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Characterization and classification of soils under different landforms using RS and GIS: A case study of Sawangi watershed of Yavatmal district, Maharashtra

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Abstract
In the present investigation was carried out in Sawangi watershed of Yawatmal district, Maharashtra, the main objectives of this investigation is to characterize and classification the soils of the Sawangi watershed as well as evaluate for sustainable management of the natural resources. An attempt has been made to integrate the visual interpretation of ALOS-DEM, sentinel 2A data and subsequent ground truth verification for delineation of landforms map and soil series. Soil resource inventory at 1:10,000 scale was developed using base map by establishing the soil-landform relationship. Ten soil series have been identified with fourteen soil phases from the landform units. The soils were very shallow to very deep (14 to150 cm) in depth, soil slope is very gently sloping (1–3%) to steeply sloping (30-50%), exhibits colour in (dark reddish brown to dark yellowish brown) hue 2.5 YR, 5 YR and 10 YR, value 3 to 5, and chroma 1 to 4. The soil reaction (pH) are slightly acidic to strongly alkaline (6.55 to 8.94) in nature and electrical conductivity (EC) were (0.12 to 4.40) dSm^{-1} increasing trend with depth is noticed, very low to medium in organic carbon content, calcium carbonate ranged from (2.71 to 12.44%), exchangeable cations were found in the order to $Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$ indicated and cation exchange capacity (CEC) varies from (31.39 to 70.43) cmol (p+) kg^{-1} indicates in all the soils. The soils having clayey to sand clay loam in texture, bulk density were (1.4 to 1.8) Mg m^{-3} and AWC ranged from (8.3 to 31.2%) in the different horizons of the soil, This soil comes under *Vertisols, Inceptisols* and *Entisols* soil orders. Based on the different landforms and soil characteristics, these soils are classified as Typic Haplusterts, Lithic Ustorthents, Vertic Haplustepts, and Sodic Haplusterts at the subgroup level.

Keywords: Soil characterization, classification, land evaluation, landform

Introduction

Soil characterization determines the soil's individual inherent potentials and constraints for crop production besides giving detailed information about the different soil properties. Characterization and systematic classification of dominant soil groups is an essential tool and a pre-requisite for soil fertility evaluation and efficient soil-fertilizer-water management practices and, thus, crop management. The ability of the land to produce is limited and the limits to produce are set by soils, climate, landforms conditions and farming situations. Further, the capacity of soil to produce is also limited and constrains are due to intrinsic characteristics, agro-ecological settings, use and management (FAO Statistics, 2007-08). Information on the soil characteristics and quality has been recognized as an important requirement in the planning process for sustainable management of land resource towards crop planning. Studies on soil genesis have shown that soils from different parent materials show variation in depth, colour, texture, structure, consistence and development of diagnostic sub-surface horizons and morphological properties (Tamgadge *et al*., 1999) [7] and these variations are attributable to orientation of topography and landforms. Landform features are manifestations of underlaying parent material and the nature and duration of their processes. Site-specific geomorphological interpretation is a pre-requisite for landforms mapping and subsequent analysis of the landform-soil relationships. The soil and landform relationship on a toposequence plays a vital role in classification of landforms (Adams and Walker 1975). Generally, soils developing in any given landform show very close relationship with different slope units of the landforms and the toposequence (Dent and Young 1981). Detailed geomorphological site analysis is generally adopted for high intensity soil mapping of an area in a precise manner (Wright 1993). The inter-relationships between landforms and soils are linked to the interaction of landforms, bedrock geology and hydrological systems under a specific climatic condition (Gerrard 1990).

Landforms situated at varying elevation have pronounced effect on the physical and physico-chemical properties of the soils (Gaikward *et al*., 1986). Sharma *et al*., (1996) [15] studied morphology, physicochemical and chemical characteristics of soils in basaltic terrain and observed that the soils at elevated topography were shallow to moderately shallow, clayey to loamy skeletal and yellowish brown, whereas the soils at lower topography were deep to very deep, fine loamy to fine and grayish. The present investigation was undertaken to analyse the geomorphological features, soils and their physical and chemical characteristics for their characterization and classification in a toposequence of Sawangi watershed in Yavatmal district of Maharashtra.

Material and Methods

Study area

The Sawangi watershed area is located between 20^{o} 15' 47" to 20^{o} 20' 42" N latitude and 77^{o} 35' 27" to 77^{o} 42' 54" E longitude, The elevation ranges from 161 to 356 m (WGS 84 datum) above mean sea level (MSL). which covers an area of 11777.62 ha in Yavatmal district, Maharashtra. The average annual rainfall of 917.36 mm (decennial average of 2008-2017), out of which maximum rainfall (85.95 per cent) is received during rainy season (late June to October) and 3.14 per cent during winter (December to February). The climate is mainly hot moist to semi-arid type with annual mean maximum and minimum temperatures of 33.8 ^{o}C and 23.31 ^{o}C respectively. Soil moisture regime is *ustic* and *hyperthermic* soil temperature regime (Soil Survey Staff 2014). The geology of the study area is covered by 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). These areas crops growing are mostly under cotton, soybean, pigeon pea, sorghum, gram, wheat, and vegetables.

