



Soil Characterization and Classification in Semi-Arid Regions of Varathuru Watershed, Andhra Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Eight typical pedons representing Varathuru watershed of Chittoor district, viz Pachigunta (P1 and P2), Kalepalli (P3 and P4), Ramapuram (P5 and P6) and Oogguvaripalli (P7 and P8) in semi-arid ecosystem were studied for morphological, physical, chemical characteristics and their classification. Results indicated that, the colour of the soils varied from dark reddish brown to strong brown with sandy loam to sandy clay loam texture. These soils were slightly acid to moderately alkaline (6.03 to 8.35) in reaction and non-saline (0.02 to 0.36 dSm⁻¹). The bulk density, water holding capacity, particle density, organic carbon (OC), cation exchange capacity (CEC) and base saturation were varied from 1.34 to 1.61 Mgm⁻³, 28.44 to 48.96%, 2.24 to 2.58 Mgm⁻³, 0.09 to 0.74%, 3.68 to 20.32 cmol (p⁺) kg⁻¹ and 51.61% to 91.86%, respectively. Due to the presence of ustic soil moisture regime, isohyperthermic temperature regime and low organic matter content, the soils were classified into Typic Hapustepts (Pedons 2, 3, 4, 6 and 8), Typic Haplustalfs (Pedons 1 and 7) and Ultic Haplustalfs (pedon 5).

Keywords: *Typic haplustepts; typic haplustalfs; ultic haplustalfs; isohyperthermic; pedon; soil texture.*

1. INTRODUCTION

Utilization of soil and water resources, is the major concern in these arid and semi-arid regions accounting for more than 60 per cent of area in the country. Over 75 percent of the cropped area falls in semiarid tropical region and most of the drought prone districts are concentrated in Andhra Pradesh, Maharashtra, Tamil Nadu, Karnataka and Rajasthan. Hence, management of soil resources on, scientific principles is essential to maintain the present level of soil productivity and to prevent its degradation. Comprehensive use of soil rationalizes present soil usage but also shows how they can be used and managed best for agriculture. Further, food security is a challenging task faced by the populous nations like India besides huge demand for water. Hence, concept of watershed based holistic development in rainfed areas is a potential approach, which can lead to higher productivity and sustainability.

“Characterization and classification of soils are important to understand the nature of soil resources and the data generated based on the profile characteristics will serve as a benchmark for monitoring and evaluating the likely changes in soil characteristics periodically under different cropping systems because of the introduction of different soil management techniques (Ravikumar et al. 2009). More than ever before, a renewed attention is being given to soils due to rapidly declining area for agriculture, declining soil fertility, increasing soil degradation, unsystematic land use policies and irrational and imbalanced use of inputs” (Kanwar 2004). “Hence, studies on characterization and

classification of soils is needed to realize the concept of watershed approach successfully (Sitanggang et al. 2006). Keeping the above facts in view, the present study was undertaken to characterize and classify the soils of Varathuru watershed of Chittoor district” (Sahoo et al. 2019).

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in 2018 in Varathuru watershed of Chittoor district in Andhra Pradesh situated between 13° 16' to 13° 12' N latitudes and 79°15' to 79° 19' E longitudes, with an average elevation ranging from 324 to 356 m msl. The total geographical area of watershed is about 2695 ha. The mean annual soil temperature was about 33.37°C. The average rainfall in the watershed was 923.48 mm.

2.2 Natural Vegetation

The natural vegetation of the study area was *Acacia nilotica*, *Acacia auriculata*, *Azadirachta indica*, *Palmyra palm*, *Parthenium hysterophorus*, *Pogamia pinnata*, *Phoenix Sylvestris*, *Pterocarpus santalinus*, *Tamarindus indica*,

2.3 Survey Methods

For soil resource inventory digital cadastral map (1:10000) prepared by using Toposheet and False colour composite were used for site selection and profile excavation. Based on geomorphic- soil relationship, eight profiles were exposed and studied (Fig. 1).

