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Characterization and Classification of Soils of Valsad taluka, Valsad District, Gujarat

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Abstract: Five representative pedons (P1 Umarsadi; P2 Segvi; P3 Chikla; P4 Bagal; and P5 Faldhara) from different landforms of Valsad taluka in the coastal region of Valsad district, Gujarat were studied for their morphological, physical, and chemical properties. The soils were deep to very deep, well to imperfectly drained, slightly alkaline to strongly alkaline (pH 7.8 to 9.7), non-saline to saline (0.1 to 4.4 dS m^{-1}), low to high in organic carbon (2.4 to 12.3 g kg^{-1}) and $CaCO_3$ (0.2 to 19.5%), and medium to high in CEC [21.8 to 69.9 (p+) kg^{-1}]. Soil texture varied from sandy clay loam to clay with clay content ranging from 21.2 to 53.5%. Bulk density was lower in P5 (1.28-1.33 Mg m^{-3}) than the other pedons (1.21-1.48 Mg m^{-3}). Saturated hydraulic conductivity (sHC) was less than the critical limit of 1.0 cm hr^{-1} in P3, and generally low due to high (>15) exchangeable sodium percentage (ESP) and exchangeable magnesium percentage (EMP). Pedon P1 was classified as *Sodic Haplusterts* and P4 as *Typic Haplusterts*. The pedon P2 with an argillic horizon (<35 cm thickness) in the deeper layers was classified as *Inceptic Haplustalfs.* The pedon P3 with lithological discontinuity was classified as *Typic Ustifluvents* and P5 *as Vertic Haplustalfs*. The pedons P1, P3 and P4 were developed in the basaltic alluvial parent material, and their sub-surface properties were influenced by the paleosols. The pedons P1, P2, and P5 under perennial crops such as mango and eucalyptus have higher organic carbon and lower bulk density. Management measures are required to reduce subsoil sodicity, and sustain crop production in the heavy textured soils.

Key words*:* *Coastal soils, salinity, sodicity, Vertisols, Inceptisols, Alfisols*

Introduction

India supports 17.5% of the world's population only with 2.4% of the geographical area and 9% arable lands. The demand for food, fuel, and energy has increased manifold, and the growing population need to be fed with shrinking and deteriorating land and water resources (Sarkar *et al*. 2009). Being integral to all functions of terrestrial ecosystems, soils are intended to produce food for the ever-increasing global population. The ability of the soils to support, and sustain biomass production is dependent on inherent soil characteristics, and management practices (Bouma 1989, Paustian *et al*. 2016). Therefore, a detailed study of soil resources is a pre-requisite for developing sustainable management strategies. It is essential to generate sufficient soil data

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concerning their morphology, physical and chemical properties, to characterise the soils and assess their potentials and limitations.

With the longest share of the Indian coastline, the coastline of Gujarat runs for a distance of about 1214.7 km. The coastal districts cover about 68% area of the state (Nayak 2017). Valsad is one of the coastal districts where rice, sugarcane, mango, and sapota are the major cultivated crops. Valsad taluka in Valsad district comprises many landforms which are continuously influenced by the geomorphic processes such as erosion, sediment transport and deposition as well as sea-level changes (Nayak *et al*. 2010). The detailed soil information of Valsad district is limited (Sharma *et al*. 2006). Therefore, the present study as a part of the Land Resource Inventory programme (at 1;10000 scale) of the ICAR-NBSS&LUP, was carried out for a comprehensive characterisation of soils of Valsad taluka, Valsad district, Gujarat in order to generate more pertinent soil information for better agricultural land use plans.

Materials and Methods

Valsad taluka lies between 20° 17' 30" and 20° 35' 18"N latitudes and 72° 48' 10" and 73° 07' 51" E longitudes at an elevation ranging from 5 to 51 m msl (Table 1). It falls under agro ecological sub-region 5.3 (Mandal *et al*. 2014) and characterized by *ustic* soil moisture and *hyperthermic* soil temperature regimes (Soil Survey Staff 2003). Typically, the summer period is from April to June when temperature ranges from a maximum of 38°C to a minimum of 27°C. During winter (December to February), the maximum temperature is around 28°C and the minimum temperature is 12°C. The average annual rainfall is around 2100 mm most of which occurs during the southwest monsoon (July–September).

