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Characterization and Classification of the Soils of Brahmanakotkur Watershed in Kurnool District of Andhra Pradesh

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Eleven typical pedons representing major landforms in semi-arid ecosystem of Brahmanakotkur watershed in Kurnool district of Andhra Pradesh *viz*., plains and uplands originated from limestone, dolomite, quartzite and shale parent materials under varying land uses were studied for their morphological characteristics, physical and chemical properties, soil genesis and taxonomy. The soils were neutral to strongly alkaline (pH 7.01 to 8.86) in reaction, non-saline (EC 0.10 to 0.58 dS m^{-1}), shallow, deep and very deep in depth and had isohyperthermic temperature and ustic soil moisture regimes. The texture, organic carbon (OC), cation exchange capacity (CEC) and base saturation were ranged from gravelly sandy loam to clay, 0.10 to 5.8 g kg^{-1}, 8.11 to 61.72 cmol(p^+)kg^{-1} and 69.1 and 99.1%, respectively. Pedon 11 was placed under Entisol due to absence of sub-surface diagnostic horizon and was classified as Lithic Ustorthent whereas pedons 4, 8 and 9 were grouped under Inceptisol due to presence of cambric (Bw) sub-surface diagnostic horizon and classified as Lthic Haplustept and Typic Haplustept. However, the remaining pedons were placed under Vertsiol due to presence of more than 30% clay in all the horizons, slickensides and wedge shaped aggregates in sub-surface horizons and cracks in surface horizons and were classified as Typic Haplustert, Sodic Haplustert, Typic Calciustert and Leptic Calciustert.

Key words: Characterization, classification, watershed, cambic horizon, slickensides, Entisol, Inceptisol, Vertisol

Soil is the vital natural resource for the survival of life on the earth and its assessment is the prerequisite for the determination of productivity of soil and the sustainability of the ecosystem. The biggest challenge to the mankind today, is to provide the basic necessities for living, from the ever shrinking and non-renewable soil resource (Lal 2013). Precise scientific information on characteristics, potentials, limitations and management of different soils are indispensible for planned development of soil resources to maintain their productivity and to meet the demands for the future. Soil characterization provides the information for understanding of the physical, chemical, mineralogical and microbiological properties of the soils which are highly essential to grow crops, sustain forest and grasslands as well as to support homes and society structures (Devi *et al.* 2015). The coupling of soil characterization and soil classification is a powerful tool for development of management strategies for food security and environmental sustainability.

Watershed is a holistic approach for rainfed areas, which can lead to higher productivity and sustainability through conservation of soil and water resources (Patil *et al.* 2016). Brahmanakotkur watershed in Kurnool district of Andhra Pradesh is pre-dominantly under rainfed farming with erratic rainfall distribution associated with low crop productivity and needs site-specific information in terms of soil characteristics, their productivity potentials and limitations. This kind of information is not available for Kurnool district in general and Brahmankotkur watershed in particular. Hence, the

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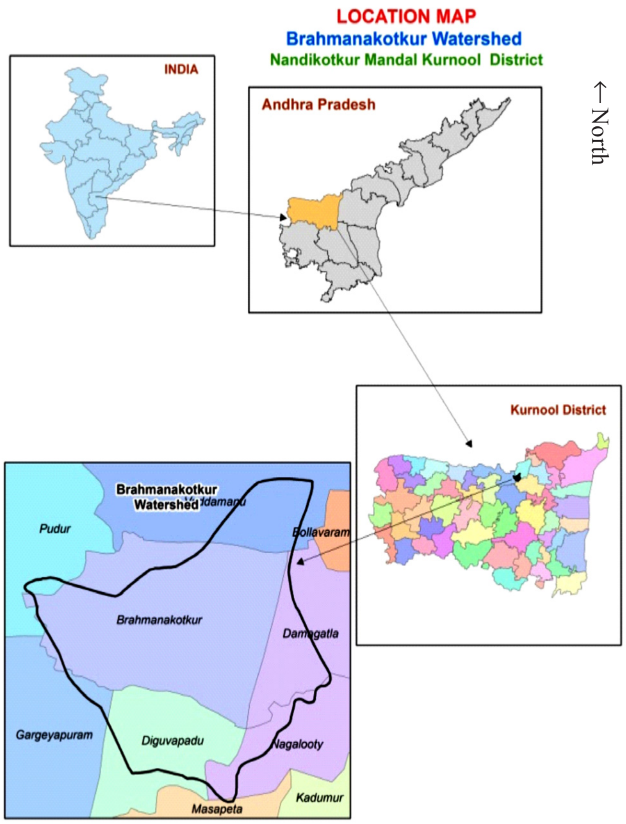

Fig. 1. Location map of Brahmanakotkur watershed

present investigation was undertaken to characterize and classify the soils of Brahmankotkur watershed.

Materials and Methods

The study area of Brahmankotkur watershed is located in Kurnool district of Andhra Pradesh (Fig. 1). It lies between 15°46′ and 15°50′ N latitudes and 78°09′ and 78°13′ E longitudes. It has a total geographical area of 2,931 ha and comprises of four villages namely, Gargeyapuram, Diguvapadu, Paipalem and Damagatla. The soils in the watershed were developed from limestone, dolomite, quartzite and shale. The climate of the watershed was semi-arid monsoonic with distinct summer, winter and rainy seasons. The mean annual rainfall recorded in the last 10 years (2008 to 2017) was 543 mm of which 96.3% was received during May to November months. The mean annual temperature was 28.9 °C with mean summer temperature of 34.9 °C and mean winter temperature of 25.6 °C. The maximum temperature recorded for the last ten years was 40.6 °C and the minimum temperature was 17.4 °C in the months of May and December, respectively. The soil moisture regime has been computed as ustic and soil temperature regime as isohypertherrmic. The natural vegetation of the watershed comprises of *Acacia nilotica, Borassus flabellifer, Tamarindus indica, Tephrosia purpurea, Parthenium hysterophorus, Azadirachta indica, Abutilon indica, Cyperus rotundus, Sygium cumini, Cassia auriculata, Cynodon dactylon and Calotropis gigantean etc.*

