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Full Research Article

Soil Resource Mapping and Assessment of Soils at Different Physiographic Divisions in Selected Mandals of Prakasam District, Andhra Pradesh: A Remote Sensing and GIS Approach

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Abstract

A rapid reconnaissance soil survey of Markapur, Kambham, Giddalur and Komarulu mandals of Prakasam district, Andhra Pradesh was carried out in 2009-10 for soil resource mapping using a hard copy of geo-referred false colour composite image of IRS-P6, LISS-III, and Survey of India (SOI) topo-maps no. 57 I/16, 57 M/1, 57 M/2, 57 M/3, 57 M/4, 57 M/5 and 57 M/6 of 1:50,000 scale as auxiliary data set. The study area lies between 15°30' to 16°00' N latitudes and 78°45' to 79°30' E longitudes with total geographical area of 3, 52,185 ha. Alluvium, quartzite, sandstone and shale were main geologic formation. Physiographically, soils of hill side slope and undulating pediments developed over mixed geology of quartzite, sandstone and shale 1apped into 9 mapping units. Likewise, Soils of pediplains and stream bank developed over shale are light to dark coloured, deep to very deep and have fine loamy to fine texture and low fertile. These soils are mostly under rainfed cultivation in pediplains and waste land in stream bank extended over 51.2% of the total area and mapped into 7 mapping units. Based on soil limitations, soils of undulating pediments and hill side slope are grouped under land capability class VI and VII whereas soils pediplains and stream bank was under land capability class II and III respectively.

1. Introduction

Soils are considered as the integral part of the landscape and their characteristics are largely governed by landforms on which they are developed (Ram et al., 2010). The modern agriculture requires precise information on various agro-climatic parameters like soil types, rainfall, temperature, water resources etc. (Ghosh, 1991; Hallmark et al., 2006). The properties of a soil are basic attributes that influence directly the soil response to any specific use. The usefulness of a soil, however, is not solely due to its inherent qualities but the qualities which affect its capacity to respond to the inputs and management for a specific use or a combination of uses (Ram et al., 2010). Land resources, particularly soil and water, are limited in extent; the efficient and sustainable utilization is imperative, particularly when the population pressure is increasing alarmingly (Patil et al., 2010). For optimum utilization of available land resources on the sustainable basis, timely and reliable information on soil regarding their nature, extent and spatial distribution along with their potentials and limitations is important (Shalima Devi and Anil Kumar, 2008).

Soil resource inventory provides an insight into the potentialities and limitation of soil for its effective exploitation. It also provides adequate information in terms of land form, terraces, vegetation as well as characteristics of soils (viz., texture, depth, structure, stoniness, drainage, acidity, salinity and so on) which can be utilized for sustainable agriculture. The technological advancements in the field of remote sensing and Geographical Information System have been a boon for such surveys. The modern remote sensing technologies using sensors in the visible, infrared, thermal and microwaves regions of the electro-magnetic spectrum are of immense use in evaluation, monitoring and management of land, water and crop resources (Das et al., 2009).

In view of ever-increasing population in India and the fact that area expansion for agriculture is not feasible, cropping intensity has to be increased, and therefore there is urgency for developing efficient nutrient management strategies for sustaining higher crop productivity and soil health under intensive agriculture systems. Hence, in order to suggest suitable management practices and remedial measures for various soils limitations, a systematic study of the soils of Markapur, Kambham, Giddalur and Komarulu Mandals of Prakasam district, Andhra Pradesh was carried out using remote sensing and GIS technique.

2. Materials and Methods

A rapid reconnaissance soil survey of Markapur, Kambham, Giddalur and Komarulu mandals of Prakasam district, Andhra Pradesh was carried out in 2009-10 for soil resource mapping using a hard copy of geo-referred false colour composite image of IRS-P6, LISS-III, and Survey of India (SOI) topo-maps no. 57 I/16, 57 M/1, 57 M/2, 57 M/3, 57 M/4, 57 M/5 and 57 M/6 of 1:50,000 scale as auxiliary data set. The procedure involved for soil resource mapping includes landscape, physiography, slope, land use, soil characteristics, selection and acquisition of data, pre field interpretation, ground truth verification and post field interpretation.

The study area lies between 15°30' to 16°00' N latitudes and 78°45' to 79°30' E longitudes with total geographical area of 3, 52,185 ha (Figure 1). Alluvium, quartzite, sandstone and shale are main geologic formation in the survey area. The mean annual precipitation (1950-1980) was 874 mm, of which 78.7 percent occurs between July to November. The climate is semi-arid type and mean annual temperature is 28.9°C whereas mean summer soil temperature and mean winter soil temperature is 29.1°C and 28.1°C, respectively. The soil moisture regime is 'ustic' and soil temperature regime is 'isohyperthermic' (Soil Survey Staff, 1998).

Physiographically, the area has been divided into hill side, undulating pediments, pediplains and stream bank. The hills sides are steep to very steep (25-50%) slope and occur at an altitude between 260 to 871 m above MSL whereas most of the area surrounding hills represents very gently to moderate (1-10%) slopes of pediments, pediplains and stream bank and occur at an altitude between 120 to 240 m above MSL. The study area is directly drained by river Gundlakamma and its tributaries and the drainage pattern is sub-parallel to parallel with moderate to severe soil erosion. Soil pedons were studied in different physiographic units. Horizon wise sample were collected from typical pedons and analyzed and classified with standard procedure (Jackson, 1979; Black, 1985; Soil Survey Staff, 1998). Erdas Imagine 8.5 and Arc GIS 8.1 software was used for soil resource mapping.