Natural vegetation comprises of acacia (*Acacia nilotica*); ber (*Zizipus jujuba*), palas (*Butea monosperma*), datura (*Datura stramonium*), teak (*Tectona grandis*), bamboo (*Dendrocalamus calostachyus*), prosopis (*Prosopis juliflora*) and tamarind (*Tamarindus indica*). The major cultivated crops are perennial fruit crops such as mango, sapota, and rice. Geographically, Valsad taluka belongs to the western coastlands of the Deccan Peninsula. Major geological formations are the Quaternary alluvium, sandstone, limestone and Deccan trap basalt (Central Ground Water Board 2013). The major landforms are pediment, plateau, coastal plain, and alluvial plain.

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). Five 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 (Bhattacharyya *et al.* 2009). The soils were classified as per Keys to Soil Taxonomy (Soil Survey Staff 2014).

Results and Discussion

Morphological characteristics

Morphological characteristics of the soils are presented in table 2. The soils were deep to very deep and appeared to be mass depositions of basaltic alluvium over the paleosols (Nayak *et al*. 2000). The drainage varied from well-drained (Segvi, Bagal and Faldhara) to moderately well-drained (Umarsadi) to imperfectly drained (Chikla). The imperfect to moderate soil drainage could be attributed to landform characteristics such as lower elevation and soil properties such as high soil content and poor hydraulic conductivity (Rao *et al*. 2004; Chinchmalatpure *et al*. 2005).

With respect to colour (moist), the hue varied from 10YR to 7.5YR, value 3 to 5 and chroma 2 to 6. The Umarsadi pedon was dark brown (10YR3/3) at the surface and dark grayish brown (10YR3/3) to dark brown (10YR3/3) in the sub-surface. The Segvi pedon

Table 1. Landscape characteristics of pedons in Valsad taluka, Valsad district, Gujarat

Pedon, Village	Location	Landform	Elevation above mean sea level (m)	Slope (%)	Drainage	Parent material	Land use
P1, Umarsadi	20°32'03" N 72°59'41" E	Pediment	42	1-3	Moderately well drained	Basaltic alluvium	Eucalyptus
P2, Segvi	20°31'40" N 72°58'09" E	Plateau	51	1-3	Well drained	Granite-gneiss	Mango
P3, Chikla	20°33'30" N 72°53'55" E	Coastal flood plain	5	0-1	Imperfectly drained	Flood alluvium	Rice
P4, Bagal	20°31'25" N 72°50'30" E	Alluvial plain	33	1-3	Well drained	Basaltic alluvium	Cotton
P5, Faldhara	20°27'33" N 73°05'59" E	Plateau	55	3-8	Well drained	Red bole granite	Mango

was dark brown (7.5YR3/2) at the surface and brown (7.5YR4/4) to strong brown (7.5YR4/6, 7.5YR5/6) in the sub-surface. In Chikla pedon, discontinuity in the hue was observed, and abrupt change in colour was evident in the sub-surface layers. The surface was brown (10YR4/3) in colour whereas it varied from dark yellowish brown (10YR4/4) to strong brown (7.5YR5/6) in the sub-surface. The Faldhara pedon was brown (7.5YR4/3) in the surface and strong brown in the sub-surface. The increased redness in soils of Segvi and Faldhara indicates that they were base leached under humid climate. Similarly, Nayak *et al*. (2000) observed dark brown surface and reddish yellow sub-surface soils in the Bhal region of Gujarat. The increase in the values of chroma and value with depth indicates the increase in brown and yellow colour with depth. Though the parent material is generally the basaltic alluvium for most of the soils, marine sediments and depositions by rivers from various sources could be the reason for the colour variation in substratum in the study area (Nayak *et al*. 2000; Bhandari *et al*. 2005).

Soil texture varied from sandy clay loam to clay in both surface and sub-surface horizons. Similar to this study, clay to clay loam soils in the coastal regions were characterized and reported earlier (Nayak *et al.* 2000; Chinchmalatpure *et al*. 2008). The heavy texture is due to the clay rich basaltic parent material. The structure of the pedons varied from moderate to strong, angular blocky in (single grain in Chikla pedon) and angular blocky to sub-angular blocky in the sub-surface. The sub-surface horizons of Umarsadi and Bagal pedons have well-developed slicken-sides of varying thickness (29-60 cm), with mostly angular blocky structure. Strong coarse angular blocky structure in the sub-surface horizons with slicken-sides is common in the coastal regions of western India (Chinchmalatpure *et al*. 2008). These researchers reported the occurrence of Vertisols with large slicken-sides and 1-2 cm wide cracks upto 100 cm in Samni farm, Bharuch. The Chikla pedon under rice cultivation exhibited a single grain structure in its surface horizon due to clay dispersion caused by sodicity.