A detailed soil survey was conducted using 1:10,000 scale base map as per the procedure outlined by AIS&LUS (1970). Auger bores, mini pits, road cuts and pedons located on plains and uplands were studied. The detailed morphological description of these eleven pedons was studied in the field as per the procedure outlined in Soil Survey Manual (Soil Survey Division Staff 2015). Horizon-wise soil samples were collected and analyzed for important physical and chemical properties by standard procedures (Jackson 1973) and studied for their genesis. The soils were classified taxonomically (Soil Survey Staff 2014).

Results and Discussion

On the basis of soil correlation, eleven typifying pedons (soils), seven in uplands and four in plains, were identified in the watershed (Table 1).

Soil morphology

The morphological characteristics of the soils are presented in table 2. The solum depth varied from shallow to very deep in depth. The soils were poorly to well drained. The colour in pedons 1, 2, 3, 5, 8 and 10 varied from very dark grey to strong brown with a hue of 10YR, value ranged from 3 to 5 and chroma varied between 1 and 6. Pedon 11 showed brown to reddish yellow colour with a hue of 7.5YR, value of 7 and chroma of 6. In pedons 6 and 7 the colour varied from very dark grey to yellowish brown with a hue of 7.5YR and 10YR, value varied from 3 to 5 and chroma ranged from 1 to 4. In case of pedons 4 and 9, colour varied from strong brown to yellowish red with a hue of 5YR and 10YR, value ranged from 3 to 5 and chroma varied from 3 to 8 (Table 2). The colour appears to be the function of chemical and mineralogical composition of the soil (Sireesha and Naidu 2013). Surekha *et al.* (1997) observed 10YR hue, value 3 to 5 and chroma 1 to 2 in Vertisols of Andhra Pradesh. Low chroma in surface horizons of pedons was due to the fact that surface horizons were moist than sub-surface horizons (Khanday *et al.* 2017). The dark colour of black soils was due to domination of highly dispersed forms of clay-humus complex in the predominantly smectite dominated soils and decrease in organic matter was responsible

Table 1. Site characteristics of pedons in watershed area

Pedons	Location	Elevation (m)	Physiography	Slope (%)	Drainage	Family
P1	15°49′00.9″ N 78°09′51.9″ E	328	Uplands	1-3	Somewhat poorly drained	Fine, smectitic, isohyperthermic, Typic Haplustert
P2	15°48′46.7″ N 78°10′11.3″ E	324	Uplands	1-3	Somewhat poorly drained	Fine-loamy, smectitic, isohyperthermic, Sodic Haplustert
P3	15°48′28.8″ N 78°10′30.6″ E	318	Uplands	1-3	Somewhat poorly drained	Fine, smectitic, isohyperthermic, Typic Calciustert
P4	15°49′14.7″ N 78°11′20.1″ E	315	Uplands	1-3	Somewhat poorly drained	Fine-loamy, smectitic, isohyperthermic, Lithic Haplustept
P5	15°48′28.8″ N 78°10′30.6″ E	298	Plains	0-1	Somewhat poorly drained	Fine, smectitic, isohyperthermic, Leptic Calciustert
P6	15°47′52.1″ N 78°11′30.4″ E	299	Plains	0-1	Poorly drained	Fine, smectitic, isohyperthermic, Sodic Haplustert
P7	15°47′22.6″ N 78°12′07.3″ E	303	Plains	0-1	Poorly drained	Fine, smectitic, isohyperthermic, Typic Haplustert
P8	15°46′34.6″ N 78°09′45.1″ E	344	Uplands	3-5	Well drained	Fine-loamy, mixed, isohyperthermic, Typic Haplustept
P9	15°46′19.7″ N 78°10′47.7″ E	354	Uplands	3-5	Well drained	Loamy-skeletal, mixed, isohyperthermic, Typic Haplustept
P10	15°48′11.6″ N 78°12′56.7″ E	308	Plains	0-1	Poorly drained	Fine, smectitic, isohyperthermic, Typic Calciustert
P11	15°46′56.3″ N 78°11′44.9″ E	330	Uplands	3-5	Well drained	Loamy-skeletal,mixed, isohyperthermic, Lithic Ustorthent

for colour change in deeper layers (Rao *et al.* 1995). The colour variation in all the soils was mainly due to the differences in relief and consequent transportation of products of weathering or reduction of Fe and Mn (Somasundaram *et al*. 2010).

The soils of watershed showed wide textural variations ranging from sandy loam to clay. The wide textural variation might be due to variation in parent material, topography, *in-situ* weathering and translocation of clay by eluviations and age of the soils. Pedons 1 to 4 and 7 to 11 showed fine to very coarse, week to strong and sub-angular to angular blocky structure whereas pedons 5 and 6 exhibited medium to very coarse, moderate to strong and angular blocky structure in the surface horizons. Most of the soils in the watershed showed angular and sub-angular blocky structure. The blocky structures were attributed to the presence of higher quantities of clay fraction and the sharp edges in angular blocky structure in sub-surface horizons of all pedons was due to the high clay content (Kadao *et al.* 2003).

