarse-loamy, mixed, hyperthermic typic natrargids, respectively. The pedons P3 with an argillic horizon and ESP <15 was classified as coarse-loamy, mixed, hyperthermic typic haplargids. The pedons P4 and P5 with cambic horizons and ESP >15 were classified as fine-loamy, mixed, hyperthermic sodic haplocambids and pedon P6 was classified as fine-loamy, kaolinitic, hyperthermic sodic haplocambids.

Conclusion

Six pedons from the arid region of Gujarat were characterised for their morphological, physical, and chemical properties. The great variation in depth of the soils indicate that the soil formation was influenced by variation in elevation of the different landforms, slope, and earlier geomorphic processes of arid regions. The coarse-loamy texture of the soils indicates that erosion and aeolian activity were the common processes in the study area. Suitable management measures need to be implemented to alleviate the effects of subsoil sodicity and sustain crop production in these sodic soils.

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Table 4. Chemical characteristics of the studied pedons

Pedon	Depth (cm)	Horizon	pH	EC ($dS\ m^{-1}$)	$CaCO_3$ (%)	OC (%)	Exch. Ca	Exch. Mg	Exch. Na	Exch. K	CEC	BS (%)	ESP
							c mol p^+ kg^{-1} soil						
P1	0-9	Ap	9.1	1.15	11.5	1.35	1.17	0.72	7.72	0.39	12.1	82.4	63.8
	9-23	Bw	9.2	0.65	12.0	0.71	0.89	0.50	3.00	0.26	12.9	35.8	23.3
	23-68	Bt1	8.9	0.93	4.5	0.55	1.41	1.01	8.87	0.51	21.8	54.0	40.7
	68-105	Bt2	9.1	0.82	5.1	0.35	1.07	0.70	8.22	0.47	18.6	56.2	44.2
	105-122	Bt3	9.1	0.81	6.9	0.28	1.63	0.97	8.38	0.51	20.2	56.8	41.5
P2	0-8	Ap	8.7	0.22	7.6	1.01	1.33	0.69	0.93	0.43	12.9	26.1	7.2
	8-23	Bw	9.0	0.26	8.2	0.82	1.27	0.66	1.70	0.57	11.3	37.0	15.0
	23-57	Bt1	9.4	0.88	5.1	0.71	1.68	1.12	16.76	0.59	29.1	69.1	57.6
	57-89	Bt2	9.1	1.43	7.1	0.59	1.71	1.02	18.08	0.53	29.9	71.2	60.5
	89-123	Bt3	9.3	1.03	17.2	1.78	1.41	0.68	8.55	0.32	16.2	67.6	52.8
P3	0-12	Ap	8.1	0.12	2.8	0.74	1.92	0.38	0.87	0.59	21.0	17.8	4.1
	12-34	Bw1	8.1	0.12	3.1	0.66	1.80	0.33	0.77	0.51	21.8	15.6	3.5
	34-57	Bt	8.3	0.15	17.2	0.62	1.99	0.33	0.97	0.51	21.8	17.3	4.4
	57-95	Bw2	8.5	0.21	26.1	0.39	2.10	0.39	0.77	0.28	17.8	19.8	4.3
P4	0-17	Ap	8.6	3.76	3.0	1.13	1.69	0.69	17.75	0.53	18.6	110.9	95.4
	17-48	Bw1	9.1	1.54	2.4	1.15	1.31	0.51	19.06	0.61	24.2	88.5	78.8
	48-70	Bw2	9.4	1.21	26.1	0.47	1.48	0.36	14.46	0.36	14.5	114.3	99.7
P5	0-16	Ap	8.8	0.44	2.9	0.39	2.39	1.24	7.89	0.97	37.2	33.5	21.2
	16-42	Bw1	9.0	0.52	2.2	0.33	2.38	1.32	14.13	0.81	38.8	47.9	36.4
	42-78	Bw2	8.7	1.30	2.1	0.25	2.30	1.52	16.76	0.83	44.5	48.1	37.7
	78-90	Bw3	9.2	1.11	7.3	0.19	1.64	1.02	14.13	0.39	22.6	75.8	62.5
P6	0-17	Ap	8.5	0.16	10.6	0.62	1.01	0.45	0.50	0.32	7.2	31.2	6.9
	17-44	Bw1	9.4	0.38	10.2	0.37	1.02	0.54	2.23	0.36	10.5	39.4	21.2
	44-73	Bw2	9.3	0.51	3.0	0.33	1.03	0.79	8.87	0.53	13.7	81.6	64.7
	73-117	Bw3	9.4	0.81	12.0	0.29	1.21	0.33	9.20	0.43	15.3	72.7	60.1
	117-130	Bw4	9.5	0.78	23.9	0.21	1.06	0.61	2.93	0.18	6.4	73.8	45.8

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