The pedons of Umarsadi and Bagal were firm (moist), very sticky and very plastic (wet) in consistence. The Segvi pedon was friable at surface and firm in the sub-surface, sticky and plastic and has thick, broken lime nodules in sub-surface horizons, which violently effervescence with HCl. The Chikla pedon was loose at the surface and from friable to firm in the sub-surface in moist consistence whereas the wet consistence varied widely (Table 2). In Faldhara pedon, surface cracks >1 cm wide which extended to 40 cm depth were observed; similar observations were made earlier in Vertisols in coastal Gujarat region (Nayak *et al*. 2000, Chinchmalatpure *et al*. 2008; Kumar *et al*. 2017).

Physical characteristics

The particle size data indicates that sand content varied from 25.8 to 65.4% in surface horizons and from 20.8 to 68.7% in the sub-surface horizons (Table 3). The silt content varied widely, ranging from 1.4 to 32.6% in surface and from 6.2 to 37.1% in the sub-surface. The clay content varied from 33.1 to 41.6% in surface and from 23.2 to 53.5% in the sub-surface. The high clay content could be attributed to clay rich basaltic alluvium. Clay rich Vertisols (~60% clay content) in coastal districts of Gujarat is common (Chinchmalatpure *et al.* 2008; 2014b).

The irregularly distributed sand content with depth in Chikla pedon could be attributed to earlier cyclic deposition episodes of basaltic alluvium with varying particle size materials and sedimentation velocity (Agarwal *et al*. 1996). A similar irregular pattern of sand distribution with depth was reported by Patel *et al.* (2017) in the Bhal region of Gujarat. The nearly uniform clay content up to a depth of 83 cm in the Segvi pedon indicates that the pedon was formed by deposition of clay-rich basaltic alluvium. Chinchmalatpure *et al*. (2014a) also indicated a similar depth distribution of clay in the coastal soils. However, the clay increase from 35.1 to 43.8% in the Segvi pedon indicates the clay illuviation process and formation of an argillic (Bt) horizon. In Faldhara pedon, occurrence of the Bt horizon

Table 2. Morphological characteristics of the soils of Valsad taluka, Valsad district

Pedon	Depth (cm)	Boundary[1]		Munsell Colour	Texture[2]	Structure[3] S G T	Consistency[4]		Roots[5]		Effervescence[6]	Other features[7]
		C	T				Moist	Wet	S	Q		
Pedon1 (Umarsadi)												
A	0-18	c	s	10YR3/3	c	m 2 sbk	fi	vs vp	m	m	slight	-
Bw1	18-43	g	s	10YR3/2	c	m 2 sbk	fi	vs vp	m	c	slight	pf
Bss1	43-74	g	s	10YR3/2	c	m 2 abk	fi	vs vp	f	f	slight	ss
Bss2	74-97	g	s	10YR3/3	c	m 2 abk	fi	vs vp	vf	f	slight	ss
Bw2	97-152	-	-	10YR3/3	c	m 2 sbk	fi	vs vp			slight	-
Pedon 2 (Segvi)												
Ap	0-15	c	s	7.5YR3/2	cl	m 2 sbk	fr	s p	c	c	violent	-
Bw1	15-44	c	s	7.5YR3/2	cl	m 2 sbk	fi	s p	m	c	violent	-
Bw2	44-83	c	s	7.5YR4/4	cl	m 3 sbk	fi	s p	f	m	violent	ct
Bt1	83-112	g	s	7.5YR4/6	c	m 3sbk	fi	s p	f	c	violent	ct
Bt2	112-135	-	-	7.5YR5/6	c	m 2sbk	fi	s p	f	f	violent	-
Pedon 3 (Chikla)												
Ap	0-9	c	s	10YR4/3	scl	sg	l	ssps	f	m	slight	-
Bw1	9-34	a	s	10YR4/3	cl	m 2sbk	fr	ssps	f	m	strong	-
Bw2	34-52	c	s	10YR4/4	c	m 2sbk	fi	s p	-	-	violent	-
2C1	52-81	a	w	10YR5/2	scl	m 1sbk	fr	sssp	-	-	violent	round pebbles
3C2	81-91	c	s	7.5YR5/3	scl	m 1sbk	fr	ns np	-	-	strong	-
4C1	91-98	a	w	7.5YR5/3	scl	m 1 sbk	fr	sssp			violent	-
4C2	98-150	-	-	10YR5/4	scl	m 2sbk	fr	sssp			violent	-
Pedon 4 (Bagal)												
Ap	0-16	c	s	10YR3/3	c	m 1sbk	fr	vs vp	f	c	-	-
Bw1	16-45	g	s	10YR3/3	c	m 2 sbk	fi	vs vp	f	f	-	pf
Bss1	45-70	g	s	10YR3/2	c	m 2 abk	fi	vs vp	vf	f	-	ss
Bw2	70-105	g	s	10YR3/2	c	m 2 abk	fi	vs vp	-	-	-	pf
Bw3	105-132	-	-	10YR4/3	c	m 2sbk	fi	vs vp	-	-	-	-
Pedon 5 (Faldhara)												
Ap	0-20	c	s	7.5YR4/3	scl	m 2 sbk	fr	ssps	f	m	slight	-
Bt1	20-50	g	s	7.5YR3/2	sc	m 2 sbk	fi	s p	f	c	strong	-
Bt2	50-81	g	s	7.5YR4/6	sc	m 2 sbk	fi	s p	vf	f	strong	ct
Bt3	81-105	g	s	7.5YR4/6	c	m 2 sbk	fi	s p	-	-	strong	-