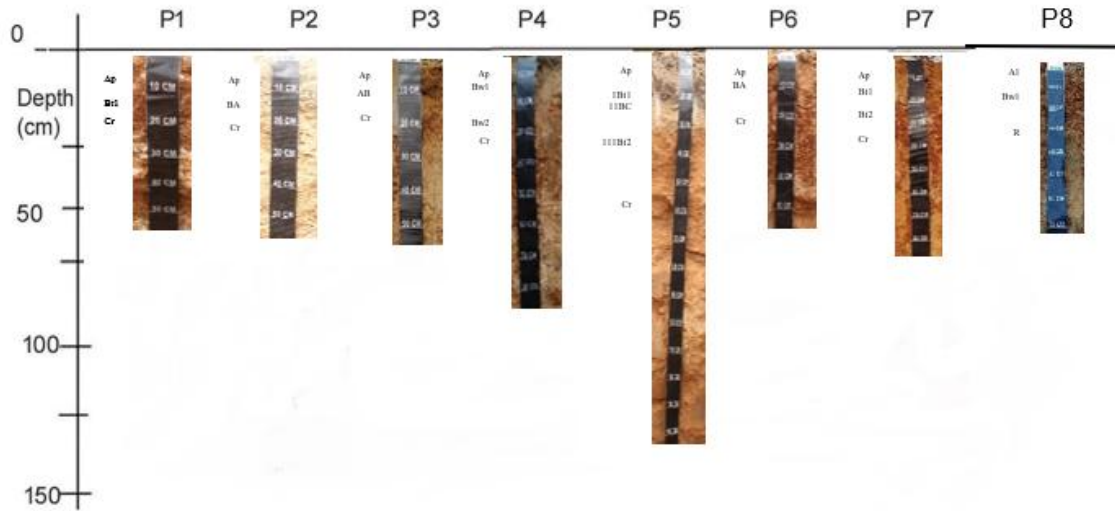


Fig. 1. Horizon differentiation of the profiles

2.4 Soil Sampling and Preparation for the Laboratory Analysis

“Morphological characteristics such as different horizons, depth, soil colour, texture were demarked in each pedon in the field and were recorded according to Soil Survey Staff (1998) for soil profile description. Sampling of each pedon was done under pedological horizons and 2-3 kg of soil was collected. Soil colour was determined by using Munsell colour chart. Particle size distribution, particle density and bulk density of the soils was determined by International pipette method” (Piper 1950), Pycnometer method (Means and Parcher 1963) and core method (Blake 1965), “respectively. The pH and electrical conductivity of the soils in soil: water (1:2.5) suspension was measured by glass electrode and conductivity meter, respectively” (Jackson 1973). “Calcium carbonate in soil samples was estimated by rapid titration method” (Puri 1949). “CEC was determined by neutral normal ammonium acetate extraction” (Bower et al. 1952). “Exchangeable calcium and magnesium were also determined in neutral normal ammonium acetate extract by Versenate titration method” (Chopra and Kanwar 1991). “The soils of study area were classified according to Keys to Soil Taxonomy” (Soil Survey Staff 2014).

3. RESULTS AND DISCUSSION

Morphological characteristics: Morphological characteristics of study area are presented in Table 1. “The studied pedons were moderately

shallow to deep and exhibited A-B-C horizons except P2, P3 and P6 which exhibited transitional horizon (AB and BA respectively) in profile development. Horizon boundaries of the all the pedons varied from clear to diffuse in distinctness and smooth to wavy in topography. The colour of the studied pedons varied from dark reddish brown (2.5 YR) to strong brown (10 YR) with dominant hue of 10YR, value (2.5-5) and chroma (1-6). This variation in the soil colour was a function of textural makeup, topographic position, mineralogy, chemical composition and moisture regimes of the soil” (Sujatha et al. 2021).

3.1 Physical Characteristics

“The results on physical characteristics of soils are presented in Table 1. The texture of the studied pedons varied from sandy loam to sandy clay loam. The soils of P1, P2 and P8 were sandy clay loam in texture in all horizons, whereas pedons P3, P4, P5, P6 and P7 were sandy loam at surface horizons and sandy clay loam at sub-surface horizons. These differences were caused by topographic position, nature of parent material, *in-situ* weathering and translocation of clay and age of soils” (Deepika et al., 2021). The water holding capacity of the soils was higher in pedon P1 (48.96 to 46.55 %) whereas the low water holding capacity was observed in P3 (33.94 to 29.20 %). Bulk density of pedons varied from 1.34 to 1.61 Mgm^{-3} and increasing pattern in pedons 1, 3, 6 and 8 were observed with depth, which may be ascribed to progressive compaction and lower organic matter.

