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Characterization and classification of soils under different landforms using geospatial technology in Kupti watershed of Yavatmal district, Maharashtra

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Abstract
The present investigation was carried out in the Kupti watershed of Yavatmal district, Maharashtra for the characterization and classification of soils. Soil survey at 1:10000 scale was carried out using base map and landform-soil relationship was established. Ten soil series have been tentatively identified. The representative pedons of each soil series were analysed for different parameters. The soils of very gently sloping and gently sloping plateau top were shallow to slightly deep, well drained to somewhat excessively drained, clay loam to clay, moderate to severely eroded and classified as Lithic Ustorthent and Vertic Haplustept whereas, most soils occurring on very gently sloping lower and upper alluvial plains were deep, well drained, brown (7.5YR 3/2 and 10 YR 4/2) in colour, calcareous, clay loam to clay in texture, moderately eroded and classified as Vertic Haplustept and Typic Haplustert. The soils of pediment occurring on gently to moderately sloping lands were very shallow to moderately deep, clay in texture, moderately eroded were classified as Lithic Ustorthent and Typic Haplustert. The soils of escarpments on moderately steeply sloping lands were shallow, well drained, clay loam, very severely eroded and classified as Lithic Ustorthent. Surface horizons of most of the soils exhibit medium, moderate subangular blocky structure whereas, it is sub-angular to angular blocky in the sub-surface horizons.

Keywords: characterization and classification, watershed, landform

Introduction
With the increase in human and animal population, nutrient depletion of soils for more food production is on the increase. However, the capacity of a soil to produce is limited and the limits to production are set by intrinsic characteristics, agro-ecological settings, use and management. Planning for sustainable use of lands demands systematic appraisal of our soil resources with respect to their extent, distribution, characteristics, behaviour and use potential, which is very important for developing an effective land use system for augmenting agricultural production on a sustainable basis.

In developing countries, where research funds are limited, the availability of pedogenic information and proper classification of soils will be of great importance. The knowledge of soils with respect to their characteristics, properties, classification, distribution and potential uses is always needed for sustainable land use planning. Landscapes position influences runoff, drainage, soil temperature, soil erosion, soil depth and hence soil formation. Different soil properties encountered along landscapes will affect the patterns of plant production, litter production and decomposition, which will definitely have effects on carbon (C) contents of the soil. Soil properties such as clay content and its distribution with depth, sand content and pH have been shown to be highly correlated with landscape position while organic matter has been shown to vary with slope position.

The investigations reported in this article were conducted in an agricultural watershed that represents semi-arid region of the Vidarbha region in Maharashtra. The characterization and classification of the soils of Kupti watershed is presented.

Material and Methods
The study was taken up in a Kupti watershed (Fig.1) located at 20° 15” 47” to 20° 20” 42” N latitude and 77° 35” 27” to 77° 42” 54” E longitude, covering an area of 11257.1 ha and elevation varying from 340 m to 470 m above the mean sea level (MSL).

The study area is falling under the Survey of India toposheet of 55 L/11 (1:50,000) and agro-ecologically it is placed in 'hot moist to semi-arid AESR 6.3. Geologically, the area is mainly occupied by the Deccan trap formation known as basalt flows, which belongs to Sahyadri group of Ajanta and Chikhli formations. (District Resource Map, Yavatmal District, Maharashtra of Geological survey of India, 2001). The average annual rainfall of (2005-2015) is about 798 mm, temperature rises rapidly after February till May which is the hottest month of the year with mean daily maximum temperature 42.8° C during May and the mean daily minimum 21.2° C. After October, the day and night temperatures decrease rapidly. January is usually the coldest month with the mean daily maximum temperature at 29.6° C and the mean daily minimum at 13.9° C. The relative humidity ranges from 44.3 % to 54.6 %.

Soil survey at 1:10000 scale was carried out using base map and landform-soil relationship was established. Soil pedons were georeferenced (Table 1). Landform map of the watershed was prepared using LANDSAT-8 remote sensing data. Physical properties of the soils, such as particle size distribution were determined by the international pipette method (Klute, 1986) [12]. The bulk density was determined by clod coating method (Black and Hartge, 1986) [5]. The hydraulic conductivity was measured by constant head method described by Klute and Dirksen (1986) [13]. Chemical properties like pH and EC of the soil suspension (1:2 ratio) was determined by the methodology of Jackson (1973) [9]. For the determination of soil organic carbon (SOC), the modified Walkley and Black wet oxidation method was used (Walkley and Black, 1934; Jackson, 1973) [27, 9]. The free calcium carbonate was determined by rapid titration method (Piper, 1966) [20]. The exchangeable cations and cation exchange capacity of soils were determined using methods outlined by Richards (1954) [22].

Table 1: Geo-referencing of soil pedons

Sl. No.	Pedons	Latitude (N)	Longitude (E)
1	P1	20^{O} 16“ 35’	77^{O} 41“ 0’
2	P2	20^{O} 17“ 10’	77^{O} 41“ 23’
3	P3	20^{O} 16“ 44’	77^{O} 42“ 34’
4	P4	20^{O} 16“ 11’	77^{O} 42“ 02’
5	P5	20^{O} 17“ 11’	77^{O} 42“ 14’
6	P6	20^{O} 16“ 53’	77^{O} 41“ 17’
7	P7	20^{O} 17“ 33’	77^{O} 42“ 22’
8	P8	20^{O} 17“ 24’	77^{O} 42“ 11’
9	P9	20^{O} 17“ 12’	77^{O} 41“ 56’
10	P10	20^{O} 17“ 04’	77^{O} 42“ 03’