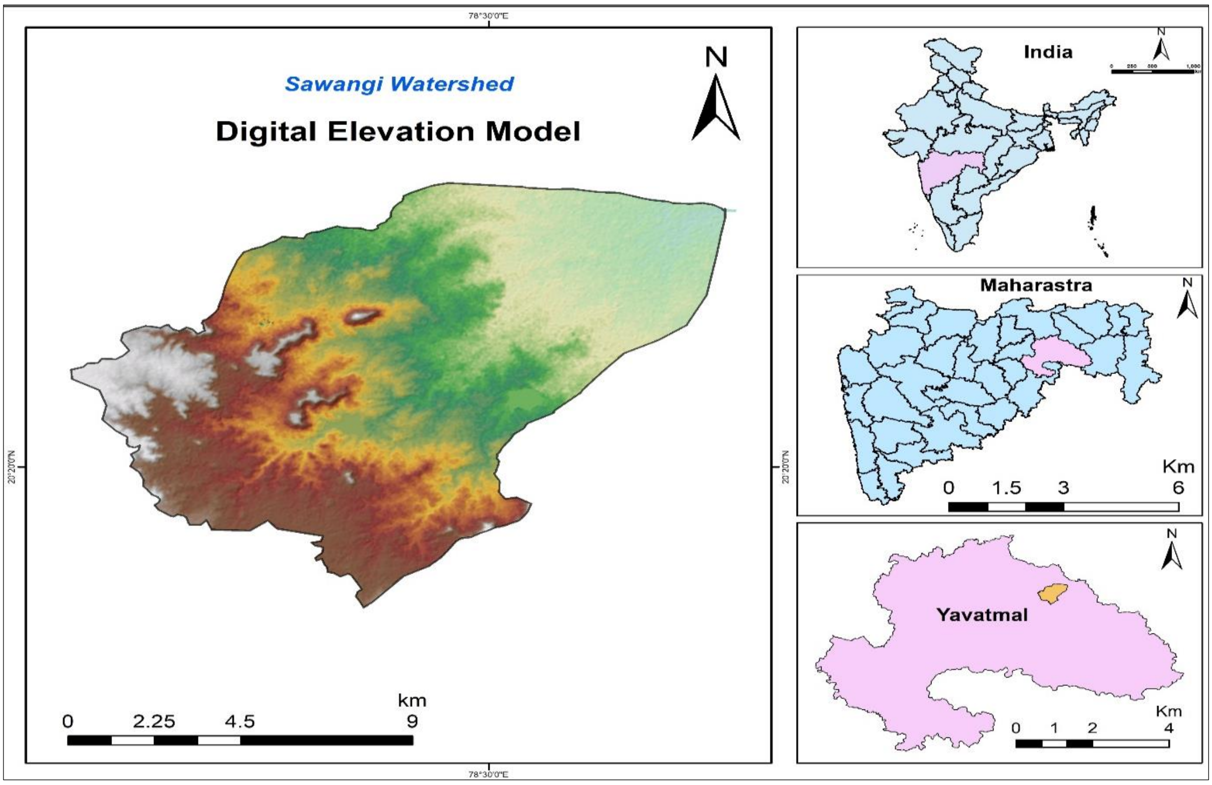

Fig 1: Location map of Sawangi watershed

Data used

The remote sensing data used were - Sentinel-2A (10m), ALOS PALSAR DEM (Digital Elevation Model) (12.5M), Landsat-5 TM (Thematic Mapper) and Landsat-8 OLI (Operational Land Imager). The satellite image was used as delineation of landforms and base map for location of sample areas, ground truth sites and planning to traverse in the field and other details.

Methods

Soil survey at 1:50,000 scale was carried out using base map and landform-soil relationship was established. Soil pedons were georeferenced (Table 1). Nearly 2.0 kg of representative soil sample from each horizon from representative pedons were collected for laboratory analysis. Soil clods were collected from different horizons for the determination of bulk density. The analysis of physical, chemical and nutrient properties of collected samples were carried out using standard procedures (Black 1965; Jackson 1967; Lindsay and Norvell 1978) [8]. The soils were classified as per Soil Taxonomy (Soil Survey Staff 2003). Physical properties of the soils, such as particle size distribution were determined by the international pipette method (Klute, 1986) [11]. The bulk density was determined by clod coating method (Black and Hartge, 1986) [10]. Chemical properties like pH and EC of the soil suspension (1:2 ratio) was determined by the methodology of Jackson (1973) [8]. For the determination of soil organic carbon (SOC), the modified Walkley and Black wet oxidation method was used (Walkley and Black, 1934; Jackson, 1973) [31, 8]. The free calcium carbonate was determined by rapid titration method (Piper, 1966) [19]. The exchangeable cations and cation exchange capacity of soils were determined using methods outlined by Richards (1954).

Results and Discussion

Landform studies

A detailed landform site analysis was carried out based on relief amplitude, position in toposequence, contours and drainage channel networks (Wright 1993). The landforms identified based on visual interpretation of ALOS-DEM, sentinel 2A data and subsequent ground truth verification, a landform map has been prepared and the different landforms identified were as follows *viz.*, mound, plateau, denuded plateau, escarpment, upper pediment, lower pediment, alluvial plain, pediplain, upper valley, lower valley and waterbody depict (Fig. 2).