3. Result and Discussion

3.1. Soil resource mapping

The soil resource mapping units were systematically examined, described, classified and mapped into 16 mapping units covering an area of 3, 52,185 ha (Table 1; Figure 2 and 3). Out of total geographical area surveyed, 35.4% of the total area mapped into 4 mapping units under hill side slope. Likewise, 12.2% of the total area mapped into 5 mapping units under undulating pediments and rest of the area (51.2%) mapped into 7 mapping units under pediplains and stream bank.

3.2. Soil morphology

The soils of hill side slope and pediments are shallow to moderately deep, well drained and rapidly permeable. They are brown (7.5 YR 4/4) to dark brown (7.5 YR 3/4) in colour and have fine loamy texture with subangular blocky structure. (pedon 1, 2,3 and Table 2). These soils are mostly under forest land and open scrub. Soils of pediplains and stream bank developed over shale are yellowish red (5 YR 4/6) to dark reddish brown (5 YR 3/3) in colour and have clay loam to clay texture with fine, weak to medium, subangular blocky structure and occur on very gently to gently (1-5%) sloping land (pedon 4,5,6,7,8). These soils are mostly under rainfed cultivation in pediplains and waste land in stream bank. Soils of pediplains developed over shale and slate are dark brown (10 YR 4/3) to very dark brown (10 YR 3/2), in colour and have clay texture with fine, medium to strong, subangular blocky to angular blocky structure, cracking, calcareous and occur on very gently to gently (1-5%) sloping land (pedon 9).

3.3. Physico-chemical characteristics

Granulometric data indicated that the clay content varied from 25-31% in hill side slope and undulating pediments and 24-61% in pediplains and stream bank respectively (Table 3). The high clay content in soils of pediplains was due to deposition of finer fractions from hill side slope and undulating pediments (Ram et al., 2010; Rao et al., 2008, Taha and Nanda, 2003) and shale parent material. The enrichment of clay content in lower horizon was due to illuviation or vertical migration of clay (Sarkar et al., 2002). Sand and silt content in all the pedons ranged from 31-63% and 8-26% respectively. Sand content in soils of higher altitude was higher and decreased with increasing depth whereas silt content in all the pedons have irregular trend with the depth. Bulk density and particle density of the soils ranged from 1.55-1.85 Mg m^{-3} and 2.48-2.61 Mg m^{-3} respectively. Many researchers also reported

Table 1: Area under various soil resource mapping units

Landscape	Physio-graphy	Mapping units	Area in ha.	Area (%)	Description
Mixed geology of quartzite, sandstone and shale complex,	hill side	CGn8c1	69094	19.6	Steep to very steep (25-50%) slopes, forest land with 20-40% vegetative canopy, severe erosion, unmanaged.
		CGn8c2	31264	8.9	Steep to very steep (25-50%) slopes, forest land with 40-60% vegetative canopy, severe erosion, unmanaged.
		CGn8d1	22939	6.5	Steep to very steep (25-50%) slopes, open scrub with 10-20% vegetative canopy, severe erosion, unmanaged.
		CGn8d2	1489	0.4	Steep to very steep (25-50%) slopes, open scrub with 20-40% vegetative canopy, severe erosion, unmanaged.
	Undulating pediments	CGu4c1	4366	1.2	Gentle to moderate (3-10%) slope, forest land with 10-20% grass & bushy vegetation cover, unmanaged, severe erosion.
		CGu4c2	9140	2.6	Gentle to moderate (3-10%) slope, forest land with 10-20% grass & bushy vegetation cover, unmanaged, severe erosion.
		CGu4d1	20910	5.9	Gentle to moderate (3-10%) slope, forest land with 40-60% grass & bushy vegetation cover, unmanaged, severe erosion.
		CGu4d2	5025	1.4	Gentle to moderate (3-10%) slope, open scrub with 10-20% bushy vegetation cover, unmanaged, severe erosion.
		CGu4d3	3571	1.0	Gentle to moderate (3-10%) slope, open scrub with 20-40% bushy vegetation cover, unmanaged, severe erosion.
Shale	Stream banks	SHg3a1	484	0.1	Very gentle to gentle (1-5%) slopes, open scrub with 10-20% bushy vegetation, unmanaged to poorly managed, moderate to severe erosion.
	Upper pe-diplains	SHv3a1	86783	24.6	Very gentle to gentle (1-5%) slopes, agriculture with rainfed cultivation, unmanaged to poorly managed, moderate to severe erosion.
		SHv3a2	21478	6.1	Very gentle to gentle (1-5%) slopes, rainfed cultivation with irrigation at places, moderately managed, slight to moderate erosion.
Shale	Upper pe-diplains	SHv3ad1	24138	6.9	Very gentle to gentle (1-5%) slopes, open scrub with 10-20% bushy vegetation cover and rainfed cultivation at places, unmanaged, moderate to severe erosion.
	Lower pe-diplains	SHw2a1	38852	11.0	Nearly level to very gentle (0-3%) slopes, agriculture with rainfed cultivation, poorly managed, moderate erosion.
		SHw2a2	1168	0.3	Nearly level to very gentle (0-3%) slopes, agriculture with rainfed cultivation, moderately managed, moderate erosion.
	Alluvial plain	ALg4ad1	7510	2.1	Nearly level to very gentle (0-3%) slopes, agriculture with irrigated cultivation, well managed, slight to moderate erosion.
	Miscellaneous	River	1454	0.4	-
		Water bodies	2520	0.7	
		Total	352185	100.0	

