



Characterization of Some Chemical Qualities of Red Ferruginous Soils (Inceptisols, Alfisols and Ultisols) Affected by Water Erosion in Kolar District of Karnataka, India

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Abstract: Soil qualities need to be assessed to evaluate the loss of productivity under various landforms and land covers. Nine profiles in three transects associated with severely eroded lands were studied and soil samples were collected in Kolar district, Karnataka for the evaluation of some chemical quality indicators viz. pH, EC, CEC, and base saturation. Finer particles were removed by run-off and most of the soil became lighter in texture with gravels. Bases were removed by leaching hence the soil became strongly acidic at JKT-3 pedon compared to slightly acidic at less eroded land at BGH-1 pedon and deposited soils at JKT-5 pedon. Similar trend was observed with EC (0.17 dS m^{-1}) (Profile mean) at BKH-2 pedon representing severely eroded land and 0.89 dS m^{-1} at JKT-5 pedon of the depositional phase. Cation Exchange Capacity was least at BKH-2 of severely eroded land (Profile mean: $8.12 \text{ cmol kg}^{-1}$) and highest at JKT-1 of flat fallow land located at the summit (Profile mean: $14.04 \text{ cmol kg}^{-1}$). Base Saturation was least at JKT-3 of severely eroded land (Profile mean: 6.65%) and highest at JKT-5 of deposited valley soil (Profile mean: 42.76%). There was positive relationship of clay content with higher pH (0.29^*), EC (0.42^*), CEC (0.36^*) and BS (0.57^{**}). Stable microaggregates recorded positive relationship with CEC (0.60^{**}) and OC (0.49^{**}). These four soil chemical quality indicators can be considered for Minimum Data Set (MDS) for soil quality assessment. Moreover, soil pH, EC, CEC, and BS were very poor due to severe erosion and showed strong relationship with erosion and deposition phases under various land uses and land covers. Severely affected soil chemical qualities by water erosion indicate that the soil approaches complete degradation. It needs immediate attention for liming and soil and water conservation measures to improve the soil quality and productivity.

Key words: pedon, microaggregates, cation exchange capacity.

Introduction

Land cover and land use managements are the major factor that protects soil quality and its degradation deteriorates the sustainability of ecosystem (Amundson *et al.* 2015). An undisturbed ecosystem maintains soil quality indicators in condition however human interventions like agricultural activities disturb the land

and also soil qualities. Agricultural activities such as tillage, agro-chemical application, poor land cover and unprotected land uses are aggravating land degradation processes. Water erosion is the major degradation process among others that reduces soil quality. If the soil erosion occurs in harmony with nature, it never declines soil quality and productivity, however, the accelerated or induced erosions by human intervention is more harmful

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for agricultural production and productivity. Physical and chemical properties of soils, which are governed by the principle of physical chemistry are the worthy indicators for soil functions and they point out its status. Soil and land degradation process affects the soil qualities based on its intensity. Soil properties such as pH, EC, CEC and base saturation are prone to degradation process especially by water erosion. Run-off and water transmittance affect the soil properties depending on the land use and land cover conditions.

Several studies are carried out to determine the topography as the dominant factor influencing the soil properties but poor land cover and improper land uses severely affect the soil properties and declines its optimum qualities. Continuous leaching of soil due to slope, high rainfall and poor vegetation cover leads to loss of bases like calcium, magnesium, sodium, and potassium. Water movement removes anions like carbonate, sulphate, bicarbonates, and chlorites. Leaching of bases and loss of organic matter makes the soil weak and become dispersive in nature. Subsequently, the active part of soil fractions like organic and mineral clay particles are lost and it reduces ion exchange capacity of soil (Seybold *et al.* 2005). Frequent leaching reduces soil pH and the soil becomes acidic with low electrolyte concentrations. Cation exchange capacity and base saturation are reduced due to leaching and erosion and it will not support agricultural production (Pal *et al.* 2014). Therefore, the impact of water erosion on soil properties in undulating and severely eroded region in different land forms and land uses were examined in Kolar district representing the semi-arid tropical climate of Karnataka.