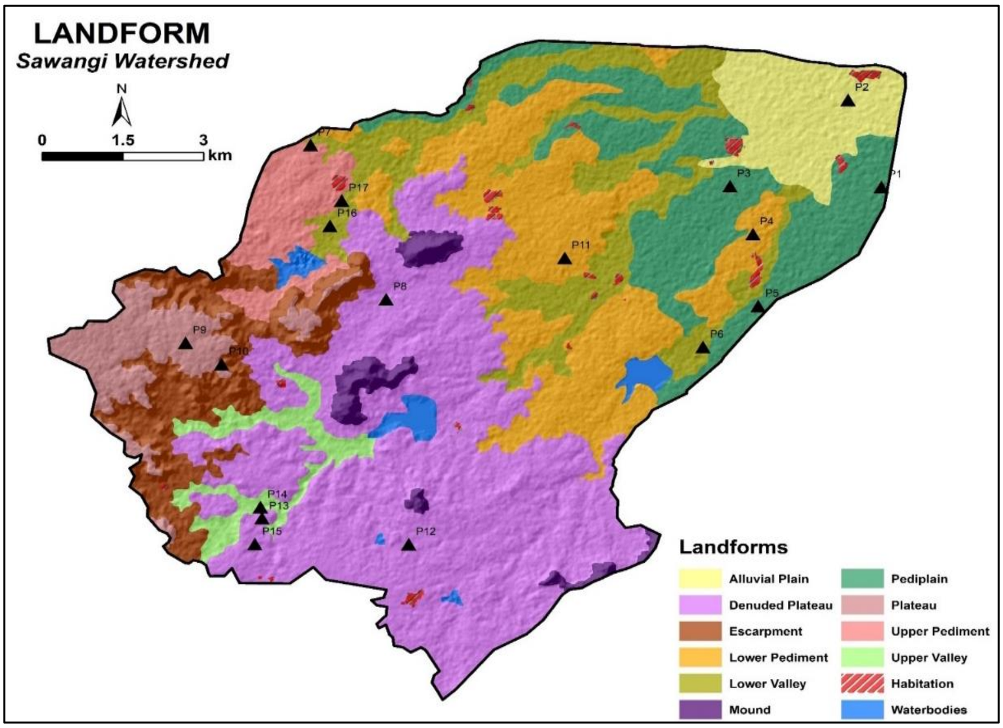

Fig 2: Landform map of Sawangi watershed

A review of data shows (Table 2) that the denuded plateau is the major landform portion of the watershed involving an area of 3849.19 ha representing about 32.68 per cent of the total geographic area (TGA) of the watershed, followed by lower pediment 1854.51 ha (15.75 % of TGA). The upper valley and lower valley cover an area of 322.32 ha (2.74 % of TGA) and 1254.04 ha (10.65 % of TGA) respectively. Escarpment occupies 876.25 ha (7.44 % of TGA) and pediplain involving 1463.94 ha (12.43 % of TGA). Upper pediment and alluvial plain cover an area of 435.13 ha (3.69 % of TGA) and 619.44 ha (5.25 % of TGA) respectively. The mound and plateau cover area of 238.73 ha (2.03 % of TGA) and 540.58 ha (4.59 % of TGA). Waterbody occupies an area of 170.27 ha (1.44 % of TGA) and habitation 80.51 ha (0.68 % of TGA.

Table 1: Extend and distribution of different landform units of Sawangi watershed

Sl. No.	Landform units	Area (ha)	% TGA
1	Mound	238.73	2.03
2	Plateau	540.58	4.59
3	Denuded Plateau	3849.19	32.68
4	Escarpment	876.25	7.44
5	Upper Pediment	435.13	3.69
6	Lower Pediment	1854.51	15.75
7	Alluvial Plain	619.44	5.25
8	Pediplain	1463.94	12.43
9	Upper Valley	322.32	2.74
10	Lower Valley	1254.04	10.65
11	Habitation	80.51	0.68
12	Waterbody	170.27	1.44
	Total Geographic Area (TGA)	11777.62	100

Soil Morphological Characteristics

The soil morphological description of the study area will be presented in the (table 2). The depth of different pedons of study area of Sawangi watershed ranges from 10 cm to 150+ cm and found to have deep to very deep solum. Pedon 2, 3, 4, 5 and 10 were shallow to moderately deep (25 -50 cm), Pedons 6 and 7 were deep (50-100 cm) whereas the pedons 1, 8 and 9 were very deep (>100 cm) respectively. Nasre *et al*. (2013). The identified that, soil depth is correlated between slope and degree of soil erosion. It was noticed that soils developed on mount, denuded plateau, escarpments and upper pediment were shallow and soils developed on pediplain, lower pediment, alluvial plains, plateau, and valleys were deep to very deep. The soil colour of different pedons of the study area were varied from dark reddish brown to very dark grayish brown in colour. Whereas hue in the range of 2.5 YR, 5 YR, and 10 YR, value of 3 to 5 and chroma in the range of 1 to 4 respectively. This may be due to moist conditions prevailing for a longer period favoring reduction of iron under impeded drainage (Prasad *et al*., 1989), and complexion and chelation of organic colloids on the surface of smectite (Singh *et al*., 1994) [94]. The surface horizon soils of all pedons have well developed sub angular blocky structures. The sub-surface horizon had sub angular blocky to angular blocky structures. Some of the pedons (P8 and P9) in the sub-surface horizon having cracks, slickensides, and pressure faces were associated with course, strong, and angular blocky structures. This may be attributed to the high shrink and swelling phenomena of smectite clay present in the soil (Prasad *et al*., 1989). All the pedons observed soil consistence varied from loos to hard, firm to friable, and non-sticky and non-plastic to very sticky and very plastic in dry, moist and wet conditions, respectively. The effervescence all the pedons observed slight to strong effervescence (with 10 per cent HCl). 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)

Soil Physical Characteristics

The particle size distribution observed that the clay content varied from 26.5 to 71.3 per cent in the surface horizons and sub-surface ranged from 17.8 to 77.2 per cent. The silt and sand content varied from from 5.9 to 47.8 per cent and from 1.7 to 76.2 per cent respectively. All the pedons have clay contents increased with depth. Basalt, being the parent material of these soils, is known to produce higher amount of clay (Pal and Deshpande, 1987; Eswaran *et al*., 1988; Sannigrahi *et al*., 1992; Gaikwad and Tamgadge, 1993) [7]. The variation in soil separation may be due to soil developed on different physiographic units and its parent material (Murthy *et al.* 1994) [13]. The development of varied particle size fractions may be due to the illuviation and transportation of finer particles from higher to lower elevations and partly because of an active churning process resulting from swelling and shrinking nature of the clay minerals. The bulk density of the soils varied from 1.39 to 1.81 Mg m^{-3}. The increase of bulk density with depth of soil may be attributed to over-burden pressure causing compaction in the subsurface horizons (Ahuja *et al*., 1988) [17], on the other hand, the surface soils are less compact probably due to high amount of organic matter and plant root concentration (Coughlan *et al*., 1986). The available water content varies from 8.3 per cent to 22.0 per cent in the surface horizons and its related to clay content and organic matter. The AWC increased with an increase in clay content. This trend can be attributed to high amounts of 2:1 type smectitic clay. A linear relationship between clay content and moisture retention was also reported (Nagar *et al*., 1995; Balpande *et al*., 2007) [3, 15]. The water holding capacity ranged from 31.9 to 46.5 per cent in the surface horizons of soil. These differences in water holding capacity were due to variation in the depth, clay, silt and organic carbon content of the pedons.