Table 1. Physical characteristics of different pedons

Pedon No. & Horizon	Depth (m)	Horizon boundary	Colour (moist)	Sand (%)	Silt (%)	Clay (%)	Textural	Bulk density	Particle density	Water holding capacity	Pore space	Volume expansion	WHC/Clay
				(2.0-0.05 mm)	(0.05-0.002 mm)	(<0.002 mm)							
								(Mg/mg3)	(%)	(%)	(%)		
Pedon 1 Fine loamy, mixed, iso hyperthermic, Typic Hapustalfs													
Ap	0.00– 0.23	c-s	2.5 YR 2.5/4	64.79	10.99	24.22	scl	1.54	2.26	48.96	65.09	11.11	2.02
Bt1	0.23– 0.54	d-w	5 YR 3/4	61.12	12.48	26.4	scl	1.45	2.37	46.55	59.51	10.35	1.76
Cr	0.54			Weathered gneiss									
Pedon 2 Fine loamy, mixed, iso hyperthermic, Typic Haplustepts													
Ap	0.00– 0.24	c-s	5 YR 4/1	63.56	11.53	24.91	scl	1.41	2.31	39.15	51.88	4.1	1.57
BA	0.24– 0.56	d-w	10 YR 5/4	66.73	9.22	24.05	scl	1.43	2.48	31.46	40.63	4.62	1.31
Cr	0.56			Weathered gneiss									
Pedon 3 Fine loamy, mixed, iso hyperthermic, Typic Haplustepts													
Ap	0.00– 0.23	c-s	10 YR 3/6	70.55	9.97	19.48	sl	1.47	2.45	33.94	44.18	7.22	1.74
AB	0.23– 0.55	d-w	10 YR 4/3	68.91	11.65	19.44	sl	1.52	2.58	29.20	41.49	3.25	1.5
Cr	0.55			Weathered gneiss									
Pedon 4 Fine loamy, mixed, iso hyperthermic, Typic Haplustepts													
AP	0.00– 0.20	d-s	7.5 YR 4/4	68.86	13.16	17.98	sl	1.5	2.5	28.44	38.52	2.43	1.58
Bw1	0.20– 0.54	d-w	7.5 YR 4/6	57.95	19.49	22.56	scl	1.49	2.40	45.49	56.3	12.78	2.02
Bw2	0.54– 0.86	d-w	10 YR 5/3	61.03	18.66	20.31	scl	1.54	2.45	39.99	53.04	8.2	1.97
Cr	0.86			Weathered gneiss									
Pedon 5 Fine loamy, mixed, iso hyperthermic, Ultic Haplustalfs													
Ap	0.00– 0.23	c-s	10 YR 3/2	71.76	10.71	17.53	sl	1.50	2.42	31.55	42.62	6.26	1.8
1Bt1	0.23– 0.31	c-s	5 YR 4/4	65.51	14.18	20.31	scl	1.34	2.5	38.81	47.55	5.36	1.91
11BC	0.31– 0.80	c-s	7.5 YR 5/6	89.21	4.03	6.76	s	1.35	2.57	48.15	39.91	2.71	7.12
111Bt2	0.80– 1.41	c-s	7.5 YR 4/4	7.84	42.87	49.29	sic	1.55	2.24	42.51	50.99	8.25	0.86
Cr	1.41			Weathered gneiss									
Pedon 6 Fine loamy, mixed, iso hyperthermic, Typic Haplustepts													
Ap	0.00– 0.17	c-s	7.5 YR 4/6	69.23	15.25	15.52	sl	1.38	2.46	31.54	45.68	3.01	2.03
BA	0.17– 0.54	d-w	5 YR 3/4	63.39	9.69	26.92	scl	1.44	2.41	34.74	44.09	5.87	1.29
Cr	0.54			Weathered gneiss									
Pedon 7 Fine loamy, mixed, iso hyperthermic, Typic Haplustalfs													
Ap	0.00– 0.27	c-s	5 YR 3/4	73.82	8.75	17.43	sl	1.51	2.36	29.46	41.88	3.66	1.69
Bt1	0.27– 0.56	d-w	5 YR 3/4	64.77	12.22	23.01	scl	1.45	2.38	40.26	51.17	9	1.75
Bt2	0.56– 0.85	d-w	5 YR 4/4	63.87	14.77	21.36	scl	1.55	2.44	36.27	49.33	7.41	1.7