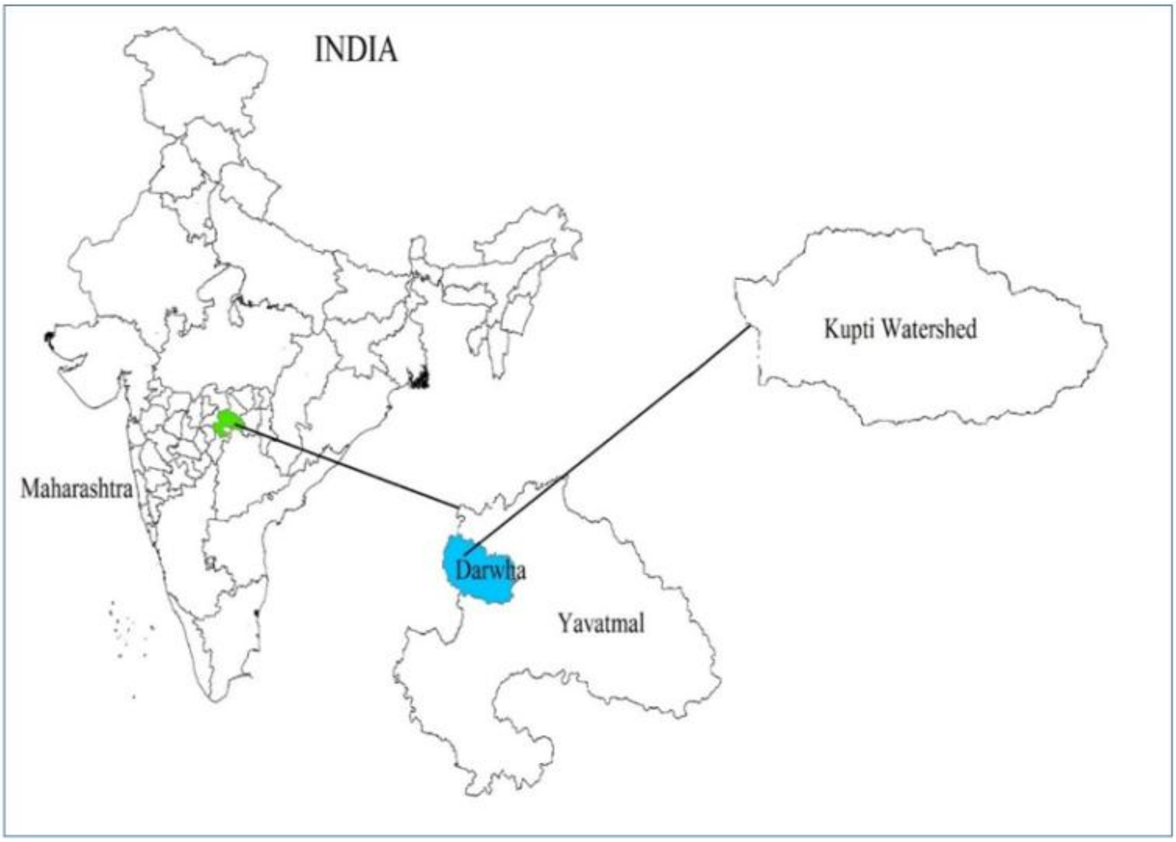

Fig 1: Location map of Kupti watershed

Results and Discussion

Landform classification

The watershed represents typical basaltic terrain, which shows topography expressed by the different heights of the plateau related to the different basaltic flows. These steps are indicative of successive geological horizons of the different lava flows one above the other intervening intertrappean beds forming the terrace levels due to their lesser resistance capacity (Anon. 1995) [2]. Subsequent diastrophic movement and sub aerial processes have given rise to appreciable regional and local variations in landscape evolution.

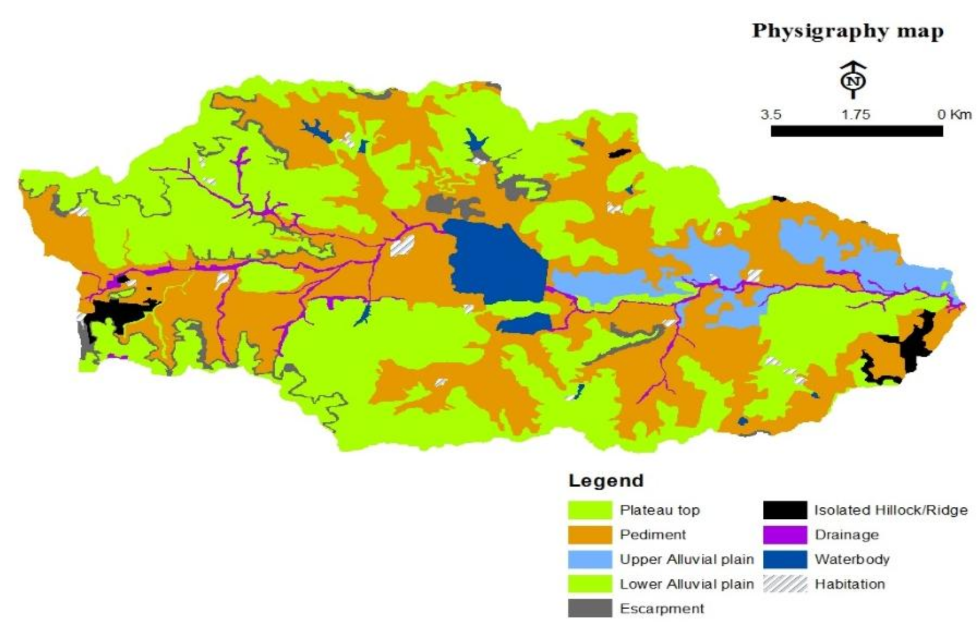

Fig 2: Landform map of Kupti watershed

Based on interpretation of satellite data, SOI toposheet and subsequent ground truth verification, nine major landform units *viz*. (i) Plateau top (ii) Pediment (iii) Upper Alluvial plain (iv) Lower Alluvial plain (v) Escarpment (vi) Isolated Hillock/Ridge and (vii) Drainage line were identified and the landform map (Fig. 2) was generated.

Perusal of data (Table 2) shows that the plateau is the major landform in the watershed occupying an area of 4749 ha representing 42.2 per cent of total geographic area (TGA) of watershed, followed by pediment 4255 ha (37.8 % of TGA). Upper alluvial plain and lower alluvial plain cover area of 605 ha (5.4 % of TGA) and 603 ha (5.4 % of TGA) respectively. Escarpment occupies 259 ha (2.3 % of TGA) and Isolated hillock occupies 148 ha (1.3 % of TGA). Drainage lines cover an area of 99 ha (0.9 % of TGA).