Soil Chemical Characteristics

The soil reaction of the study area was slightly acidic to strongly alkaline reaction with the pH values varying from 6.55 to 8.63 in surface horizons and from 6.84 to 8.94 in subsurface horizons. The pH value generally increased with depth may be due to higher exchangeable Na+ and ESP in the subsurface soils (Garg, 2000). The electrical conductivity of soil was normal to high and varied from 0.12 to 0.87 dSm^{-1} in all the pedons but pedon 9 observed exceptional results which is varied from 0.39 to 4.40 dSm^{-1}. The organic carbon content in soils ranged from 0.29 to 1.83 per cent. Almost all the pedons observed a decreasing trend in organic carbon with depth of soil, mainly due to the accumulation of plant residues on the soil surface and less movement to the subsurface horizon due to the rapid rate of mineralization at a higher temperature and adequate soil moisture level (Rao *et al*., 2008; Dahifale *et al*., 2009) [22]. The calcium carbonate in all the pedons ranged from nill to 14.68 per cent in different horizons and showed increasing trends with soil depth, which indicates leaching down of calcium salt and subsequent precipitation at lower depth may be due to high pH level (Pal *et al.*, 2000; Challa *et al.*, 2000 and Kuchanwar *et al*., 2017). The exchangeable calcium and magnesium were the dominant exchange complex followed by sodium and potassium cation observed in all the pedons. The exchangeable cations were found in the order Ca2+>Mg2+>Na+>K+ indicating the presence of calcium bearing minerals in parent rocks (Sarkar *et al*., 2001; Maji *et al*., 2005) [12]. The exchangeable calcium and potassium decreased while magnesium and sodium increased with depth. Similar results were reported by Kadam *et al*., (2013) [5], Nimkar *et al*., (1992) [16]; Thumbal and Patil, (2015). The cation exchange capacity of soils varies from 31.39 to 70.43 cmol (p+) kg^{-1} indicates (Table 3) in all the pedons. The higher CEC value in some horizons are attributed to the higher amount of clay and smectite type of clay minerals, whereas low CEC value results from the high amount of sand content and mixed type of minerals (Kaushal *et al*., 1986; Balpande *et al*., 1996) [10]. This indicates that base saturation in all the pedons varied from 76.9 to 113.3 per cent, which is more than 100 per cent due to the presence of Ca-zeolites (Pal *et al.*, 2006). The exchangeable sodium percentage ranged from 0.90 to 21.50 per cent. The exchangeable sodium percentage observed in all the pedons increased with soil depth.

Table 2: Morphological properties typical pedons in Sawangi watershed

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Coarse fragments (%)	Structure			Consistence			Porosity		Roots		Effervescence	Nodules		Other features
		D	T				S	G	Ty	D	M	W	S	Q	S	Q		S	Q	
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts																				
Ap	0-17	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	c	m	ev	m	m	
Bw1	17-59	c	s	10YR 3/1	c	-	m	3	sbk	-	fr	vsvp	vf	m	c	m	ev	m	m	
Bw2	59-92	c	s	10YR 3/3	c	-	m	3	sbk	-	fr	vsvp	vf	m	c	m	ev	m	m	
Bw3	92+	c	s	10YR 3/4	c	-	m	2	sbk	-	fr	vsvp	vf	m	c	m	ev			
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-16	-	-	10YR 3/2	c	-	m	2	sbk	-	-	-	-	-	-	-	-	-	-	-
Cr	16-36	-	-	10YR 5/2	gr. sl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-15	c	s	10YR 3/3	cl	-	m	2	sbk	sh	fr	sssp								
R	15+																			
Pedon 4: Nimgawhan-1 series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
A	0-14	a	s	2.5YR 3/3	gr. l	-	m	1	sbk	-	-	-	vf	m	f	m	-	-	-	-
Cr	14+																			
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-15			5YR 3/3	l	-	m	2	sbk	l	fr	sssp	f	m	-	-	-	-	-	-
R	15-23																			
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts																				
Ap	0-20	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	m	m	ev	m	m	

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Coarse fragments (%)	Structure			Consistence			Porosity		Roots		Effervescence	Nodules		Other features
		D	T				S	G	Ty	D	M	W	S	Q	S	Q		S	Q	
Bw	20-44	c	s	10YR 3/1	c	-	m	3	sbk	-	fi	vsvp	vf	m	m	f	ev	m	m	
Cr	44+	c	s		scl	>90	-	-	-	-							ev			
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts																				
Ap	0-16	c	s	10YR 3/1	c	-	m	2	sbk	h	fr	vsvp	vf	m			e			
Bs	16-30	a	s	10YR 3/2	c	-	m	3	sbk		fi	vsvp	vf	f			e			
R/Cr	30+					>90														
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts																				
Ap	0-19	c	s	10YR 3/2	cl	-	m	2	sbk	l	fr	sp	f	m	f	m	ev	m	m	
Bw1	19-52	c	s	10YR 3/2	cl	-	m	3	sbk		fr	sp	f	m	f	m	ev	m	m	
Bw2	52-88	c	s	10YR 3/2	c	-	m	3	sbk		fr	sp	f	m	f	f	ev	m	m	
Bw3	88-122	c	s	10YR 3/1	c	-	m	3	abk		fi	vsvp	vf	m			ev	f	m	pf
Bw4	122-150	c	s	10YR 3/1	c	-	m	3	abk		fi	vsvp	vf	m			ev	f	m	pf
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts																				
Ap	0-18	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	-	-	ev	m	m	
Bw1	18-48	c	s	10YR 3/2	c	-	m	3	sbk		fi	vsvp	vf	m	-	-	ev	m	m	
Bss1	48-73	c	s	10YR 3/3	c	-	m	3	abk		fi	vsvp	vf	m	-	-	ev	m	m	ss
Bss1	73-102	c	s	10YR 3/3	c	-	m	3	abk		fi	vsvp	vf	m	-	-	ev	m	m	ss
Bc	102+	c	s	10YR 3/4	c	>60	m	2	abk		fi	vsvp	vf	m	-	-	ev	m	m	pl/gr
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents																				
Ap	0-18			10YR 3/1	c	-	m	2	sbk	h	fr	vsvp	vf	m						
Cr	18-30			10YR 5/3		-														