Table 2: Morphological characteristics of the pedons*

Horizon	Depth (m)	Colour (moist)	Texture	Structure	Gravel (%)	Consistence: Dry	Consistence: Moist	Consistence: Wet	Cutans/ Slickensides/ cracks (cm)	Boundary	Pores	Roots	Effervescence
Pedon 1: Loamy skeletal, mixed, isohyperthermic, Typic Ustorthents													
AC	0-23	7.5YR 3/4	Scl	m2sbk	36	Dsh	mfr	wss wps	-	cs	f-f	f-f	-
Cr	23-55	Weathered quartzite and sandstone											
Pedon 2: Fine loamy, mixed, isohyperthermic, Typic Ustorthents													
AC	0-18	5 YR 4/6	Scl	m1sbk	25	Dsh	mfr	wss wps	-	cs	c-vf-f	vf-f-p	-
Cr	18-55	Weathered quartzite and sandstone											
Pedon 3: Fine loamy, mixed, isohyperthermic, Typic Ustorthents													
Ap	0-15	5 YR 4/4	Scl	m1sbk	20	Dsh	mfr	ws wp	-	cs	c-vf-f	vf-f-f	es
AC	15-29	5 YR 4/4	Scl	m1sbk	25	Dh	mfr	ws wp	-	gs	c-vf-f	vf-f	
Cr	29-63	Weathered quartzite and sandstone											
Pedon 4: Fine loamy, mixed, isohyperthermic, Typic Haplustepts													
Ap	0-18	7.5YR 5/4	Scl	sbk-1-m	12	Dsh	mfr	ws wp	-	cs	f-vf	vf	es
Bwk1	18-42	7.5YR 4/4	Scl	sbk-2-m	25	Dsh	mfr	ws wp	-	cs	f-vf	vf	es
Bwk2	42-65	5 YR 4/4	Cl	sbk-2-m	8	Dh	mfr	ws wp	-	gs	f-vf	vf	ev
Bwk3	65-1.05	5 YR 4/4	Cl	sbk-2-m	8	Dh	mfr	ws wp	-	-	f-vf	-	ev
Pedon 5: Fine loamy, mixed, isohyperthermic, Typic Haplustepts													
Ap	0-13	7.5YR 4/6	Scl	m1sbk	8	Dsh	mfr	wss wps	-	cs	c-vf-f	vf-f-p	ev
A12	13-32	5 YR 4/6	Scl	m1sbk	17	Dh	mfr	ws wp	-	cs	c-vf-f	vf-f-f	ev
Bwk1	32-50	5 YR 4/6	Scl	m1sbk	20	Dh	mfr	ws wp	-	gs	c-vf-f	vf-f	ev
Bwk2	50-76	7.5YR 4/6	Cl	m1sbk	22	Dh	mfr	ws wp	-	gs	c-vf-f	-	ev
Bwk3	76-1.20	7.5YR 4/6	Cl	m1sbk	20	Dh	mfr	ws wp	-	-	c-vf-f	-	ev
Pedon 6: Fine loamy, mixed, isohyperthermic, Typic Haplustepts													
Ap	0-13	7.5YR 4/6	Scl	m1sbk	20	Dsh	mfr	ws wp	-	cs	c-vf-f	vf-f-p	ev
A12	13-33	5 YR 4/6	Scl	m2sbk	10	Dh	mfr	ws wp	-	cs	c-vf-f	vf-f-f	ev
Bwk1	33-58	5 YR 4/6	Cl	m2sbk	10	Dh	mfr	ws wp	-	gs	c-vf-f	vf-f	ev
Bwk2	58-85	5 YR 4/6	Cl	m2sbk	8	Dh	mfr	ws wp	-	gs	c-vf-f	-	ev
Bwk3	85-1.10	5 YR 4/6	Scl	m2sbk	10	Dh	mfr	ws wp	-	-	c-vf-f	-	ev
Pedon 7: Fine loamy, mixed, isohyperthermic, Typic Haplustepts													
Ap	0 -15	5 YR 3/4	Scl	m2sbk	-	Dh	mfr	ws wp	-	cs	c-vf-f	vf-f-p	es
Bw1	15 -40	5 YR 3/3	Scl	m2sbk	-	Dh	mfi	ws wp	-	cs	c-vf-f	vf-f-f	es
Bw2	40 -60	5 YR 3/3	Sc	m2sbk	8	Dh	mfi	ws wp	-	gs	c-vf-f	vf-f	es
BC	60 -86	5 YR 3/3	Sc	m2sbk	30	Dh	mfi	ws wp	-	cs	c-vf-f	-	ev
Cr	86-1.10	Weathered quartzite and sandstone											
Pedon 8: Fine, smectitic, isohyperthermic, Typic Natrustalfs													
Ap	0 -15	10 YR 4/3	Cl	m2sbk	-	Dsh	mfr	ws wp	-	cs	c-vf-f	vf-f-f	e
Bt1	15 -42	10 YR 4/3	C	m2sbk	-	Dh	mfi	ws wp	tn-py	cs	c-vf-f	vf-f-f	es
Bt2	42 -75	10 YR 4/4	C	m2sbk	-	Dh	mfi	ws wp	tk-py	gs	c-vf-f	vf-f	es
Bt3	75 -1.10	10 YR 4/4	C	m2sbk	-	Dh	mfi	ws wp	tk-py	-	c-vf-f	-	es
Pedon 9: Very fine, smectitic, isohyperthermic, Typic Haplusterts													
Ap	0-15	10 YR 3/2	C	m2sbk	-	Dh	mfi	ws wp	2-5	cs	f-vf	vf	es
Bw1	15-35	10 YR 3/2	C	m2sbk	-	Dh	mfi	ws wp	2-3	gs	f-vf	vf	es
Bwssk1	35-65	10 YR 3/2	C	m2sbk	-	Dvh	mfi	wvs wvp	pf	cs	f-vf	vf	ev
Bwssk2	65-90	10 YR 3/2	C	m2abk	-	Dvh	mvfi	wvs wvp	ss	cw	f-vf	-	ev
Bwssk3	90-1.20	10 YR 3/2	C	m2abk	-	Dvh	mvfi	wvs wvp	ss	-	f-vf	-	ev