Material and Methods

A large tract of eroded lands exists in the Southern parts of Karnataka. The information and reports available with ICAR-NBSS & LUP and ISRO-NRSA was studied and it was confirmed through reconnaissance survey. Karnataka State Remote Sensing Application Center, Bangalore published

natural resource reports (SNRIS 2006) and district-wise land degradation status for Karnataka. According to the report, the Kolar district is severely affected by erosion hence district was selected for the investigation (Fig. 1). The climate is semi-arid tropical monsoon with an annual rainfall of about 733 mm. The maximum rainfall is received during the month of August through October. The mean annual temperature is 24.4°C. April and May are the hottest months whereas December and January are the coolest months. The PET, computed (Doorenbos and Puritt 1977) using the modified Penman's methods, ranges from 67.4 mm in the month of December to 157 mm in the month of May in Kolar. Imageries of Kolar district at 1:50000 scales (57G/15, 57G/16, 57K/03, 57K/04 and 57K/08) were collected from Karnataka Remote Sensing Application Center (KRSAC), Bangalore. All the imageries were interpreted in conjunction with respective toposheets, based on the tonal variations, texture and pattern. Lowlands were demarcated along the water bodies, since they were clearly visible on the imageries. The uplands with dark brown colour and light patches were demarcated on the imageries. Based on the tonal variations and pattern, the upland areas were further divided into summits and midlands. It showed that the uplands are in different phases of erosion. Many places in the uplands were observed with white patches in the imageries and they were identified as gravelly or boulder lands from the toposheets. Large areas with very dark brown patches were demarcated in the uplands as rocks. Rocky areas and land with boulders were not considered for the present study. Out of 5 imageries interpreted for Kolar district, two imageries namely 57G/15 and 57K/03 representing the different intensity of erosions were selected for the characterization of erosion status in the district in association with some chemical properties. These two imageries cover major areas of Siddlaghatta, Chintamani and Srinivaspur taluks of Kolar district. Based on the variation in tone and pattern, three transects were selected covering uplands and lowlands.

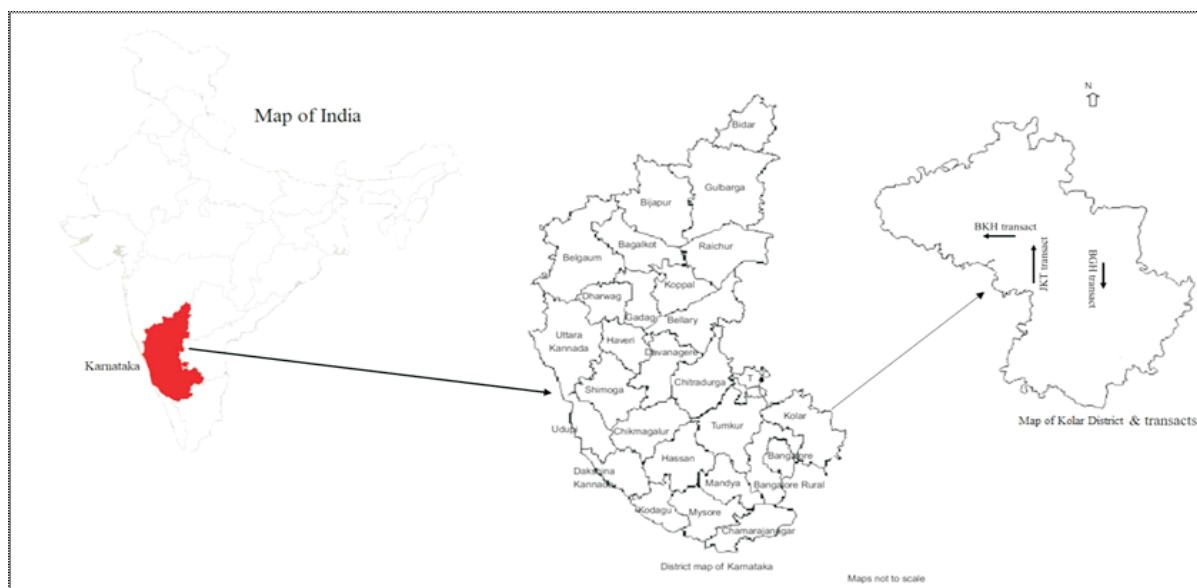


Fig.1. Location map of study area in Kolar district, Karnataka and three selected transects

Transects marked at the time of interpretations were traversed in the field to study the landform and soil relationships. All three transects were traversed in the field. The first transect was located in Siddlaghatta taluk near Jangamakote village, hence named as Jangamakote transect (Fig. 2). Elevation of this transect, which represents lateritic areas, ranged from 880 to 920 m MSL. It consisted of both uplands and lowlands. Lowlands are nearly level and intensively cultivated. The soils were very deep and not much gravels were observed on the surface. Upland consisted of summit and midlands were under reserved forest (*Eucalyptus*), natural scrub and agricultural crops. Surfaces of this area were observed with rock fragments and the soil was moderately shallow. Lateritic mass was observed in those places. Five representative sites were selected for profile study in this transect i.e. three sites in summits, one site from the midland and one site from the lowland. The second transect was also located in Siddlaghatta taluk near Bhaktarahalli village and named as Bhaktarahalli transect (Fig. 3). This transect was also in the lateritic area. Elevation of this transect ranged from 880 to 900 m MSL. The upland was under different land uses (Fig. 3,5). Summit areas were cultivated with field crops and mulberry as the soil was deep with less gravels

