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Research article

Morphological characteristics and degradation vulnerability of hill side slope soils under natural forest and agroforestry in semi-arid Telangana, India

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Abstract

A study was conducted in the natural forest and agroforestry land uses in the semi-arid ecosystem in Telangana, India to understand the morphological properties of soils in a profile and their vulnerability towards land degradation. A total of five pedons were morphologically studied, four from natural forest and one from agroforestry from the hill side slopes landform of the study area. Soils from the agroforestry ecosystem possess dark reddish brown, sandy loam A horizons and dark reddish brown, sandy clay loam B horizons with dominant sub angular blocky soil structure. Soils of natural forest ecosystems had a dominant soil texture of sandy clay loam at the surface and sandy clay in the subsurface, indicating the process of clay illuviation. Land degradation vulnerability was assessed using the properties *viz.* thickness of the surface horizon, surface texture, surface structure, erosion, bulk density, pH and organic carbon, available P and K of the surface as indicators. It was found that P3 (0.89) was very high, P1 (0.72), P2 (0.78), and P4 (0.78) were high, and P5 (0.69) was medium in its land degradation vulnerability status. The very high vulnerability of P3 could be attributed to the very severe erosion, lower pH of 5.35 and medium status of organic carbon (0.71), available P and K. The soil reaction, organic carbon content, texture, structure, and nutrient status could thus be considered as good soil quality indicators to assess the land degradation.

Keywords: Agroforestry, Forest ecosystem, Land degradation, Soil characteristics

Introduction

In India, arid and semi-arid regions cover around 61% of the total geographical area, of which semi-arid regions cover around 34%. In general, arid and semi-arid ecosystems are fragile due to unfavourable physical, chemical and biological characteristics. Semi-arid environments possess limitations of productivity due to climate, particularly rainfall and temperature, long dry spells, high potential evapotranspiration, shorter growing period, soil moisture stress, salt accumulation, soil erosion, and decline in soil fertility. These threats make semi-arid ecosystems the most vulnerable in India. Telangana state in southern India experiences a semi-arid sub-tropical climate. According to NBSS &LUP, 2005, Telangana and Andhra Pradesh have a total of 54.5% of degraded area to the total geographical area of the country. The effects of climate change along with intensive agriculture have resulted in soil degradation in Telangana. Semi-arid environments in the south Deccan plateau are characterized by low and erratic rainfall, which directly influences soil properties and their development as well as the yield and productivity of crops. The soils of this region are highly diverse and are prone to both natural and anthropogenic degradation (Pal *et al*., 2000).

Land degradation refers to the decline in the capacity of an ecosystem to carry out its duties. The changes in land use, deforestation, poor management of forests, etc., lead to land degradation (Bhattacharyya *et al*., 2015). Land use has significant effects on soil morphological properties, particularly dynamic, including soil colour value, structure, root abundance, porosity, etc. (Grossman *et al*., 2001). Soil morphological studies provide knowledge on external features and structures of the soil body in a profile that includes colour, texture, structure, consistence, roots, mottles, etc., that are related to the physical, chemical, and mineralogical properties of soils (Bhattacharyya *et al*., 2006). Soil colour helps to identify the successions of soil horizons in a soil profile and it indirectly influences the soil physico-chemical and biogeochemical reactions in soils. Understanding the soil colour helps in interpreting acquired soil properties, which are dependent on pedogenic processes. Soil structure is another important morphological property which influences several soil reactions related to aeration, moisture, permeability, water holding capacity and soil fertility. Soil consistency is an indication of the relationship between soil and moisture, making it a function of the soil-water relationship. The higher the total and fine clay, the higher the stickiness and plasticity. With changes in landforms, the properties such as depth, texture, colour, structure, and diagnostic horizons vary (Zhang *et al*., 2018). The depth of horizons, porosity, soil colour, roots, drainage, soil texture, *etc*., could be morphological indicators of soil quality. Lands with better texture, structure, organic carbon, and available nutrients are less vulnerable to degradation. The changes in the soil properties thus affect the vulnerability towards land degradation. Since the morphological properties are categorical descriptors, it hinders their use as such. However, there are a few studies employing morphological characteristics of the soil surface in evaluating soil quality (Calero *et al*., 2018).

The utilization of soil profile morphological properties as land degradation vulnerability indicators remains limited. Land degradation could result from changes in climate or land use, etc. The physical factors that lead to degradation include variations in slope, land use, and soil characteristics, such as erodibility and unsustainable management practices (Dubovyk, 2017). The effect of land-use types on soil morphological quality is less explored (Vasu *et al*., 2021). In this context, the two different land uses, *viz*., natural forest and agroforestry, belonging to the hillside slopes landform in a semi-arid ecosystem, were considered to evaluate the morphological properties of soils and their vulnerability to land degradation.

Materials and Methods

Description of the study area: The study was carried out in Mahabubnagar Rural mandal of Mahabubnagar district, Telangana, located between 77° 49′ 43.133″ to 77° 59′ 33.183″ E longitudes and 16° 38′ 31.415″ to 16° 46′ 21.897″ N latitudes covering an area of 144.97 sq. km. (Fig.1). The area experiences a semi-arid sub-tropical climate with an annual average rainfall of 613.3 mm and total potential evapotranspiration (PET) of 1806.3 mm, much higher than the amount of rainfall received. The mean annual air temperature is between 23.4 and 33.4°C. The mean annual soil temperature (MAST) is greater than 22°C and the difference between MSST and MWST is less than 5ºC with an 'isohyperthermic' soil temperature regime and soil moisture regime is "ustic". Geologically, the study area belongs to the granite gneiss of Archaean origin, dating back to the lower Precambian age. The major landforms of the area were hillside slopes, uplands, and the lowlands. The soils of the study area belonged to *Alfisols, Inceptisols and Vertisols* orders.