The consistence of the soils varied from soft to extremely hard (dry), friable to extremely firm (moist) and slightly plastic and slightly sticky to very sticky and very plastic (wet). Presence of extremely hard, extremely firm and slightly plastic and slightly sticky to very sticky and very plastic consistence might be due to large amount of expanding clay minerals. Pedons 4, 8 and 9 exhibited cambic (Bw) sub-surface diagnostic horizon, pedon 11 showed no diagnostic horizon and all the remaining pedons exhibited slickensides and pressure faces indicating development of Bss, sub-surface diagnostic horizon and also gave strong effervescence with HCl. All these pedons showed clear and smooth boundaries in surface horizons and diffuse and wavy boundaries in the sub-surface horizons, except in pedons 5 and 11, wherein pedon 5 showed diffuse and wavy boundary in the surface layers and pedon 11 showed clear and smooth boundary in the sub-surface horizon.

Physical characteristics

The detailed physical characteristics of the soils were presented in table 3. Particle size analysis revealed that the clay content varied from 18.1 to 57.4%. The enrichment of clay in Bw and Bss horizons of all pedons was primarily due to *in-situ* weathering of parent material. The increasing trend of clay with depth was primarily due to vertical migration of clay (Vedadri and Naidu 2018). More or less increase in clay content with depth was noticed in pedons 1, 4 and 5 which might be due to variability of weathering in different horizons. Silt fraction ranged from 5.6 to 52.2%. Silt content, in general, exhibited an irregular trend with depth, which might be due to variation in weathering of parent material

Table 2. Morphological characters of the soils

Pedon No. and Horizon	Depth (m)	Colour Moist	Texture	Structure			Consistence			Efferve-scence	Boundary		Cutans			Pores		Roots		Other features
				S	G	T	Dry	Moist	Wet		D	T	TY	TH	Q	S	Q	S	Q	
Pedon 1 Typic Haplustert (Upland)																				
Ap	0.00 – 0.20	Dark yellowish brown (7.5 YR 3/2)	cl	m	2	sbk	h	vfi	sp	-	c	s	-	-	-	-	-	f	f	-
Bw	0.20 – 0.51	Dark yellowish brown (7.5 YR3/1)	c	vc	3	abk	eh	efi	vsvp	-	d	w	-	-	-	-	-	-	-	pressure faces
Bss1	0.51 – 0.92	Dark brown (10 YR3/3)	c	vc	3	abk	eh	efi	vsvp	es	d	w	-	-	-	-	-	-	-	slickensides
Bss2	0.92 – 1.20	Dark brown (10 YR3/3)	c	vc	3	abk	eh	efi	vsvp	es	a	w	-	-	-	-	-	-	-	slickensides
Cr	1.20	Weathered gneiss mixed with lime																		
Pedon 2 Sodic Haplustert (Upland)																				
Ap	0.00 – 0.21	Very dark brown (10 YR 2/2)	cl	m	2	sbk	vh	vfi	vsvp	-	c	s	-	-	-	-	-	f	f	-
Bw	0.21 – 0.52	Very dark grey (10 YR 3/1)	sicl	vc	3	abk	eh	efi	vsvp	-	c	w	-	-	-	-	-	f	f	pressure faces
Bss1	0.52 – 0.91	Very dark grey(10 YR 3/1)	cl	vc	3	abk	eh	efi	vsvp	-	c	w	-	-	-	-	-	f	f	slickensides
Bss2	0.91 – 1.23	Very dark brown(10 YR 2/2)	sic	vc	3	abk	eh	efi	vsvp	es	c	w	-	-	-	-	-	-	-	slickensides
Bss3	1.23 – 1.50+	Very dark grey(10 YR 3/1)	sic	vc	3	abk	eh	efi	vsvp	es	-	-	-	-	-	-	-	-	-	slickensides
Pedon 3 Typic Calciustert (Upland)																				
Ap	0.00 – 0.20	Black (10YR 2/1)	sicl	m	2	sbk	h	vfi	sp	-	c	s	-	-	-	-	-	f	f	-
Bw	0.20 – 0.54	Very dark grey(10 YR 3/1)	cl	c	3	abk	vh	efi	vsvp	-	d	w	-	-	-	-	-	-	-	pressure faces
Bss1k	0.54 – 0.90	Very dark grey(10 YR 3/1)	sic	c	3	abk	vh	efi	vsvp	es	d	w	-	-	-	-	-	-	-	slickensides
Bss2	0.90 – 1.20+	Black(10YR 2/1)	sic	c	3	abk	vh	efi	vsvp	es	-	-	-	-	-	-	-	-	-	slickensides
Pedon 4 Lithic Haplustept (Upland)																				
Ap	0.00 – 0.22	Strong brown (7.5 YR 4/6)	cl	c	2	sbk	vh	fi	sp	-	c	s	-	-	-	-	-	f	f	-
Bw	0.22 – 0.50	Brown (7.5 YR 4/4)	cl	c	3	abk	vh	vfi	vsvp	-	a	s	-	-	-	-	-	f	f	-
R	0.50	Granite – gneiss																		
Pedon 5 Leptic Calciustert (Plain)																				
Ap	0.00 – 0.21	Very dark grey (10 YR 3/1)	cl	m	2	abk	vh	vfi	sp	-	d	w	-	-	-	-	-	f	f	-
Bwk	0.21 -0.53	Dark brown(10 YR3/3)	c	vc	3	abk	eh	efi	vsvp	-	d	w	-	-	-	-	-	f	f	pressure faces
Bss1	0.53 – 0.90	Very dark brown (10 YR 2/2)	c	vc	3	abk	eh	efi	vsvp	es	a	s	-	-	-	-	-	-	-	slickensides
R	0.90	Limestone																		
Pedon 6 Sodic Haplustert (Plain)																				
Ap	0.00 – 0.24	Dark brown (7.5YR 3/2)	c	c	2	abk	vh	vfi	sp	-	d	w	-	-	-	-	-	f	f	-
Bw	0.24 – 0.52	Very dark grey (7.5YR3/1)	c	vc	3	abk	eh	efi	vsvp	-	d	w	-	-	-	-	-	-	-	pressure faces
Bss1	0.52 – 0.81	Dark brown (10YR3/3)	c	vc	3	abk	eh	efi	vsvp	es	d	w	-	-	-	-	-	-	-	slickensides
Bss2	0.81 – 1.00	Dark brown (10YR3/3)	cl	vc	3	abk	eh	efi	vsvp	es	a	g	-	-	-	-	-	-	-	slickensides
R	1.00	Limestone																		
Pedon 7 Typic Haplustert (Plain)																				
Ap	0.00 – 0.20	Dark brown (7.5YR 3/3)	c	c	2	sbk	vh	vfi	sp	-	c	s	-	-	-	-	-	f	f	-
Bw	0.20 – 0.44	Very dark brown(7.5YR(2./3)	c	vc	3	abk	eh	efi	vsvp	-	d	w	-	-	-	-	-	f	f	pressure faces
Bss1	0.44 – 0.76	Black (10YR 2/1)	cl	vc	3	abk	eh	efi	vsvp	es	d	w	-	-	-	-	-	-	-	slickensides
Bss2	0.76 – 1.20+	Dark brown(10YR 3/3)	cl	vc	3	abk	eh	efi	vsvp	es	-	-	-	-	-	-	-	-	-	slickensides