*Symbols are used according to Soil Survey Manual (Soil Survey Staff 1998; AIS&LUS 1970)

Table 3: Physico-chemical characteristics of the pedons

Depth	Sand	Silt	Clay	pH	EC	OC	$CaCo_3$	Exchangeable Bases [cmol (p^+) kg^{-1}]						ESP	BS	BD	PD	Porosity
(m)		(%)		(1:2)	(dsm^{-1})	(%)	(%)	Ca	Mg	Na	K	Sum	CEC		(%)	(Mg m^{-3})		(%)
Pedon 1: Loamy skeletal, mixed, isohyperthermic, Typic Ustorthents																		
0-23	57	14	29	6.4	0.2	0.42	0.8	5.1	1.8	0.1	0.2	7.1	11.2	0.6	63.6	1.74	2.59	33
Pedon 2: Fine loamy, mixed, isohyperthermic, Typic Ustorthents																		
0-18	59	16	25	7.3	0.26	0.59	0.5	5.1	2.1	0.3	0.3	7.8	12.4	2.8	63.3	1.63	2.58	37
Pedon 3: Fine loamy, mixed, isohyperthermic, Typic Ustorthents																		
0-15	57	18	25	7.8	0.3	0.39	0.8	10.5	3.6	0.2	0.3	14.6	19.7	1.2	74.2	1.68	2.59	35
15-29	49	20	31	8.1	0.3	0.33	0.5	13.8	4.2	0.2	0.4	18.6	25.2	1.0	73.8	1.72	2.56	33
Pedon 4: Fine loamy, mixed, isohyperthermic, Typic Haplustepts																		
0-18	59	17	24	9.9	1.36	0.11	4.8	12.3	9.9	12.0	0.5	34.7	44.4	27.1	78.1	1.63	2.50	35
18-42	53	18	29	9.8	1.33	0.12	11.0	11.7	11.1	13.0	0.6	36.4	46.2	28.1	78.8	1.65	2.52	35
18-42	44	25	31	10.0	1.53	0.17	9.0	13.8	8.7	13.3	0.5	36.3	46.3	28.7	78.5	1.62	2.48	35
65-1.05	45	23	32	10.0	2.0	0.17	3.3	11.1	9.0	11.7	0.5	32.4	40.1	29.3	80.7	1.59	2.48	36
Pedon 5: Fine loamy, mixed, isohyperthermic, Typic Haplustepts																		
0-13	52	21	27	8.0	0.30	0.39	5.0	19.8	11.1	0.3	0.4	31.6	39.2	0.7	80.6	1.55	2.52	38
13-32	47	24	29	8.2	0.34	0.33	9.8	21.3	8.7	0.4	0.5	30.9	38.4	1.1	80.4	1.58	2.51	37
32-50	46	24	30	8.0	0.39	0.27	12.3	15.3	8.1	0.3	0.5	24.2	29.5	1.1	82.1	1.60	2.54	37
50-76	45	25	30	8.0	0.37	0.21	14.5	11.7	10.2	0.3	0.5	22.7	29.1	1.1	78.1	1.57	2.57	39
76-1.20	47	26	27	8.1	0.23	0.20	14.3	12.3	9.9	0.3	0.6	23.1	32.5	1.0	71.2	1.57	2.55	38
Pedon 6: Fine loamy, mixed, isohyperthermic, Typic Haplustepts																		
0-13	63	12	25	9.1	1.1	0.22	9.0	10.8	10.5	7.2	0.6	29.1	36.1	19.9	80.7	1.75	2.61	33
13-33	52	17	31	8.5	1.6	0.27	7.3	11.1	9.6	11.8	0.7	33.2	39.1	30.2	84.8	1.73	2.55	32
33-58	45	18	37	9.1	1.6	0.15	5.5	11.1	10.8	13.3	0.6	35.8	42.6	31.3	84.1	1.69	2.53	33
58-85	43	19	38	9.4	2.1	0.10	6.3	12.3	12.3	12.9	0.6	38.1	46.5	27.8	81.9	1.68	2.52	33
85-1.10	44	18	38	9.6	1.9	0.08	6.8	12.3	12.9	13.2	0.4	38.8	46.8	28.2	82.9	1.68	2.52	33
Pedon 7: Fine loamy, mixed, isohyperthermic, Typic Haplustepts																		
0-15	59	16	25	7.6	0.3	0.50	0.8	10.5	9.6	0.1	0.3	20.5	27.1	0.2	75.6	1.55	2.56	39
15-40	55	14	31	7.8	0.2	0.47	1.2	12.9	9.0	0.2	0.4	22.5	30.1	0.6	74.7	1.58	2.56	38
40-60	53	11	36	8.2	0.3	0.38	4.0	12.3	6.9	0.2	0.3	19.8	26.4	0.8	74.9	1.58	2.53	38
60-86	53	12	35	8.2	0.2	0.20	5.3	12.0	8.1	0.3	0.3	20.7	26.4	1.1	78.5	1.59	2.51	37
Pedon 8: Fine, smectitic, isohyperthermic, Typic Natrustalfs																		
0 -15	48	19	33	8.2	0.5	0.29	1.8	11.1	9.0	4.9	0.6	25.6	35.2	13.9	72.6	1.68	2.59	35
15 -42	43	18	39	9.0	0.7	0.24	1.8	12.9	8.1	5.6	0.6	27.2	35.6	15.7	76.3	1.72	2.56	33
42 -75	45	15	40	9.1	1.0	0.24	2.5	12.3	7.8	9.7	0.3	30.1	35.9	26.9	83.8	1.68	2.59	35
75 -1.10	44	16	40	9.0	1.5	0.20	2.3	9.3	8.4	8.2	0.3	26.2	35.1	23.3	74.7	1.72	2.56	33
Pedon 9: Very fine, smectitic, isohyperthermic, Typic Haplusterts																		
0-15	41	12	47	8.1	0.31	0.41	5.3	10.8	8.7	0.7	0.9	21.0	27.6	2.4	76.2	1.78	2.58	31
15-35	37	12	51	8.6	0.33	0.39	6.0	12.9	8.1	4.0	0.9	25.9	31.0	12.8	83.5	1.85	2.52	27
35-65	33	10	57	8.7	0.34	0.36	6.5	13.8	8.1	5.7	0.4	28.1	34.1	16.8	82.3	1.75	2.51	30
65-90	31	8	61	8.8	0.58	0.36	6.5	12.3	9.0	6.9	0.5	28.8	36.6	18.9	78.6	1.78	2.55	30
90-1.20	34	9	57	8.9	0.72	0.33	6.5	9.9	10.2	9.5	0.5	30.1	34.3	27.8	87.9	1.67	2.60	36