Major land uses are rice, pigeon pea, sorghum, cotton, castor, mango, and vegetable crops like cowpea, chillies, tomato, and onion. Neem (*Azadirachta indica*), Pongame (*Pongamia pinnata*), *Cassia tora* and *Jaali* (*Prosopis juliflora)* were the dominant natural vegetation. Forestry covers only 2.43% of the total area spread in 3.52 sq.km. This was found mainly in the hillside slope landform. Among the 18 soil series identified in the study area, only one series was identified in hill side slopes landforms.

Soil sampling and analysis: The study area was surveyed for land resource inventory at a 1:10000 scale. A total of 114 soil profiles were studied for their morphological characteristics during the survey. All the morphological properties were studied and described according to the Soil Survey Manual (Soil Survey Staff, 2012). The depth of the soils, diagnostic horizons, and boundaries of horizons were described for all the pedons. The feel method was used to arrive at the soil textural class at the field level. Rock fragments were described by size, kind, and volume. The shape, size, and grade describe soil structure. Soil consistency and plasticity were tested for moist soils. The quantity and size of roots, as well as pores, were described in each layer. Soil colour was determined using the Munsell soil colour chart (Munsell Color Company, 2013). The soil colour determination includes hue, value and chroma of optimum moist soil.

The pedon locations and the site characteristics are presented in Table 1. Pedons were located at an elevation from 528 to 555 m above mean sea level. The pedons from natural forestry were located at 10 to 15% slope (strongly sloping) and the agroforestry ecosystem recorded a slope of 3 to 5% (gently sloping). The soils were well drained, with a groundwater table> 50 m deep, moderate to very severe erosion and medium to very rapid runoff. Master profile or typifying pedon was identified based on the central characteristics, considering it as a representative of the landform, and the typifying pedon here was pedon P1. Hence, horizon-wise soil samples were collected from the typifying pedon, air-dried, ground, sieved (<2 mm) and analysed for soil physical and chemical properties. Particle size analysis was carried out using the International pipette method (Piper, 1950). The soil pH and EC were determined by potentiometric and conductometric methods respectively (Jackson, 1973), organic carbon by wet oxidation method (Walkley and Black, 1934), calcium carbonate equivalent (CCE) by acid neutralization method (Piper, 1966), cation exchange capacity and exchangeable cations by 1 *N* ammonium acetate (pH 7.0) displacement method (Sarma *et al*., 1987). Base saturation was estimated as the ratio of total bases to cation exchange capacity. These soils were classified as per the USDA soil taxonomy (Soil Survey Staff, 2014).

Land degradation vulnerability: The status of land degradation was assessed by considering the climatic, soil physical and chemical variables, assigning grades for each parameter depending on its impact on soil degradation in the study area. These were carried out based on Expert opinion (EO). Expert opinion using indicators/ questionnaires is a method used at the global level to assess land/soil degradation to understand the severity/extent/ degree based on soil-related factors such as erosion, fertility, productivity, *etc.*, to result in classifying the degradation (Kapalanga, 2008). The EO-based parameters considered are total rainfall, dry months, thickness of surface horizon, surface texture, surface structure, erosion at the surface, and coarse fragments, etc. (Table 2). To know the status of land degradation, values have been assigned to the related soil parameters (Modified from Anil Kumar *et al*., 2017). The parameters considered here included rainfall and dry months of the study area, thickness of the surface horizon, surface texture, surface structure, erosion, bulk density, pH and organic carbon, and available P and K of the surface. To identify the vulnerability of soil towards land degradation, sensitivity scores were assigned to each parameter. Sensitivity scores in the range 1 to 5 were assigned to each class based on the importance of the parameter on land degradation. The highest score assigned to each parameter was 1. The lowest score varied from 2 to 5 in this study. The lowest score was 2 in the case of surface soil parameters such as texture, structure, and bulk density, whereas it was 3 in the case of parameters like rainfall, dry months, thickness of surface horizon, coarse fragments in the control section, surface pH, available P and K, it was 4 in organic carbon in the surface horizon and it was 5 in the case of erosion. These scores of corresponding soils were divided by the total scores of all parameters to arrive at the land degradation. In the present study, the total value of all parameters assigned was 36. The scores of corresponding soils were divided by the total scores of the parameters to arrive at the value of land degradation. The land degradation vulnerability criteria are presented in Table 2, where <0.50 is very low, 0.50-0.60 is low, 0.60 to 0.70 medium, 0.70 to 0.80 high and >0.80 is very high in vulnerability status.

Results and Discussion

A total of five pedons were studied, of which four were from natural forest ecosystems and one from an agroforestry system in the study area. These belonged to the hillside slopes landform of the study area. The photos of the profiles are presented in Fig. 2. The profile P1 is located at the summit, profiles P2 and P3 are at the shoulder slopes, P4 at the foot slope, and P5 at the toe slope of the hillside slope landform.