Contd...

Pedon 8 Typic Haplustept (Upland)																				
Ap	0.00 – 0.20	Dark yellowish brown(10YR 4/4)	sicl	m	2	sbk	h	vfi	ssps	-	c	s	-	-	-	-	-	f	f	-
Bw1	0.20 – 0.45	Dark yellowish brown(10YR4/6)	scl	m	2	sbk	sh	fi	sssp	-	d	w	-	-	-	-	-	-	-	-
Bw2	0.45 – 0.60	Dark yellowish brown(10YR 3/4)	scl	m	2	sbk	sh	fi	sssp	-	c	s	-	-	-	-	-	-	-	-
R	0.60	Shale																		
Pedon 9 Typic Haplustept (Upland)																				
Ap	0.00 – 0.18	Strong brown (7.5YR4/6)	sl	f	1	sbk	s	fr	ssps	-	c	s	-	-	-	-	-	f	f	-
Bw1	0.18 – 0.40	Strong brown (7.5YR4/6)	gscl	m	2	sbk	sh	fi	sssp	-	d	w	-	-	-	-	-	-	-	-
Bw2	0.40 – 0.55	Strong brown (7.5YR4/6)	gscl	m	2	sbk	sh	fi	sssp	-	c	s	-	-	-	-	-	-	-	-
R	0.55	Dolamite																		
Pedon 10 Typic Calciustert (Plain)																				
Ap	0.00 – 0.30	Very dark grey (7.5YR3/1)	c	m	2	sbk	vh	vfi	sp	-	c	s	-	-	-	-	-	f	f	-
Bw	0.30 – 0.62	Black (10YR 2/1)	c	vc	3	abk	eh	efi	vsvp	-	d	w	-	-	-	-	-	-	-	pressure faces
Bss1	0.62 – 0.90	Very dark brown(10YR 2/2)	c	vc	3	abk	eh	efi	vsvp	ev	d	w	-	-	-	-	-	-	-	slickensides
Bss2k	0.90 – 1.20	Black (10YR 2/1)	sic	vc	3	abk	eh	efi	vsvp	ev	d	w	-	-	-	-	-	-	-	slickensides
Bss3k	1.20 – 1.60+	Dark brown (10YR 3/3)	c	vc	3	abk	eh	efi	vsvp	ev	-	-	-	-	-	-	-	-	-	slickensides
Pedon 11 Lithic Ustorthent (Upland)																				
Ap	0.00 – 0.18	Reddish yellow (7.5 YR6/6)	gsl	f	1	sbk	s	fr	ssps	-	c	s	-	-	-	-	-	f	f	-
A2	0.18 – 0.35	Reddish yellow (7.5 YR6/6)	gsl	f	1	abk	sh	fr	ssps	-	c	s	-	-	-	-	-	-	-	-
R	0.35	Quartzite																		

Texture : c – clay, cl – clay loam, l – loam, s – sand, sl – sandy loam, scl – sandy clay loam, sc – sandy clay, ls – loamy sand

Structure : Size (S) – vf – very fine, f – fine, m – medium, c – coarse; Grade (G) – O – structureless, l – weak, 2 – moderate, 3 – strong; Type (T) cr – crumb, sg – single grain, abk – angular blocky,sbk – sub-angular blocky.

Consistence :

Dry : s – soft, l – loose, sh – slightly hard, h – hard, vh – very hard, eh – extremely hard

Moist : l – loose, fr – friable, fi – firm, vfi – very firm, efi – extremely firm

Wet : so – non-sticky, ss – slightly sticky, s – sticky, vs – very sticky; po – non-plastic, ps – slightly plastic, p – plastic, vp – very plastic

Cutans : Ty – type – t – Argillan, Th – Thickness, tn – thin, th – thick, Quantity (Q), p – patchy, c – continuous

Pores : Size (S) f – fine, m- medium, c- coarse; Q – Quantity, f – few, c – common, m - many

Roots : Size (S) f – fine, m- medium, c- coarse; Q – Quantity, f – few, c – common, m - many

Effervescence : es – strong effervescence, ev – violent effervescence

Boundary : D – Distinctness, c – clear, g – gradual, d – diffuse, T – Topography; s – smooth; w – wavy