[1]Boundary: D - Distinctness g = gradual, c = clear; T – Topography s = smooth; w = wavy
[2]Texture: c = clay, sc = sandy clay, cl = clay loam; scl = sandy clay loam
[3]Structure:(Size: c = coarse, m = medium); (Grade: 1 = weak, 2 = moderate, 3 = strong): (Type: abk = angular blocky, sbk = subangular blocky, sg = single grain)
[4]Consistence: Moist: fr = friable, fi = firm, vfi = very firm; Wet: s = sticky, vs – very sticky; p – plastic, vp – very plastic
[5]Roots: (Size: vf = very fine, f = fine, m = medium, c = course); (Quantity: f = few, c = common, m = many)
[6]Reaction to diluted HCl
[7]Othe features: pf = pressure face; ss = slickenside; ct = cutans

Table 3. Physical characteristics of the soils of Valsad taluka, Valsad district

Pedon No. and Horizon	Depth (cm)	Sand (0.05-2.0 mm)	Silt (0.002-0.05 mm)	Clay (<0.002 mm)	Bulk density (Mg m^{-3})	Saturated hydraulic conductivity (cm hr^{-1})
		(%)	(%)	(%)		
Pedon 1 (Umarsadi)						
A	0-18	25.8	32.6	41.6	1.34	1.7
Bw1	18-43	20.8	37.1	42.1	1.32	1.6
Bss1	43-74	25.8	28.2	46.0	1.36	0.8
Bss2	74-97	20.8	32.6	46.6	1.33	1.0
Bw2	97-152	30.8	22.8	46.4	1.34	0.7
Pedon 2 (Segvi)						
Ap	0-15	35.8	29.1	35.1	1.33	7.4
Bw1	15-44	31.8	32.6	35.6	1.30	7.2
Bw2	44-83	43.4	21.5	35.1	1.32	11.2
Bt1	83-112	38.4	17.8	43.8	1.31	15.7
Bt2	112-135	38.4	18.0	43.6	1.31	11.7
Pedon 3 (Chikla)						
Ap	0-9	48.4	18.5	33.1	1.21	0.1
Bw1	9-34	38.4	22.8	38.8	1.48	0.1
Bw2	34-52	33.4	21.7	44.9	1.32	0.1
2C1	52-81	68.7	2.5	28.8	-	0.1
3C2	81-91	48.7	27.8	23.5	-	0.1
4C1	91-98	70.2	6.6	23.2	-	0.1
4C2	98-150	70.2	6.4	23.4	-	1.1
Pedon 4 (Bagal)						
Ap	0-16	44.4	14.4	41.2	1.34	15.0
Bw1	16-45	42.4	16.4	41.2	1.36	6.4
Bss1	45-70	37.4	16.4	46.2	1.31	2.5
Bw2	70-105	37.4	16.4	46.2	1.32	2.3
Bw3	105-132	42.4	6.4	51.2	1.30	1.7
Pedon 5 (Faldhara)						
Ap	0-20	65.4	1.4	33.2	1.28	1.1
Bt1	20-50	45.2	11.4	43.4	1.31	10.3
Bt2	50-81	50.7	6.2	43.1	1.33	13.2
Bt3	81-105	40.2	6.3	53.5	1.30	9.0

immediately beneath the surface horizon suggests clay illuviation process, which is more important pedogenic process than argilli-turbation (Pal *et al*. 2012).