Among these five soils, P1 soils recorded the central characteristics (surface thickness, soil colour, structure, gravelliness, and presence of clay cutans) identified as the typifying pedon. It lies between 16° 46′ 12.91″ N Latitude and 77°56′08.22″ E Longitude at the Venkatapur village of Mahabubnagar Rural block of Mahabubnagar district, Telangana. The study site is located at the summit of the hills with undulating topography around. The typifying pedon was identified from the field cultivated to vegetables, chillies, and tomatoes in the natural forest ecosystem converted to agriculture. The natural vegetation includes Neem (*Azadirachta indica*), Pongame (*Pongamia pinnata*), Cassia (*Cassia tora*), and Kabul Acacia (*Prosopis juliflora).*

Morphological properties

Agroforestry ecosystem: The soils from the agroforestry ecosystem (P1) have dark reddish brown, sandy loam A horizons and dark reddish brown, sandy clay loam B horizons. The hue varied from 5 YR to 2.5 YR, value 3 and chroma 2 to 3 with depth (Table 3). The darker colour could be due to oxidation and intense leaching of bases, leaving sesqui-oxides (Sharma *et al*., 1996). The surface was weak, fine subangular blocky, and the subsurface was moderate, medium subangular blocky in structure. The dry consistency was loose at the surface

Table 1. Locations and site characteristics

Pedon*	Latitude (N)	Longitude (E)	Elevation (m)	Land use	Slope (%)	Erosion	Run off
P1	16^0 46′12.91″	77^{0}56′08.22″	555	Natural forestry and mixed agriculture, cultivated to vegetables	3-5	Moderate	Medium
P2	16^0 42′43.94″	77^{0}58′29.20″	541	Natural forestry	10-15	Very severe	Very rapid
P3	16^0 46′06.59″	77^{0}55′51.73″	536	Natural forestry	10-15	Very severe	Very rapid
P4	16^0 39′28.54″	77^{0}52′50.19″	532	Natural forestry	10-15	Severe	Very rapid
P5	16^0 45′08.97″	77^{0}55′58.82″	528	Natural forestry	15-25	Very severe	Very rapid

*All pedons were well drained and ground water table was >50 m

Table 2. Assigning grades to soil parameters to assess land degradation vulnerability

Rain fall (mm)	Dry months	Thickness of surface horizon (cm)	Surface texture	Surface structure	Erosion	Bulk density surface (g/cm^3)	Coarse fragments control section vol (%)	pH surface	OC surface horizon (%)	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Land degradation vulnerability criteria
>4000 = (1)	<5.0 = (1)	>20 = (1)	scl = (1)	1 f gr, 1 f cr, 1 m sbk = (1)	Very slight = (1)	<1.2 = (1)	<35 = (1)	6.0-7.3 = (1)	>2.5 = (1)	> 22 = (1)	>280 = (1)	<0.50 = very low
3500-4000 = (2)	5.0-5.5 = (2)	10-20 = (2)	gscl = (2)	2 m sbk, 2 f sbk, 1 f sbk = (2)	Slight = (2)	>1.2 = (2)	35-60 = (2)	5.5-6.0 = (2)	1.5-2.5 = (2)	11-22 = (2)	118-280 = (2)	0.50-0.60 = low
<2500= (3)	5.5-6.0 = (3)	<10 = (3)	sc, sl = (2)		Moderate = (3)		>60 = (3)	7.3-7.8 = (2)	0.75-1.5 = (3)	<11 = (3)	<115 = (3)	0.60-0.70 = medium
	>6.0= (3)				Severe = (4)			<5.5 = (3)	<0.75 = (4)			0.70-0.80 = high
					Very severe =(5)			>7.8 = (3)				>0.80= very high

scl: Sandy clay loam; sl: Sandy loam; sc: Sandy clay; g: Gravelly; eg: Extremely gravelly; f: Fine; m: Medium; 1: Weak; 2: Moderate; gr: Granular; cr: Crumb; sbk: Sub angular blocky; OC: Organic carbon; P: Phosphorus; K: Potassium

and it varied from very friable to friable with depth when wet. The surface was slightly sticky and slightly plastic. Stickiness and plasticity increased with depth. Gravelliness increased with depth from gravelly to extremely gravelly. The surface had common medium roots and many medium pores, whereas there were very few fine roots, as well as common fine pores in the subsurface. The cultivation influences the upper surface of the soil profile and physical properties worsen when compared to the natural ecosystem. Similar findings have been observed by Paltineanu *et al*. (2020).

Natural forest ecosystem: The surface soil colour was dark reddish brown in P2 (5YR 3/4), P3 (5YR 3/3) and P5 (5YR 3/2) with variations in chroma. In P4, it was brown in colour (7.5YR 3/4) (Table 3). The subsurface soils were dark red (2.5YR 3/6) in P2 and dark reddish brown (2.5 YR 3/4) in P3. In P4, the subsurface soil colour varied with hue from 5 YR to 7.5 YR, value 3 and chroma 3 to 4. In P5, the subsurface was having a hue of soil colour varying from 2.5 to 5, value 3 and chroma 2 to 4. The addition of organic matter is the reason for the darker soils. Along with the chemical and mineralogical makeup of soils, the darker colour could be a result of topography and textural differences (Walia and Rao 1997; Chandrashekhar *et al.,* 2017). Darker soils absorb more solar radiation and tend to become hotter. Rubrifaction, ferralitization, braunification, and ferrugination are the major processes that result in the development of soil colour. The dark reddish brown to reddish brown colour (7.5YR to 2.5YR) of all the pedons was the result of a combination of all these processes.