and Midland was under *Eucalyptus* plantations. The soils were deep with gravels on the surface. Two representative sites were selected for profile studies in this transect i.e., one at the summit and another at the midland. Third transect was located in Srinivasapur taluk near Bagalahalli village and named as Bagalahalli transect (Fig. 4). Elevations of this transect ranged from 840 to 860 m MSL. This gently sloping land consisted of summits and midlands associated with deep red soils and was under cultivation. Two representative sites were selected for profile studies in this transect i.e., one at the summit and another at the midland. Details of pedon sites are furnished in table 1. Soil samples were collected from each horizon and processed. Soil properties were analyzed with standard procedure. Soil texture was analysed with International pipette method (Richerds 1954) and microaggregates with the procedure described by (Sarma and Das 1996). Soil reaction (Jackson 1973), electrical conductivity (Jackson 1973), Cation Exchange Capacity and organic carbon (Walkley and Black 1934) were analysed with standard procedure. Base Saturation was calculated by divide the sum of the Ca, Mg, Na and K (the bases) in meq/100g soil by the CEC. Multiply the result by 100%. Descriptive statistics and correlation analysis was done in Excel Stat. with $p < 0.05$.

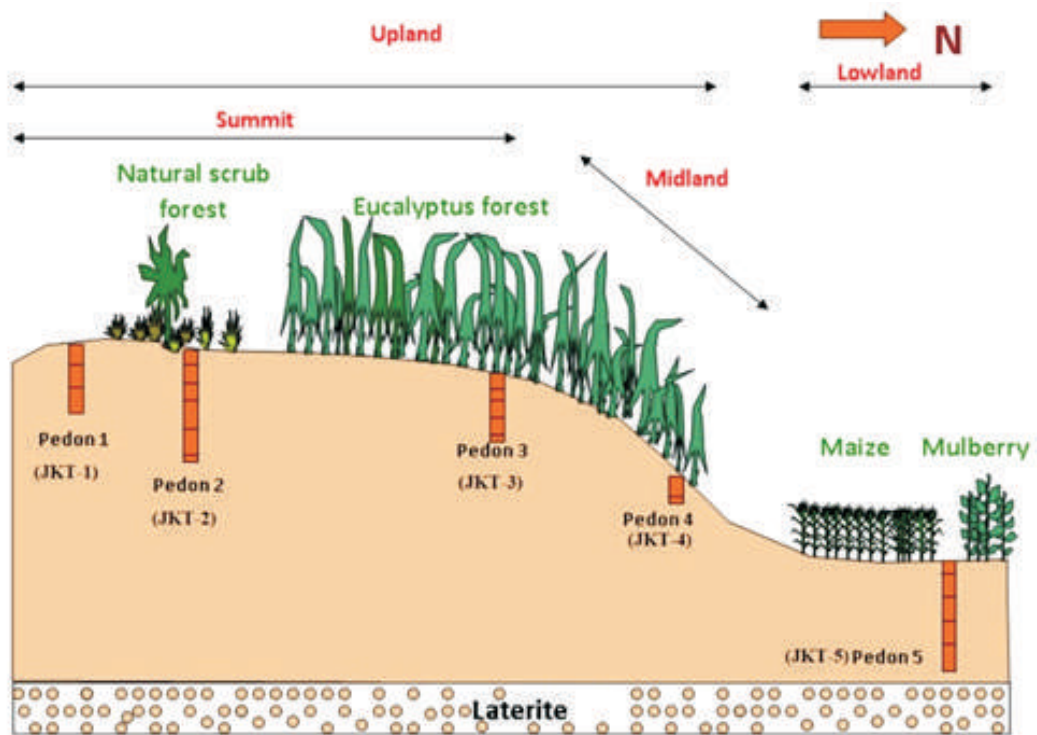


Fig.2. Jangamakotai transact and pedons location

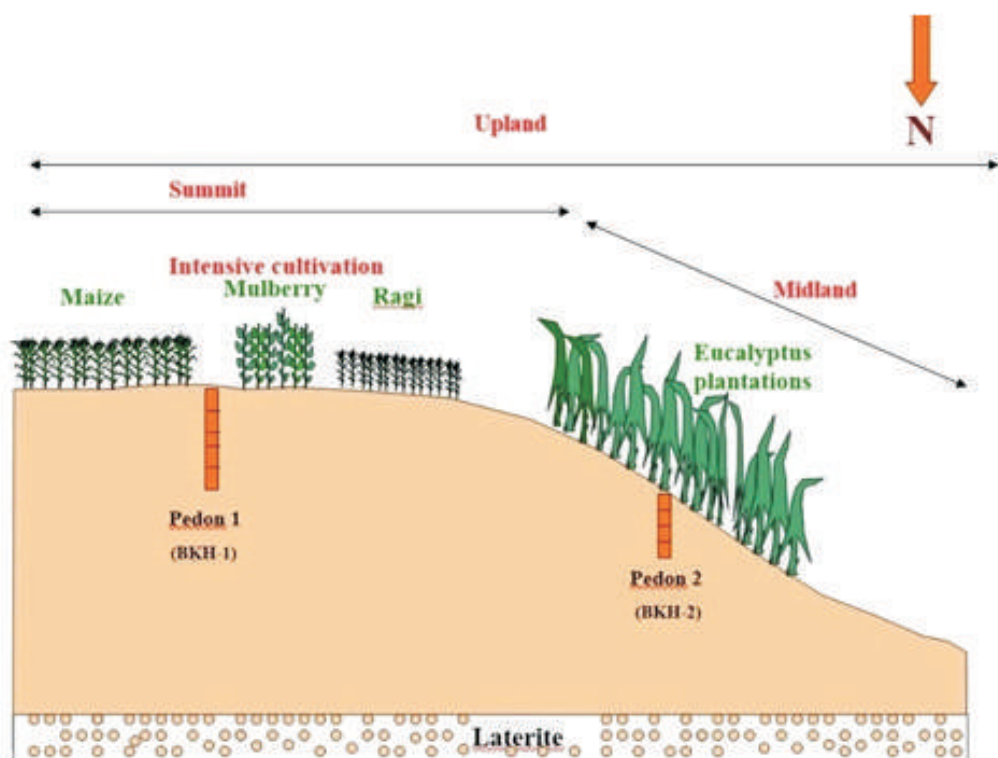


Fig.3. Bhaktarahalli transact and pedons location

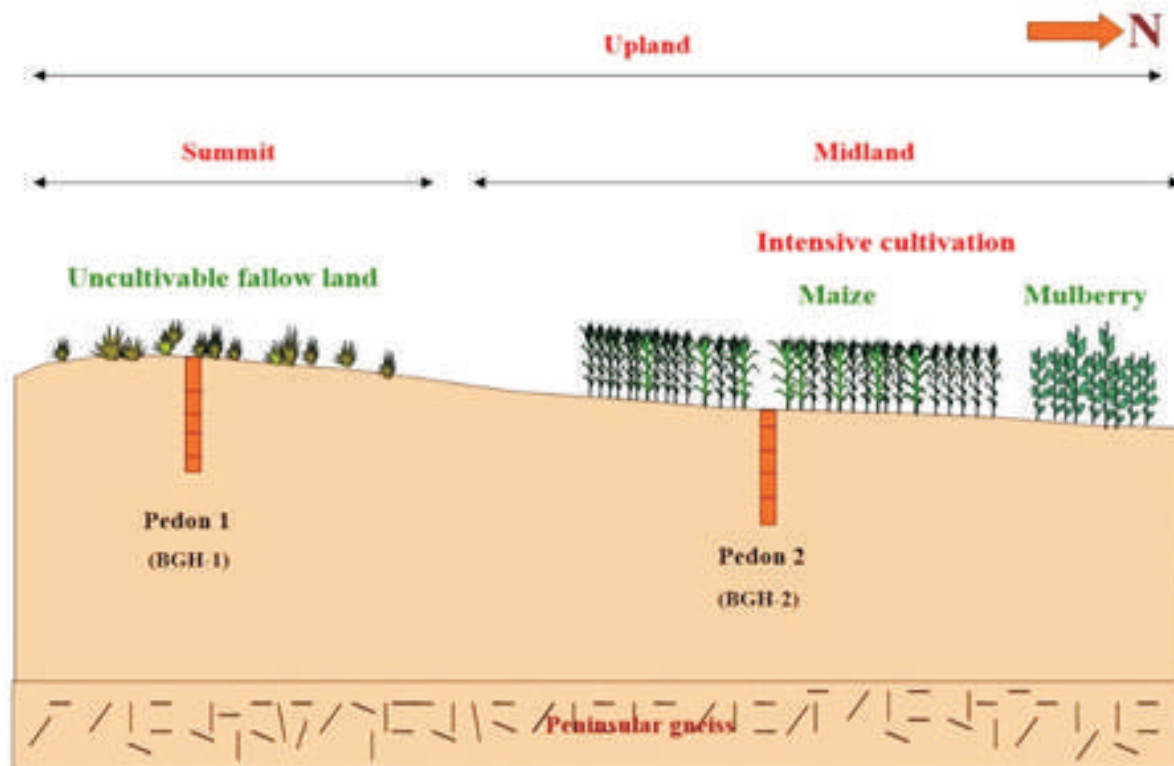


Fig. 4. Bagalahalli transect and pedons location

Result and Discussion

Soil physical properties

The pedon sites of JKT-1, JKT-3, JKT-4, BKH-2 and BGH-1 had high proportion of gravels and sand. There was sparse vegetation on these pedon sites compared to JKT-2 (Forest cover) with poor soil aggregate

owing to severe loss of bases and formation of gravelly and sandy soil (Rajan *et al.* 2014). Further, the microaggregates were in lesser amounts in these pedons compared to less eroded lands such as JKT-2, BKH-1, and BGH-2 (Table 2). Soil aggregations support the conservation of soil finer particles and organic carbon indicates how the slope gradients could be related to variation in soil properties (Gessler *et al.* 2000).

Table 1. Details of site characteristics and Pedons locations in Kolar district