Bulk density (BD) varied from 1.21 to 1.34 Mg m^{-3} in surface horizons and from 1.31 to 1.43 Mg m^{-3} in sub-surface horizons. The BD was lower in Faldhara pedon (1.28-1.33 Mg m^{-3}) than the other pedons due to addition of organic matter through long-term plantation. Saturated hydraulic conductivity (sHC) varied from 0.1 to 15.0 cm hr^{-1} in surface horizons and from 0.1 to 15.7 cm hr^{-1} in the subsurface horizons. The sHC of Chikla pedon was lower than the critical limit of 1 cm h^{-1} (Pal *et al*. 2012), which was also observed in coastal Gujarat and was attributed to high soil ESP, SAR, and exchangeable cations present in the groundwater (Chinchmalatpure *et al.* 2014a).

Chemical characteristics

The soil reaction varied from slightly alkaline to strongly alkaline, and the pH generally increased with depth. The Umarsadi pedon was alkaline (8.2-8.7) in the sub-surface horizons (Table 4). The Chikla pedon was strongly alkaline with pH >9.0 in its sub-surface horizons. The high pH could be attributed to high ESP of these soils, and its origin may be multiple sources such as parent materials with Na-bearing minerals, groundwater, and sea-water intrusion in the coastal areas. Similar to the present study, Patel *et al*. (2017) recorded high pH in clay soils with high Na^{+} in their exchange complex. Moreover, slightly alkaline to alkaline soils in the coastal region of south Gujarat were reported by Chinchmalatpure *et al*. (2014a) indicating the wide occurrence of sodic soils in the study area. The comparatively low pH of Faldhara pedon than other pedons may be due to the influence of *Eucalyptus* plantations which reduces the pH in the surface layers due to organic matter decomposition (Datta *et al*. 2017).

Electrical conductivity (EC) varied from 0.2 to 4.4 dS m^{-1} in surface horizons and from 0.1 to 1.1 dS m^{-1} in the sub-surface horizons (Table 4). The EC of Chikla pedon in its surface was higher than 4 dS m^{-1} indicating saline soils, and it may be due to the tidal deposits of salts and further accumulation caused by the high evapotranspiration in the summer period under semi-arid conditions (Nayak *et al.* 2000; Pal *et al.* 2012). Similarly, Chinchmalatpure *et al*. (2014a) observed high surface salinity (ECe 70-132 dS m^{-1}) in the coastal soils of southern Gujarat. Similarly, Rao *et al*. (2004) showed the occurrence of highly saline soils (EC 25-65 dS m^{-1}) due to shallow groundwater in Anand district of Gujarat.

The free $CaCO_3$ content varied from 0.8 to 18.5% in surface and from 0.2 to 19.5% in the sub-surface. The $CaCO_3$ content was more than 15% in the control section of Segvi pedon (Table 4). The higher $CaCO_3$ content may be due to the formation of pedogenic carbonate facilitated by the semi-arid climate and calcium-rich parent material (Pal *et al*. 2012; Vasu *et al*. 2018). Chinchmalatpure *et al*. (2014b) also recorded >15% $CaCO_3$ throughout the depth in coastal soils. Organic carbon varied from 6.7 to 12.3 g kg^{-1} in surface and from 2.4 to 10.5 g kg^{-1} in the sub-surface. Organic carbon was moderate in the surface layers of the pedons, due to intensive cultivation, and high because of leaf-litter addition by plantations such as mango, sapota and *Eucalyptus*. It generally decreased with depth. However, an irregular trend was observed in the Chikla pedon which may be due to the coastal sediments in the lower layers deposited by tidal flooding episodes during the earlier period (Agarwal *et al*. 1996; Bhandari *et al*. 2005).

Exchangeable bases were in the order of Ca^{2+}> Mg^{2+}> Na^{+}> K^{+} in all the pedons except in the Segvi pedon. The high exchangeable Ca^{2+} and Mg^{2+} content indicate that these soils were formed from the basaltic parent material. Moreover, the exchangeable Mg^{2+} was nearly equal to Ca^{2+} or high in Chikla pedon which is possibly caused by rapid formation pedogenic $CaCO_3$ (Pal *et al*. 2012). Similarly, Chinchmalatpure *et al*. (2014b) reported high exchangeable cations in the coastal Vertisols of Bharuch district. The base saturation is high (~100%) in all the pedons and the cation exchange capacity varied from 25.7 to 65.3 cmol (p^{+}) kg^{-1} at the surface and from 21.8 to 69.9 cmol (p^{+}) kg^{-1} in the