Table 2: Extent and distribution of landform units of Kupti watershed.

Sl. No.	landform unit	Area (ha)	% TGA
1	Plateau top	4749	42.2
2	Pediment	4255	37.8
3	Upper alluvial plain	605	5.4
4	Lower alluvial plain	603	5.4
5	Escarpment	259	2.3
6	Isolated hillock/ridge	148	1.3
7	Drainage	99	0.9
8	Waterbody	417.8	3.7
9	Habitation	120.9	1.1
Total Geographic Area (TGA)		11257.1	100

Morphological properties

Soil development in the area is not far different than the general pattern of soil evolution on basaltic landscape under the semi-arid climatic conditions. Major morphologic variations in these soils, however, are attributed to topographic differences- directly through the controlling influence of topography on gravity flow, run-off, infiltration and temperature flux, as well as indirectly through its bearing on micro-climate and biotic factors (Anon., 1995) [2]. The detailed soil morphological properties of the study area are presented in table 3.

The morphological characteristics of soils of Kupti watershed showed that most of the soils were very shallow to moderately deep (18-150 cm depth) with colour in hue 10 YR, value ranging from 3 to 5 and chroma 1 to 4 except few pockets in the study area with red soils. These soils vary from very dark brown to very dark grayish brown in colour. This may be due to reduction of iron under impeded drainage (Prasad *et al*., 1989) [21] and complexion and chelation of organic colloids on the surface of smectite (Singh *et al*., 1994) [24]. The surface soils of all pedons have well developed sub angular blocky structure except pedon P5, which has angular blocky structure. These pedons (P2, P3, P5 and P7) exhibit cracks, slickensides and pressure faces in the pedons. All the pedons except P1, P2, P4 and P10 showed slight to strong effervescence (with 10 per cent HCl), however the degree of severity increases with depth. On the other hand, effervescence in pedon P5, P7 and P8 was violent, this has been mainly due to the leaching of bicarbonates during rainy season from the upper layers due to subsequent precipitation and prevailing semi-arid climatic conditions (Balpande *et al*., 1996) [4]. The slickensides were more developed and cracks were extended upto slickensides zone in P7 whereas, no cracks were found throughout the horizon in P8. Pressure faces was observed in P3, P5 and P7. Structure of sub-surface soils was observed to increase in terms of size, types and grades which might be due to overburden created by upper soil material. The soil horizons having pressure faces and slickensides possess coarse, strong, angular blocky structures. This may be attributed to high shrink and swell phenomena of smectite clay present in these soils (Prasad *et al*., 1989) [21].

Physical properties

The soils are clayey in texture and the clay content varies from 23.8 to 63.3 per cent and it increases with depth in all the pedons. However, basalt being the parent material of these soils have produced higher amount of clay (Pal and Deshpande, 1987; Eswaran *et al*., 1988 and Sannigrahi *et al*., 1992 and Gaikwad and Tamgadge, 1993) [18, 7, 23, 8]. The variation in soil separates may be due to soil developed on different physiographic units and its parent material (Murthy *et al*., 1994) [15]. The bulk density was quite variable in different horizons and varied from 1.33 to 1.68 Mg m^{-3}. It was relatively lower in the surface horizons and increases with depth in all the soils that may be due to comparatively more organic matter in the surface horizons and higher swelling pressure and compaction caused due to smectitic clay content in the subsoil (Ahuja *et al*., 1988) [1]. Similar results were found by Kadam *et al*., (2013) [10] and Kuchanwar *et al*., (2017) [14]. Considerable reduction in hydraulic conductivity with depth was also observed that can be attributed to the inherent clayey nature of these soils resulting into slow water transmission (Kadu *et al*., 1993) [11]. The value of COLE ranged from 0.07 to 0.15 cm cm^{-1}, indicating swell shrink activities in these soils due to predominance of smectitic clay (Balpande *et al*., 1996) [4]. Available water content ranged from 7.4 per cent to 16.8 per cent in the surface horizon and it increased with depth. This trend can be attributed to high amounts of 2:1 type smectitic clay, which has large surface area and swell-shrink properties. A linear relationship between clay content and moisture retention was also reported by Nagar *et al*. (1995) [16] and Balpande *et al*. (2007) [3]. In general, it is seen that the soils developed over escarpment and pediments retained less water, while those developed over plateau top and alluvial plain retained more water at both the pressures (i.e. -33 kPa and -1500 kpa). It is also observed that there is a variation in soil moisture content within different horizons. This might be attributed to the variation in soil texture, bulk density, clay mineralogy and/or organic matter content in soils developed over different landform positions and/or different horizons (Table 4).