Soil texture is one of the properties that is considered with much importance with regard to soil degradation (Anil Kumar *et al*., 2017). The surface soil texture was sandy clay loam in P2, P3, and P5, whereas it was sandy loam in P4. The removal of finer particles by erosion is responsible for the occurrence of coarse-textured soil in P1 (agroforestry) and P4. Land use also affects soil properties such as texture (Lepcha and Devi, 2020). The subsurface texture was sandy clay in P2, P3, and P5 and it varied from sandy clay loam to sandy clay in P4. All these indicated a clear increase in clay with depth, which could be due to granite-gneiss parent material coupled with leaching of clay particles to the lower layers, indicating the process of illuviation (Nagendra and Patil, 2015; Karthika *et al*., 2022). The gravel percentage increased with depth from 30 to 50% in P2 and from 30 to 65% in P3. In P4 and P5, the gravel content varied from 40% in the surface to 30% in the subsurface of P4 and 65% in the surface to 40% in the subsurface in P5. The soils P2, P3 and P5 recorded a clear, smooth boundary at the surface, whereas it was abrupt and smooth in P4. All the soils recorded a gradual, smooth boundary at the subsurface. Similar results were obtained by Deressa *et al*. (2018).

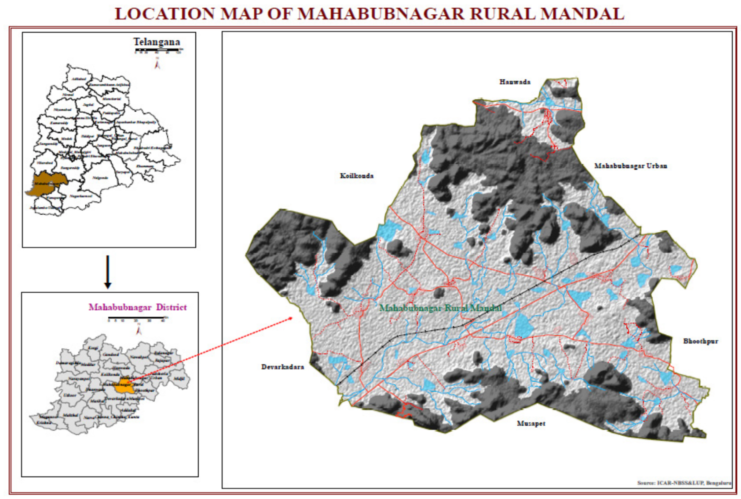
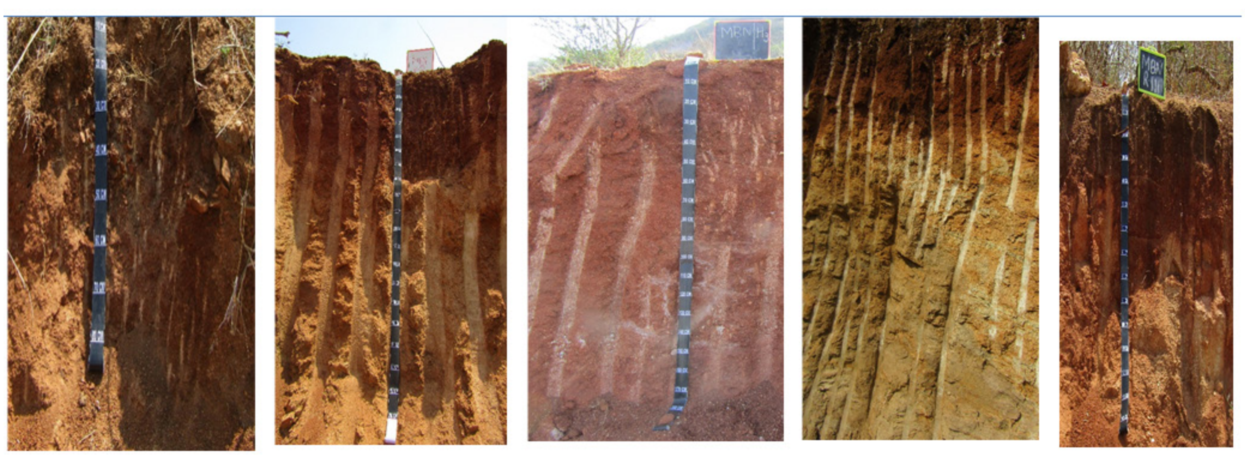


Fig 1. Location map of the study area

The dominant soil structure was subangular blocky. It was weak medium in P2 and P3 and weak fine in P4 and P5 at the surface. In the subsurface, the dominant structure was moderate to medium subangular blocky. In P2, the surface soil was slightly hard when dry and the moist soil consistency was friable, moderately sticky, and plastic. In P3, the surface soil was slightly hard when dry and very friable in consistency when wet. The stickiness and plasticity increased with depth from slightly sticky and plastic to moderately sticky and plastic. The structure and consistency of soils are influenced by clay fraction and clay minerals (Thangasamy *et al*., 2005). In P4 and P5, surface soils were loose and very friable in consistency, respectively, when dry and wet. The stickiness and plasticity increased with depth. Soil consistency is highly dependent on organic matter and soil texture (Wani *et al*., 2016). Relatively higher clay towards the depth justifies higher stickiness and plasticity. A few very fine and medium roots were present on the surface and very fine and fine roots at the sub-surface of P2 and P4. Common fine roots were present on the surface in P3, and many fine roots were present in P5.

Cutans were present in the subsurface of all the soils. These soils, in general, are moderately deep, well-drained, with rapid permeability and are subjected to moderate erosion and medium runoff. Soil erosion is an important parameter that determines the degradation status of a soil. When proper conservation measures are absent, soil erosion could be serious and result in the continuous loss of fine particles and nutrients, leaving the surface coarser and ultimately leading to an unproductive soil over a period of time (Anil Kumar *et al*., 2017).