Table 3. Physical characteristics of the soils

Pedon No. and Horizon	Depth (m)	Sand (%) (0.05-2.0 mm)	Silt (%) (0.002-0.05 mm)	Clay (%) (<0.002 mm)	Bulk density (Mg m^{-3})	Water holding capacity (%)	COLE
Pedon 1 Typic Haplustert (Upland)							
Ap	0.00 – 0.20	35.0	25.5	39.5	1.25	60.2	0.22
Bw	0.20 – 0.51	25.0	30.0	45.0	1.18	60.5	0.22
Bss1	0.51 – 0.92	23.5	30.5	46.0	1.22	65.5	0.21
Bss2	0.92 – 1.20	16.0	37.0	47.0	1.28	61.5	0.17
Cr	1.20	Weathered gneiss mixed with lime					
Pedon 2 Sodic Haplustert (Upland)							
Ap	0.00 – 0.21	22.8	42.0	35.2	1.17	67.2	0.21
Bw	0.21 – 0.52	14.4	52.2	33.4	1.30	62.9	0.22
Bss1	0.52 – 0.91	22.9	46.3	30.8	1.33	65.3	0.21
Bss2	0.91 – 1.23	8.4	50.8	40.8	1.37	60.8	0.21
Bss3	1.23 – 1.50+	15.5	40.6	43.9	1.36	60.2	0.22
Pedon 3 Typic Calciustert (Upland)							
Ap	0.00 – 0.20	14.4	52.1	33.5	1.18	65.2	0.18
Bw	0.20 – 0.54	22.9	46.3	30.8	1.29	60.4	0.20
Bss1k	0.54 – 0.90	8.4	50.8	40.8	1.33	62.3	0.21
Bss2	0.90 –1.20+	15.4	40.7	43.9	1.35	60.2	0.21
Pedon 4 Lithic Haplustept (Upland)							
Ap	0.00 – 0.22	22.4	43.3	34S.3	1.37	52.7	0.17
Bw	0.22 – 0.50	22.42	43.27	34.31	1.29	54.3	0.13
R	0.50	Granite- gneiss					
Pedon 5 Leptic Calciustert (Plain)							
Ap	0.00 – 0.21	37.4	31.3	31.3	1.24	52.0	0.22
Bwk	0.21 – 0.53	21.3	33.9	44.8	1.21	52.7	0.18
Bss1	0.53 – 0.90	12.7	29.9	57.4	1.31	55.7	0.18
R	0.50	Limestone					
Pedon 6 Sodic Haplustert (Plain)							
Ap	0.00 – 0.24	25.3	32.0	42.7	1.17	56.1	0.12
Bw	0.24 – 0.52	24.4	19.9	55.7	1.25	54.3	0.12
Bss1	0.52 – 0.81	14.5	33.1	52.4	1.28	55.5	0.16
Bss2	0.81 – 1.00	41.5	20.2	38.3	1.38	52.9	0.21
R	1.00	Limestone					
Pedon 7 Typic Haplustert (Plain)							
Ap	0.00 – 0.20	22.7	32.3	45.0	1.32	49.5	0.15
Bw	0.20 – 0.44	16.4	35.5	48.1	1.22	48.7	0.14
Bss1	0.44 – 0.76	24.6	39.9	35.5	1.32	48.0	0.16
Bss2	0.76 – 1.20+	22.8	37.3	39.9	1.34	44.5	0.19
Pedon 8 Typic Haplustept (Upland)							
Ap	0.00 – 0.20	19.8	47.8	32.4	1.53	30.5	-
Bw1	0.20 – 0.45	60.9	13.1	26.0	1.30	21.3	-
Bw2	0.45 – 0.60	70.1	5.6	24.3	1.19	20.3	-
R	0.60	Shale					
Pedon 9 Typic Haplustept (Upland)							
Ap	0.00 – 0.18	58.6	26.9	14.5	1.42	30.8	-
Bw1	0.18 – 0.40	54.6	20.1	25.3	1.39	24.1	-
Bw2	0.40 – 0.55	56.4	18.5	25.1	1.22	23.4	-
R		Dolomite					
Pedon 10 Typic Calciustert (Plain)							
Ap	0.00 – 0.30	18.2	38.6	43.2	1.45	46.2	0.22
Bw	0.30 – 0.62	12.6	37.3	50.1	1.43	54.3	0.21
Bss1	0.62 – 0.90	12.9	31.7	55.4	1.52	56.8	0.22
Bss2k	0.90 – 1.20	8.6	45.5	45.9	1.45	57.8	0.20
Bss3k	1.20 – 1.60+	9.6	38.1	52.3	1.50	40.0	0.23
Pedon 11 Lithic Ustorthent (Upland)							
Ap	0.0 – 0.18	58.4	22.4	19.2	1.51	20.3	-
A2	0.18 – 0.35	61.5	20.4	18.1	1.62	20.1	-
R	035	Quartzite					

or *in-situ* formation (Kumar and Naidu 2012). The sand content ranged from 8.4 to 70.1%. Higher sand content was observed in surface horizons than those of sub-surface horizons, which was opposite to clay content and was due to surface impoverishment of finer particles by runoff water (Surekha *et al.* 1997).