Table 3: Physical properties of soils of watershed

Horizon	Depth (cm)	Particle Size Distribution				Bulk Density (Mg m^{-3})	Water Retention			WHC
		Sand (%)	Silt (%)	Clay (%)	Class		-33 kPa	-1500 kPa	AWC (%)	
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts										
Ap	0-17	4.8	29.8	65.5	clay	1.5	50.9	34	16.9	42.5
Bw1	17-59	2.3	27.1	70.6	clay	1.6	50.6	31.7	18.9	42.1
Bw2	59-92	7.3	26.5	66.2	clay	1.5	36	20.6	12.7	38.1
Bw3	92+	8.5	29.3	62.2	clay	1.5	31	22.3	13.5	37.6
Weighted mean		4.54	27.40	68.06		1.58	45.42	28.14	16.29	40.76
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents										
Ap	0-16	39.8	22.6	37.6	clay loam	1.5	31.7	17.9	13.8	46.5
Cr	16-36	76.2	5.9	17.8	sandy loam	1.6	28.8	19.3	9.5	43.4
Weighted mean		60.05	13.33	26.62		1.56	30.09	18.68	11.41	44.79
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents										
Ap	0-15	24.4	33.6	42.0	clay	1.6	30.1	17.8	12.3	31.9
Pedon 4: Nimgawhan series - Loamy mixed, hyperthermic, Lithic Ustorthents										
A	0-14	25.7	47.8	26.5	loam	1.5	36.4	25.7	10.7	42.7
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents										
Ap	0-15	36.2	27.3	36.4	clay loam	1.4	30.5	14.4	16.1	43.1
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts										
Ap	0-20	7.3	21.4	71.3	clay	1.6	36.6	24	12.6	38.1
Bw	20-44	12.6	33.6	53.8	clay	1.6	34	22	12.0	36.7
Cr	44+	62.7	9.3	28.0	sandy clay loam	1.7	22.6	13.1	9.5	24.8
Weighted mean		10.20	28.05	61.75		1.61	35.18	22.91	12.27	37.32
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts										
Ap	0-16	3.0	25.5	71.5	clay	1.4	43.8	29.2	11.5	40.7
Bs	16-30	1.7	21.8	76.4	clay	1.7	40.7	28.9	15.4	36.5
Weighted mean		2.39	23.81	73.80		1.53	42.35	29.06	13.30	38.73
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts										
Ap	0-19	45.8	15.5	38.7	sandy clay loam	1.6	21.8	11.6	8.3	46.0
Bw1	19-52	46.7	22.8	30.4	sandy clay loam	1.7	21.2	10.9	10.2	40.8
Bw2	52-88	35.8	40.1	24.1	loam	1.6	24.7	13	11.7	48.9
Bw3	88-122	12.2	31.3	56.2	clay	1.7	44.1	26.1	15.5	48.3
Bw4	122-150	10.0	27.5	62.2	clay	1.8	49.8	26.5	21.0	49.2
Weighted mean		29.31	28.82	41.73		1.67	32.65	17.85	13.55	46.69
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts										
Ap	0-18	10.7	22.3	67.0	clay	1.5	49	27	22.0	43.7

Bw1	18-48	5.0	22.3	72.6	clay	1.5	49	26.7	22.3	47.2
Bss1	48-73	4.5	22.5	73.0	clay	1.6	55.4	32.2	25.2	47.4
Bss1	73-102	2.2	20.6	77.2	clay	1.7	67.4	39	28.4	55.1
Bc	102+	2.9	20.4	76.7	clay	1.8	60.4	39.3	31.2	57.4
Weighted mean		5.09	21.88	73.04		1.59	55.80	31.60	24.69	48.87
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents										
Ap	0-18	25.3	16.0	58.7	clay	1.6	39.2	27.3	11.9	42.7
Cr	18-30	4.2	18.0	77.8	clay	1.7	38.1	28	16.4	34.0
Weighted mean		16.85	16.79	66.36		1.67	38.76	27.58	13.71	39.25