P1 P2 P3 P4 P5

Fig 2. Soil profiles of the study area

Table 3. Morphological properties of the pedons

Horizon	Depth (cm)	Boundary	Matrix colour		Texture	Gravel (%)	Structure	Consistency				Roots	Pores	Coats/ Films
			Dry	Moist				D	M	S	P	Qty Sz	Qty Sz	
Pedon 1														
Ap	0-16	a s	5 YR 3/3	5YR 3/2	g sl	35 fg cg	1 f sbk	l	v fr	ss	sp	c m	m m	-
Bt1	16-44	c s		5 YR 3/2	eg scl	65 fg cg	2 m sbk		Fr	ms	vp	vf f	c f	tn p
Bt2	44-77			2.5 YR 3/3	eg scl	75 fg cg	2 m sbk		Fr	ms	mp			tn p
Cr														
Pedon 2														
A	0-12	c s	5 YR 5/4	5 YR 3/4	scl	30 fg cg	1 m sbk	sh	Fr	ms	mp	f vf, m	m f	
Bt1	12-29	g s		2.5 YR 3/6	sc	40 fg cg	2 m sbk		Fr	ms	mp	f vf m	m c	tk p
Bt2	29-53	g s		2.5 YR 3/6	sc	50 fg cg	2 m sbk		Fr	ms	mp	f vf, f	m c	tk p
Bt3	53-75	g s		2.5 YR 3/6	sc	50 fg cg	2 m sbk		Fr	ms	mp	f vf f	m c	tk p
Cr														
Pedon 3														
A	0-19	c s	5 YR 3/4	5 YR 3/3	scl	30 fg	1 m sbk	sh	v fr	ss	sp	c f	c vf	
Bt1	19-45	g s		2.5 YR 3/4	sc	45 fg	1 m sbk		Fr	ms	mp	c f	c vf	tk c
Bt2	45-73	g s		2.5 YR 3/4	sc	45 fg	1 m sbk			ms	mp			tk c
BC	73-99	g s		2.5 YR 4/6	sc	65 fg	1 m sbk			ms	mp			tk p
Cr														
Pedon 4														
A	0-20	a s	7.5 YR 5/4	7.5 YR 4/4	sl	40 fg cg	1 f sbk	l	v fr	s0	p0	f vf m	m c	
Bt1	20-41	g s		7.5 YR 3/3	scl	40 fg cg	1 m sbk		fr	ms	mp	c vf f	m c	tn p
Bt2	41-62	g s		5 YR 3/4	sc	30 fg cg	2 m sbk		fr	ms	mp	f f	c m	tn p
BC	62-93			5 YR 3/3	sc	30 fg cg	2 m sbk		fr	ms	mp	f f	c m	tn p
Cr														
Pedon 5														
A	0-15	c s	5 YR 4/2	5 YR 3/2	scl	65 fg cg	1 f sbk	l	v fr	ss	sp	m f	m m	
Bt1	15-37	g s		5 YR 3/2	sc	40 fg cg	1 m sbk		fr	ms	mp	m f	m f	tn p
Bt2	37-62	g s		2.5 YR 3/4	sc	50 fg cg	2 m sbk		fr	ms	mp	m m	m m	tk
Bt3	62-80	-		2.5 YR 3/4	sc	40 fg cg	2 m sbk		fr	ms	mp	m f	m m	tk

A: Surface horizon; Ap: Cultivated A horizon; Bt: B horizon with clay illuviation; a s: Abrupt smooth; c s: Clear smooth; g s: Gradual smooth; fg: Fine gravel; cg: Coarse gravel; l: Loose; fr: Friable; vfr: Very friable; ss: Slightly sticky; ms: Moderately sticky; sp: Slightly plastic; mp: Moderately plastic; cm: Common medium; vf f: Very few fine; f vf: Few very fine; c f: Common fine; f f: Few fine; m f: Many fine; m m: Many medium; m c: Many coarse; c c: Common coarse; tn p: Thin patchy; tk: Thick scl: Sandy clay loam; sl: Sandy loam; sc: Sandy clay; g: Gravelly; eg: Extremely gravelly; f: Fine; m: Medium; 1: Weak; 2: Moderate; gr: Granular; cr: Crumb; sbk: Sub angular blocky; OC: Organic carbon; P: Phosphorus; K: Potassium

Table 4. Physico-chemical properties of pedon from agroforestry system (P1)

	Depth (cm)	Sand	Silt	Clay	pH (1:2.5)	CEC	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Sum	BS	ESP	CCE	CEC/ Clay
		(2 -0.05 mm)	(0.05-0.002 mm)	(<0.002 mm)		<--------------------c mol (+) kg^{-1}------------------->						(%)	%	%	
Pedon 1															
Ap	0-16	72.28	9.88	17.84	6.11	11.88	4.60	2.47	0.78	0.02	7.87	66	0.20	0.00	0.67
Bt1	16-44	67.86	9.19	22.95	5.84	13.54	5.53	2.07	0.15	0.06	7.81	58	0.42	0.00	0.59
Bt2	44-77	70.56	7.69	21.75	6.22	13.88	9.84	3.19	0.24	0.15	13.42	97	1.08	0.00	0.64
Cr															