The bulk density of different pedons varied from 1.17 to 1.62 Mg m^{-3} which might be due to presence of coarse texture and in some cases due to the presence of calcium carbonate and low organic carbon content. Similar results were reported by Sharma *et al.* (1994) in lower Siwaliks of Himachal Pradesh. The discrepancy in bulk density of these soils was attributed to the presence of moisture and high content of expanding type of clay minerals. Water holding capacity of different pedons varied from 20.1 to 67.2%. Pedons 2, 3, 6 and 7 have higher water holding capacity in surface horizon than in sub-surface horizons, which might be due to the presence of the higher amount of clay and organic matter in the surface soils. This variation in water holding capacity was due to changes in depth, clay, silt and organic carbon content. The high water holding capacity in clay soils was due to the high clay and less sand content as evident by highly significant and positive correlation (r = 0.631**) between water holding capacity and clay content. The irregular trend of water holding capacity with depth was due to the illuviation and eluviation of finer fractions in different horizons. The COLE values ranged from 0.12 to 0.23 and relatively higher COLE values were observed in pedons 1, 2, 3, 5, 6, 7 and 10 which might be due to relatively high percentage of smectite in clay fraction. Similarly, higher COLE values were observed in Vertisols than in Inceptisols and Alfisols (Balpande *et al.* 1997).

Chemical characteristics

The chemical characteristics of the soils are presented in table 4. The pH of the soils ranged from 7.01 to 8.86. This wide variation of pH in soils was attributed to the nature of the parent material, leaching, presence of calcium carbonate and exchangeable sodium. The increasing trend of pH with depth might be due releasing of organic acids during decomposition of organic matter and these acids might have brought down the pH in the surface soils. Higher pH in soils on gently sloping plains may be due to the presence of exchangeable bases brought by runoff water in surface horizons and also prevalence of higher temperature during most part of the year resulting accumulation of soluble salts in surface soils (Ram *et al.* 2010). The electrical conductivity (EC) in soils of watershed was ranged from 0.10 to 0.58 dS m^{-1}, indicating that the soils in watershed were non-saline. The low EC in these soils was due to leaching of soluble salts by percolating water. Organic carbon (OC) content was low to medium ranging from 0.10 to 5.8 g kg^{-1} (Table 4). All the pedons showed a decreasing trend in OC with depth which could be attributed to the fact that the surface horizons showed more organic matter content than sub-surface horizons due to the addition of plant residues and farmyard manure in surface horizons. Low OC in the soils might be attributed to the prevalence of tropical conditions, where the degradation of organic matter occurs at a faster rate coupled with low vegetative cover, there by leaving less OC in the soils (Vedadri and Naidu 2018).

The CEC in all the pedons estimated by ammonium acetate extract varied from 8.1 to 61.7 cmol(p^+)kg^{-1} soil which corresponds to clay content in the horizons, OC content and also type of clay mineral present in these soils. The free $CaCO_3$ ranged from 2.4 to 17.9% and the highest $CaCO_3$ content was noticed in pedon 5, which might be due to semi-arid climate which is responsible for the pedogenic processes resulting in the depletion of Ca^{2+} ions from the soil solution in the form of calcretes (Khanday *et al.* 2017). However, in pedons 1, 2 and 11 the $CaCO_3$ increased with depth which might be due to downward movement of calcium and its subsequent precipitation as carbonate and / or decomposition of calcium carbonate whereas the pedon 4 showed a decreasing trend with depth. The remaining pedons did not show any particular trend with depth, this may either be due to variable nature of geological material that contributed to these soils or due to rapid leaching of carbonates (Sahrawat 1999). Exchangeable bases in all pedons were in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and Ca being the dominant cation on the exchange complex. The base saturation varied from 69.1 and 99.1%. The higher base saturation observed in almost all pedons might be due to higher amount of Ca^{2+} occupying exchange sites on the colloidal complex. The differences in base saturation indicated the degree of leaching. The variation in base saturation of the soils might also be due to variation in nature and / or content of soil colloids and relatively high base saturation in surface layer could be attributed to the recycling of basic cations through vegetation (Devi and Kumar 2010). The ratio between Ca and Mg ranged from 1.42 to 8.21 and narrower Ca^{2+} / Mg^{2+} ratio was due to suppression of Ca solubility,

