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Full Length Research Paper

Characterization of soils in hot semi-arid agro-ecological region of India: A case study of Singhanhalli-Bogur microwatershed in northern transition zone of Karnataka

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The present study was undertaken to characterize soils in Singhanhalli-Bogur microwatershed located in the hot Semi-arid Agro-ecological region of India in the northern transition zone of Karnataka. Horizon-wise soil samples were collected from twenty pedon location and analysed for important physical and chemical properties. The study revealed that the distribution of soil separates varied with depth in most of the horizons whereas % coarse fragments increased with depth. The clay content was higher in the black soils than red soils. All pedons exhibited an irregular trend in silt content whereas surface horizons recorded higher sand content than sub-surface horizons. The bulk density increased with depth with black soils recording higher bulk densities than red soils. In addition, surface horizons recorded lower bulk densities that sub-surface horizons. The field capacity and water holding capacity of the black soils was higher than the red soils but however, the red soils showed higher porosities than the black soils. The pH was slightly acidic to alkaline and increased with depth. The soils were non-saline and all pedons exhibited an irregular trend in electrical conductivity. The organic carbon ranged from low to high whereas in most pedons the CaCO3 followed an irregular trend with the black soils showing higher $CaCO_3$ content than the red soils. The distribution exchangeable bases on the exchange complex was in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. The black soil pedons recorded higher CEC and per cent base saturation than the red soil pedons.

Key words: Singhanhalli-Bogur, soil characterization, microwatershed, Karnataka, soil resource inventory.

INTRODUCTION

Sustainable management of soil resources is essential for food security, maintenance of environment and general well-being of the people but the indiscriminate use of soil resources coupled with lack of management has, however, led to degradation echoing the concern of planners, researchers and farmers (Annon, 2003). It is essential to enhance soil productivity in order to meet the future demand. Soil resource inventory through characterization of resources provides an insight into the potentials and limitations of soil productivity and a framework for the management of soil resources which is needed to realize the concept of watershed development approach successfully (Lal, 2004). An intimate knowledge of the kind of soils and their spatial distribution is a prerequisite in developing rational land use plan for agriculture, forestry, irrigation, drainage etc. (Sehgal et al., 1989).

While soil resource inventory provides an insight into the

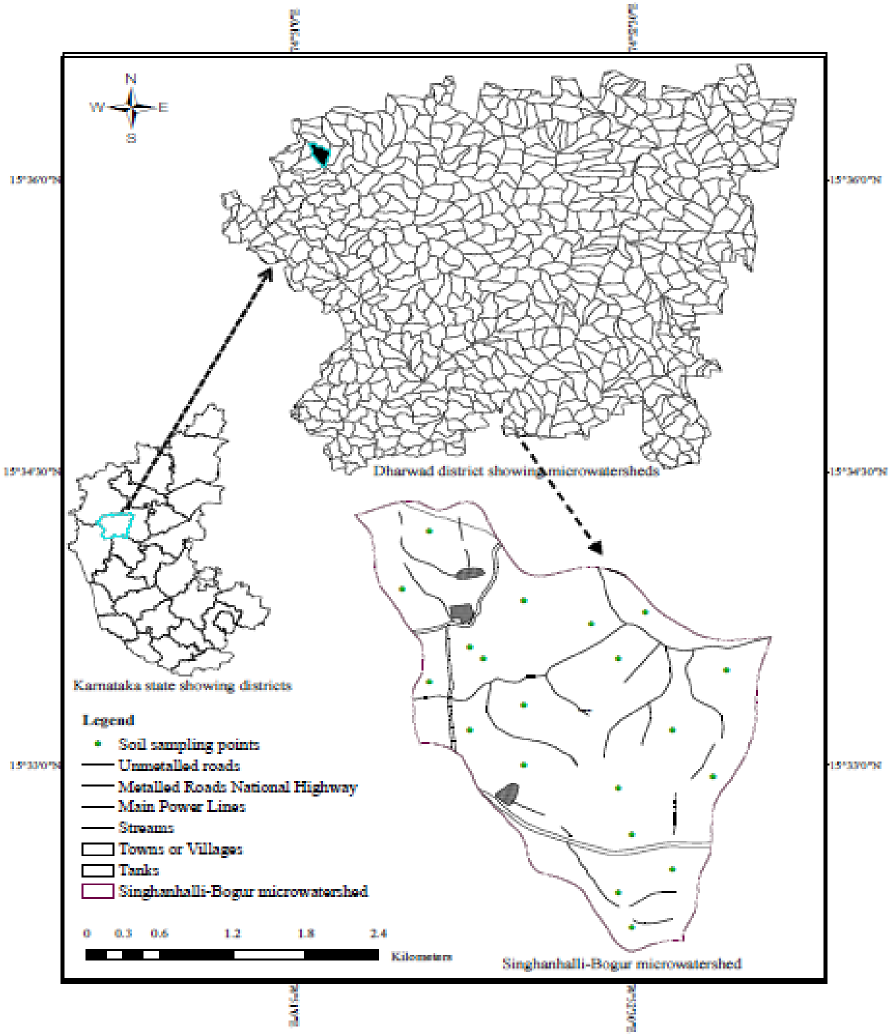

Figure 1. Map of study area.

potentialities and limitations of soil for its effective exploitation, the spatial and quantitative information on soil resources on a microwatershed scale contributes significantly to soil conservation and erosion control planning and management of the watershed environment (Sharma, 2010). Reconnaissance and detailed survey of soil resources have been carried out in several micro-watersheds of Karnataka by students as well as government agencies like the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) and Soil and Land Use Survey of India (SLUSI).

However, such studies have not been undertaken in Singhanhalli-Bogur microwatershed. The study area is highly affected by water erosion due to high rates of deforestation and unsustainable land use practices which had intensified due to the deplorable socio-economic conditions. In addition, the population in this area is characterized by high poverty, rapid population growth and high illiteracy rates. As a result, this area has undergone several changes in forest/land use as a result of human influence causing degradation of soil resources. Information on soils of the study area, in respect of their extent on a particular landscape and their characteristics in terms of potentials and constraints is therefore required so that the precious soil resources may be put to judicious use without allowing it to degrade further. Keeping these in view, the present study was undertaken.

MATERIALS AND METHODS

Description of the study area

Singhanhalli-Bogur micro-watershed is located between 15°31'30.30" to 15°34'49.45" N latitude and 74°50'47.46" to 74°53'35.67" E longitude in Dharwad taluk of Dharwad district

Table 1. Morphological features of soil in study area.