Table 4: Chemical properties of soils of watershed

Horizon	Depth (cm)	pH	EC dS m^{-1}	OC g kg^{-1}	$CaCO_3$ (%)	Exchangeable bases				Total cations	CEC	Base saturation (%)	ESP
						Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}				
						cmol (p^{+}) kg^{-1}							
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts													
Ap	0-17	7.92	0.38	1.18	5.42	34.00	25.60	0.87	1.33	61.80	65.22	85.6	1.33
Bw1	17-59	7.95	0.28	0.44	6.45	35.60	31.80	0.71	0.61	68.72	64.42	99.5	1.10
Bw2	59-92	8.26	0.16	0.44	14.68	33.80	32.80	0.63	0.15	67.38	61.57	81.2	1.06
Bw3	92+	8.16	0.34	0.41	12.40	32.40	34.80	0.64	0.10	67.94	62.36	76.9	1.28
Weighted mean		8.06	0.26	0.58	9.21	34.66	31.01	0.71	0.58	66.96	63.54	90.38	1.13
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents													
Ap	0-16	7.62	0.18	0.73	5.13	36.40	18.40	1.02	0.31	56.13	51.30	113.3	1.99
cr	16-36	7.51	0.11	0.41	6.84	39.60	14.40	1.17	0.10	55.27	53.40	103.5	2.19
Weighted mean		7.56	0.14	0.55	6.08	38.18	16.18	1.10	0.19	55.65	52.47	107.85	2.10
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents													
Ap	0-15	6.82	0.83	0.59	3.28	23.60	17.60	0.41	0.15	41.76	39.57	105.6	1.04
Pedon 4: Nimgawhan series - Loamy mixed, hyperthermic, Lithic Ustorthents													
A	0-14	6.82	0.17	1.83	12.44	30.80	22.40	0.49	0.20	53.89	50.00	107.8	0.98
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents													
Ap	0-15	6.96	0.12	0.7	0.00	27.20	9.60	0.41	0.26	37.47	36.52	102.6	1.12
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts													
Ap	0-20	8.32	0.14	0.59	11.61	53.20	7.60	0.78	0.51	62.09	65.22	95.2	1.20
Bw	20-44	8.24	0.13	0.50	9.45	45.20	10.40	0.63	0.26	56.49	59.13	95.5	1.07
cr	44+	8.20	0.14	0.23	10.24	36.00	12.40	0.51	0.15	49.06	48.70	92.5	1.05
Weighted mean		8.28	0.14	0.54	10.43	48.84	9.13	0.70	0.37	59.03	61.90	95.38	1.12
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts													
Ap	0-16	6.69	0.87	0.88	4.28	40.00	22.40	0.69	0.67	63.76	57.39	111.1	1.20
Bw	16-30	6.84	0.76	0.79	2.71	41.60	16.00	0.50	0.41	58.51	55.65	105.1	0.90
Weighted mean		6.76	0.82	0.84	2.28	40.75	19.41	0.60	0.55	61.31	56.58	108.31	1.06
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts													
Ap	0-19	8.20	0.17	0.63	9.41	24.80	9.00	0.38	0.36	34.54	31.39	97.3	1.21
Bw1	19-52	8.30	0.15	0.53	11.97	23.20	11.80	0.43	0.30	35.73	33.48	86.4	1.28
Bw2	52-88	8.41	0.14	0.41	11.45	26.00	12.36	0.55	0.25	39.16	39.13	88.9	1.41
Bw3	88-122	8.74	0.31	0.47	9.69	30.60	15.20	1.83	0.21	**47.84**	51.30	101.0	3.57
Bw4	122-150	8.94	0.40	0.47	12.45	29.60	16.60	3.70	0.20	**50.10**	50.87	100.5	7.27
Weighted mean		8.53	0.23	0.49	11.09	26.95	13.25	1.38	0.26	41.83	41.86	94.34	2.94
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts													
Ap	0-18	8.63	0.39	0.44	5.42	29.60	19.60	5.74	0.72	55.66	51.74	90.1	9.30
Bw1	18-48	8.78	0.25	0.44	5.56	28.80	13.60	9.57	0.77	52.74	47.39	88.8	13.11
Bss1	48-73	8.71	1.33	0.41	6.70	23.60	17.20	14.43	0.82	56.05	51.30	91.4	15.54
Bss2	73-102	7.95	2.80	0.38	7.70	29.60	24.00	20.52	0.82	74.94	70.43	106.4	19.13
Bc	102+	8.31	4.40	0.29	10.83	27.60	25.60	21.30	0.76	75.26	69.83	107.8	21.50
Weighted mean		8.50	1.27	0.42	6.42	27.89	18.50	13.20	0.79	60.38	55.67	94.68	14.75
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents													
Ap	0-18	6.55	0.82	0.79	2.71	31.20	44.00	0.74	0.56	76.50	68.65	85.2	1.08
cr	18-30	7.20	0.12	0.73	3.14	31.60	42.80	0.66	0.31	75.37	65.74	83.0	1.00
Weighted mean		6.81	0.54	0.77	2.88	31.36	43.52	0.71	0.46	76.05	67.49	84.33	1.05

Soil classification

Based on morphological and physico-chemical properties, the soil series were grouped into different taxonomical classes as per the criteria of Soil Taxonomy (Soil Survey Staff 1992) (Table 6). The soils of series 9, this is developed on lower valley. These soils are deep, black in coloured, clayey in texture (>30% clay) and characterized by deep wide cracks (2-5 cm wide and 48-102 cm depth in soil) 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 is classified under order the *Vertisol.* The soils qualify for very fine, smectitic, hyperthermic, Sodic Haplusterts. The soils of series 1, 6, 7 and 8 are moderately shallow to deep, with occurrence 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. Through the prevailing ustic moisture regime in the watershed, these soils are classified under order the *Inceptisol* and 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. The soils of series 2, 3, 4, 5, and 10 are very shallow to moderately shallow. These soils lacking subsurface diagnostic horizons that do not qualify for other orders are classified under the order *Entisols*. The series are classified under suborders orthents are further subdivided into Ustorthent great groups because of ustic moisture regime. These soils were further divided into Lithic subgroups based on presence or absence of lithic or paralithic contact.

Table 5: Differentiating characteristics of typical pedons of different soil series of Sawangi watershed

Soil series	Landform	Geology/ Parent material	Soil Depth (cm)	Soil texture	Surface stoniness (%)	Colour	Reaction	Slope (%)	Erosion	Drainage	Salinity/ Sodicity
Bhamb	Pediplain	Basalt	150	clay	<3	10YR3/2	ev	1-3	Moderate	Well drained	-
Dongarkharda	Upper Valley	Basalt	50	clay loam	<3	10YR3/2	ev	3-8	severe	Well drained	-
Jalka	Denuded Plateau	Basalt	25	clay	<3	10YR3/3	-	3-8	severe	Well drained	-
Nimgawhan	Escarpment	Basalt	25	loam	>75	2.5YR3/3	-	8-15	Severe	Well drained	-
Nimgawhan-2	Denuded Plateau	Basalt	25	clay	<3	5YR3/3	-	1-3	Moderate	Well drained	-
Pimpalkhuti	Lower Pediment	Basalt	50	clay	<3	10YR3/2	ev	1-3	Moderate	Well drained	-
Potgawhan	Plateau	Basalt	50	clay	3-15	10YR3/1	e	1-3	Moderate	Well drained	-
Sawangi	Alluvial Plain	Basalt	150	sandy clay loam	<3	10YR3/2	ev	3-8	Severe	Well drained	-
Soyati	Lower valley	Basalt	100	clay	<3	10YR3/2	ev	1-3	Moderate	Moderately well drained	Moderate
Warna	Upper pediment	Basalt	50	clay	<3	10YR3/1	e	3-8	Moderate	Well	-