Table 3: Morphological properties typical pedons in Kupti watershed

Horizon	Depth (cm)	Boundary	Matrix colour	Texture	Coarse fragments	Structure	Consistence	Nodule	Roots	Efferve-scence	Additional Notes
P1	**Clayey smectitic, hyperthermic, Lithic Ustorthent (Gently sloping)**										
Ap	0-16	a s	5 YR 3/4	Gravelly clay	25	m1sbk	l vfr sssp	F	-	-	
AC	16-41	a s	5 YR 3/4	Gravelly clay	30-40	m1sbk	l vfr sssp	F	-	-	
R	41+	Rock with boulders									
P2	**Clayey, smectitic, hyperthermic, Vertic Haplustept (Gently sloping)**										
Ap	0-13	c w	5YR 3/2	Silty clay	1-3 %	m2sbk	sh vfr sssp	-	f m	-	
Bw	13-38	c b	5YR 3/2	Silty clay	1-3 %	m2sbk	h fr vsvp	-	f f	-	1 cm wide cracks up to 23 cm
Cv	38-70	Weathered parent material									
R	70+	Hard rock									
P3	**Fine, smectitic, hyperthermic (calcareous) Vertic Haplustept (Very gently sloping)**										
Ap	0-15	c w	10 YR 3/2	Clay loam	3-5 %	m2sbk	sh fr sssp	f f	f f	E	
Bw1	15-29	g s	10 YR 3/1	Loam	3-5 %	m2sbk	sh fr sssp	f c	f f	E	
Bw2	29-73	a w	10 YR 3/1	Silt loam	-	m2sbk	sh fr sssp	f m	vf vf	Es	Pressure face
Cr	73-90	Rock with boulders and soils									
R	90+	Hard rock									
P4	**Clayey, smectitic, hyperthermic Lithic Ustorthent (Moderately sloping)**										
Ap	0-18	a w	10YR 3/2	Gravelly silty clay	25-30 %	m2sbk	sh fr sssp	f c		-	
R	18+	Hard rock									
P5	**Fine smectitic, hyperthermic Vertic Haplustept (Gently sloping)**										
Ap	0-20	c s	10 YR 4/2	Clay	-	m1abk	sh fr sssp	-	f c	Ev	
Bt1	20-38	g s	10 YR 3/2	Clay	-	m2abk	h fr sssp		f f	Ev	Clay cutans
Bt2	38-55	a b	10 YR 3/2	Gravelly clay	20	m2abk	vh vfr vssp		vf vf	Ev	Pressure face
Bc	55-80	-	10 YR 4/3	Gravelly clay	30-40 %	m1abk	l fr sssp		vf vf	Ev	
Cr	80+										
P6	**Fine smectitic, hyperthermic (calcareous) Typic Haplustert (Very gently sloping)**										
Ap	0-17	c s	10 YR 3/2	Clay	-	m2sbk	vh vfr vsvp	-	-	E	
Ap2	17-27	a s	10 YR 3/1	Clay	-	m2sbk	sh fr sssp	-	-	E	
Bw	27-42	c s	10 YR 2/1	Clay	-	m2sbk	h fr ssvp	-	-	Ev	
Bss	42-67	a b	10 YR 2/1	Clay	-	m2abk	vh vfr vsvp	-	-	Ev	
BC	67-82	a b	10 YR 4/2	Clay	-	m2sbk	Vh	-	-	Ev	
Cr	82+										
Horizon	**Depth (cm)**	**Boundary**	**Matrix colour**	**Texture**	**Coarse fragments**	**Structure**	**Consistence**	**Nodule**	**Roots**	**Efferve-scence**	**Additional Notes**
P7	**Fine, smectitic, hyperthermic Typic Haplustert (Gently sloping)**										
Ap	0-20	g s	10 YR 3/2	Clay	-	m3sbk	vh fr vsvp	-	f f	Ev	0.5 mm wide cracks
Bw1	20-39	g s	10 YR 2/1	Clay	-	m2sbk	vh fr vsvp	-	vf f	Ev	Pressure face
Bw2	39-61	g s	10 YR 2/1	Clay	-	m2sbk	vh fr vsvp	f f	vf f	Ev	Pressure face
Bss	61-92	a b	10 YR 2/1	Clay	-	c3abk	vh fr vsvp	-	vf f	Ev	Slickenside
BC	92-114	a b	10 YR 4/2	Clay	-		h fr sssp	-	vf f	Ev	
P8	**Fine, mixed, hyperthermic, Typic Haplustept (Very gently sloping)**										
Ap	0-18	a s	7.5 YR 4/2	Clay loam	-	m2sbk	l l sssp	-	f f	Ev	
Bw1	18-39	c s	7.5 YR 3/2	Clay	-	m2sbk	sh l sssp	Ca nodules	vf vf	Ev	No cracks throughout pedon layer
Bw2	39-71	g s	7.5 YR 3/1	Clay	-	m2sbk	h vfr sssp	Ca nodules	vf vf	Ev	
Bw3	71-114	a s	10 YR 3/1	Clay	-	m3sbk	vh fr vsvp	Ca nodules	Nil	Ev	
Bw4	114-145	a s	10 YR 3/1	Clay	-	m3sbk	h fr vsvp	Ca nodules	Nil	Ev	
P9	**Fine, smectitic, hyperthermic (calcareous) Typic Haplustert (Very gently sloping)**										
Ap1	0-12	c s	7.5 YR 3/2	Clay	-	m1sbk	s s n_0p_0	f c	-	E	
Ap2	12-26	c s	7.5 YR 3/3	Clay	-	m1sbk	h fr sssp	vf c	-	E	
Bw	26-52	c s	10 YR 3/2	Clay	-	m2sbk	h fr sssp	f f	-	Ev	
Bss1	52-92	c s	10 YR 3/2	Clay	-	m2abk	vh fr vsvp	vf f	-	Ev	
Bss2	92-132	c s	10 YR 2/1	Clay	-	m2abk	vh fr vsvp	-	-	Ev	
BCk	132-150	a b	10 YR 5/2	Clay	-	-	l s sssp	-	-	Ev	

P10	**Fine, mixed, hyperthermic Lithic Ustorthent (Moderately steep sloping)**										
Ap	0-16	a w	2.5 YR 5/2	Clay loam	-	m1sbk	sh fr	-	f f	-	
Cr	16-35	Hard rock									