Pedon	Horizon	Depth (cm)	Colour		Texture	Structure			Consistence			Roots		Boundary		Other Salient Features
			Dry	Moist		S	G	T	Dry	Moist	Wet	S	Q	D	T	
Black Soil Pedons																
1	Ap	0-12	10YR3/2	10YR3/2	cl	f	1	gr	h	sfr	s p	vf f	p f	c	s	Pressure faces and wedge shaped aggregating slickensides were observed between depth of 29-110+ cm but were more prominent in lower horizons. 5-8 cm wide cracks from surface up to 35 cm depth were observed.
	A2	12-29	10YR3/3	10YR3/2	c	m	2	gr	vh	vfr	vs vp	vf f	a f	g	s	
	Bss1	29-56	10YR4/2	10YR3/2	c	m	2	sbk	vh	vfr	vs vp	vf f	f f	g	s	
	Bss2	56-85	10YR4/2	10YR3/2	c	m	2	abk	vh	vfr	vs vp	vf	f	g	s	
	Bss3	85-110+	10YR3/3	10YR3/3	c	m	2	abk	vh	vfr	vs vp	vf	f	g	s	
2	Ap	0-14	10YR5/8	10YR5/6	cl	f	1	gr	sh	sfr	ss ps	f	p	c	s	Pressure faces and intersecting slickensides were more predominant in Bss1, Bss2 and Bss3 horizons within 14-62 cm with 6-8 cm wide cracks from surface up to 25 cm depth.
	Bss1	14-34	10YR5/4	10YR5/3	cl	m	2	gr	h	sfr	s p	vf	p	g	s	
	Bss2	34-51	10YR4/3	10YR3/3	c	m	2	sbk	vh	vfr	s p	vf	f	g	s	
	Bss3	51-62	10YR4/3	10YR4/3	c	m	2	sbk	vh	vfr	s p	vf	f	g	s	
	BC	62-85	10YR6/4	10YR3/4	c	m	2	gr	l	vfr	ss ps	-	-	g	s	
3	Ap	0-35	10YR3/3	10YR3/4	sc	f	2	gr	h	sfr	s p	vf f m	p p f	c	s	Slight and strong effervescence was observed at 0-57cm and 57-130+ cm respectively; few very fine, plenty very fine and plenty fine carbonate concretions were observed at 0-57cm, 57-87 cm and 87-130+ cm respectively; pressure faces, intersecting slickensides and a calcic horizon were observed between 57-130+ cm.
	A2	35-57	10YR3/3	10YR3/3	c	f	2	sbk	h	sfr	s p	vf f m	p p f	c	s	
	Bssk1	57-87	10YR3/3	10YR3/3	c	f	2	sbk	h	sfr	vs vp	f	f	c	s	
	Bssk2	87-105	10YR3/2	10YR3/3	c	f	2	sbk	h	sfr	vs vp	f	f	g	s	
	Bssk3	105-118	10YR3/3	10YR4/4	gc	f	2	abk	h	sfr	vs vp	f	f	g	s	
	Bssk4	118-130+	10YR3/3	10YR3/3	gc	f	2	abk	h	sfr	vs vp	-	-	g	s	

Table 1. Cont'd

4	Ap	0-24	10YR5/4	10YR4/3	cl	f	2	gr	h	sfr	s p	vf f m	p p p	a	s	Very slight to slight effervescence was observed at 0-73 cm while strong effervescence was observed at 73-135+ cm; few very fine, few fine, and plenty fine carbonate concretions were observed at 0-24cm, 46-111cm and 24-46cm and 111-135+ cm respectively; pressure faces and well developed slickensides between 24-126 cm with calcic horizon dominating at 73-135+ cm.
	Bss1	24-46	10YR5/4	10YR4/3	c	f	2	gr	h	fr	s p	vf f	p p	a	s	
	Bss2	46-73	10YR4/4	10YR5/4	c	vf	2	sbk	vh	vfr	vs vp	vf f	f f	c	s	
	Bss3	73-111	10YR5/6	10YR5/6	c	vf	2	abk	vh	vfr	vs vp	vf f	f f	c	s	
	Bss4k	111-126	10YR5/4	10YR5/6	c	vf	2	abk	vh	vfr	vs vp	vf	f	c	s	
	Bk	126-135+	10YR5/4	10YR5/4	c	f	2	gr	h	fr	ss ps	-	-	c	s	
5	Ap	0-27	10YR4/3	10YR3/3	c	f	2	sbk	h	sfr	s p	vf f m	p p m	c	s	Slight effervescence and few fine carbonate concretions were observed at 92-120+ cm; well-developed slickensides and pressure faces were observed at 45-120+ cm depth but were more predominant in Bss1, Bss2, Bss3 and Bss4 horizons. Cracks 6-8 cm wide were observed from surface to 50 cm depth.
	A2	27-45	10YR4/3	10YR3/3	c	f	2	sbk	h	sfr	s p	vf f	p p	g	s	
	Bss1	45-65	10YR3/4	10YR3/3	gc	f	2	abk	vh	sfr	vs vp	vf f	f f	g	s	
	Bss2	65-92	10YR3/4	10YR3/3	c	f	2	abk	vh	vfr	vs vp	vf f	f f	a	s	
	Bss3	92-112	10YR4/3	10YR3/3	c	f	2	abk	vh	vfr	vs vp	vf f	f f	a	s	
	Bss4	112-120+	10YR4/3	10YR3/3	c	f	2	abk	vh	vfr	vs vp	f	f	g	s	

in the northern transition zone of Karnataka, India (Figure 1). The study area lies in the Decca plateau in the hot semi-arid agro-ecological region 6 and sub-region 6.4, having medium to high available water content with a length of growing period of 150-180 days. The climate is characterized by hot and humid summer and mild and dry winter.

The study area receives an annual average rainfall of 755.2 mm, which distributed over May to October and annual temperature ranging from 24 - 28 °C and having Ustic Soil Moisture and Isohyperthermic soil temperature regimes (Amara et al., 2013). The highest elevation is 754 m above mean sea level and the relief is very gently to strongly sloping. The general slope is towards the northeast, southeast and southwest but it is more in the southwest direction. The drainage pattern is parallel.

Soils are derived from chlorite schist with shale as dominant parent material containing banded iron oxide quartzite. The soils are coarse textured and shallow at the higher elevations but gradually fineness and depth increases towards the lower elevations. The main soil types are black and red soils but the red soils are in higher proportion than the black soils. The natural vegetation mainly comprised of trees and shrubs including Acacia (*Acacia auruculiformis*), Neem (*Azadirachta indica*) and Eucalyptus (*Eucalyptus sideroxylon* and *Eucalyptus regnana*).

Soil survey and characterization

A detailed soil survey of the study area was carried out using IRS P6 LISS-IV satellite image and Dharwad

Table 1. Cont'd.

Pedon	Horizon	Depth (cm)	Colour		Texture	Structure			Consistence			Roots		Boundary		Other Salient Features
			Dry	Moist		S	G	T	Dry	Moist	Wet	S	Q	D	T	
Red Soil Pedons																
6	A	0-22	5YR5/4	2.5YR5/3	gsl	f	2	gr	l	sfr	so po	vf	f	c	s	About 30 and 46% fine gravels at 0-22 and 22-48 cm, 35% fine gravels at 48-76cm and 56% very fine gravels at 76-106cm were observed with clay skins present between 22-76 cm depth.
	Bt1	22-48	5YR5/4	5YR4/4	gsl	f	2	gr	l	sfr	ss ps	f	p	g	s	
	Bt2	48-76	5YR5/4	2.5YR4/3	gsl	c	2	gr	l	sfr	ss ps	vf	f	g	s	
	BC	76-106	5YR4/6	5YR4/6	gsl	c	2	gr	h	fr	ss ps	vf	f	g	s	
7	Ap	0-25	7.5YR6/4	7.5YR5/4	gsc	f	2	gr	l	l	so po	vf f m	p f f	c	s	About 23% fine and 32% fine gravels were observed at 0-25 cm and 52-90 cm respectively.
	AC	25-52	7.5YR5/4	7.5YR5/6	cl	f	2	gr	h	fr	ss ps	vf f m	f f f	c	s	
	BC	52-90	7.5YR5/4	7.5YR5/6	gscl	f	2	gr	l	fr	ss ps	vf f	f f	a	s	
8	A	0-11	7.5YR6/4	7.5YR5/4	gsl	m	2	gr	l	l	so po	vf f	f f	a	s	About 33% medium, 28% fine, 23 and 33% coarse gravels at 0-11, 11-30, 30-56 and 56-80 respectively with weathered shale at 56-80 cm were observed.
	Bw1	11-30	7.5YR6/6	7.5YR5/6	gsl	m	2	gr	l	fr	ss ps	vf f m	f f f	a	s	
	Bw2	30-56	7.5YR6/6	7.5YR5/6	gsl	m	2	gr	l	fr	ss ps	f m	f f	a	s	
	BC	56-80	7.5YR5/4	7.5YR4/4	gsl	c	2	gr	l	l	so po	f	f	a	s	