Table 6: Soil series and phases of Sawangi watershed

Landform	Soil series	Soil map unit	Mapping legend	Brief description of soil series	Area (ha)	TGA (%)
Pediplain	Bhamb	1	Bha5mB2	Deep, well drained, very dark grayish brown, clayey soils on very gently sloping pediplain with clay surface with moderate erosion.	1480.8	12.6
Upper Valley	Dongarkharda	2	Don2fC3	Shallow, well drained, very dark grayish brown, clay loam soils on gently sloping upper valley with clay loam surface with severe erosion.	322.3	2.7
Denuded Plateau	Jalka	3	Jal1mC3	Very shallow, well drained, dark brown, clayey soils on gently sloping denuded plateau with clay surface with severe erosion.	565.0	4.8
Escarpment	Nimgawhan	4	Nim1dF4	Very shallow, well drained, dark reddish brown, loamy soils on steeply sloping escarpment with loam surface with very severe erosion	878.0	7.5
	Nimgawhan	5	Nim1fC2	Very shallow, well drained, dark reddish brown, clay loamy soils on gently sloping escarpment with clay loam surface with very moderate erosion	258.7	2.2
Denuded Plateau	Nimgawhan-2	6	Nim1mB2	Very shallow, well drained, dark reddish brown, clay soils on very gently sloping denuded plateau with clay surface and moderate erosion	117.0	1.0
	Nimgawhan-2	7	Nim1mC2	Very shallow, well drained, dark reddish brown, clay soils on gently sloping denuded plateau with clay surface and moderate erosion	2993.0	24.8
Lower Pediment	Pimpalkhuti	8	Pim2mB2	Shallow, well drained, very dark grayish brown, clayey soils on very gently sloping lower pediment with clay surface and moderate erosion.	1006.0	8.5
	Pimpalkhuti	9	Pim2mC2	Shallow, well drained, very dark grayish brown, clayey soils on gently sloping lower pediment with clay surface and moderate erosion.	864.2	7.3
Plateau	Potgawhan	10	Pot2mB2	Shallow, well drained, very dark grayish brown, clayey soils on very gently sloping plateau with clay surface and moderate erosion.	540.6	4.6
Alluvial Plain	Sawangi	11	Saw5hC3	Deep, well drained, very dark grayish brown, sandy clay loam soils on gently sloping alluvial plain with sandy clay loam surface and severe erosion.	702.9	6.0
Lower Valley	Soyati	12	Soy4mB2n1	Deep, moderately well drained, very dark grayish brown, clayey soils on very gently sloping lower valley with clay surface, moderate erosion and moderate sodicity.	738.3	6.3
	Soyati	13	Soy4mC3	Deep, moderately well drained, very dark grayish brown, clayey soils on gently sloping lower valley with clay surface and severe erosion	529.5	4.5
Upper Pediment	Warna	14	War2mC2	Shallow, well drained, very dark gray, clayey soils on gently sloping upper pediment with clay surface and moderate erosion.	442.2	3.8
Miscellaneous (habitation / waterbodies / hills)					409.0	3.5
Total					11777.6	100.0

Table 7: Taxonomic classification of soils

Pedon No.	Soil series	Order	Sub order	Great group	Sub group
P1	Bhamb	Inceptisols	Ustepts	Haplustepts	Vertic Haplustept
P2	Dongarkharda	Entisols	Orthents	Ustorthents	Lithic Usterthent
P3	Jalka	Entisols	Orthents	Ustorthents	Lithic Usterthent
P4	Nimgawhan	Entisols	Orthents	Ustorthents	Lithic Usterthent
P5	Nimgawhan-2	Entisols	Orthents	Ustorthents	Lithic Usterthent
P6	Pimpalkhuti	Inceptisols	Ustepts	Haplustepts	Lithic Haplustept
P7	Potgawhan	Inceptisols	Ustepts	Haplustepts	Lithic Haplustept
P8	Sawangi	Inceptisols	Ustepts	Haplustepts	Typic Haplustept
P9	Soyati	Vertisols	Usterts	Haplusterts	Sodic Haplustert
P10	Warna	Entisols	Orthents	Ustorthents	Lithic Usterthent