Taluk	Transect location	Pedon no.	Location of pedons	Landforms	Land use	Slope (%)	Run-off	Erosion status	Surface stoniness (cm)	Depth of soil (cm)
Siddlaghatta	Jangamakote	1	13° 16' 36.71" N 77° 51' 26.79" E	Very gently sloping upland	Current fallow	1-3	Medium	Moderate	2-7.5	80
		2	13° 16' 53.49" N 77° 52' 02.71" E	Very gently sloping upland	Scrub land	1-3	Slow	Slight	<2	>150
		3	13° 17' 08.49" N 77° 52' 00.20" E	Very gently sloping upland	Eucalyptus forest	3-5	Medium	Moderate	<2	119
		4	13° 17' 13.17" N 77° 51' 59.84" E	Moderately sloping upland	Eucalyptus forest	5-10	Very rapid	Severe	7.5-25	55
		5	13° 17' 17.89" N 77° 52' 04.94" E	Very gently sloping lowland	Cultivated land	1-3	Slow	Slight	<2	>150
	Bhaktarahalli	6	13° 19' 47.88" N 77° 50' 57.07" E	Very gently sloping upland	Cultivated land	1-3	Slow	Moderate	<2	>150
		7	13° 19' 51.41" N 77° 50' 50.46" E	Gently sloping upland	Eucalyptus forest	3-5	Rapid	Moderate	2-7.5	126
Srinivasapur	Bagalahalli	8	13° 17' 20.26" N 78° 05' 43.88" E	Very gently sloping upland	Current fallow	1-3	Moderate	Moderate	2-7.5	>150
		9	13° 17' 28.87" N 78° 06' 01.91" E	Very gently sloping upland	Cultivated land	1-3	Slow	Slight	<2	>150