district Toposheet as per procedure outlined Soil Survey Staff (2000). The image and scanned Toposheet were geocoded and subset was created in ArcGIS 10.1 on a 1:12,500 scale. The area was then intensively traversed and 20 pedon locations were fixed based on soil heterogeneity. At each pedon location, a fresh profile was opened and horizon-wise soil samples were collected and analyzed for important physical and physicochemical properties following standard procedures. After the correlation of soil properties, 10 representative soil pedons (5 black soil and 5 red soil pedons) were selected.

RESULTS AND DISCUSSION

Physiography - soil relationship of the study area

The relationship between physiography of an area and soils has been widely recognized as the factors involved in the physiographic processes corresponding close to that of soil formation. This relationship between landscape features and soil conditions makes possible for prediction about the nature and distribution pattern of different soils. In the present study, three major physiographic units, namely upland, undulating midlands and lowlands were identified. The results showed that there had been changes in the morpho-

Table 1. Cont'd.

9	A	0-11	7.5YR6/6	7.5YR6/4	gsl	f	2	gr	sh	fr	s p	vf f	f p	a	s	About 20% rock fragments and weathered quartzite at 23-40 cm and lithic contact were observed. Clay skins around ped and clay bridging between sand grains.
	Bt	11-23	7.5YR6/6	7.5YR5/6	gsl	f	2	gr	h	sfr	ss ps	vf	f	a	s	
	BC	23-40	7.5YR6/6	7.5YR5/6	gsl	f	2	gr	h	fr	s p	vf	f	a	s	
10	A	0-38	7.5YR6/4	7.5YR5/4	gsl	f	2	gr	l	fr	so po	vf f m c	p p p f	a	s	About 24, 25 and 27% very fine, medium and coarse gravels were observed at 0-38, 38-64 and 64-100 cm with weathered shale between 38-100 cm. Clay skins around ped and clay bridging between sand grains.
	Bt	38-64	7.5YR6/4	7.5YR5/4	gsl	f	2	gr	l	fr	so po	vf f m c	p p p f	a	s	
	BC	64-100	7.5YR5/4	7.5YR4/4	gsl	m	2	gr	l	fr	so po	vf f	f f	a	s	

Texture: c – clay, cl – clay loam, sc – sandy clay, gc – gravelly clay, gcl – gravelly clay loam, gsc – gravelly sandy clay, gscl – gravelly sandy clay loam. Structure: Size (S): vf – very fine, f – fine, m – medium, c – coarse; Grade (G): 1 – weak, 2 – moderate, 3 – strong; Type (T): cr – crumb, sg – single grain, abk – angular blocky, sbk – sub-angular blocky. Consistence: Dry: s – soft, l – loose, sh – slightly hard, h – hard, vh – very hard. Moist: l – loose, sfr – slightly friable, fr – friable, vfr – very friable, fi – firm, vfi – very firm. Wet: so – non-sticky, ss – slightly sticky, s – sticky, vs – very sticky, po – non-plastic, ps – slightly plastic, p – plastic, vp – very plastic. Roots: Size (S): vf – very fine, f – fine, m – medium, c – coarse; Quantity (Q): f – few, c – common, m – many, p – plenty. Boundary: Distinctness (D): a – abrupt, c – clear, g – gradual, d – diffuse; Topography (T): s – smooth, w – wavy, i – irregular, b – broken.

Table 2. Distribution of soil separates in pedons.

Pedon No.	Horizon	Depth (cm)	Gravel (Coarse fragment) (%)	Coarse Sand (%)	Fine Sand (%)	Total Sand (%)	Silt (%)	Clay (%)	Textural Class
Black Soil Pedons									
1	Ap	0 - 12	2.04	16.8	24.1	40.9	19.5	39.6	cl
	A2	12 - 29	1.56	12.9	23.2	36.1	22.3	41.6	c
	Bss1	29 - 56	5.53	13.3	22.4	35.7	22.2	42.1	c
	Bss2	56 - 85	1.07	13.2	22.1	35.3	20.9	43.8	c
	Bss3	85 - 110+	1.85	13.8	23.1	36.9	20.5	42.6	c
2	Ap	0 - 14	7.28	16.2	12.2	28.4	36.8	34.8	cl
	Bss1	14 - 34	4.46	12.2	13.4	25.6	36.1	38.3	cl

Table 2. Cont'd

	Bss2	34 - 51	3.94	18.8	14.4	33.2	21.6	45.2	c
	Bss3	51 - 62	11.33	17.8	12.7	30.5	20.3	49.2	c
	BC	62 - 85	14.65	18.6	13.8	32.4	20.3	47.3	c
	Ap	0 - 35	5.36	11.6	29.6	41.2	19.6	39.2	sc
	A2	35 - 57	4.77	10.6	24.4	35	19.4	45.6	c
3	Bssk1	57 - 87	5.85	14.3	17.5	31.8	20.8	47.4	c
	Bssk2	87 - 105	12.36	9.8	17.2	27	21.4	51.6	c
	Bssk3	105 - 118	15.67	7.8	20.3	28.1	20.1	51.8	gc
	Bssk4	118 130+	15.78	7.6	19.8	27.4	19.2	53.4	c
	Ap	0 - 24	3.15	19.7	20.6	40.3	20.4	39.3	cl
	Bss1	24 - 46	5.31	12	24.6	36.6	23.1	40.3	c
4	Bss2	46 - 73	12.02	13.8	25.3	39.1	17.5	43.4	c
	Bss3	73 - 111	9.39	11.5	24.8	36.3	14.5	49.2	c
	Bss4k	111 - 126	9.59	12.8	24.6	37.4	12.8	49.8	c
	Bk	126 -135+	4.83	10.7	21.3	32	17.4	50.6	c
	Ap	0 - 27	9.05	20.2	18.1	38.3	21.4	40.3	c
	A2	27 - 45	14.4	11.1	24	35.1	24.2	40.7	c
5	Bss1	45 - 65	18.56	10.7	24.3	35	22.1	42.9	gc
	Bss2	65 - 92	14.57	8.6	22.8	31.4	24.3	44.3	c
	Bss3	92 - 112	4.44	9.2	19.5	28.7	21.2	50.1	c
	Bss4	112 - 120+	6.36	10.4	18.8	29.2	17.6	53.2	c

logical, physical and chemical properties of soils due to change of slope and landform (Tables 1, 2, 3 and 4). It was evident that landform had played a major role in influencing these properties with the effect of other parameters like water erosion, climate and environmental conditions.