Pedon No. & Horizon	Depth (m)	Horizon boundary	Colour (moist)	Sand (%)	Silt (%)	Clay (%)	Textural	Bulk density	Particle density	Water holding capacity	Pore space	Volume expansion	WHC/Clay
				(2.0-0.05 mm)	(0.05-0.002 mm)	(<0.002 mm)							
								(Mg/mg3)	(%)	(%)	(%)		
Cr	0.85		Weathered gneiss										
Pedon 8 Fine loamy, mixed, iso hyperthermic, Typic Haplustepts													
A1	0.00– 0.24	c-s	7.5 YR 3/4	71.77	7.05	21.18	scl	1.45	2.42	38.02	50.75	5.45	1.79
Bw1	0.24– 0.71	d-w	10 YR 3/6	67.98	8.04	23.98	scl	1.61	2.41	33.63	48.49	6.16	1.4
R	0.71		Hard Granite Gneiss										
Min				7.84	4.03	6.76		1.30	2.24	28.00	39.00	2.43	0.86
Max				89.20	42.90	49.29		1.60	2.58	49.00	65.00	12.78	7.12

Table 2. Physico-chemical properties of different pedons

Pedon No. & Horizon	Depth (m)	pH (1:2.5)		EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	CEC	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	BSP (%)	ESP (%)
		H ₂ O	1N KCl										
Pedon 1													
Ap	0.00– 0.23	6.57	5.46	0.12	0.65	4.4	16.01	8.1	4.7	0.24	0.19	82.69	1.53
Bt1	0.23– 0.54	6.03	5.24	0.1	0.18	2.98	12.14	5.1	3.8	0.19	0.11	75.86	1.61
Cr	0.54												
Pedon 2													
Ap	0.00– 0.24	7.51	6.67	0.33	0.74	5.83	16.48	9.2	5.5	0.22	0.22	91.86	1.34
BA	0.24– 0.56	8.14	7.61	0.25	0.15	7.25	14.96	6.5	3.7	0.22	0.08	70.16	1.46
Cr	0.56												
Pedon 3													
Ap	0.00– 0.23	6.88	6.18	0.02	0.46	2.5	11.45	6.4	3.4	0.21	0.11	88.39	1.80
AB	0.23– 0.55	7.18	6.15	0.19	0.09	3.45	10.38	5.2	3.2	0.25	0.08	84.14	2.44
Cr	0.55												
Pedon 4													
Ap	0.00– 0.20	6.11	5.47	0.1	0.53	2.03	11.61	6.2	2.4	0.33	0.16	78.32	2.87
Bw1	0.20– 0.54	7.14	6.41	0.08	0.37	3.93	13.83	8.2	3.6	0.24	0.22	88.61	1.72
Bw2	0.54– 0.86	7.57	6.79	0.13	0.32	2.98	12.57	6.6	3.6	0.32	0.16	84.98	2.55
Cr	0.86												
Pedon 5													
Ap	0.00– 0.23	8.12	7.34	0.36	0.44	6.3	10.06	5.2	2.6	0.19	0.17	81.09	1.89