Table 2. Physico-chemical properties of Soils

Depth (cm)	Horizon	Particle size distribution			Textural Classes (USDA)	Gravels (Vol. %)	Micro- aggregate (%)	pH	EC (dS m ⁻¹)	CEC (cmol p ⁺) kg ⁻¹)	BS (%)	OC (%)	Exchangeable cations (cmol (p ⁺) kg ⁻¹)			
		Sand (%)	Silt (%)	Clay (%)									Ca	Mg	Na	K
Pedon JKT -1 :Loamy-skeletal, mixed, isohyperthermic Typic Rhodustults																
0-13	A	4 8.75	14.56	36.69	sc	20	16.4 0	4.93	0.29	15.94	10.62	0.71	1.35	0.17	0.10	0.08
13-36	Bt1	38.90	24.95	36.15	cl	65	21.05	4.95	0.23	13.98	17.11	0.71	1.86	0.38	0.10	0.05
36-80	Bt2	55.39	16.23	28.38	scl	60	25.70	5.01	0.27	12.20	22.90	0.39	2.20	0.4 5	0.10	0.05
Pedon JKT - 2: Fine, mixed, isohyperthermic Typic Paleustults																
0-15	A	58.97	10.91	30.12	scl	<5	15.10	5.38	0.37	12.60	25.4 4	1.29	2.64	0.37	0.11	0.09
15-35	Bt1	50.33	3.71	4 5.96	sc	<5	21.58	5.34	0.32	10.88	26.14	1.19	2.4 4	0.25	0.10	0.05
35-65	Bt2	4 6.10	4.96	4 8.94	sc	<5	26.20	5.19	0.23	8.10	31.72	1.16	2.17	0.29	0.08	0.03
65-96	Bt3	4 5.74	8.52	4 5.74	c	<5	28.69	5.16	0.24	13.99	32.88	1.12	4.14	0.33	0.10	0.03
96-115	Bt4	4 2.90	8.11	4 8.99	c	<5	28.4 8	5.87	0.33	14.4 0	33.58	0.77	4.36	0.33	0.11	0.03
115-150	Bt5	4 3.96	7.78	4 8.25	c	4 5	29.20	6.21	0.23	16.30	24.54	0.71	3.59	0.29	0.09	0.03
Pedon JKT-3 : Loamy-skeletal, mixed, isohyperthermic Typic Rhodustults																
0-13	A	68.19	6.66	25.15	scl	15	10.4 0	4.79	0.23	11.10	6.34	1.09	0.4 6	0.10	0.08	0.06
13-39	Bt1	68.76	5.24	26.00	scl	20	15.69	4.73	0.20	11.00	7.36	1.06	0.60	0.08	0.09	0.05
39-60	Bt2	51.01	11.89	37.10	sl	50	18.20	4.82	0.19	10.90	9.04	0.97	0.79	0.07	0.09	0.03
60-91	Bt3	39.76	20.58	39.66	sc	65	21.59	4.68	0.22	12.11	7.62	0.77	0.74	0.06	0.10	0.03
91-119	Bt4	51.95	17.03	31.02	scl	75	22.80	4.59	0.31	13.50	2.87	0.71	0.22	0.04	0.10	0.03
Pedon JKT-4 : Clayey-skeletal, mixed, isohyperthermic Typic Dystrustepts																
0-16	A	66.4 2	0.90	32.68	scl	50	8.10	5.01	0.24	11.20	10.64	0.37	1.04	0.02	0.08	0.05
16-55	Bw	4 8.28	7.35	44.37	sc	65	13.80	5.21	0.23	12.10	14.76	0.24	1.38	0.21	0.13	0.07
Pedon JKT-5 :Fine, mixed, isohyperthermic Ultic Haplustalfs																
0-15	Ap	52.20	8.27	39.53	sc	<5	13.4 0	5.35	1.19	12.60	31.03	0.97	3.28	0.42	0.12	0.09
15-32	Bt1	39.60	3.62	56.78	c	<5	16.58	5.64	0.95	12.55	38.16	0.90	4.12	0.46	0.13	0.07
32-60	Bt2	33.68	10.4 8	55.84	c	<5	17.80	6.13	0.85	13.70	39.18	0.84	4.69	0.48	0.16	0.04
60-84	Bt3	33.30	9.57	57.14	c	<5	19.25	6.4 5	0.71	14.25	39.12	0.71	4.90	0.49	0.14	0.03
84-105	Bt4	34.4 3	16.34	49.23	c	<5	15.69	6.75	0.57	12.60	42.00	0.64	4.69	0.43	0.14	0.04
105-136	BC	37.85	17.34	44.81	cl	<5	11.50	6.64	0.55	8.50	67.10	0.32	5.14	0.38	0.14	0.04