Table 4: Physical properties of soils of watershed

Horizon	Depth (cm)	BD (Mg m^{-3})	HC (cm hr^{-1})	Mechanical composition (%)			COLE (cm cm^{-1})	Water Retention		
				Sand (%)	Silt (%)	Clay (%)		-33 kPa	-1500 kPa	AWC (%)
P1	**Clayey smectitic, hyperthermic, Lithic Ustorthent (Gently sloping)**									
Ap	0-16	1.55	0.38	20.5	21.2	58.3	0.13	34.7	22.9	11.8
AC	16-41	1.58	0.66	23.4	30.6	45.9	0.09	40.6	27.2	13.4
P2	**Clayey, smectitic, hyperthermic, Vertic Haplustept (Gently sloping)**									
Ap	0-13	1.46	0.19	3.0	43.4	53.6	0.12	38.4	25.1	13.3
Bw	13-38	1.41	0.12	4.2	36.6	59.2	0.13	42.9	27.0	16.0
P3	**Fine, smectitic, hyperthermic (calcareous) Vertic Haplustept (Very gently sloping)**									
Ap	0-15	1.64	0.39	38.7	33.2	28.1	0.04	21.4	9.0	12.5
Bw1	15-39	1.68	0.40	23.1	41.2	35.7	0.06	35.6	18.6	17.0
Bw2	39-73	1.71	0.99	18.5	57.7	23.8	0.02	27.6	24.0	3.6
P4	**Clayey, smectitic, hyperthermic Lithic Ustorthent (Moderately sloping)**									
Ap	0-18	1.68	0.59	7.9	37.7	54.4	0.12	34.0	26.6	7.4
P5	**Fine smectitic, hyperthermic Vertic Haplustept (Gently sloping)**									
Ap	0-20	1.51	0.45	23.5	33.7	42.8	0.08	34.7	20.6	14.0
Bt1	20-38	1.46	0.15	16.7	31.5	51.8	0.11	35.4	20.8	14.6
Bt2	38-55	1.38	0.28	15.3	21.4	63.3	0.15	38.5	21.3	17.2
Bc	55-80	1.62	0.32	28.6	30.4	41.1	0.08	32.5	16.9	15.6
P6	**Fine smectitic, hyperthermic (calcareous) Typic Haplustert (Very gently sloping)**									
Ap1	0-17	1.68	0.41	13.8	35.4	50.8	0.11	41.5	27.8	13.7
Ap2	17-27	1.60	1.14	21.2	25.4	53.4	0.11	39.1	27.1	12.0
Bw	27-42	1.63	1.43	22.4	23.7	53.9	0.12	45.7	30.5	15.2
Bss	42-67	1.58	1.61	21.8	30.5	47.7	0.10	47.7	29.4	18.3
BC	67-82	1.40	0.81	27.0	31.0	42.0	0.08	37.3	23.1	14.3
P7	**Fine, smectitic, hyperthermic Typic Haplustert (Gently sloping)**									
Ap	0-22	1.33	0.30	5.9	32.0	62.1	0.14	48.7	31.9	16.8
Bw1	22-39	1.34	0.15	4.9	32.4	62.8	0.15	49.1	25.4	23.6
Bw2	39-61	1.33	0.47	3.0	40.7	56.4	0.12	46.8	27.8	18.9
Bss	61-94	1.46	0.22	2.2	47.9	49.9	0.11	47.9	28.8	19.1
BC	94-114	1.48	0.46	24.7	36.7	38.6	0.07	37.3	21.0	16.2
P8	**Fine, mixed, hyperthermic, Typic Haplustept (Very gently sloping)**									
Ap	0-18	1.68	0.53	25.4	29.9	44.7	0.09	17.0	8.5	8.6
Bw1	18-39	1.63	0.49	19.7	39.3	41.0	0.08	34.0	18.6	15.4
Bw2	39-71	1.43	0.34	11.9	30.0	58.1	0.13	38.5	23.2	15.2
Bw3	71-114	1.51	0.51	21.2	34.7	44.1	0.09	40.8	24.9	16.0
Bw4	114-145	1.52	1.62	29.1	25.7	45.2	0.09	37.3	27.4	9.9

Cont. ….

Horizon	Depth (cm)	BD (Mg m^{-3})	HC (cm hr^{-1})	Mechanical composition (%)			COLE (cm cm^{-1})	Water Retention		
				Sand (%)	Silt (%)	Clay (%)		-33 kPa	-1500 kPa	AWC (%)
P9	**Fine, smectitic, hyperthermic (calcareous) Typic Haplustert (Very gently sloping)**									
Ap1	0-12	1.56	0.32	19.0	27.6	53.4	0.11	34.1	22.7	11.4
Ap2	12-26	1.46	0.36	12.1	26.8	61.1	0.14	37.6	24.8	12.8
Bw	26-52	1.44	0.81	20.6	32.6	46.8	0.10	39.9	26.6	13.3
Bss1	52-92	1.42	0.52	6.3	39.3	54.5	0.12	44.6	27.9	16.6
Bss2	92-132	1.41	0.71	12.1	38.7	49.2	0.10	48.9	30.5	18.4
BCk	132-150	1.62	1.43	26.7	31.2	42.2	0.08	31.4	21.5	9.8
P10	**Fine, mixed, hyperthermic Lithic Ustorthent (Moderately steep sloping)**									
Ap	0-16	1.72	1.02	30.9	29.2	39.9	0.07	23.4	14.1	12.5