Table 4. Chemical characteristics of the soils of Valsad taluka, Valsad district

Pedon No. and Horizon	Depth (cm)	pH	EC (dS m^{-1})	OC (g kg^{-1})	$CaCO_3$ (%)	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	BS (%)	ESP	EMP
						---------------cmol (p^+) kg^{-1}---------------							
Pedon1 (Umarsadi) : *Fine, smectitic, hyperthermic Sodic Haplusterts*													
A	0-18	8.4	0.6	12.3	5.5	36.9	15.5	0.6	6.7	65.3	96	10.3	23.8
Bw1	18-43	8.6	0.7	8.5	4.5	35.0	15.3	0.4	11.4	66.0	94	17.3	23.2
Bss1	43-74	8.7	0.6	10.7	4.3	33.6	15.2	0.4	12.5	68.4	90	18.2	22.2
Bss2	74-97	8.4	0.3	8.1	3.8	34.3	18.5	0.4	10.7	66.8	95	16.1	27.8
Bw2	97-152	8.2	1.5	6.3	4.8	32.0	19.6	0.4	10.4	69.9	89	14.9	28.0
Pedon 2 (Segvi) : *Fine-loamy, (calcareous), smectitic , hyperthermic, Inceptic Haplustalfs*													
Ap	0-15	8.2	0.2	9.7	18.5	41.9	7.5	0.7	0.6	47.5	100	1.2	15.7
Bw1	15-44	8.2	0.2	4.7	18.3	45.8	7.1	0.5	0.5	49.0	100	1.1	14.4
Bw2	44-83	8.5	0.2	10.5	19.5	43.5	5.8	0.6	0.6	39.1	100	1.5	14.9
Bt1	83-112	8.4	0.2	4.0	18.5	43.3	8.5	0.6	0.5	32.5	100	1.5	26.1
Bt2	112-135	8.3	0.2	2.7	18.0	40.2	10.8	0.6	0.4	39.8	100	1.1	27.1
Pedon 3 (Chikla) : *Fine-loamy, smectitic, hyperthermic, Typic Ustifluvents*													
Ap	0-9	7.6	4.4	6.7	1.0	6.5	9.8	1.1	13.2	27.5	100	47.8	35.7
Bw1	9-34	8.9	1.1	7.4	1.8	7.3	12.0	1.8	11.1	33.1	97	33.5	36.3
Bw2	34-52	9.1	1.1	8.1	2.0	9.0	14.0	2.3	14.2	42.5	92	33.4	32.9
2C1	52-81	9.2	0.6	7.1	2.3	7.4	9.0	2.0	8.5	31.7	85	26.7	28.5
3C2	81-91	9.2	1.3	4.6	7.8	16.2	16.3	2.5	15.2	35.8	100	42.5	45.7
4C1	91-98	9.6	0.6	4.3	1.8	7.0	8.2	2.1	8.7	21.8	100	39.7	37.5
4C2	98-150	9.7	0.3	2.4	2.0	3.9	7.0	2.3	7.8	23.5	89	33.1	30.0
Pedon 4 (Bagal) : *Fine, smectitic, hyperthermic, Typic Haplusterts*													
Ap	0-16	8.0	0.2	8.4	0.8	42.6	11.9	0.6	0.5	48.8	100	1.1	24.5
Bw1	16-45	8.2	0.2	5.3	0.9	41.0	12.9	0.5	0.6	46.3	100	1.3	27.8
Bss1	45-70	8.4	0.2	4.1	0.7	40.3	14.4	0.5	1.2	46.3	100	2.6	31.1
Bw2	70-105	8.4	0.3	3.8	0.5	41.9	16.7	0.5	1.7	47.2	100	3.6	35.5
Bw3	105-132	8.4	0.3	3.7	0.2	36.1	18.0	0.4	1.9	47.9	100	4.0	37.5
Pedon 5 (Faldhara) : *Fine-loamy, smectitic, hyperthermic, Vertic Haplustalfs*													
Ap	0-20	7.8	0.4	10.5	4.3	34.8	9.9	0.5	0.4	42.3	100	1.1	23.3
Bt1	20-50	8.3	0.1	3.7	10.3	35.8	13.4	0.4	0.6	43.1	100	1.4	31.0
Bt2	50-81	8.4	0.2	4.9	9.0	33.1	14.9	0.4	0.7	40.6	100	1.8	36.8
Bt3	81-105	8.4	0.2	3.7	10.0	44.1	24.6	0.4	0.8	41.5	100	2.0	59.2

sub-surface. The high CEC and base saturation is due to high clay content, the dominance of smectite type of clay, and basaltic parent material (Pal *et al*. 2006; Bhattacharyya *et al*. 2015). Earlier, Ravisankar *et al.* (2010) reported smectite as one of the dominant minerals present in the coastal mud-flat soils of Gujarat. The ESP varied from 1.1 to 47.8, indicating the high concentration of exchangeable Na, in the pedons of Umarsadi and Chikla. The EMP was also high, which ranged from 14.4 to 59.2 and impaired the hydraulic conductivity of the soils.