Table 4. Chemical properties of the soils

Pedon No. and horizon	Depth (m)	pH (1:2.5)	EC (dS m^{-1})	Organic carbon (g kg^{-1})	$CaCO_3$ (%)	CEC [cmol(p^+) kg^{-1}] (1 *N* NH_4 OAc, pH 7.0)	Exchangeable bases [cmol(p^+)kg^{-1}] (1 *N* NH_4OAc, pH 7.0)				Base saturation (%) (1 *N* NH_4 OAc, pH 7.0)	ESP (%)
							Ca^{2+}	Mg^{2+}	Na^+	K^+		
Pedon 1 Typic Haplustert (Upland)												
Ap	0.00 – 0.20	8.36	0.19	3.4	3.9	30.7	19.5	7.4	2.68	0.76	98.7	8.7
Bw	0.20 – 0.51	8.57	0.23	1.9	10.2	35.9	20.8	8.1	3.80	0.52	92.3	10.5
Bss1	0.51 – 0.92	8.79	0.14	0.7	11.7	32.2	20.1	7.1	3.86	0.46	94.9	11.6
Bss2	0.92 – 1.20	8.78	0.31	0.6	13.7	40.7	21.2	7.6	5.06	0.48	84.3	12.4
Cr	1.20	Weathered gneiss mixed with lime										
Pedon 2 Sodic Haplustert (Upland)												
Ap	0.00 – 0.21	8.33	0.15	2.6	5.1	28.6	20.0	5.1	2.54	0.51	98.1	8.8
Bw	0.21 – 0.52	8.40	0.18	2.6	6.5	29.7	21.1	4.2	3.61	0.31	98.3	12.1
Bss1	0.52 – 0.91	8.61	0.22	1.2	7.7	34.9	21.8	6.3	5.82	0.31	97.9	16.6
Bss2	0.91 – 1.23	8.52	0.13	0.7	10.5	37.3	20.9	8.2	7.45	0.39	98.9	19.9
Bss3	1.23 – 1.50+	8.64	0.20	0.3	11.8	37.5	20.2	8.4	8.15	0.35	98.7	21.6
Pedon 3 Typic Calciustert (Upland)												
Ap	0.00 – 0.20	8.28	0.21	2.1	4.2	32.6	20.1	9.1	2.41	0.50	98.4	7.3
Bw	0.20 – 0.54	8.50	0.10	1.3	6.4	35.9	25.4	5.6	3.24	0.32	96.2	9.0
Bss1k	0.54 – 0.90	8.86	0.23	0.4	16.9	38.6	26.5	7.1	3.89	0.29	97.8	10.0
Bss2	0.90 – 1.20+	8.81	0.31	0.1	10.6	39.6	26.0	8.5	4.01	0.38	98.0	10.1
Pedon 4 Lithic Haplustept (Upland)												
Ap	0.00 – 0.22	8.25	0.16	5.2	7.6	25.0	15.6	5.1	2.29	0.91	95.5	9.1
Bw	0.22 – 0.50	8.31	0.16	4.1	4.7	26.1	14.5	6.5	0.94	0.59	86.0	3.5
R	0.50	Granite – gneiss										
Pedon 5 Leptic Calciustert (Plain)												
Ap	0.00 – 0.21	8.62	0.14	3.0	14.1	34.4	22.5	4.6	3.69	0.46	90.6	10.7
Bwk	0.21 – 0.53	8.71	0.26	1.3	17.9	40.9	28.2	5.6	5.53	0.28	96.6	13.5
Bss1	0.53 – 0.90	8.73	0.24	0.9	10.3	61.7	34.0	10.0	7.31	0.30	84.5	11.9
R	0.90	Limestone										
Pedon 6 Sodic Haplustert (Plain)												
Ap	0.00 – 0.24	8.55	0.13	3.6	11.3	40.9	29.5	6.0	3.47	0.51	96.3	8.4
Bw	0.24 – 0.52	8.82	0.25	2.2	12.4	39.3	28.5	5.5	4.51	0.35	98.8	11.4
Bss1	0.52 – 0.81	8.80	0.40	1.3	11.9	40.0	25.5	7.4	5.71	0.36	97.4	14.2
Bss2	0.81 – 1.00	8.85	0.44	1.2	11.5	36.8	20.2	8.3	6.35	0.32	95.4	17.2
R	1.00	Limestone										
Pedon 7 Typic Haplustert (Plain)												
Ap	0.00 – 0.20	8.15	0.16	5.0	7.4	40.8	28.2	7.2	2.65	0.95	95.4	6.4
Bw	0.20 – 0.44	8.45	0.16	4.1	8.4	41.1	26.1	9.9	3.38	0.57	97.0	8.2
Bss1	0.44 – 0.76	8.78	0.17	1.7	6.8	33.3	20.1	9.1	3.35	0.41	98.8	10.0
Bss2	0.76 – 1.20+	8.78	0.27	1.1	8.8	38.4	25.3	6.7	4.11	0.49	95.3	10.7
Pedon 8 Typic Haplustept (Upland)												
Ap	0.00 – 0.20	7.06	0.20	0.4	6.4	14.5	8.2	4.9	0.46	0.28	95.1	3.1
Bw1	0.20 – 0.45	7.99	0.27	3.6	4.2	11.4	5.1	3.1	0.91	1.63	93.6	7.9
Bw2	0.45 – 0.60	7.81	0.58	2.2	5.2	10.9	4.4	2.2	0.66	1.49	80.0	6.0
R	0.60											
Pedon 9 Typic Haplustept (Upland)												
Ap	0.00 – 0.18	7.04	0.11	1.0	5.4	8.8	5.11	3.0	0.48	0.21	99.1	5.4
Bw1	0.18 – 0.40	7.01	0.24	3.1	4.1	10.1	4.12	2.9	0.95	1.01	88.5	9.3
Bw2	0.40 – 0.55	7.56	0.46	2.4	5.2	10.1	3.89	2.0	1.03	0.05	69.1	10.1
R	0.55											
Pedon 10 Typic Calciustert (Plain)												
Ap	0.00 – 0.30	8.34	0.28	2.1	11.5	39.6	31.2	3.8	1.22	0.50	92.7	3.0
Bw	0.30 – 0.62	8.72	0.15	1.9	12.8	47.4	35.0	6.4	2.47	0.31	93.0	5.2
Bss1	0.62 – 0.90	8.81	0.25	1.7	10.7	57.0	33.6	15.9	4.66	0.29	95.4	8.1
Bss2k	0.90 – 1.20	8.66	0.39	1.4	16.3	40.5	26.5	7.0	5.57	0.24	97.0	13.7
Bss3k	1.20 – 1.60+	8.71	0.31	1.3	17.1	41.3	25.5	7.5	6.10	0.27	95.3	14.8
Pedon 11 Lithic Ustorthent (Upland)												
Ap	0.0 – 0.18	7.10	0.15	5.8	2.4	8.66	4.56	3.1	0.50	0.40	98.8	5.7
A2	0.18 – 0.35	7.50	0.12	4.3	2.5	8.11	4.51	2.0	0.42	0.30	89.8	5.1
R	0.35	Quartzite										

substitution of Mg^{2+} or Ca^{2+} by plants and recycling of unusual amount of Mg (Sharma *et al*. 2011). The data also reveals that pedons 1, 2, 6 and 10 are sodic in nature as reflected from ESP values (>15%) of these soils. This may be due to occurrence of sodium ion enriched through runoff water.