The lowlands were situated at 0 to 5% slopes having grayish green tones with red patches, undulating midlands at 5 to 15% slopes having checker board pattern with light grayish tones and medium to coarse textures, whereas uplands were situated at more than 15% slopes having checker board pattern and grayish green tones with slight pinkish spots. The soils in low-lowlands were deep to very deep, sandy clay to sandy clay loam and clay, moderate to strong and sub-angular to angular blocky, sticky to very sticky and plastic to very plastic especially for the black soils and in some cases, non-sticky and non-plastic especially for the red soils. These soils were slightly eroded and exhibited better chemical properties and fertility status than the soils of other land forms. The soils in the undulating

Table 2. Cont'd

Pedon No.	Horizon	Depth (cm)	Gravel (Coarse fragment) (%)	Coarse Sand (%)	Fine Sand (%)	Total Sand (%)	Silt (%)	Clay (%)	Textural Class
Red Soil Pedons									
6	A	0 - 22	30.69	48.8	20	68.8	18.4	12.8	gsl
	Bt1	22 - 48	45.89	42.6	20.4	63	19.9	17.1	gsl
	Bt2	48 - 76	35.55	44.1	18.7	62.8	18.9	18.3	gsl
	BC	76 - 106	56.32	58.6	22.1	80.7	11.4	7.9	gsl
7	Ap	0 - 25	22.76	33.8	14.1	47.9	15.3	36.8	gsc
	AC	25 - 52	9.7	20	19.8	39.8	20.8	39.4	cl
	BC	52 - 85	31.8	31.2	19.4	50.6	14.3	35.1	gscl
8	A	0 - 11	32.69	37.1	24.8	61.9	18.9	19.2	gsl
	Bw1	11 - 30	28.03	55.5	11.2	66.7	14.6	18.7	gsl
	Bw2	30 - 56	22.84	57.8	10.7	68.5	15.1	16.4	gsl
	BC	56 - 80	32.62	50.8	11.6	62.4	18.5	19.1	gsl
9	A	0 - 11	15.28	48.1	22.9	71	15.3	13.7	gsl
	Bt	11 - 23	16.74	44.6	21.1	65.7	16.4	17.9	gsl
	BC	23 - 40	19.53	52.3	13.9	66.2	18.6	15.2	gsl
10	A	0 - 38	23.57	53.2	16.8	70	16.8	13.2	gsl
	Bt	38 - 64	24.47	44.8	16.8	61.6	19.3	19.1	gsl
	BC	64 - 100	26.92	57.1	14.3	71.4	17.2	11.4	gsl

midlands were moderately deep to deep, sandy loam to clay loam and sandy clay loam, weak to moderate and granular to sub-angular blocky, slightly sticky and slightly plastic to sticky and plastic. These soils were moderately eroded and showed moderate to good chemical properties and fertility status, whereas the soils in the uplands were shallow to moderately deep, sandy loam, weak granular structure and non-sticky and non-plastic to slightly sticky and slightly plastic. These soils were severely to very severely eroded and showed poor to fairly good chemical and fertility status. Norton et al. (1998) observed similar relationship between slope, erosion and chemical properties.

Gradual decrease in sand content with depth and accumulation of clay in subsurface was observed. This might be due to the eluviation of clay from surface layers and its accumulation in subsurface layers under the influence of rainfall. In the black soils, the clay content was highest followed by sand and silt content, whereas in the red soils, the sand content was highest followed by silt and clay. The sand content decreased, while clay content increased with depth. This might be attributed to translocation of clay from the surface to subsurface layers as was also reported by Satyavathi and Reddy (2003) and Reddy et al. (2013). Among the soil separates, the sand content decreased with depth, silt distribution was irregular and the clay content increased with depth in majority of the pedons. The finer fractions of soil increased from the surface to subsurface. This might be due to surface enrichment of sand fraction in surface horizons that followed removal of finer particles by clay eluviation and surface runoff. The results showed that the red soils, due to their location in the sloping uplands, were more easily eroded than the black soils. The effect of erosion was evident by accumulation of eroded materials in the

Table 3. Physical properties of pedons.

Pedon No.	Horizon	Depth (cm)	Bulk Density (Mg m^{-3})	Field Capacity (%)	Maximum Water Holding Capacity (%)	Porosity (%)
Black Soil Pedons						
1	Ap	0 - 12	1.22	31.5	59.31	44.15
	A2	12 - 29	1.23	35.43	68.07	50.19
	Bss1	29 - 56	1.26	30.92	65.81	44.91
	Bss2	56 - 85	1.28	34.53	68.27	49.81
	Bss3	85 - 110+	1.28	35.14	68.46	46.04
2	Ap	0 - 14	1.21	37.06	70.02	54.72
	Bss1	14 - 34	1.24	29.84	55.63	48.68
	Bss2	34 - 51	1.26	31	57.82	46.79
	Bss3	51 - 62	1.26	33.14	66.8	48.3
	BC	62 - 85	1.26	34.25	69.13	46.79
3	Ap	0 - 35	1.18	40.14	77.03	55.47
	A2	35 - 57	1.23	38.47	73.18	53.58
	Bssk1	57 - 87	1.26	36.18	70.01	52.45
	Bssk2	87 - 105	1.24	33.24	67.32	49.43
	Bssk3	105 - 118	1.26	33.1	64.81	47.92
	Bssk4	118 130+	1.28	32.05	63.44	45.66
4	Ap	0 - 24	1.22	38.21	75.14	53.96
	Bss1	24 - 46	1.23	36.03	72.82	52.08
	Bss2	46 - 73	1.23	34.41	69.41	50.57
	Bss3	73 - 111	1.24	35.08	71.38	48.68
	Bss4k	111 - 126	1.26	35.44	74.24	46.79
	Bk	126 -135+	1.26	36.11	76.8	44.91

Table 3. Cont'd

5	Ap	0 - 27	1.18	39.43	74.21	53.58
	A2	27 - 45	1.22	35.77	69.14	50.89
	Bss1	45 - 65	1.25	34.81	68.11	49.06
	Bss2	65 - 92	1.27	34.62	68.03	48.3
	Bss3	92 - 112	1.28	37.31	70.44	46.04
	Bss4	112 - 120+	1.23	38.14	73.1	44.15
			Red Soil Pedons			
6	A	0 - 22	1.38	13.61	25.24	47.92
	Bt1	22 - 48	1.33	16.56	37.16	49.81
	Bt2	48 - 76	1.41	17.34	32.04	46.79
	BC	76 - 106	1.44	11.1	16.22	45.66
7	Ap	0 - 25	1.4	28.71	59.01	47.17
	AC	25 - 52	1.44	32.34	64.14	45.66
	BC	52 - 85	1.51	32.03	61.26	43.02
8	A	0 - 11	1.32	18.33	36.58	50.19
	Bw1	11 - 30	1.34	16.52	32.44	49.43
	Bw2	30 - 56	1.38	16.01	31.01	47.17
	BC	56 - 80	1.4	14.28	28.48	47.92
9	A	0 - 11	1.38	14.82	29.43	47.92
	Bt	11 - 23	1.43	15.42	35.31	46.04
	BC	23 - 40	1.47	16.12	22.48	44.53
10	A	0 - 38	1.36	17.13	34.61	48.68
	Bt	38 - 64	1.38	15.32	28.43	45.28
	BC	64 - 100	1.45	19.11	35.18	47.92

midlands and lowlands. As a result, the soils at these landscape positions were moderately deep to deep and very deep with finer texture. Soil erosion might have been a dominant soil forming process in the study area as was also evident by Sawhney et al. (1992) in semiarid and arid tracts of Punjab and Reddy et al. (2013) in Basaltic Terrain of Central India. In addition, it was observed that land use in the study area might have influenced the erosion of soils in the order of agriculture > open scrub > plantation > forest soil. The sediment yield and total runoff water increase was observed to be directly proportional to the slope %. However, soils on gentle slopes and covered with vegetation were less susceptible to erosion than uncovered areas.