that, the higher bulk density in sub-surface horizons are may be due to high clay content, greater compaction in swelling clay soils and low organic carbon (Ashok Kumar and Prasad, 2010; Ahuja et al., 1988; Jewitt et al., 1979). Rao et al. (2008) reported that the lower bulk density of surface soils was due to higher organic carbon (Rao et al., 2008).

The physiographic variation of pH was very high, which ranged from 6.4-8.1 in hill side and undulating pediments and 8.0-10.0 in pediplains and stream bank. Slope and physiography was significantly dominant on soil pH and the soil pH increased from the higher slope to the lower slope. The variation of pH with depth may be due to intensive weathering and subsequent leaching of bases in sloping landforms (Nayak et al., 2002; Patagundi et al., 1996, Bhadrapur and Seshagiri Rao, 1979). Electrical conductivity of soils was in the range of 0.20 to 2.1 dS m^{-1}. Organic carbon content of soils ranged from 0.08-0.59% and decreased with depth. Organic carbon was lower in throughout the pedons due to high temperature, low vegetation, having high pH and $CaCO_3$ (Bhattacharya et al., 2004, Govindarajan and Datta, 1968). The $CaCO_3$ content ranged from 0.5-14.5.0% which noticed higher in pediplains. The high $CaCO_3$ in the soils may be due to semi-arid climate which is responsible for the pedogenetic processes resulting in the depletion of Ca^{2+} ions from the calcretes with the concomitant increase in ESP with depth (Ashok Kumar and Prasad 2010; Vaidya and Pal, 2002; Balpande et al., 1996). The CEC of the soils varied from 11.2-46.8 cmol (p^+) kg^{-1} which corresponds to clay content in the horizons. Exchangeable bases in all the pedons irrespective of landforms were almost in the order: $Ca^{2+} \geq Mg2^{+} > Na^{+} > K^{+}$ and the base saturation varied from 63.3-87.9%.

The available nitrogen, phosphorus and potash in all the physiographic divisions of the district ranged from 58.1-376.3 kg ha^{-1}, 6.8-28.4 kg ha^{-1} and 67.2-257.6 kg ha^{-1}, respectively (Table 4). Low NPK content in these soils could be attributed to low organic carbon content (Prasuna Rani et al., 1992), fixation of released phosphorus by clay minerals and oxides of Fe and Al (Vijay Kumar et al., 1994), weathering of K bearing minerals and also release of K from organic residues (Rao et al., 2008; Sharma and Anil Kumar, 2003). The available sulphur content in the soils of the district varied from 2.7-15.1 mg kg^{-1} indicating that the soil of the district was also deficient in available sulphur.