Soil classification

The soils were classified based on climate parameters, soil morphology, physical and chemical properties according to soil taxonomy (Soil Survey Staff 2014). The study area qualifies for *ustic* soil moisture and *hyperthermic* soil temperature regimes (Soil Survey Staff 2003). Hence, all the soils were classified under *ustic* and *hyperthermic* at the great group level.

The Umarsadi pedon has slickensides with 25 cm or more thickness in their sub-surface horizons. The CEC (66.0 cmol $\{p^+\}kg^{-1}$) and base saturation (93%) are high. The ESP is more than 15, CEC/clay ratio >0.9. Therefore, it was classified as *Fine, smectitic, hyperthermic Sodic Haplusterts*. The Segvi pedon has an argillic horizon with <35 cm thickness in the deeper layers with more than 35% clay. Moreover, >15% $CaCO_3$ was present throughout the control section. The CEC/Clay ratio is >0.7. It was classified as *Fine-loamy, (calcareous), smectitic, hyperthermic, Inceptic Haplustalfs* (Soil Survey Staff 2014).

The Chikla pedon with varying texture from clay to clay loam to sandy clay loam indicate the lithological discontinuity and it was formed from different parent materials. The pedon showed no differentiating horizon development and most of the physical and chemical properties including pH, EC, CEC, BS, ESP and EMP showed irregular distribution with depth. At 85-155 cm depth, 0.24% of OC was recorded. Hence, it was classified as *Fine-loamy, smectitic, hyperthermic, Typic Ustifluvents*. The Bagal pedon was similar to Umarsadi except that the ESP was <15, therefore, it was classified as *Fine, smectitic, hyperthermic Typic Haplusterts.* The Faldhara pedon was similar to Segvi and it has 10 cm or wide cracks up to a depth of 40 cm. It was classified as *fine-loamy, smectitic, hyperthermic, Vertic Haplustalfs*.

Conclusions

The soils of Valsad taluka, Valsad district deep to very deep, fine-loamy to fine in textural class. The Faldhara and Segvi pedons were calcareous whereas Umarsadi pedon was alkaline. The drainage of the soils occurring the lower elevation is generally poor, and the well-drained soils under deep-rooted crops indicate the influence of land use on soil physical properties. The Umarsadi, Chikla, and Bagal soils were developed in the basaltic alluvial parent material, and their sub-surface properties were influenced by the earlier marine deposits. The Umarsadi, Segvi, and Faldhara soils under plantation crops such as Mango and Eucalyptus have higher organic carbon, and in turn, lower bulk density. The saturated hydraulic conductivity was generally low due to high ESP and EMP. Management measures are required to sustain crop production in the heavy textured soils to reduce subsoil sodicity.

References

Agarwal, R.P., Dotiwala, S., Mitra, D.S. and Bhoj, R. (1996). The paleo delta of the Proto Vatrak and Proto Mahi rivers of north-eastern Gujarat, India: A remote sensing interpretation. *Geomorphology* **15**, 67-78.

AIS&LUS (1970). *Soil Survey Manual*. All India Soil and Land Use Survey Organisation, New Delhi, pp.1-63.

Bhandari, S., Mauray, D.M. and Chamyal, L.S. (2005). Late Pleistocene alluvial plain sedimentation in Lower Narmada Valley, Western India: Palaeo environmental implications. *Journal of Asian Earth Sciences* **24,** 433-444.

Bhattacharyya, T., Chandran, P., Ray, S.K., Pal, D.K., Mandal, C. and Mandal, D.K. (2015). Distribution of zeolitic soils in India. *Current Science* **109,** 1305-1313.

Bhattacharyya, T., Sarkar, D. and Pal, D. K. (2009). Soil Survey manual. NBSS & LUP Publication No. 146, India pp 400.

Bouma, J. (1989). Using soil survey data for quantitative land evaluation. *Advances in Soil Science* **9,** 177–213.

Central Ground Water Board (2013). Ground Water Year Book 2012-13. Ministry of Water Resources. Government of India. Faridabad.

Chinchmalatpure, A.R., Bardhan, G., Nayak, A.K., Rao, G.C., Chaudhari, S.K. and Sharma, D.K. (2014a). Effect of sodium adsorption ratio with different electrolyte concentrations on saturated hydraulic conductivity of selected salt affected soils of Gujarat. *Journal of the Indian Society of Soil Science* **62**, 1-8.

Chinchmalatpure, A.R., Rao, G.C., Arora, S., Khandelwal, M.K. and Sharma, D.K. (2014b). Impact assessment of aniline plant treated effluent irrigation in Vertisols surrounding Bharuch. *Journal of the Indian Society of Soil Science* **62**, 168-173.