Morphological properties of pedons

Depth

The soils of the study area were shallow to very deep (Figure 2). Shmoista et al., (2010) reported the occurrence of shallow (<50 cm), moderately deep (50 to 100 cm) and deep (>100 cm) red and black soils of India. The depth of the soils in the study area was somewhat shallow to moderate in the steeper slopes and deep to very deep in the gentle slopes. The depth of the upland pedons was comparatively less than the lowland pedons. This variation in depth might be due to variation in topography. Variation in depth in relation to physiography and slope, mainly because of non-availability of adequate amount of water for prolonged period in the upland soils associated with

Table 4. Chemical properties of pedon.

Pedon No.	Horizon	Depth (cm)	pH	EC ($dS\ m^{-1}$)	Organic carbon ($g\ kg^{-1}$)	Free CaCO3 (%)	Exchangeable cations ($cmol(p+)\ kg^{-1}$)				Sum of exchangeable bases ($cmol(p+)\ kg^{-1}$)	CEC ($cmol(p+)\ kg^{-1}$)	Base Saturation (%)
							Ca	Mg	Na	K			
Black Soil Pedons													
1	Ap	0 - 12	7.45	0.24	9.8	5.25	25.40	5.20	6.52	3.58	40.70	51.55	78.95
	A2	12 - 29	7.10	0.06	7.4	4.50	13.10	15.10	2.61	2.05	32.86	42.07	78.11
	Bss1	29 - 56	7.83	0.10	1.2	3.25	19.65	1.25	4.78	1.80	27.48	35.83	76.70
	Bss2	56 - 85	8.25	0.22	1.6	3.50	21.70	3.65	6.09	0.77	32.21	40.86	78.83
	Bss3	85 - 110+	8.36	0.14	5.1	2.50	24.20	1.10	6.96	2.30	34.56	45.26	76.36
2	Ap	0 - 14	6.10	0.06	1.01	0.50	8.90	3.30	1.74	4.36	18.30	25.93	70.57
	Bss1	14 - 34	7.59	0.12	3.9	0.75	9.95	8.05	3.04	4.10	25.14	32.13	78.24
	Bss2	34 - 51	7.80	0.15	3.5	1.00	8.55	8.65	2.61	0.50	20.31	27.36	74.23
	Bss3	51 - 62	7.42	0.09	4.5	1.00	8.30	7.50	2.18	3.34	21.32	27.84	76.58
	BC	62 - 85	7.90	0.17	2.0	2.50	9.45	2.10	2.61	2.56	16.72	24.04	69.55
3	Ap	0 - 35	7.72	0.24	1.2	3.50	13.15	2.50	3.48	3.22	22.35	29.15	76.67
	A2	35 - 57	8.55	0.09	6.6	11.25	24.85	3.15	3.48	3.91	35.39	40.88	86.57
	Bssk1	57 - 87	6.21	0.07	2.0	13.50	24.20	3.60	6.96	7.83	42.59	45.62	93.36
	Bssk2	87 - 105	8.71	0.11	5.5	18.75	37.90	4.60	7.83	9.13	59.46	61.87	96.10
	Bssk3	105 - 118	8.79	0.11	3.9	16.00	32.00	0.95	10.43	11.30	54.68	57.96	94.34
	Bssk4	118 130+	8.84	0.12	2.3	18.00	43.05	3.35	8.70	10.00	65.10	65.99	98.65
4	Ap	0 - 24	8.35	0.07	0.4	4.00	27.55	5.75	1.74	1.74	36.78	43.93	83.72
	Bss1	24 - 46	7.78	0.12	3.1	3.50	24.85	1.05	1.74	1.48	29.12	38.15	76.33
	Bss2	46 - 73	8.29	0.08	1.2	3.50	22.60	5.40	3.04	3.04	34.08	40.56	84.02
	Bss3	73 - 111	8.54	0.07	0.8	13.75	7.20	1.65	3.91	3.91	16.67	22.89	72.83
	Bss4k	111 - 126	8.59	0.07	1.6	2.25	20.40	8.60	3.91	4.34	37.25	42.84	86.95
	Bk	126 -135+	8.61	0.06	2.3	12.00	16.40	16.00	3.48	3.91	39.79	44.05	90.33
5	Ap	0 - 27	7.35	0.17	7.0	1.75	21.90	3.20	5.65	1.79	32.54	38.88	83.69
	A2	27 - 45	7.63	0.20	0.8	0.50	15.30	7.10	7.83	0.51	30.74	36.17	84.99
	Bss1	45 - 65	7.82	0.14	5.9	1.50	12.20	15.05	8.70	1.02	36.97	42.82	86.34
	Bss2	65 - 92	7.91	0.11	7.4	1.25	17.80	6.70	10.87	1.53	36.90	44.14	83.60
	Bss3	92 - 112	8.44	0.07	6.6	1.75	26.05	8.85	10.87	1.79	47.56	54.05	87.99
	Bss4	112 - 120+	8.60	0.10	0.8	1.25	27.60	4.30	11.30	0.51	43.71	51.54	84.81

Table 4. Cont'd.

Pedon No.	Horizon	Depth (cm)	pH	EC (dS m^{-1})	Organic carbon (g kg^{-1})	Free CaCO3 (%)	Exchangeable cations (cmol(p+) kg^{-1})				Sum of exchangeable bases (cmol(p+) kg^{-1})	CEC (cmol(p+) kg^{-1})	Base Saturation (%)
							Ca	Mg	Na	K			
Red Soil Pedons													
6	A	0 - 22	6.10	0.16	6.6	8.75	7.25	0.15	0.44	0.77	8.61	14.97	57.52
	Bt1	22 - 48	7.22	0.04	6.2	9.25	9.45	1.70	1.74	0.51	13.40	20.33	65.91
	Bt2	48 - 76	7.64	0.04	6.2	9.75	10.45	0.95	2.17	0.51	14.08	20.57	68.45
	BC	76 - 106	8.02	0.17	3.5	1.00	7.35	3.85	2.61	0.51	14.32	20.83	68.75
7	Ap	0 - 25	7.33	0.19	18.7	0.50	7.80	3.75	6.09	0.77	18.41	29.19	63.07
	AC	25 - 52	7.09	0.15	7.8	0.25	8.60	3.00	7.39	1.02	20.01	30.32	66.00
	BC	52 - 85	7.00	0.07	10.1	0.75	8.50	3.00	7.39	0.26	19.15	28.09	68.17
8	A	0 - 11	6.08	0.06	6.6	0.50	4.75	7.65	0.87	2.05	15.32	28.51	53.74
	Bw1	11 - 30	6.30	0.07	20.3	1.00	11.95	2.85	1.30	0.77	16.87	33.14	50.91
	Bw2	30 - 56	6.40	0.12	11.3	2.50	8.05	8.75	1.74	0.26	18.80	29.53	63.66
	BC	56 - 80	6.52	0.13	5.1	2.25	5.90	1.50	2.61	1.27	11.28	22.22	50.77
9	A	0 - 11	5.65	0.10	22.2	1.75	5.30	5.00	0.87	0.52	11.69	20.18	57.93
	Bt	11 - 23	6.28	0.08	7.8	1.50	10.55	1.65	0.44	0.77	13.41	24.79	54.09
	BC	23 - 40	6.63	0.11	6.2	2.25	10.90	2.15	1.30	0.52	14.87	28.12	52.88
10	A	0 - 38	6.31	0.10	21.8	1.50	8.00	5.70	1.74	0.76	16.20	27.84	58.19
	Bt	38 - 64	6.10	0.16	12.1	7.50	6.60	6.15	1.74	0.26	14.75	26.54	55.58
	BC	64 - 100	5.85	0.06	13.7	2.25	4.70	6.40	1.74	0.51	13.35	31.02	43.04