Table 5: Chemical properties of soils of watershed

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	OC (%)	$CaCO_3$ (%)	Exchangeable cations				Sum	CEC	BS (%)	ESP
						Ca^{2+}	Mg^{2+}	Na^+	K^+				
						----------------------(cmol (p+) Kg^{-1})--------------------							
P1	**Clayey smectitic, hyperthermic, Lithic Ustorthent (Gently sloping)**												
Ap	0-16	6.8	0.11	1.38	3.46	13.60	12.13	1.73	2.18	29.64	29.79	99.50	5.81
AC	16-41	6.8	0.20	0.78	4.83	17.20	15.87	1.85	1.52	36.44	38.80	93.92	4.77
P2	**Clayey, smectitic, hyperthermic, Vertic Haplustept (Gently sloping)**												
Ap	0-13	6.7	0.15	0.45	3.81	23.60	15.60	1.22	0.60	41.02	42.13	97.37	2.90
Bw	13-38	6.7	0.15	0.39	4.19	23.60	15.20	0.88	0.40	40.08	39.56	101.31	2.22
P3	**Fine, smectitic, hyperthermic (calcareous) Vertic Haplustept (Very gently sloping)**												
Ap	0-15	8.2	0.27	0.33	6.19	38.26	16.23	0.88	0.65	56.02	54.75	102.32	1.61
Bw1	15-39	8.4	0.25	0.31	14.94	36.80	17.56	0.95	0.50	55.81	54.43	102.54	1.75
Bw2	39-73	8.3	0.26	0.28	9.44	33.60	20.01	1.02	0.60	55.22	55.07	100.27	1.85
P4	**Clayey, smectitic, hyperthermic Lithic Ustorthent (Moderately sloping)**												
Ap	0-18	7.6	0.11	0.39	6.81	21.60	14.26	0.34	0.18	36.38	35.12	103.59	0.97
P5	**Fine smectitic, hyperthermic Vertic Haplustept (Gently sloping)**												
Ap	0-20	8.4	0.23	0.62	14.46	22.65	9.16	0.81	0.86	33.48	29.79	112.39	2.72
Bt1	20-38	8.4	0.21	0.39	18.08	22.61	16.34	0.83	0.51	40.29	38.80	103.84	2.14
Bt2	38-55	8.5	0.21	0.31	16.71	20.13	16.81	0.90	0.46	38.30	36.72	104.30	2.45
Bc	55-80	8.7	0.21	0.11	27.58	15.34	17.23	0.89	0.41	33.87	29.10	116.9	3.06
P6	**Fine smectitic, hyperthermic (calcareous) Typic Haplustert (Very gently sloping)**												
Ap1	0-17	8.1	0.25	1.15	9.46	43.60	19.23	0.67	0.61	64.11	50.58	126.75	1.32
Ap2	17-27	8.4	0.18	0.76	10.96	32.38	21.34	0.69	0.30	54.71	51.96	105.29	1.33
Bw	27-42	8.4	0.21	0.79	12.96	30.28	23.61	0.72	0.30	54.91	53.35	102.92	1.35
Bss	42-67	8.5	0.21	0.68	20.46	30.26	24.12	0.83	0.35	55.57	52.66	105.53	1.58
BC	67-82	8.4	0.21	0.50	27.33	26.74	27.43	0.87	0.30	55.34	53.35	103.73	1.63
P7	**Fine, smectitic, hyperthermic Typic Haplustert (Gently sloping)**												
Ap	0-22	8.2	0.19	0.88	9.83	33.12	20.16	0.98	1.27	55.52	51.27	108.29	1.91
Bw1	22-39	8.3	0.19	0.65	11.33	33.05	16.63	1.04	0.76	51.48	49.89	103.19	2.08
Bw2	39-61	8.2	0.21	0.66	11.46	33.20	17.21	1.04	0.66	52.11	54.74	95.20	1.90
Bss	61-94	8.3	0.21	0.63	12.33	32.41	17.83	0.97	0.61	51.82	49.19	105.35	1.97
BC	94-114	8.3	0.20	0.18	23.33	27.51	17.87	1.04	0.51	46.93	39.49	118.84	2.63

	Contd…												
Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	OC (%)	$CaCO_3$ (%)	Exchangeable cations				Sum	CEC	BS (%)	ESP
						Ca^{2+}	Mg^{2+}	Na^+	K^+				
						----------------------(cmol (p+) Kg^{-1})--------------------							
P8	**Fine, mixed, hyperthermic, Typic Haplustept (Very gently sloping)**												
Ap	0-18	8.3	0.20	0.46	5.58	20.23	7.14	0.90	0.66	28.93	26.33	109.87	3.42
Bw1	18-39	8.3	0.21	0.19	10.58	19.36	14.37	0.90	0.41	35.04	38.11	91.94	2.36
Bw2	39-71	8.4	0.20	0.24	16.08	17.36	27.46	0.97	0.41	46.20	42.26	109.32	2.30
Bw3	71-114	8.3	0.22	0.30	16.33	15.87	28.87	0.90	0.35	46.00	42.96	107.08	2.09
Bw4	114-145	8.4	0.23	0.16	27.58	15.14	30.12	0.90	0.35	46.52	34.64	134.30	2.60
P9	**Fine, smectitic, hyperthermic (calcareous) Typic Haplustert (Very gently sloping)**												
Ap1	0-12	8.3	0.22	0.65	7.96	33.20	14.00	0.76	0.41	48.37	48.50	99.73	1.57
Ap2	12-26	8.3	0.17	0.63	8.71	35.16	15.26	0.69	0.31	51.43	49.89	103.09	1.38
Bw	26-52	8.3	0.18	0.59	9.96	34.12	15.20	0.76	0.30	50.39	49.19	102.44	1.55
Bss1	52-92	8.3	0.20	0.53	14.71	29.60	19.20	0.76	0.31	49.88	49.19	101.40	1.55
Bss2	92-132	8.4	0.22	0.59	16.46	27.65	22.36	0.76	0.41	51.18	51.27	99.82	1.48
BCk	132-150	8.5	0.21	0.27	28.08	19.60	21.36	0.89	0.30	42.07	38.11	110.39	2.34
P10	**Fine, mixed, hyperthermic Lithic Ustorthent (Moderately steep sloping)**												
Ap	0-16	8.1	0.21	0.17	7.81	26.00	18.80	0.68	0.55	46.02	44.26	103.98	1.54

Chemical properties

Soils were slightly to strongly alkaline and pH (6.7 to 8.7) increased down the profile. The EC of all the pedons is much less than 1 dSm^{-1}, indicating no salinity hazards (Table 5). All the soils are calcareous in nature and the $CaCO_3$ content varied from 4.30 to 19.85 per cent in different horizons with a tendency to increase with depth. It was observed that calcium carbonate is low in soils developed on plateau top whereas it was high in the soils of pediments and alluvial plains. This may be due to the leaching of calcium salts from up-slope and its deposition down the slope. Similar results were observed by Pal *et al*. (1999) [19], Challa *et al*. (2000) [6] and Kuchanwar *et al*., (2017) [14]. The organic carbon in surface soils varied from a minimum of 0.17 per cent in pedon P10 to a maximum of 1.38 per cent in pedon P1 and showed decreasing trend with depth. The cation exchange capacity of the soils was high and it varied from 26.33 to 53.35 C mol (p+) kg^{-1}. It was high due to predominance of smectitic mineralogy of these soils. The exchangeable calcium was the dominating cation on the exchange complex followed by magnesium, potassium and sodium. The exchangeable calcium and potassium decreased while magnesium and sodium increased with depth. Similar result were reported by Kadam *et al*. (2013) [10], Nimkar *et al*. (1992) [17] Thumbal and Patil, (2015) [26].