Chinchmalatpure, A.R., Khandelwal, M.K. and Rao, G.C. (2008). Characterization and classification of salt-affected soils of Samni farm, Bharuch district, Gujarat. *Agropedology* **18,** 71-75.

Chinchmalatpure, A.R., Nayak, A.R. and Rao, G.C. (2005). Soil survey interpretation of salt affected black soils of Jambusar taluka of Bharuch district of Gujarat State for suggested land use planning. *Agropedology* **15**, 22-28.

Datta, A., Basak, N., Chinchmalatpure, A.R., Banyal, R., and Chaudhari, S.K. (2017). Land-use influences soil properties of sodic land in northwest India. *Journal of Soil Salinity and Water Quality* **9**, 178-186.

Kumar, K., Patel, J.M., Pawar, S.L., Singh, N., and Patil, R.G. (2017). Land characterization and soil-site suitability evaluation of Banana growing areas of South Gujarat, India. *Journal of Applied and Natural Science* **9**, 1962 -1969.

Mandal, C., Mandal, D.K., Bhattacharyya, T., Sarkar, D., Pal, D.K. (2014). Revisiting agro-ecological sub-regions of India- A case study of two major food production zones. Current Science **107**, 1519–1536.

Nayak, S. (2017). Coastal zone management in India - present status and future needs. *Geo-spatial Information Science* **20**, 174-183.

Nayak, S.R., Hegde, V.S., Shalini, G., Rajawat, A.S., Girish, K.H., Jayakumar, S. and Suryanarayana. A. (2010). Geomorphic processes in the vicinity of the Venkatapur river mouth, Central West Coast of India: Implications for estuarine sedimentation. *Journal of Coastal Research* **265**, 925–934.

Nayak, A.K., Rao, G.C., Chinchmalatpure, A.R. and Singh, R. (2000). Characterization and classification of some salt-affected soils of Bhal region of Gujarat. *Agropedology* **10,** 152-158.

Pal, D.K., Wani, S.P. and Sahrawat, K.L. (2012). Vertisols of tropical Indian Environments: Pedology and edaphology. *Geoderma* **189-190**, 28-49.

Pal, D.K., Bhattacharyya, T., Ray, S.K., Chandran, P., Srivastava, P., Durge, S.L. and Bhuse, S.R. (2006). Significance of soil modifiers (Ca-zeolites and gypsum) in naturally degraded Vertisols of the Peninsular India in redefining the sodic soils. *Geoderma* **136,** 210-228.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P. and Smith, P. (2016). Climate smart soils. *Nature* **532**, 49–57.

Patel, P.K., Jakasaniya, M.S., Shinde, R.D. and Patel, R.B. (2017). Characterization of salt-affected soils of Dhokla taluka of Bhal region in Gujarat. *International Journal of Chemical Studies* **5**, 581-585.

Rao, G.C., Nayak, A.K., Chinchmalatpure, A.R., Nath, A. and Babu, V.R. (2004). Growth and yield of *Salvadora persica*: A facultative halophyte grown on saline black soil (*Vertic Haplustept*). *Arid Land Research and Management* **18,** 51-61.

Ravisankar, R., Senthilkumar, G., Kiruba, S., Chandrasekaran, A. and Jebakumar, P.P. (2010). Mineral analysis of coastal sediment samples of Tuna, Gujarat, India. *Indian Journal of Science and Technology* **3**, 774-780.

Sarkar, D., Chaturvedi, A. and Mahapatra, S.K. (2009). New vistas in perspective of land use planning. *Journal of the Indian Society of Soil Science* **57**, 587-600.

Sharma, J. P., Giri, J. D., Shyampura, R. L. and Gajbhiye, K. S. (2006). Soil series of Gujarat. NBSS & LUP Publication No. 120, Nagpur – 440010. pp. 329.

Soil Survey Division Staff (2015). Soil Survey Manual (Indian Print), USDA Handbook 18, Washington, DC.

Soil Survey Staff (2003). Keys to Soil Taxonomy, 9^{th} Edition (USDA, NRCS : Washington, DC).

Soil Survey Staff (2014). Keys to Soil Taxonomy, 12^{th} Edition (USDA, NRCS : Washington, DC).

Vasu, D., Tiwary, P., Chandran, P., Singh, S.K., Ray, S.K., Butte, P. and Parhad, V. (2018). A conceptual model of natural land degradation based on regressive pedogenesis in semiarid tropical environments. *Land Degradation & Development* **29**, 2554-2567.