removal of finer particles and their deposition in the lowlands might have resulted in the development of shallow soils in the uplands and deep to very deep soils in the lowlands. The soils on very gently sloping lands were deep to very deep, those on gently sloping lands were moderate to very deep, whereas the soils on moderately sloping lands were moderately deep to deep.

Horizon differentiation in the red soil pedons was relatively easier compared to that of the black soil pedons because of argilli-pedoturbation in the latter. In the red soils, horizons were identified based on colour texture, abundance of coarse fragments and presence or absence of clay skins on ped surfaces, whereas in the black soil pedons, horizon differentiation was mostly based on the prominence, abundance and intersection of slickensides.

The soils of the upland pedons showed varying degree of profile development from A-C to A-B-C and were eroded. The depth of the Cr horizons in the upland and midland pedons was less compared to the lowland pedons. According to Dasog and Patil (2011) and Reddy *et al*. (2013), the removal and deposition of soil particles from different physiographic positions may result to varying degree of profile development between the uplands and undulating midlands.

Colour

All the black soils had colours in the hue of 10YR throughout the profile and the dominant colour was reddish brown to dark brown. The value ranged from 3 to 6 and chroma from 2 to 8. The darker colour of the

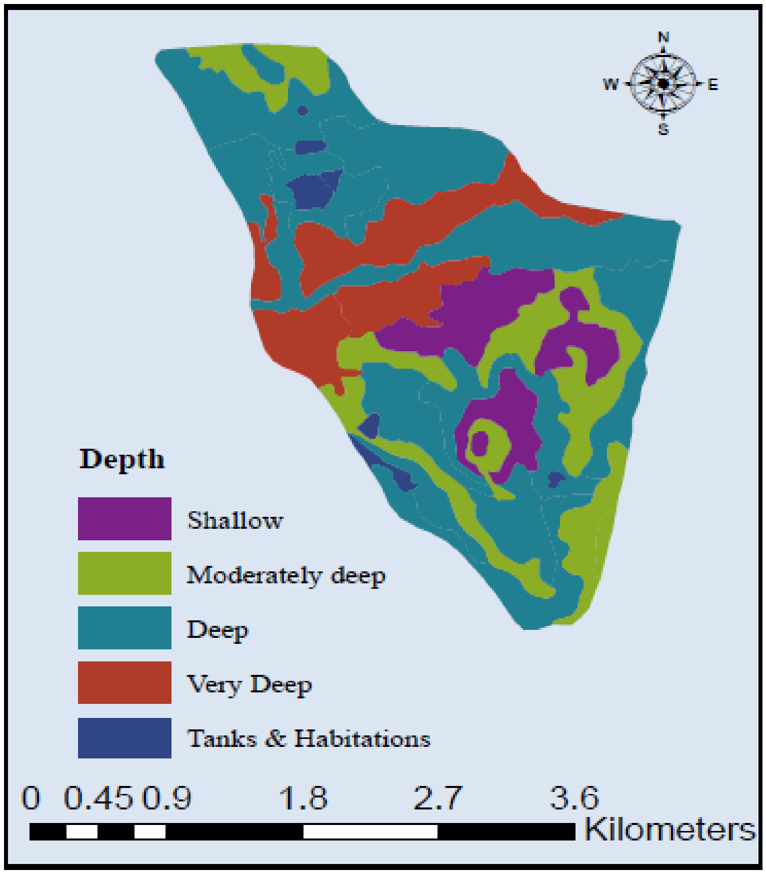

Figure 2. Depth classes in Singhanhalli-Bogur microwatershed

black soils might be attributed to the clay-humus complex in the presence of lime. The colour of the surface horizons varied from dark brown to yellowish and brown due to the high amount of ferruginous quartzite materials. The dark colour might be attributed to the presence of iron sulphide and manganese oxide in combination with the organic complex as was also observed by Patil and Dasog (1999) and Gangopadhyay et al. (2012). The red soils had colours in the hue of 7.5YR to 5YR. The values ranged between 3 to 5 and chroma between 2 and 6, which indicated very good drainage condition. The presence free iron oxide concretions might have played an important role in imparting red colour to the soils. In the red soil pedons, the surface horizons were darker than the subsurface horizons. The darker colour of the surface horizons might be attributed to the presence of high organic matter content, whereas the lighter colour of the subsurface horizons might be due to low organic matter content and higher iron oxide content.

Texture

The texture of the black soil pedons varied from clay to clay loam with high clay content in the subsurface horizons (Figure 3). Surface horizons were clay loam. In general, the morphogenetic expression of some black soils showed considerable homogeneity. However, prominent slickensides and pressure faces were observed at depth more than 30 cm in all the black soil pedons. The black soil pedons were characterized by the presence of cracks varying in width from 1 to 10 cm, extending to depth of 50 cm. These cracks remain open for periods varying from 90 to 150 cumulative days. The variation in the volume of cracks might be attributed to the variation in contents of cementing materials and exchangeable Na^+. If the cementing materials like iron and aluminium hydroxides were more, the extent of cracks will be less due to reduction in swelling property. If the soil is having more exchangeable Na^+, more will be the swelling and development of wider cracks. In the red soil pedons, texture varied from clay to clay loam, sandy clay loam and sandy loam. The lesser mobilization and translocation of finer fractions might have resulted to the clay loam texture. According to Pulakeshi et al. (2014), deposition of finer fractions and differences in physiography is a major soil forming processes leading to the variation in texture.