Table 5. Nutrient status of the soils

Pedon	Dry BD g cm^{-3}	pH	EC (dS m^{-1})	OC (%)	P (kg/ ha)	K (kg/ ha)	S (ppm)	B (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
P1	1.46	6.11	0.179	1.93	26	544	34.16	0.80	0.78	12.94	21.20	0.70
P2	1.63	5.81	0.072	0.95	5	299	27.50	0.30	0.74	8.32	21.78	0.38
P3	1.55	5.35	0.098	0.71	5	87	21.66	0.31	1.72	20.68	48.40	0.30
P4	1.63	6.22	0.047	1.00	2	113	29.16	0.57	0.88	4.00	11.66	0.18
P5	1.52	7.42	0.279	2.89	118	510	10.83	0.57	1.06	9.64	6.64	1.32

Chemical properties and soil classification of pedon from agroforestry ecosystem (P1): The surface was slightly acidic with a pH of 6.1 and the subsurface was slightly acid (pH 5.84) to moderately acid (pH 6.22) (Table 4). The cation exchange capacity was 11.88 cmol (+) kg^{-1} of soil at the surface to 13.88 cmol (+) kg^{-1} at the subsurface. Exchangeable Ca, Mg and Na increased with depth, whereas exchangeable K decreased from surface to subsurface. Soils were rich in bases and the base saturation increased from 68 to 97 with depth. CEC/clay ranged between 0.59 and 0.67.

Clay illuviation was recorded in pedon 1 with an increase in clay from 17.84 to 22.95% (Karthika *et al*., 2022), indicating the presence of an argillic horizon, which has resulted in classifying these soils under the *Alfisols* order. Since the soil moisture regime is ustic, the soils are keyed out to *ustalfs* suborder. In the argillic horizon, the hue was redder with 2.5 YR to 5 YR and a value of 3 or less, which keyed out the soils to *Rhodustalfs* great group and it was *Typic Rhodustalfs* at the sub-group level. The mean annual soil temperature (MAST) is greater than 22°C and the difference between MSST and MWST is less than 5°C; hence belongs to the isohyperthermic soil temperature regime. The CEC clay ratio was found to be greater than 0.6, indicating the superactive cation exchange activity class. The clay mineralogy class was identified as mixed. The particle size class was found to be loamy-skeletal due to less than 35% (by weight) clay in the fine-earth fraction and > 35% gravels in the pedon. Hence, at the family level, the pedon was keyed out as a member of the loamy-skeletal, mixed, superactive, isohyperthermic family of *Typic Rhodustalfs* (Karthika *et al*., 2021).

Nutritional status of soils: The soil reaction varied from pH 5.35 in P3 to 7.42 in P5 (Table 5). Electrical conductivity values were low, < 2 dS $m^{-1,}$ in all the soils. Organic carbon status was high (>0.75%) in all the soils except in P3, which was medium with a value of 0.71%. The presence of moist/ dry deciduous forests or mixed forests with scattered trees, with grasslands and scrub vegetation towards the lower canopy, ensures a robust root system, enabling better recycling of organic carbon. The root rhizosphere activities and microbial processes could improve the microbial biomass carbon, too, resulting in a higher organic carbon content in soil. Higher carbon content in the soil indicates better quality of the soil and thereby less degradation vulnerability. Differences in soil organic carbon stocks were found to be an indicator of soil degradation (Karthika *et al*., 2021). Soil organic matter content and soil erosion are interrelated. Addition of organic matter and measures to control soil erosion are to be followed to prevent degradation happen in any ecosystem. P5 recorded higher P content (118 kg ha^{-1}), followed by P1, which recorded a medium P of 26 kg ha^{-1}. Other soils were low in available P status. Potassium content was the highest in P1 (544 kg ha^{-1}), followed by P5 (510 kg ha^{-1}) and the lowest in P3 (87 kg ha^{-1}). Sulfur and B were the highest in P1. Pedon 3 recorded higher values of Cu, Fe, and Mn, whereas Zn was higher in P5 (1.32 ppm).

Table 6. Assigned grades to soils to assess land degradation vulnerability

	Rain fall	Dry months	Thickness of surface horizon	Surface texture	Surface structure	Erosion	Bulk density surface	Coarse fragments (control section) Vol (%)	pH surface	OC surface (%)	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Land degradation vulnerability status
P1	613.3 = (3)	7= (3)	16= (2)	sl = (2)	f1sbk = (2)	Moderate = (3)	1.46= (2)	70.78= (3)	6.11 = (1)	1.93 = (2)	26 = (2)	544 = (1)	26/36=0.72 high
P2	613.3 = (3)	7 = (3)	12 = (2)	scl = (1)	m1sbk = (1)	Very severe = (5)	1.63= (2)	48.44 = (2)	5.81 = (2)	0.95 = (3)	5 = (3)	299 = (1)	28/36=0.78 high
P3	613.3 = (3)	7= (3)	19 = (2)	scl = (1)	m1sbk = (1)	Very severe= (5)	1.55= (2)	51.58 = (2)	5.35 = (3)	0.71= (4)	5 = (3)	87 = (3)	32/36=0.89 very high
P4	613.3 = (3)	7= (3)	20 = (1)	sl = (2)	f1sbk = (2)	Severe = (4)	1.63= (2)	32.87 = (1)	6.22 = (1)	1.00 = (3)	2 = (3)	113= (3)	28/36= 0.78 high
P5	613.3 = (3)	7= (3)	15 = (2)	scl= (1)	f1sbk = (2)	Very severe = (5)	1.52= (2)	44.69 = (2)	7.42 = (2)	2.89 = (1)	118 = (1)	510 = (1)	25/36= 0.69 medium