Soil genesis

The examination of soil profiles showed distinctive horizontal layers, some of which were highly visible. Significant changes occurred as the soils were developed from relatively unconsolidated parent material. Pedons 1, 2 and 4 were developed form granite–gneiss and pedon 9 was originated from dolomite, pedons 3, 5, 6, 7 and 10 were originated from limestone, pedon 11 was developed from quartz and pedon 8 was developed from shale. Simonson (1959) outlined the process of soil formation which includes a) additions of organic and mineral materials to the soil as solids, liquids and gases b) losses of these from the soil c) translocation of materials from one point to another within the soil and d) transformation of mineral and organic substances within the soil. As per the outlines, in the watershed, the addition of organic matter was noticed due to accumulation of organic matter and humus on the surface soils and to certain depth of sub-soil in all the pedons of the study area. Higher organic matter in the surface soils was due to addition of organic matter through leaf fall, stubbles, roots and organic manures restricting to the surface soils only (Devi and Kumar 2010). Further, the OC was leached to lower layers along with percolating water leading to its loss from the surface soils (Sehgal 2005). Another point of soil formation was translocation of material from one point to another within the soil. In this category eluviation and illuviation were of importance. The development of B horizons in all the pedons was a result of illuviation and eluviation. Due to these processes the cambic horizon was formed in all the pedons except pedon 11. However, pedons 1, 2, 3, 5, 6, 7 and 10 showed Bss horizon indicating development of slickensides in the B horizon which qualifies these soils to be classified under Vertisols. The Vertisols of ICRISAT farm, India were exhibiting the sub-surface horizons of Bss1, Bss2, Bss3, Bssck1, Bssck2 and Bck (Soil Survey Staff 2014).

Besides, due to transformation of minerals and organic substances, the colour and structure get transformed in the sub-soil leading to the development of cambic horizon (Bw) in pedons 4, 8 and 9. It is also revealed that the formation of smectite occurred through transformation from the weathering sequence of mica-vermiculite-smectite. However, kaolinite could be formed from montmorillonite by loss of alkalis and iron. The study area has semi-arid climate with high summer temperatures with scarce rainfall and monsoonic type of climate. Natural vegetation in watershed was annuals and short grasses. Further, the topography of the study area varied from nearly level plains to gently sloping. The interplay of climate, topography and vegetation acting on parent material over a period of time resulted in the development of different soils *viz.,* Vertisol, Inceptisol and Entisol .

Soil classification

Based on the morphological characteristics, physical and chemical properties of the typifying pedons, the soils were classified up to family level (Soil Survey Staff 2014). Pedons 4, 8 and 9 which have cambic (Bw) sub-surface diagnostic horizon only were classified under Inceptisol whereas pedons 1, 2, 3, 5, 6, 7 and 10 showed intersecting slickensides, wedge shaped aggregates, more than 30% clay in all the horizons and cracks (2-5 cm wide) in the B horizon resulting in the development of Bss horizon and were classified under Vertisol. Further, pedon 11 was classified under Entisol due to the absence of any diagnostic sub-surface horizon. Pedons 4, 8 and 9 were grouped under Ustept at sub-order level due to presence of ustic soil moisture regime and Haplustept at greatgroup level because these pedons did not have either duripan or calcic horizon and base saturation was more than 60% at a depth between 0.25 to 0.50 m from the surface. However, pedons 8 and 9 did not exhibit any intergradations with other taxa or an extra gradation from the central concept. Hence, these pedons were logically classified as Typic Haplustepts. Pedon 4 was placed under Lithic Haplustept at sub-group level due to the presence of lithic contact within 50 cm of the mineral soil surface. Pedons 1, 2, 3, 5, 6, 7 and 10 were grouped under Ustert at sub-order level due to ustic soil moisture regime. Pedons 1, 2, 6 and 7 were grouped under Haplustert at greatgroup level because these pedons did not have salic, gypsic, calcic or petrocalcic horizons within 100 cm of mineral soil surface. Pedons 3, 5 and 10 were placed under Calciustert at greatgroup level due to presence of calcic sub-surface diagnostic horizon (> 15 cm thick with $CaCO_3$) within 100 cm of mineral soil surface. Further, pedons 1 and 7 did not exhibit any intergradations with other taxa or an extra gradation from the central concept. Hence, these pedons were classified as Typic Haplustert at sub-group level.

Pedons 2 and 6 were placed under sodic Haplustert at sub-group level due to the presence of sodic horizon (ESP > 15). However, pedons 3 and 10 were classified as Typic Calciustert at sub-group level as theydid not exhibit any intergradations with other taxa or an extragradation from the central concept and pedon 5 was placed under Leptic Calciustert at sub-group level because of the presence of lithic contact within 100 cm of the mineral soil surface. Pedon 11 was classified as Orthent as it showed regular decrease in OC with depth, Ustorthent due to presence of ustic soil moisture regime and Lithic Ustorthent due to presence of lithic contact within the 50 cm of the soil surface.

Conclusions

The morphological, physical and chemical properties of Brahmanakotkur watershed soils in Kurnool district of Andhra Pradesh revealed that the soils were neutral to strongly alkaline in reaction, non-saline and low to medium in OC content. The CEC values were low to medium and exchange complex was dominated by Ca^{2+} followed by Mg^{2+}, Na^{+} and K^{+} ions. The soils were classified as Typic Haplustert, Sodic Haplustert, Typic Calciustert, Leptic Calciustert, Lithic Haplustept, Typic Haplustept and Lithic Ustorthent. Furthermore, the study revealed considerable variations in morphological, physical and chemical properties of soils as they were developed from different parent materials and landforms. The application of organic matter through green manuring or application of crop residues was highly essential not only to improve the soils properties but also to achieve sustainable productivity.

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