The texture of the surface horizons in upland pedons was sandy loam, whereas in the lowland pedons, the texture was

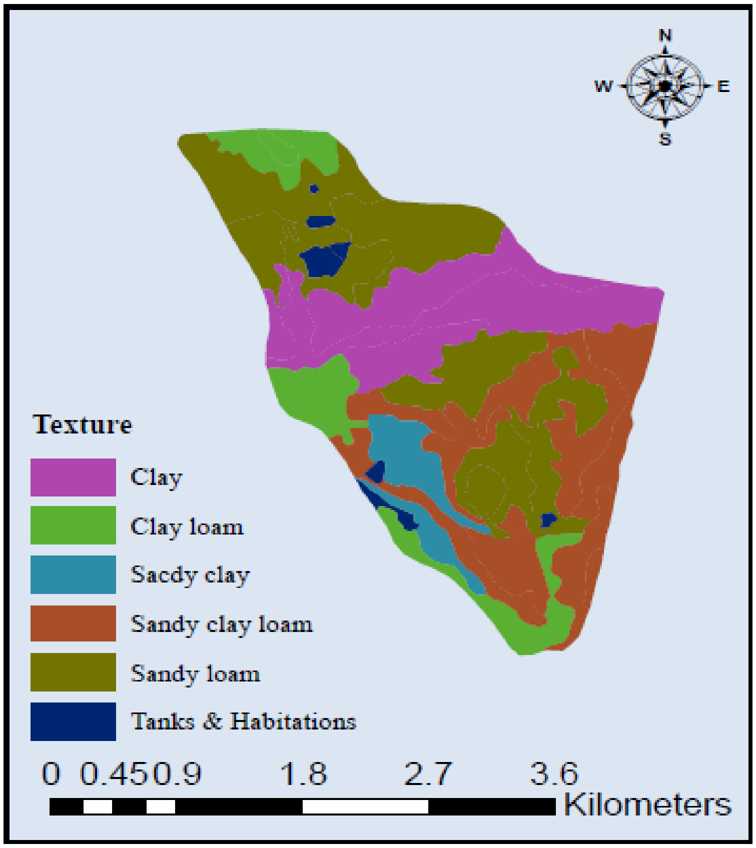

Figure 3. Texture classes in Singhanhalli-Bogur microwatershed

clay loam to sandy clay and sandy clay loam. This variation in texture was mainly due to the deposition of finer fractions from uplands. The surface horizon of the lowland pedon was finer in texture than upland and undulating midlands. This might be due to differences in physiography, resulting to the deposition of finer fractions from uplands and midlands.

Structure

The structure of the black soil pedons varied from moderate, fine granular in the surface horizons to moderate, very fine to fine angular and sub-angular blocky in the subsurface horizons. Angular blocky structure in the subsurface horizons was due to slickensides formation in these soils. The surface horizons of the black soils had moderate, medium subangular blocky structure and hard to very hard (dry) and friable to very firm (moist) consistence. The subsurface horizons had moderate to strong, medium to very coarse angular blocky structures and hard to extremely hard (dry) and firm to extremely firm (moist) consistence. According to Pulakeshi et al. (2014), these are characteristic features of black soils in South India.

In the red soil pedons, structure varied from weak to moderate, fine granular in surface horizons to weak, medium and coarse granular and moderate, fine angular to sub-angular blocky in subsurface horizons. The surface horizon of the shallow red soils in the study area had single grain to granular structure, whereas others had weak to moderate, fine to medium and granular to sub-angular blocky structures with soft to slightly hard (dry) and loose to friable (moist) consistence. The lower layers were grading from weak to moderate, fine to medium subangular blocky structure and soft to hard (dry) and friable to firm (moist) in consistence. Low clay content and type of clay mineral might be responsible for the consistence in the red soils. However, in both black and red soils, the structure of the subsurface horizon of all pedons irrespective of physiography was more developed as compared to the surface horizons. This could not be surprising as similar findings were earlier reported by Rudramurthy and Dasog (2001) and Pulakeshi et al. (2014) for red and black soils of South India.

Consistence

Consistency was directly related to the nature and amount of clay. The consistence of the black soils varied from slightly hard to hard and very hard, slightly friable to friable and extremely firm and sticky and plastic to slightly sticky and slightly plastic and sticky and plastic in dry, moist and wet conditions, respectively. This physical behaviour of soils as influenced by dry, moist and wet conditions was not only due to the textural make-up but also the clay mineral composition in these soils. The BC horizon of the red soil pedons showed a non-sticky and non-plastic, slightly sticky and slightly plastic; and sticky and plastic consistence. This might be due to less amount of clay.

The surface horizons of the black soil pedons exhibited slightly sticky and slightly plastic to sticky and plastic, slightly hard to hard and very hard and slightly friable to very friable in wet, moist and dry conditions, respectively. The subsurface horizons exhibited either sticky and plastic or very sticky and very plastic consistence, which might be due to high amount of clay. In the red soils, the consistence varied from loose to slightly hard and slightly, friable to slightly friable and very friable and non-sticky to sticky and plastic. The increase in stickiness and plasticity might be due to clay illuviation in the subsurface horizons.

Physical properties

The results of particle size distribution in soils (Table 2) revealed that the distribution of soil separates (clay, silt and sand) varied with depth in most of the horizons. The per cent coarse fragments increased with depth in all soils. The coarse fragments were mainly quartzite gravels in red soils and lime concretions in black soils. The black soils showed lower amount of gravel than the red soils.

The clay content in the black soils was higher compared to the red soils. Increase in clay content with depth was observed in the black soils which could be attributed to illuviation of the finer fraction to the lower depth and vertical migration of clay and translocation of clay from the surface to lower horizons (Dasog and Patil, 2011). In the red soil pedons, the clay content increased with depth but stabilized in the B, C or transition AC or BC horizons. The sub-surface horizons exhibited higher clay content as compared to surface horizons due to the illuviation process occurring during soil development. The surface enrichment of sand fraction in the red soils could be attributed to the removal of finer particles by clay eluviation and surface runoff. In addition, illuviation processes might have also affected the vertical distribution of silt and sand content. Most transition horizons showed higher clay content than the A or B horizons. This might be due to accumulation of clay fractions following eluviation from upper layers.

All pedons exhibited an irregular trend in silt content with depth. Such irregular trend in silt content might be due to variation in weathering of parent material (Naidu, 2002). In the black soil pedons, sub-surface horizons contained higher silt content than surface horizons, whereas in the red soil pedons, the transition AC horizons of pedons showed higher silt content than Ap and C horizons. The sand content decreased with depth in some of the pedons (Table 2) but increased with more surface enrichment of sand fraction in the surface horizons of red soils than black soils. The surface enrichment of sand fraction in the surface horizons of red soils might be related to the removal of finer particles by clay eluviation and surface runoff (Satyavathi and Reddy, 2003; Dasog and Patil, 2011; Gangopadhyay et al., 2012; Pulakeshi et al., 2014).

In general, the bulk density was observed to increase with depth in majority of the pedons (Table 3). The surface and sub-surface bulk densities of the black soils ranged from 1.18 to 1.22 Mg m^{-3} and 1.23 to 1.28 Mg m^{-3} respectively, whereas surface and sub-surface bulk densities of the red soils ranged from 1.32 to 1.40 Mg m^{-3} and 1.33 to 1.51 Mg m^{-3} respectively. Surface horizons showed lower bulk densities than sub-surface horizons. This might be attributed to clogging of pores by dispersed clays resulting from high clay content in sub-soil layers and decrease in organic carbon with depth (Pulakeshi et al., 2014). The black soil pedons showed higher bulk densities than the red soils, which could be as a result of high clay content, high CEC and high exchangeable Na^+ and Mg^+, whereas the lower bulk density of red soils might be related to increase in coarse fragments and filling of pores by illuvial materials, hence, resulting to compaction (Dasog and Patil, 2011).