Land degradation vulnerability: Field measurements, visual interpretation, and environmental indicators are among the many methodologies used to study land degradation. In this study, the field survey was utilised to understand the extent of land degradation, mainly based on the morphological characteristics. The expert opinion method was utilized in the assessment as it is one of the many methods used in assessing land degradation (Kapalanga, 2008). Besides the surface pH, BD, OC, and available nutrients, the morphological properties were assessed (Table 2 and 6) in understanding land degradation vulnerability in the soils of hillside slopes landform of semi-arid natural forest and agroforestry ecosystems. The grades were assigned to the different parameters considered and the results of vulnerability analysis are presented in Table 6. The total assigned value for all the parameters was 36 in the study. The results revealed that the land degradation vulnerability scores were 0.72, 0.78, 0.89, 0.78, and 0.69 in the studied soils. The land degradation vulnerability analysis revealed that P3 was very high (0.89), P1, P2, and P4 were high, and P5 was medium (0.69) in its status. The very high vulnerability of P3 could be attributed to the very severe erosion, lower pH of 5.35 and medium status of organic carbon (0.71), available P and K. Soils P1, P2, and P4 were rated highly vulnerable to land degradation. Coarse fragments, soil structure, and texture in P1, very severe erosion, low status of organic carbon and P in P2 and soil texture, structure, severe erosion, and low organic carbon, P and K were the reasons for their high vulnerability. Soil P5 was rated relatively less vulnerable (medium) to land degradation (0.69) because of its sandy clay loam texture, higher organic carbon, and nutrient status. It was understood that among the morphological properties, soil texture, structure and erosion exhibited huge importance in assessing the land degradation. Lands with favourable texture and structure are less prone to degradation, making them better soil quality indicators (Dharumarajan *et al*., 2017). Nutrient management and soil conservation measures need to be followed in the areas that are affected by degradation. It was also seen that the higher the organic carbon content in the soils, the less prone they are to degradation. Land with better organic carbon is considered neither degraded nor vulnerable to degradation and hence considered a good soil quality indicator by Mensah (2015).

Conclusion

Soils of both ecosystems were moderately deep, well-drained with rapid permeability and subjected to moderate erosion and medium runoff. The soils of the natural forest ecosystem were sandy clay loam in the surface and sandy clay in the subsurface, with a dominant soil structure of sub-angular blocky. The assessment of land degradation vulnerability considered soil indicators such as soil texture, structure, thickness of surface horizon, coarse fragments, erosion, pH, bulk density, organic carbon, available P and K in the surface soils. Soil P3 was rated very highly vulnerable due to the very severe erosion, lower pH, organic carbon, available P and K. The higher organic carbon and favourable texture of sandy clay loam in P5 resulted in its relatively lesser degradation of medium vulnerability. The soil reaction, organic carbon content, texture, structure, and nutrient status could thus be considered as good soil quality indicators to assess the land degradation. The soil properties, morphological as well as chemical, have significant effects on soil degradation and vulnerability potential and also in understanding the soil quality. An understanding of the soils, their quality, and the extent of degradation will help stakeholders in developing an effective land use plan and conservation measures according to the vulnerability class. Proper conservation measures have to be developed to protect these fragile ecosystems prone to degradation. Hence, there is a need for reliable and accurate measurements on soil degradation, understanding desertification, enabling the enhanced scientific needs, proper natural resource management, and aiding in policy making.

References

Anil Kumar, K.S., M. Lalitha, Sidharam Patil, B. Kalaiselvi, K. M. Nair and S.K. Singh. 2017. Assessment of land degradation vulnerability: A case study from part of the Western Ghats and west coast of India. *In: Sustainable Management of Land Resources: An Indian Perspective*. pp. 213-238.

Bhattacharyya, R., B. N. Ghosh, P. K. Mishra, B. Mandal, Ch. S. Rao, D. Sarkar, K. Das, K.S. Anil Kumar, M. Lalitha, K.M. Hati and A.J. Franzluebbers. 2015. Soil degradation in india: challenges and potential solutions. *Sustainability* 7: 3528-3570. doi:10.3390/su7043528.

Bhattacharyya, T., P. Chandran, S. K. Ray, C. Mandal, D. K. Pal, M. V. Venugopalan, S. L. Durge, P. Srivastava, P. N. Dubey, G. K. Kamble, R. P. Sharma, S. P. Wani, T. J. Rego, V. Ramesh and M. C. Manna. 2006. Morphological properties of red and black soils of selected benchmark spots in semi-arid tropics of India. *Global Theme on Agroecosytems Report No. 21.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, and Indian Council of Agricultural Research (ICAR), New Delhi, India. pp. 100.

Calero, J., V. Aranda, A. Montejo-Ráez and J.M. Martín-García. 2018. A new soil quality index based on morpho-pedological indicators as a site-specific web service applied to olive groves in the Province of Jaen (South Spain). *Computers and Electronics in Agriculture* 146: 66-76.

Chandrashekhar, Ch., M. V. S. Naidu, T. Ramprakash and D. Balahuravaiah. 2017. Characterization and classification of soils in the central parts of Prakasam district in Andhra Pradesh, India. *International Journal of Current Microbiology and Applied Sciences* 6(10): 2699-2712.

Deressa, A., M. Yli-Halla, M. Mohamed and L. Wogi. 2018. Soil classification of humid western Ethiopia: A transect study along a toposequence in Didessa watershed. *Catena* 163:184-195.

Dharumarajan, S., M. Lalitha, Rajendra Hegde, B. Somashekar and S. K. Singh. 2017. Biophysical characterization of Kangeyam grasslands for land degradation vulnerability Analysis. *Range Management and Agroforestry* 38 (1): 10-16

Dubovyk, O. 2017. The role of remote sensing in land degradation assessments: opportunities and challenges. *European Journal of Remote Sensing* 50: 601-613.