Pedon No. & Horizon	Depth (m)	pH (1:2.5)		EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	CEC	Ca ²⁺ Mg ²⁺		Na ⁺	K ⁺	BSP (%)	ESP (%)
		H ₂ O	1N KCl					[cmol (p ⁺) kg ⁻¹]					
1Bt1	0.23– 0.31	8.35	7.52	0.27	0.32	8.68	12.13	6.9	2.1	0.17	0.12	76.66	1.44
11BC	0.31– 0.80	8.14	7.36	0.06	0.19	5.83	3.68	2.2	0.4	0.05	0.03	72.84	1.34
111Bt2	0.80– 1.41	7.92	6.56	0.21	0.12	3.45	20.32	10.6	6.8	0.25	0.14	87.56	1.22
Cr	1.41	Weathered gneiss											
Pedon 6													
Ap	0.00– 0.17	6.21	5.56	0.23	0.34	2.5	9.67	3.8	2.4	0.19	0.17	67.86	1.97
BA	0.17– 0.54	6.14	5.35	0.19	0.28	5.35	17.33	5.5	4.8	0.15	0.12	61.00	0.85
Cr	0.54	Weathered gneiss											
Pedon 7													
Ap	0.00– 0.27	6.81	5.93	0.17	0.25	1.55	11.04	3.2	1.9	0.43	0.16	51.61	3.94
Bt1	0.27– 0.56	6.09	5.64	0.09	0.34	2.98	15.07	5.1	2.7	0.42	0.13	75.43	2.79
Bt2	0.56– 0.85	6.67	5.92	0.12	0.21	2.5	13.61	6.9	3.5	0.18	0.12	78.63	1.34
Cr	0.85	Weathered gneiss											
Pedon 8													
A1	0.00– 0.24	6.51	5.66	0.21	0.34	3.93	13.63	4.7	3.5	0.21	0.19	63.09	1.53
Bw1	0.24– 0.71	6.23	5.75	0.29	0.11	6.78	15.81	6.2	3.4	0.13	0.12	62.28	0.82
R	0.71	Hard Granite Gneiss											
Min		6.03	5.24	0.02	0.09	1.55	3.68	2.2	0.4	0.05	0.03	51.61	0.82
Max		8.35	7.61	0.36	0.74	8.68	20.32	10.6	6.8	0.43	0.22	91.86	3.94

Table 3. Correlation matrix among Physical and Physico-chemical properties of different pedons

Parameter	pH	EC	OC	CaCO ₃	CEC	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	BSP	ESP	Sand	Silt	Clay
pH	1													
EC	0.97**	1												
OC	-0.08	-0.09	1											
CaCO ₃	0.56**	0.62**	-0.03	1										
CEC	-0.17	-0.25	0.09	0.07	1									
Ca ²⁺	0.20	0.10	0.29	0.13	0.77	1								
Mg ²⁺	0.00	-0.13	0.18	-0.01	0.88**	0.82**	1							
Na ⁺	-0.24	-0.25	0.18	-0.57**	0.21	0.06	0.07	1						
K ⁺	-0.20	-0.25	0.67**	-0.20	0.39*	0.42*	0.40*	0.36*	1					
BSP	0.45*	0.36*	0.38*	0.03	0.08	0.65**	0.42*	-0.18	0.23	1				
ESP	-0.15	-0.14	0.09	-0.60**	-0.32*	-0.37*	-0.38*	0.84**	0.15	-0.23	1			
Sand	-0.12	0.03	0.16	0.12	-0.72**	-0.75**	-0.75**	-0.17	-0.22	-0.32*	0.21	1		
Silt	0.21	0.07	-0.16	-0.21	0.51**	0.67**	0.59*	0.19	0.22	0.42*	-0.08	-0.95**	1	
Clay	0.01	-0.13	-0.15	-0.02	0.86**	0.75**	0.83**	0.13	0.19	0.19	-0.31*	-0.95**	0.79**	1

However, P2, P4, P5 and P7 exhibited an irregular trend with depth. Similarly, increase in bulk density down the profile due to low organic matter and compaction of soil aggregates in Yerpedu mandal in Chittoor district in Andhra Pradesh (Leelavathi et al. 2009)). The lower bulk density values in the surface horizons of pedons could be related to the structural aggregation of the soils as a result of relatively high organic matter content in surface horizons than sub-surface horizons (Meghana et al., 2024).

The particle density and total porosity in studied pedons of the watershed were varied from 2.40 to 2.58 Mgm^{-3} and 38.52 to 65.09 % respectively. P1, P2, P3 and P7 showed an increasing trend of particle density with depth. And remained more or less same. Water holding capacity of watershed was varied from 28.44 % to 48.96 %. P1, P2, P3 and P8 were showed and increasing trend of water holding capacity with depth. The remaining pedons showed no particular trend with depth. These differences in water holding capacity values were due to variation in the depth, clay, silt and organic carbon content of the pedons. (Lakshmi et al. 2020).