The field capacity showed an irregular trend in majority of the pedons (Table 3). In the black soils, the field capacity ranged from 29.84 to 40.14%, whereas in the red soils, the field capacity ranged from 11.1 to 32.34%. The field capacity of the black soils was higher than the red soils. Correlation studies revealed that the field capacity was highly significantly correlated with coarse fragments, coarse sand, total sand, clay and bulk density but non-significantly correlated with fine sand. The highly significantly correlated nature of the different soil separates and other soil physical properties might have resulted to the higher field capacity of the red soils and lower field capacity of the black soils (Thangaswamy et al., 2005).

The water holding capacity of the black soil pedons varied from 55.63 to 77.03% (Table 3). These differences might be due to variation in the clay and organic carbon content of the pedons. In the red soils, most pedons exhibited low water holding capacity compared to black soil pedons. This might be attributed to high sand and less clay content exhibited by these soils. The water holding capacity of the red soil pedons varied from 16.22 to 64.14%. The C horizons showed higher water holding capacity than overlying horizons. The highly significant negative correlation (r = -0.895) obtained between the water holding capacity and total sand content could better explain the inverse relationship between water holding capacity and soil type.

High porosities were observed in the black soils than red soils. The porosity varied from 44.15 to 55.47% in the black soils and 43.02 to 50.19% in the red soils. It is generally through that black soils have low porosity than red soils but the results showed that the red soils are more porous than the black soils. This could be attributed to the fact that result is representative of the study. The correlation studies revealed that porosity was highly significantly correlated with bulk density and significantly correlated with field capacity but non-significantly correlated with coarse fragments, coarse sand, fine sand, total sand, silt, clay and water holding capacity. The correlation between porosity and bulk density was a negative and inverse relationship. This negative correlation and inverse relationship might be due to the observed low and high porosity values of red and black soils respectively (Pulakeshi et al., 2014).

Physicochemical properties

In general, the pH ranged from slightly acidic to alkaline and was observed to increase with depth (Table 4). The increase in pH with depth might be ascribed to increasing content of exchangeable bases and their incomplete downward leaching. The pH of the red soils was mostly acidic and that of the black soils was mostly alkaline. The acidic nature of the red soils could be related to their well-drained condition compared to the black soils, whereas the alkaline pH of the black soils could be due to accumulation of bases in the solum and poor leaching (Dasog and Patil, 2011; Gangopadhyay et al., 2012; Reddy et al., 2013; Pulakeshi et al., 2012; 2014). The red soil pedons showed lower pH than the black soils. The lower pH of the red soils might due to leaching out of large amount of bases from the solum as a result of high proportion of micropores, leaving behind iron and aluminium oxides. According to Sitanggang et al. (2006), such increase in soil reaction down the slope could be due to leaching of bases from higher topography and getting deposited at lower elevations. The C horizon showed higher pH than other horizons which could be due to the accumulation of bases.

All pedons exhibited an irregular trend in electrical conductivity, which ranged from 0.04 to 0.24 dS m^{-1} (Table 4), indicating that the soils were non-saline. However, the red soils showed lower electrical conductivity than the black soils which might be due to free drainage conditions favouring the removal of released bases by percolating water (Pillai and Natarajan, 2004). The slightly higher electrical conductivity of the black soils over those of the red soils might be attributed to accumulation of salt during prolong poor drainage conditions (Sitanggang et al., 2006).

The organic carbon ranged from low to high and was observed to either increase or decrease with depth or follows an irregular trend (Table 4). The distribution of organic carbon might be associated with physiography and land use. The organic carbon content of surface soils was higher than sub-surface soils in most of the pedons. The high amount of litter and crop residues at the surface layers and rapid rate of organic matter mineralization in these soils could be a major reason for the high organic carbon content in surface horizons (Ravikumar et al., 2009).

In most pedons, the $CaCO_3$ content followed an irregular trend (Table 4). Only pedon 3 exhibited calcareous nature. The free calcium carbonates in the black and red soils ranged from 0.5 to 18.75 and 0.25 to 9.75 %, respectively. The black soils showed higher $CaCO_3$ content than the red soils was in concordance with the observations made by Ravikumar et al. (2007) and Pulakeshi et al. (2014) in black soils of North Karnataka.

The exchangeable bases were in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ on the exchange complex. The trend showed that the exchange complex was mostly saturated with Ca^{2+} followed by Mg^{2+}, Na^{+} and K^{+}. This order of abundance was in accordance with Jenny's (1941) view that leaching causes preferential losses of Na^{+} and K^{+}. The higher exchangeable Ca/Mg ratio indicated a decrease in extractable magnesium content in soils. Ca^{2+} showed the strongest relationship with all the ionic species. This could be attributed to its high mobility. The low value of exchangeable monovalents compared to divalents, might be due to preferential leaching of monovalents than divalents. In pedons under forest land use, there was a decrease in bases with depth. This might be ascribed to the decomposition of leaves and litter of deciduous forest species which could have contributed to higher Ca^{2+} content in these soils resulting from biocycling (Ravikumar et al., 2009; Pulakeshi et al., 2012, 2014).

The CEC of the black and red soil pedons ranged from 22.89 to 65.99 and 14.74 to 33.14 cmol (p+) kg^{-1} respectively (Table 4). In general, the black soil pedons recorded higher CEC than the red soil pedons. The high CEC exhibited by the black soils is indicative of less weathering in these soils than the red soils. Such high CEC exhibited by the black soils might be due to the high clay content which was found to be highly significant and positively correlated (r = +0.562) with CEC. According to Dasog and Patil (2011), the clay content of soils developed on different geomorphic conditions shows significant and positive correlation with CEC. In either black or red soil pedons, the CEC was observed to either increase or decrease within the B horizons, whereas in some pedons such increase or decrease were observed within the transition horizons. The decrease in CEC with depth might be attributed to decreased organic carbon and clay content below the solum depth in these soils, whereas the increase in CEC with depth could be attributed to the illuviation of clay from surface to sub-surface horizons, resulting to accumulation of clay and hence, high CEC (Pillai and Natarajan, 2004).

The percent base saturation of the black soil pedons ranged from 69.55 to 98.65%, whereas the percent base saturation of the red soil pedons ranged from 43.04 to 68.75%. The black soils showed higher base saturation than the red soils. Due to high CEC and restricted drainage, the black soils pedons showed higher base saturation than the red soil pedons. Both the black and red soils have base saturation above 35% (by sum of cations). According to Mohan et al. (2013), the high base saturation might be due to high exchangeable bases and CEC.

CONCLUSION AND RECOMMENDATION

The present study has given an insight into the potentials and limitations of the soils of the study area. This could be used to improve the productivity and design a framework for managing the soils which is needed to realize the concept of watershed development approach successfully. The results indicated that the soil properties and management practices have influenced the kind of soils in the study area which has led to the prevalence of red and black soils with red soils covering large area. The morphological, physical and chemical characteristics of black soils were comparatively better than the red soils under the present land use systems, due to the intensively cultivated nature of red soils. As the red soils are slightly acidic, sandy clay loam to sandy loam, having low organic carbon, low CEC, low per cent base saturation and slightly higher bulk densities than black soils, these physical and chemical qualities could be improved by building up the organic matter of the soils through regular application of organic manure, crop rotation with leguminous crops and discouraging mono-cropping system. This could help to improve their characteristics and hence, productivity.

Conflict of interest

The authors declare that there are no conflicts of interest

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