Pedon BKH-1 : Clayey-skeletal, mixed, isohyperthermic Typic Rhodustalfs																
0-16	Ap	33.12	38.62	28.25	g cl	30	2.90	5.25	0.31	7.80	20.55	0.90	1.30	0.22	0.05	0.03
16-38	Bt1	4 5.52	22.75	31.72	vg cl	50	7.99	5.64	0.19	11.25	32.00	0.86	3.15	0.36	0.06	0.04
38-71	Bt2	4 0.91	10.05	4 9.04	vg c	50	12.00	6.07	0.19	12.00	38.12	0.60	4.07	0.41	0.05	0.04
71-105	Bt3	38.07	19.07	4 2.86	vg c	50	10.25	6.35	0.20	12.56	37.58	0.46	4.20	0.43	0.06	0.04
105-127	Bt4	4 0.23	14.60	4 5.17	eg c	60	13.25	6.43	0.39	10.60	44.64	0.46	4.27	0.36	0.06	0.03
127-158	Bt5	4 3.72	15.48	4 0.80	eg c	60	7.50	6.38	0.45	11.10	4 2.85	0.32	4.33	0.33	0.06	0.03
Pedon BKH-2 : Loamy-skeletal, mixed, isohyperthermic Typic Rhodustalfs																
0-17	A	35.51	34.69	29.80	g cl	35	2.70	5.05	0.17	4.50	27.88	0.82	1.01	0.11	0.09	0.04
17-49	Bt1	4 5.65	18.76	35.59	g sc	35	4.88	5.23	0.19	7.58	20.55	0.77	1.24	0.18	0.10	0.04
49-82	Bt2	37.67	29.79	32.54	vg cl	40	8.00	6.07	0.17	10.20	17.10	0.64	1.36	0.24	0.10	0.04
82-126	Bt3	36.45	29.70	35.00	eg cl	65	13.58	6.27	0.16	10.20	4 8.16	0.64	4.57	0.23	0.08	0.04
Pedon BGH-1 : Clayey-skeletal, mixed, isohyperthermic Typic Paleustalfs																
0-18	A	44.80	32.89	22.31	l	<5	2.00	5.8	0.34	8.90	18.25	0.40	1.37	0.15	0.07	0.03
18-49	Bt1	52.96	12.48	34.55	scl	<5	2.14	6.5	0.44	10.36	22.30	0.33	2.05	0.16	0.08	0.03
49-64	Bt2	51.78	7.19	4 1.03	sc	15	2.40	7.04	0.33	11.50	32.40	0.33	3.38	0.23	0.08	0.03
64-102	Bt3	4 2.42	16.92	4 0.66	cl	75	2.56	7.46	0.26	11.25	33.83	0.33	3.47	0.23	0.07	0.03
102-120	Bt4	44.46	9.37	4 6.18	c	45	1.89	7.57	0.32	9.90	38.85	0.27	3.49	0.25	0.07	0.04
120-140	Bt5	4 5.36	14.29	4 0.35	sl	30	1.70	7.67	0.35	10.90	31.31	0.23	3.05	0.25	0.07	0.03
Pedon BGH-2 : Fine-loamy, mixed, isohyperthermic Typic Paleustalfs																
0-14	Ap	69.10	0.74	30.16	sl	<5	3.10	7.23	0.53	10.60	25.73	0.60	2.31	0.27	0.08	0.06
14-49	Bt1	51.80	17.15	31.05	scl	<5	5.68	7.43	0.41	11.45	25.10	0.53	2.44	0.28	0.09	0.06
49-74	Bt2	4 8.38	17.45	34.17	scl	<5	12.20	6.67	0.47	11.90	29.14	0.53	3.01	0.31	0.11	0.04
74-97	Bt3	52.34	8.59	39.07	scl	<5	13.98	6.54	0.59	12.36	29.37	0.53	3.14	0.32	0.14	0.04
97-120	Bt4	4 5.75	9.40	44.85	sc	<5	9.87	6.6	0.65	11.40	33.20	0.46	3.27	0.33	0.15	0.04
120-140	Bt5	4 5.40	10.65	4 3.95	sc	60	5.50	6.77	0.55	9.70	4 1.87	0.40	3.51	0.35	0.16	0.04
Descriptive statistics																
Mean		46.54	14.22	39.26	-	30.00	12.80	5.93	0.38	11.42	27.98	0.66	2.75	0.28	0.10	0.04
Std. Deviation		9.32	8.87	8.63	-	25.08	8.14	0.88	0.22	2.20	13.02	0.28	1.40	0.13	0.03	0.02
Variance		86.86	78.71	74.54	-	629.07	66.29	0.78	0.05	4.82	169.56	0.08	1.97	0.02	0.00	0.00
Range		35.97	37.88	34.82	-	70.00	27.50	3.08	1.03	11.80	64.23	1.06	4.93	0.47	0.11	0.07
Minimum		33.12	0.74	22.31	-	5.00	1.70	4.59	0.16	4.50	2.87	0.23	0.22	0.02	0.05	0.03
Maximum		69.10	38.62	57.14	-	75.00	29.20	7.67	1.19	16.30	67.10	1.29	5.14	0.49	0.16	0.09

Soil reaction

Soil pH ranged from 4.59 to 7.67 due to leaching and deposition process of water erosion (Table 2). Soils occurring on steep slopes were more acidic than those on gentle slopes whereas soils in gentle slopes owing to higher leaching of bases contrary to it, soils of the valley and lower part of transacts had higher pH as expected (Hendershot *et al.* 1992). The lowest pH (4.72) was observed in JKT 3 pedon, with 3 to 5 per cent slope, where severe translocation was observed in the profile with mean clay of 31.78 per cent. The highest pH (6.16) was recorded in valley soil due to deposition and in the upland it was with forest soil (5.53) under JKT transact. Under BKH transact the highest pH (6.02) was observed in BKH 1 pedon, which was on the summit, where the land is nearly flat and intensive cultivation is practiced whereas the least pH (5.66) was recorded in BKH 2 having on sloppy land, where severe erosion and leaching were observed severe compared to BKH 1 pedon. Among Bagalahalli transact (BGH) associated with red soil (1-3 per cent slope), the lowest pH (6.87) was recorded in upland pedon of BGH 1 followed by the lowland pedon of BGH 2 (pH-7.01). Severe erosion has lowered the soil pH more than mild erosion (Fig. 5a). Hence the soil reaction can be a reliable soil quality indicator to judge the status of water erosion or more vertical movement of rainwater removing basic cations from surface to sub-surface horizons. These areas have less rainfall but rain is more concentrated with stormy rains resulting in extensive removal of bases from granite and gneiss.