Grossman, R. B., D. S. Harms, C. A. Seybold and M. T. Sucik. 2001. A morphological index for soil quality evaluation of near-surface mineral horizons. In: D.E. Stott (ed.) *Sustaining the Global Farm. Selected Papers from the 10th International Soil Conservation Organization Meeting*, Purdue University and USDA-ARS National Soil Erosion Research Laboratory (May24-29, 1999). Purdue University, West Lafayette, IN. pp. 637-640.

Jackson, M. L. 1973. *Soil Chemical Analysis.* Prentice Hall of India, New Delhi. pp. 498.

Kapalanga, T. S. 2008. A review of land degradation assessment methods. Final Report, Land Restoration Training Program, Iceland.pp. 17-68.

Karthika, K. S., K. S. Anil Kumar, R. Srinivasan, M. Chandrakala, M. Lalitha, S. Srinivas, B. P. Bhaskar and Rajendra Hegde. 2021. Land resource inventory of Mahabubnagar Rural Mandal, Mahabubnagar district, Telangana on 1:10000 scale for optimal agricultural land use planning using geo spatial techniques. *NBSS Publication No. 1153*. ICAR-NBSS&LUP, Nagpur.

Karthika, K.S., K. S. Anil Kumar, R. S. Reddy and Jagdish Prasad. 2022. Characterization and classification of major mango-supporting soils in semi-arid ecosystem of south Deccan Plateau, Telangana. *Journal of the Indian Society of Soil Science* 70 (3): 279-286.

Lepcha, N.T. and N. B. Devi. 2020. Effect of land use, season, and soil depth on soil microbial biomass carbon of eastern Himalayas. *Ecological Processes* 9: 65. https://doi.org/10.1186/s13717-020-00269-y.

Mensah, A. K. 2015. Role of re-vegetation in restoring fertility of degraded mined soils in Ghana: a review. *International Journal of Biodiversity Conservation* **7:** 57-80.

Munsell Color Company. 2013. *Munsell Soil Color Charts.* MacBeth Division of Kollmorgen Instruments Corporation, Baltimore.

Nagendra, B.R. and P.L. Patil. 2015. Characterization and classification of soil resources of Shirol West-1 micro-watershed. *Karnataka Journal of Agricultural Sciences* 28: 504-509.

Pal, D. K., G. S. Dasog, S. Vadivelu, R. L. Ahuja and T. Bhattacharyya. 2000. Secondary calcium carbonate in soils of arid and semi-arid regions of India. In: R. Lal, J.K. Kimble, H. Eswaran and B.A. Stewart (eds). *Global Climate Change and Pedogenic Carbonates.* Lewis Publishers, Boca Raton, Florida. pp. 49-85.

Paltineanu, C., R. Lacatusu, A. Vrinceanu, O. Vizitiu and A. R. Lacatusu. 2020. Comparing soil physical properties in forest soils and arable soils within heavy-clay Phaeozems: an environmental case study in Romania. *Agroforestry Systems* 94: 113-123.

Piper, C. S. 1950. *Soil and Plant Analysis*. The University of Adelaide Press, Adelaide, Australia. pp. 1-368.

Piper, C. S. 1966. *Calcium Carbonate, Soil and Plant Analysis*, A laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants. pp. 135-136.

Sarma, V. A. K., P. Krishnan and S. L. Budihal. 1987. *Laboratory Methods.* National Bureau of Soil Survey and Land Use Planning, Nagpur. pp. 1-49.

Sharma, J. P., R. J., Landey, A. R. Kalbande and C. Mandal. 1996. Morphological, physical and chemical characteristics and land use plans of different landforms in Pratapgarh region of southern Rajasthan. *Agropedology* 9: 76-83.

Soil Survey Staff. 2012. *Soil Survey Manual*. United States Department of Agriculture hand book No.18, Natural Resources Conservation Service, Washington, DC.

Soil Survey Staff. 2014. *Keys to Soil Taxonomy.*12th edn. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

Thangasamy, A., M. V. S. Naidu, N. Ramavatharam and C. Raghava Reddy. 2005. Characterisation, classification, and evaluation of soil resources in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science* 53: 11-21.

Vasu D., G. Tiwari, S. Sahoo, B. Dash, A. Jangir, R. P. Sharma, R. Naitam, P. Tiwary, K. Karthikeyan and P. Chandran. 2021. A minimum data set of soil morphological properties for quantifying soil quality in coastal agroecosystems. *Catena* 198: 105042. https://doi.org/10.1016/j.catena.2020.105042.

Walia, C. S. and Y. S. Rao. 1997. Characteristics and classification of some soils of Trans-Yamuna plains. *Journal of the Indian Society of Soil Science* 45: 156-162.

Walkley, A. and C. A. Black. 1934. An examination of digestion method for determining organic carbon in soil, effect of variation in digestion conditions and of inorganic soil constituents. *Soil Science* 63: 251-263.

Wani, S. A., G. R. Najar, T. Ali and F. Akhtar. 2016. Morphology, genesis, and classification of pear growing soils of Pulwama district in lesser Himalayas of temperate Kashmir. *Journal of Environmental Biology* 45:1021-1027.

Zhang, Y., Y. Liu, Y. Zhang, Y. I. Liu, G. Zhang and Y. Chen. 2018. On the spatial relationship between ecosystem services and urbanization: A case study in Wuhan, China. *Science of The Total Environment* 637-638: 780-790.