These soils have relatively low DTPA-Zn (0.1-0.7 mg kg^{-1}) than DTPA-Fe (2.0-20.3 mg kg^{-1}), DTPA-Mn (0.7-32.6 mg kg^{-1}) and DTPA-Cu (1.2-5.6 mg kg^{-1}). Considering the critical limit of Lindsay and Norvell (1978) for above micronutrients, available zinc in all the soil orders and physiography were deficient whereas available Fe, Mn and Cu were sufficient for normal plant growth. Similar observations were also made by several workers in soils of Prakasam, Chittoor and Nellore district of Andhra Pradesh (Singh 2008, Rao et al., 2008; Thangasamy et al., 2005; Venkatesu et al., 2002).

3.5. Land capability classification of the study area

Based on the criteria outlined by Klingebiel and Montgomery (1966), soils of the Prakasam district was classified into four land capability class. Due to moderate to very steep slope, shallow to moderately deep depth, severe erosion, gravelly texture and land use pattern, soils developed over hill side slope and undulating pediments has been grouped into land capability sub-class and unit VIIes-1, VIIes-2, VIes-1 and VIes-2. The soils developed over pediplains and stream bank was classified into the land capability sub-class and unit IIes-1, IIes-2, IIIes-1, IIIes-2 and IIIes-3 respectively. The details description of land capability classes with SRM, potentials, limitations and suggested land use is given in Table 5 and Figure 4).

3.6. Soil classification

Based on morphology, physico-chemical properties and meteorological data, soils of the Prakasam district developed over hill side and undulating pediments was classified as 'Typic Ustorthents' (pedon 1, 2, and 3). It was due to shallow depth, gravelliness and absence of diagnostic horizons other than ochric epipedon (Soil Survey Staff, 1998). Relief and time are the limiting soil forming factors for loamy skeletal texture, shallow depth and poor soil health. Soils of the pedons 4, 5, 6, and 7 developed over pediplains and stream bank have ochric epipedon and cambic diagnostic sub-surface horizon and hence, these soils grouped in order Inceptisols. Owing to 'ustic' moisture regime, 'isohyperthermic' temperature regime, absence of duripan, calcic/petrocalcic horizon within 100 cm from the mineral soil surface and less than 35% clay content, these soils grouped under 'fine loamy, mixed, isohyperthermic, Typic Haplustepts' at family level. Due to presence of argillic (Bt) sub-surface diagnostic horizon, more than 35% base saturation throughout the profile and 15% or more ESP in underlying horizons, pedon 8 was classified as 'fine, smectitic, isohyperthermic, Typic Natrustalfs'. Likewise, pedon 9 have more than 35% clay content in all horizons, slickensides, wedge shaped peds with long axes and 3-5 cm wide cracks that open and close periodically, hence, these soils classified as 'very fine, smectitic, isohyperthermic, Typic Haplusterts'.