3.2 Physico-chemical Characteristics

Data on the chemical properties are presented in the Table 2. pH of the watershed ranged from 6.03 to 8.35, according to pH classes these were slightly acid to moderately alkaline in reaction. The P2, P3, P4 and P7 showed an increasing trend with depth whereas pedon 5, 6 and 8 which showed decreasing pattern and pedon 1 did not show any particular trend with depth. The electrical conductivity varied between 0.02 to 0.36 dSm^{-1} in the studied pedons indicating that the soils were non-saline. It may be due to excess leaching of salts and due to free drainage conditions, which favoured the removal of released bases by percolating and drainage water (Suguna et al., 2023). The soils were low in organic carbon content (0.09 to 0.74%). The low organic carbon content in these pedons may be ascribed to ustic soil moisture regime, isohyperthermic temperature regime and poor vegetation (Leelavathi et al. 2009). Calcium carbonate content was varied from 1.55 to 8.68 % and could be due to ustic soil moisture regime, which is quite compatible for carbonate formation. Semi-arid climate and less rainfall as compared to annual evapotranspiration in the watershed and less available water for the leaching of insoluble carbonates and

bicarbonates of the calcium, facilitated the accumulation of CaCO_3 in these soils.

CEC of the soils was low (3.68 to 20.32 $\text{cmol (p}^+) \text{kg}^{-1}$) and depth wise distribution of CEC in soils of the profiles followed the pattern of clay distribution which influences, a significant positive correlation between CEC and clay ($r = 0.861^{**}$) and silt ($r = 0.511^{**}$) signifying that clay and silt were the principal factors that influenced CEC (Table 3). Contrarily, negative and significant correlation was observed between CEC and sand content ($r = -0.724^{**}$).

The exchangeable bases exhibited different regular and irregular trends because of topographic position. Among exchangeable cations, calcium was dominant (2.2 to 10.6 $\text{cmol (p}^+) \text{kg}^{-1}$) in all the pedons followed by magnesium (0.4 to 6.8 $\text{cmol (p}^+) \text{kg}^{-1}$), sodium (0.05 to 0.43 $\text{cmol (p}^+) \text{kg}^{-1}$) and potassium (0.03 to 0.22 $\text{cmol (p}^+) \text{kg}^{-1}$). The base saturation percentage (BSP) was ranging from 51.61 to 91.86% and high BSP was due to the occurrence of high exchangeable calcium (Vibha et al. 2019).

Soil classification: The soils of the watershed had ustic soil moisture regime (rainfall 300-1000 mm). The mean annual soil temperature was much higher than 22°C and the difference between mean summer and mean winter soil temperature was less than 6°C. Thus, the soils of the study area qualify for ustic soil moisture regime and isohyperthermic soil temperature regime. Based on the CEC / clay ratio for all the pedons was recorded as <0.7. Hence, minerology class for all the pedons was mixed.

The soils of the watershed were placed under the order Alfisols and Inceptisols. P2, P3, P4, P6 and P8, which have cambic (Bw) sub-surface diagnostic horizon only were classified under Inceptisols and these pedons were grouped under Ustepts at sub-order level due to presence of ustic soil moisture regime and Haplustepts 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 and these pedons did not exhibit any intergradation with other taxa or an extra gradation from the central concept. Hence, these pedons were logically classified as Typic Haplustepts at subgroup level (Leelavathy et al. 2014). P1, P5 and P7 have argillic (Bt) sub-surface diagnostic horizon which were classified under Alfisols and these pedons were grouped under Ustalfs at

sub-order level due to presence of ustic soil moisture regime and Haplustalfs at great group 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 and these pedons were classified into Typic Haplustalfs at sub-group level because of absence of lithic or paralithic contact within 100 cm from the surface horizon and absence of pumice or pumice like fragments and volcanic ash, absence of lamellae, sandy particles size except P5 which was classified under Ultic Haplustalfs at sub-group level due to the base saturation of argillic (Bt) horizon in P5 was < 75%. Based on particle size distribution, these soils were classified as fine loamy at family level.

4. CONCLUSION

The study indicated that there were considerable variations in the morphological, physical and chemical characteristics of the soils depending on their geomorphic position in the area. The texture of soils varied from sandy loam to sandy clay loam. Among exchangeable cations, calcium was dominant followed by magnesium, sodium and potassium. Soil classification (Inceptisols and Alfisols) revealed that sprinkler irrigation and growing of crops, viz. groundnut, redgram, oilseeds, millets, guava, custard apple and pomegranate are the best suggestions for these soils.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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