Soil classification

Based on morphometric, physical and chemical characteristics, the pedons were grouped into different taxonomical classes (Table 6). Pedon P6, P7 and P9 are deep black coloured, clayey (>30 % clay), and characterized by deep wide cracks when dry, that open and close periodically, shrink-swell properties, gilgai microrelief and very well developed slickensides close enough to intersect underlain by cambic horizon qualify for order Vertisol and meet the requirement for the subgroup Typic Haplustert with fine textural class. On the other hand, the soils having ochric epipedon underlain by cambic subsurface horizon with its upper surface boundary within 100 cm of the mineral soil surface and its lower boundary at a depth of 25 cm or more below the mineral soil surface have been classified in the order Inceptisols. Because of prevailing ustic moisture regime in the study area these soils are classified in the suborder Ustepts and qualify for Haplustepts great group. The Haplustepts great group is further divided into two subgroups *viz*. Vertic Haplustepts and Typic Haplustepts as per Soil Survey Staff, 1998 [25]. Pedon P2, P3, P5 and P8 are classified under order Inceptisols and the soils qualify for suborder Haplustepts. The soils lacking subsurface diagnosting horizons which do not qualify for other orders are classified under the order Entisols. The pedons P1, P4 and P10 coming under order Entisols are classified under suborder orthents which are lacking subsurface diagnostic horizons. The soil series classified under suborders orthents are further subdivided into Ustorthent great groups because of ustic moisture regime prevailing in the study area. These soils were further divided into Typic subgroups based on presence or absence of lithic or paralithic contact and other features qualifying for respective category (Soil Survey Staff, 1998) [25].

Table 6: Taxonomic classification of soils

Sl. No.	Soil series	Order	Sub order	Great group	Sub group
1	Kupti-1	Entisols	Orthents	Ustorthents	Lithic Ustorthent
2	Kupti-2	Inceptisols	Ustepts	Haplustepts	Vertic Haplustept
3	Kupti-3	Inceptisols	Ustepts	Haplustepts	Vertic Haplustept
4	Kupti-4	Entisols	Orthents	Ustorthents	Lithic Ustorthent
5	Kupti-5	Inceptisols	Ustepts	Haplusterts	Vertic Haplustept
6	Kupti-6	Vertisols	Usterts	Haplusterts	Typic Haplustert
7	Kupti-7	Vertisols	Usterts	Haplusterts	Typic Haplustert
8	Kupti-8	Inceptisols	Ustepts	Haplustepts	Typic Haplustept
9	Kupti-9	Vertisols	Usterts	Haplusterts	Typic Haplustert
10	Kupti-10	Entisols	Orthents	Ustorthents	Lithic Ustorthent

Landform-soil relationship

Soil development is controlled by some natural processes and conditions that sculpture the landscape they dwell in. A good correlation is discerned between landform and soil units of the area at the matching levels of abstraction. Field work was carried out using the base map in conjuction with SOI toposheet. Systematic study of soils in different landforms units that occur in the watershed area (Table 7) enabled the development of landform-soil relationship in the area. The watershed is divided into 12 land units based on landform, slope and land use, identified through combination of field assessment and interpretation of remote sensing data. The landform-soil relationship has been established based on the ground truth and analytical data. On the basis of differences and similarities in all, ten soil series (Kupti-1, Kupti-2, Kupti-3, Kupti-4, Kupti-5, Kupti-6, Kupti-7, Kupti-8, Kupti-9 and Kupti-10) are established. Their salient characteristics along with taxonomic classification are presented in table 8. These series were further used as mapping units to prepare soil map (Fig. 3) and are presented in table 10 along with the area occupied by them.

Table 7: Landform-soil relationship

Map symbol	Landform	Land use	Image Characteristics	Soil series	Slope (%)	Soil characteristics	Soil taxonomy
P3s1	Plateau (P)	Single crop (s1)	Bluish green and pink with diffuse checkerboard pattern	Kupti-1	3-5	Shallow, somewhat excessively drained, dark reddish brown (5YR 3/4M), clayey soils with sever erosion.	Lithic Ustorthent
P3s2	Plateau (P)	Single crop (s2)	Bluish green and pink with bold checkerboard pattern	Kupti-2	1-3	Mod. shallow, well drained, dark reddish brown (5YR 3/2M), clayey soils with moderate erosion.	Vertic Haplustept
P3d	Plateau (P)	Double crop (d)	Dark red tone with bold checker board pattern	Kupti-3	1-3	Mod. deep, well drained, brown (10YR 3/2M), fine soils with moderate erosion.	Vertic Haplustept
D3s	Pediment (D)	Single crop (s)	Bluish green and pink with diffuse checkerboard pattern	Kupti-4	8-15	Very shallow, well drained, brown (10YR 3/2M), clayey soils with moderate erosion.	Lithic Ustorthent
D3d	Pediment (D)	Double crop (d)	Dark red tone with bold checker board pattern	Kupti-5	5-8	Mod. deep, well drained, dark greyish brown (10YR 4/2M), fine soils with moderate erosion.	Vertic Haplustepts
D3f	Pediment (D)	Forest (f)	Bluish green tone with some pink patches	Kupti-4	8-15	Very shallow, well drained, brown (10YR 3/2M), silty loam soils with moderate erosion.	Lithic Ustorthent
D3d	Pediment (D)	Double crop (d)	Dark red tone with bold checker board pattern	Kupti-6	1-3	Mod. deep, mod. well drained, brown (10YR 3/2M), fine soils with moderate erosion.	Typic Haplustert
U2s	Upper Alluvial Plain (U)	Single crop (s)	Bluish green and pink with diffuse checkerboard pattern	Kupti-9	1-3	Deep, mod. well drained, brown (7.5YR 3/2M), fine soils with moderate erosion.	Typic Haplustert
U2d	Upper Alluvial Plain (U)	Double crop (d)	Dark red tone with bold checker board pattern	Kupti-8	1-3	Deep, well drained, brown (7.5YR 4/2M), fine soils with moderate erosion.	Typic Haplustept
L1d	Lower Alluvial Plain (L)	Double crop (d)	Dark red tone with bold checker board pattern	Kupti-7	1-3	Deep, well drained, brown (7.5YR 4/2M), fine soils with moderate erosion.	Typic Haplustert
E1w	Escarpment	Wasteland	Greenish blue with pink patches	Kupti-	>15	Shallow, well drained, reddish brown (2.5YR	Lithic