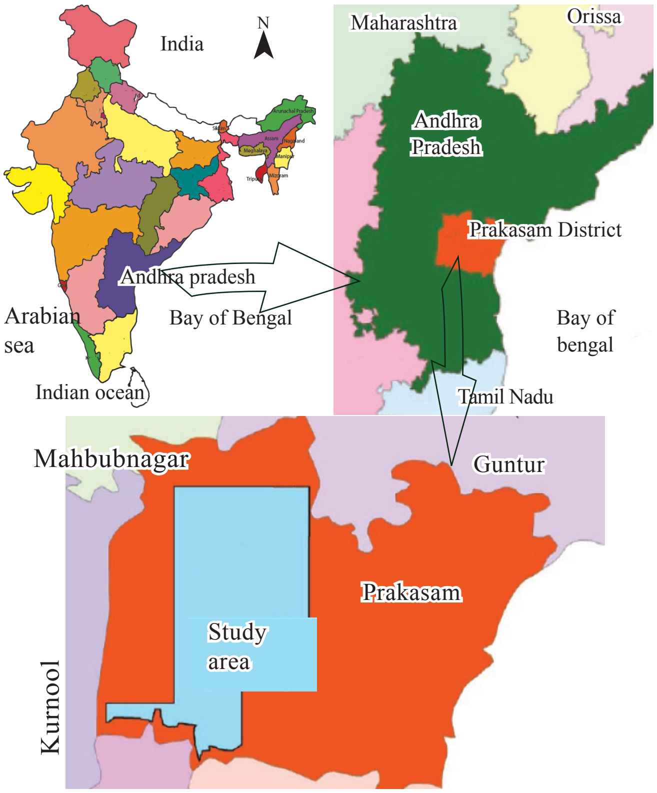

Figure 1: Location map of study area

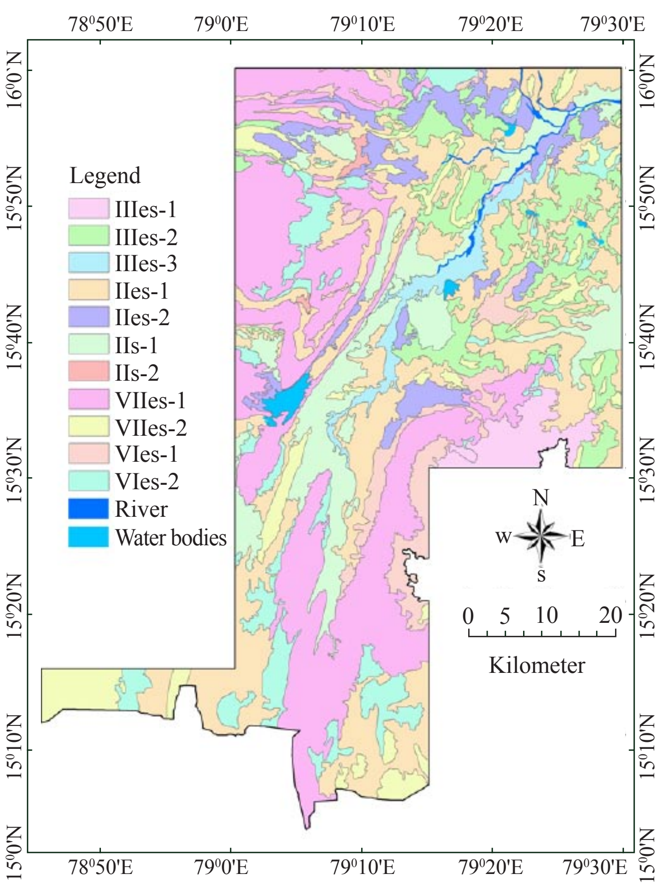

Figure 4: Land capability classification of the study area

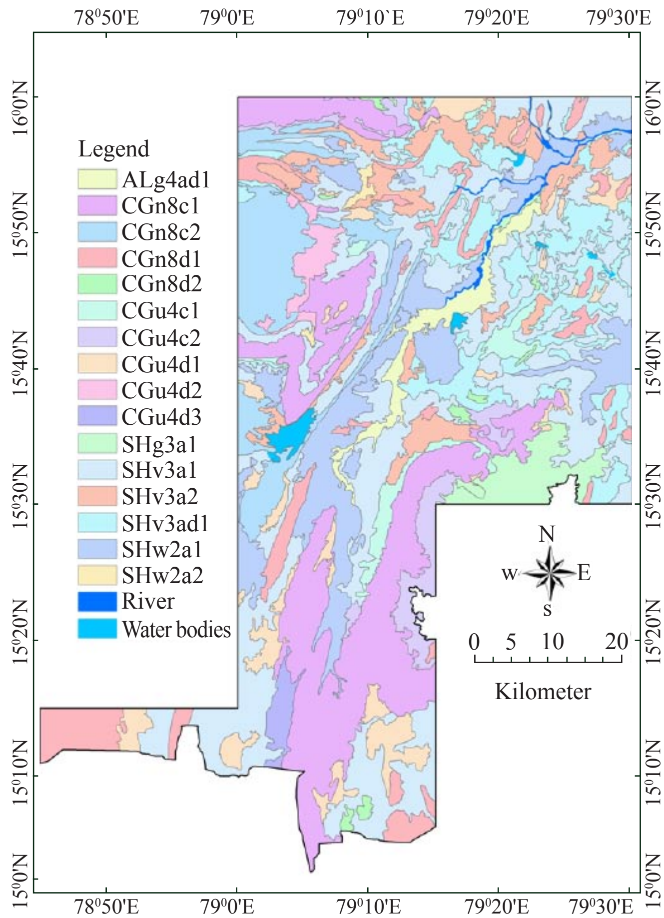

Figure 2: GIS map of the area under various soil resource mapping units

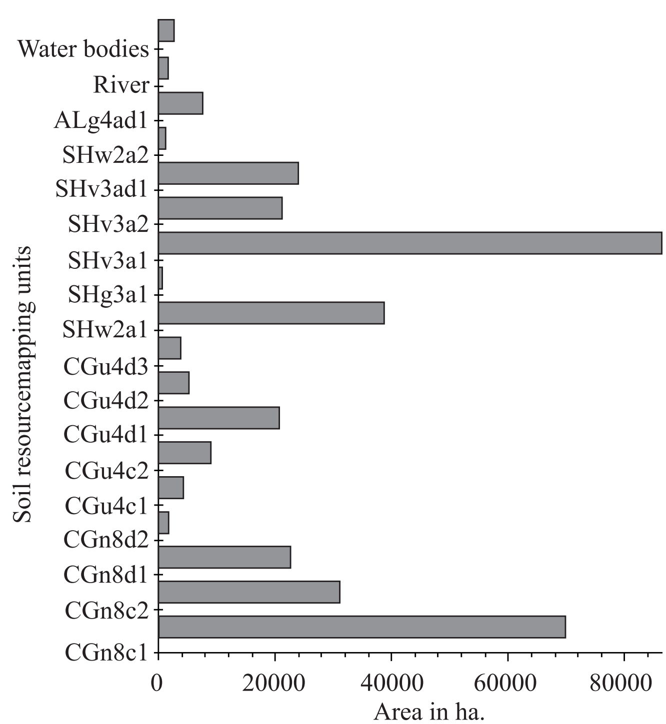

Figure 3: Area under various soil resource mapping units

Table 4: Nutrients status of the pedons

Depth (m)	Available nutrients (kg ha^{-1})			DTPA Extractable micronutrients (mg kg^{-1})				
	N	P	K	S	Fe	Mn	Cu	Zn
Pedon 1: Loamy skeletal, mixed, isohyperthermic, Typic Ustorthents								
0-23	338.7	12.0	67.2	12.2	16.1	32.6	2.2	0.4
Pedon 2: Fine loamy, mixed, isohyperthermic, Typic Ustorthents								
0-18	200.7	14.6	121.0	3.3	3.1	2.6	2.2	0.7
Pedon 3: Fine loamy, mixed, isohyperthermic, Typic Ustorthents								
0-15	301.1	20.4	114.2	3.8	2.7	11.8	1.7	0.5
15-29	276.0	19.2	113.1	3.5	4.3	2.9	2.4	0.4
Pedon 4: Fine loamy, mixed, isohyperthermic, Typic Haplustepts								
0-18	112.9	17.7	133.3	4.7	6.1	0.7	1.7	0.5
18-42	138.0	12.7	159.0	4.6	7.1	2.0	2.8	0.6
42-65	100.4	10.0	157.9	3.3	6.6	0.3	2.8	0.5
65-1.05	87.8	8.1	126.6	2.7	6.0	1.4	2.0	0.2
Pedon 5: Fine loamy, mixed, isohyperthermic, Typic Haplustepts								
0-13	238.3	20.8	122.1	4.8	4.6	16.6	2.6	0.5
13-32	200.7	20.7	154.6	4.5	4.9	6.5	2.6	0.2
32-50	138.0	14.8	143.4	3.2	4.4	6.5	2.4	0.2
50-76	112.9	11.0	159.0	3.4	3.0	4.9	2.5	0.1
76-1.20	150.5	11.4	182.6	3.2	3.1	2.8	2.4	0.1
Pedon 6: Fine loamy, mixed, isohyperthermic, Typic Haplustepts								
0-13	188.2	13.8	184.8	3.7	6.0	2.6	1.6	0.3
13-33	225.8	13.4	188.2	4.9	6.3	3.2	5.0	0.6
33-58	125.4	13.4	168.0	4.7	3.3	2.3	5.6	0.5
58-85	62.7	9.7	141.1	3.4	2.3	2.1	4.2	0.5
85-1.10	58.1	6.8	121.8	3.1	2.0	1.9	3.2	0.4
Pedon 7: Fine loamy, mixed, isohyperthermic, Typic Haplustepts								
0-15	351.2	15.1	99.7	12.1	5.6	11.5	2.0	0.7
15-40	313.6	15.6	117.6	15.1	6.0	15.8	2.4	0.5
40-60	213.2	13.6	100.8	12.6	4.8	7.7	1.8	0.4
60-86	138.0	9.5	95.2	10.9	4.3	5.8	1.5	0.4
Pedon 8: Fine, smectitic, isohyperthermic, Typic Natrustalfs								
0-15	238.3	23.7	162.4	3.4	10.1	5.6	5.4	0.7
15-42	225.8	15.2	169.1	3.3	13.9	9.4	3.9	0.5
42-75	100.4	15.3	141.1	2.7	15.3	2.6	1.2	0.3
75-1.10	62.7	14.4	99.7	6.0	13.1	1.4	1.2	0.4
Pedon 9: Very fine, smectitic, isohyperthermic, Typic Haplusterts								
0-15	376.3	28.1	255.4	12.3	20.3	0.8	2.9	0.6
15-35	351.2	28.4	257.6	6.2	18.7	2.1	3.4	0.6