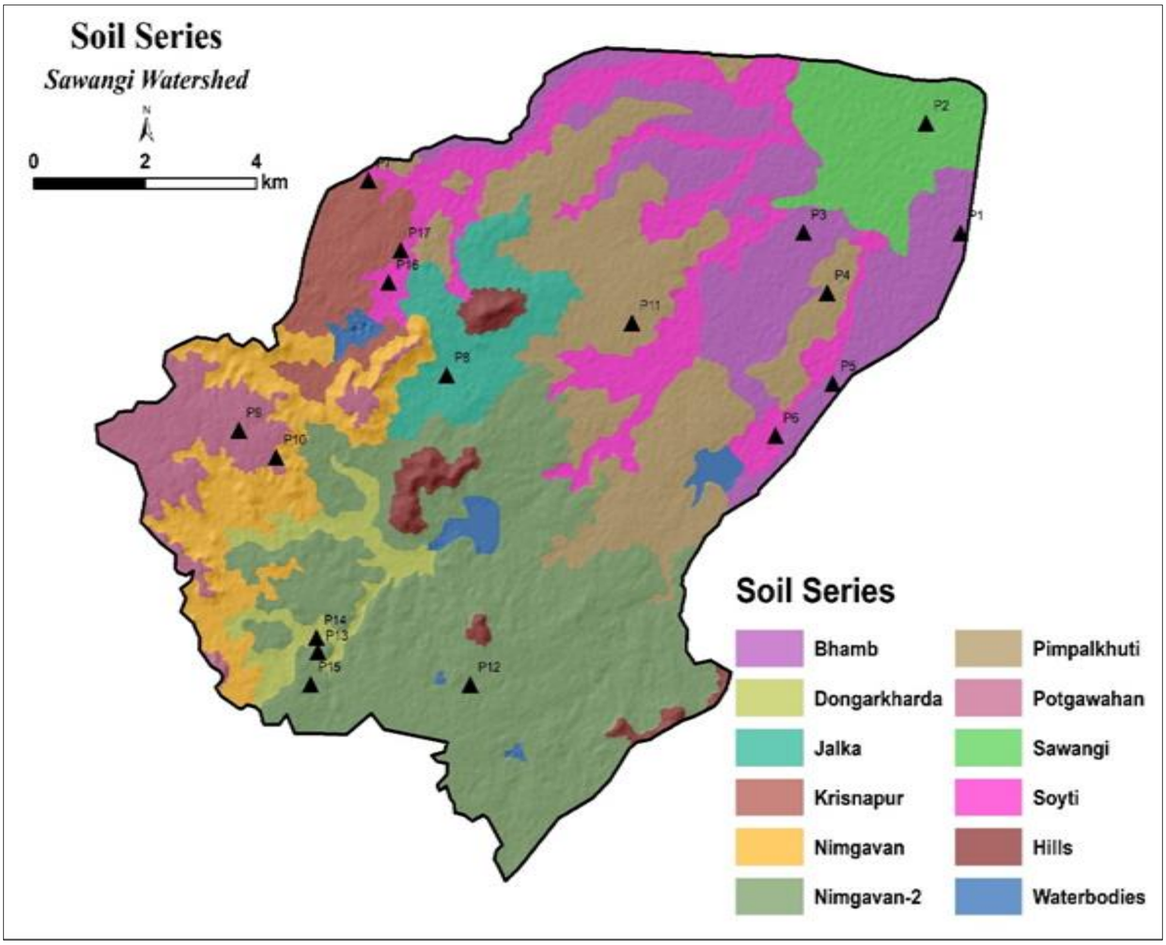

Fig 3: Soil Series map of Sawangi watershed

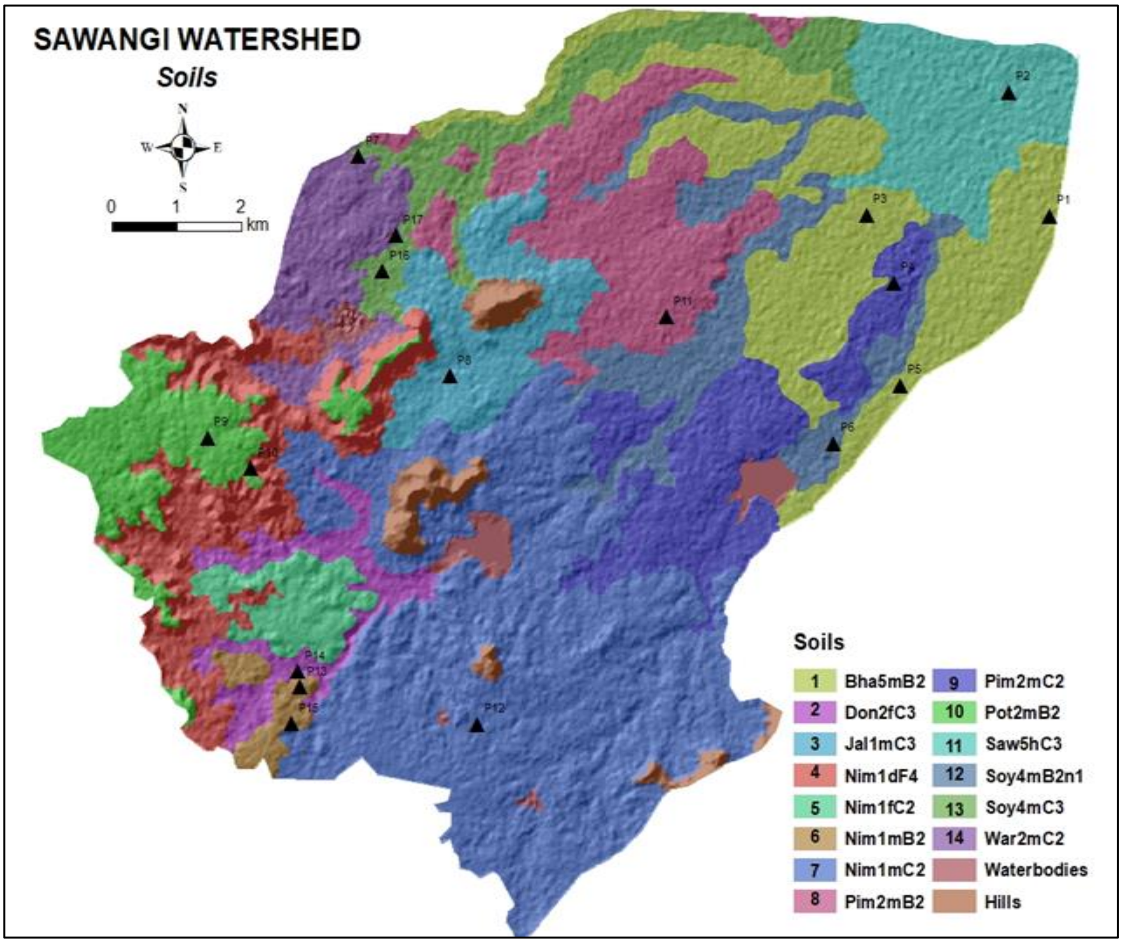

Fig 4: Soil map of Sawangi watershed

Conclusion

The soils of Sawangi watershed are grouped under ten soil series and further, they were characterized and classified. This soil comes under *Vertisols*, *Inceptisols* and *Entisols* soil orders. Based on the different landforms and soil characteristics, these soils are classified as Typic Haplusterts, Lithic Ustorthents, Vertic Haplustepts, and Sodic Haplusterts at the subgroup level. The major landform units identified in the study are mound, plateau, denuded plateau, escarpment, upper pediment, lower pediment, alluvial plain, pediplain, upper valley, lower valley and waterbody. These landforms have developed mainly due to the control slope position and moisture availability. The most soils covering on denuded plateau and escarpments on gently sloping to moderately steeply sloping lands are shallow, reddish brown to dark reddish brown (2.5YR 3/3M and 5YR 3/3M) in colour, well drained, clay loam to loam, very severely eroded and classified as Lithic Ustorthent. The soils of upper valley, plateua, lower and upper pediment occurring on very gently to gently sloping are shallow, very dark grayish brown (10YR3/2), clay in texture, moderately eroded are classified as Lithic Ustorthent and Lithic Haplustert. The soils of pediplain, alluvial plain and lower valley occurring on gently sloping are deep, very dark grayish brown (10YR3/2), clay to sandy clay loam in texture, moderately to severe erosion are classified as Typic Haplustept, Typic Haplustert and Vertic Haplustert. The surface horizons of all soil series show medium, moderate subangular blocky structure while, medium, moderate subangular blocky to angular blocky structure found in sub-surface horizons.

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