	(E)	(w)		10		5/3M), fine soils with, moderate erosion.	Ustorthent
E1f	Escarpment (E)	Forest (f)	Bluish green tone with some pink patches	Kupti-10	>15	Shallow, well drained, reddish brown (2.5YR 5/3M), fine soils with, moderate erosion.	Lithic Ustorthent

Table 8: Description and classification of soils of Kupti watershed

Pedon No.	Series name	Series description	Taxonomic classification
P1	Kupti-1	Shallow, dark reddish brown, clay, noncalcareous, extremely drained, severe eroded, gently sloping, plateau top	Clayey, hyperthermic Lithic Ustorthent
P2	Kupti-2	Shallow, dark reddish brown, silty clay, noncalcareous, well drained, moderately eroded, very gently sloping	Clayey, smectitic, hyperthermic, Vertic Haplustept
P3	Kupti-3	Slightly deep, brown, clay loam, moderately calcareous, well drained, moderately eroded, very gently sloping	Fine smectitic, hyperthermic (calcareous) Vertic Haplustept
P4	Kupti-4	Very shallow, brown, clay, moderately calcareous, well drained, moderately eroded, moderately sloping	Clayey, smectitic, hyperthermic Lithic Ustorthent
P5	Kupti-5	Moderately deep, dark greyish brown, clay, strongly calcareous, well drained, moderately eroded, gently sloping	Fine smectitic, hyperthermic Vertic Haplustept
P6	Kupti-6	Moderately deep, brown, clay, strongly calcareous, moderately well drained, severe eroded, very gently sloping	Fine smectitic, hyperthermic (calcareous) Typic Haplustert
P7	Kupti-7	Deep, brown, silty clay, moderately calcareous, well drained, moderately eroded, very gently sloping	Fine, smectitic, hyperthermic Typic Haplustert
P8	Kupti-8	Deep, brown, clay, moderately calcareous, well drained, moderately eroded, very gently sloping	Fine, mixed, hyperthermic, Typic Haplustept
P9	Kupti-9	Deep, brown, clay, moderately calcareous, moderately well drained, moderately eroded, very gently sloping	Fine, smectitic, hyperthermic (calcareous) Typic Haplustert
P10	Kupti-10	Very shallow, reddish brown, clay loam, moderately calcareous, well drained, moderately eroded, moderately steep sloping	Fine, mixed, hyperthermic Lithic Ustorthent

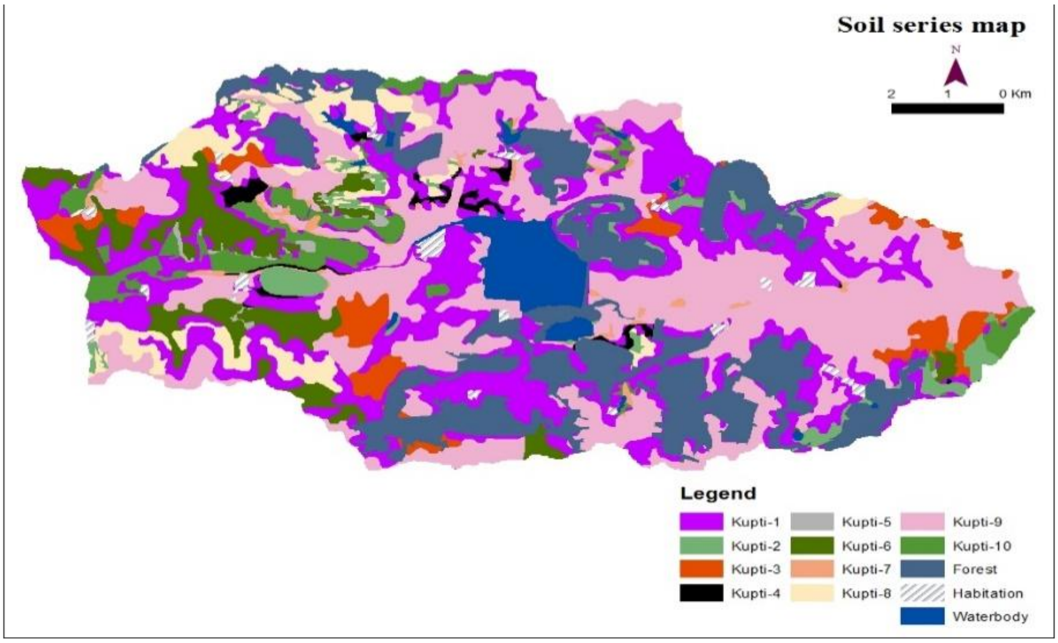

Fig 3: Soil map (Series) of Kupti watershed

Conclusion

The study of characterization and classification of soils under different landform in Kupti watershed reveled that the soils of very gently sloping and gently sloping plateau top are shallow to slightly deep, well drained to somewhat excessively drained, clay loam to clay, moderate to severely eroded and classified as Lithic Ustorthent and Vertic Haplustept whereas, most soils occurring on very gently sloping lower and upper alluvial plains are deep, well drained, brown (7.5YR 3/2 and 10 YR 4/2) in colour, calcareous, clay loam to clay in texture, moderately eroded are classified as Vertic Haplustept and Typic Haplustert. The soils of pediment occurring on gently to moderately sloping lands are very shallow to moderately deep, clay in texture, moderately eroded are classified as Lithic Ustorthent and Typic Haplustert. The soils of escarpments on moderately steeply sloping lands are shallow, well drained, clay loam, very severely eroded and classified as Lithic Ustorthent. Surface horizons of most of the soils exhibit medium, moderate subangular blocky structure whereas, it is sub-angular to angular blocky in the sub-surface horizons.

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