35-65	351.2	17.7	125.4	5.2	14.5	1.4	2.9	0.7
65-90	313.6	13.8	140.0	3.9	10.7	1.7	2.5	0.5
90-1.20	301.1	14.8	151.2	3.4	10.0	1.7	3.0	0.5

Table 5: Land capability classification of the study area

LCC	SRM	Description	Major limitations	Suggested land use
IIs-1 IIs-2 IIes-1 IIes-2	SHw2a1 SHw2a2 SHv3a1 SHv3a2	Good cultivable land with slight limitations	Low fertile, impeded sub-surface drainage, alkali in nature	Suitable for a variety of crops including legume and pulses with proper management of sustainable agriculture.
IIIes-1 IIIes-2 IIIes-3	SHg3a1 SHv3ad1 ALg4ad1	Moderately good cultivable land for sustainable agriculture	Low fertile, impeded sub-surface drainage, heavy texture and high swell-shrink potential reduces the choice of multiple crops. Alkali in nature	Suitable for a variety of crops including legume and pulses with proper management of sustainable agriculture.
VIes-1 VIes-2	CGu4c1 CGu4c2 CGu4d1 CGu4d2 CGu4d3	Non-arable land, well suitable land for grazing or forestry	Gentle to moderate slope, shallow to moderately deep depth, unmanaged, severe erosion	Intensive soil conservation and management practices required for grazing and forestry.
VII-es-1 VII-es-2	CGn8c1 CGn8c2 CGn8d1 CGn8d2	Non-arable land, fairly-well suitable land for grazing or forestry	Steep to very steep slope, shallow depth, severe erosion, gravelly texture, unmanaged	Intensive soil conservation and management practices required for grazing and forestry.

4. Conclusion

It can be concluded that, soils of hill side slope and undulating pediments developed over quartzite, sandstone and shale are shallow to moderately deep, light coloured, well drained and low fertile whereas soils of pediplains and stream bank developed over shale are light to dark coloured, deep to very deep and have fine loamy to fine texture and low fertile. Physiography and landscape significantly affects the soil genesis, nature and properties of soils. The land capability classes IIs-1 to IIIes-3 are suitable for a variety of crops including legume and pulses by adopting proper management recommended for sustainable agriculture. Likewise, the land capability classes VIes-1 to VII-es-2 are not suitable for agriculture but this land can be utilized as grazing and forestry by adopting intensive soil conservation and management practices.

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