Electrical conductivity

Electrical conductivity was severely affected by leaching and erosion caused by rainwater. EC varied from 0.16 to 1.19 dS m⁻¹ (Highest in lowland valley) among different horizons of soil profiles (Fig. 5b). The low mean EC was recorded in two pedons of severely eroded lands under JKT-3 (0.23 dS m⁻¹) and BKH-2 (0.17 dS m⁻¹) which were located in sloppy area (Table 2). Sloppy land accelerates the overland flows which carry electrolytes in the surface and sub-surface of low land

soil respectively. In JKT transacts the highest mean EC (0.80 dS m⁻¹) of the profile was recorded at the lowland (JKT 5) mainly due to accumulation of salts from upland followed by JKT 2 (natural forest land- 0.29 dS m⁻¹) where the leaching and erosion could be less among upland area. The highest cumulative mean for bases (Ca, Mg, Na and K) was recorded in lowland soil (JKT 5) (5.10 cmol kg⁻¹) followed by JKT 2 (3.68 cmol kg⁻¹) located in natural forest and JKT 1 (2.29 cmol kg⁻¹) a cultivable fallow. The least mean EC (0.23 dS m⁻¹) was recorded at JKT 3 pedon, where severe sheet erosion and clay rich sub-surface horizons are exposed, as eucalyptus plantations will not allow undergrowth via allelopathy and some root exudates, which may not permit beneficial microflora or fauna to grow. Clay illuviation being the basic pedogenic process in these soils resulting in well-developed argillic horizon overlain by a thin coarse surface horizon under the influence of sealing and crusting of pore spaces disallowing water to infiltrate and allow soil clay and finer particles to translocate along with solutes. Bases were the least (0.76 cmol kg⁻¹) among all the pedon in the transact which might be due to severe leaching. In Bhaktarahalli transact, the EC was the highest in upland pedon, where intensive agriculture was practiced, its mean EC was 0.29 dSm⁻¹ near leveled land. BKH 2, severely eroded land of sloppy areas had large proportion of gravels on the surface. Severe erosion and leaching of soil have reduced the solute concentration (EC was 0.17 dS m⁻¹). Water erosion and leaching of solutes on sloppy land has reduced the cumulative mean bases concentration (2.37 cmol (p+) kg⁻¹) compared to upland pedon of BKH-2 (4.00 cmol kg⁻¹). Under Bagalahalli transact (BGH), the highest EC (0.53 dS m⁻¹) and bases (3.42 cmol (p+) kg⁻¹) were recorded with lowland pedon of BGH-2 compared to upland pedon (EC: 0.34 dS m⁻¹, bases: 3.12 cmol kg⁻¹).

Cation exchange capacity

Organic and inorganic clay particles play a major role in optimum CEC status. Erosion has severely affected the CEC at different horizons (Fig. 5c). Mean profile CEC was varying from 8.12 to 14.04 cmol (p+)

kg⁻¹ (Table 2). Where the erosion was severe, the CEC was low and vice versa. In JKT transact, the highest CEC was with cultivable fallow land [JKT-4 : 14.04 cmol (p+) kg⁻¹] on the summit followed by natural forest (JKT-4 : 12.71 cmol (p+) kg⁻¹), intensive cultivation in valley [JKT-5: 12.37 cmol (p+) kg⁻¹], and severely eroded afforested land (JKT-3: 11.72 cmol (p+) kg⁻¹). Least CEC was observed with very severely eroded toe land [JKT-4 : 11.65 cmol (p+) kg⁻¹]. Among the erosional phase of the transact, the loss of clay due to erosion between natural forest (JKT-2- with highest amount of clay) and severely eroded land [JKT 4 ; lowest clay 29 per cent], which have affected the CEC with intensive erosion. In BKH transact, the highest CEC was observed with less eroded cultivable nearly leveled land [BKH-1: 10.89 cmol (p+) kg⁻¹] followed by severely eroded afforested land [BKH-2: 8.12 cmol (p+) kg⁻¹]. Similar observation has been reported by Chandran *et al.* 2005) in the sloppy high rainfall region of Kerala. Clay content of BKH-1 was 39.64 per cent and in BKH-2 it was 33.23 per cent, which was 16 per cent lesser due to erosion by water. The BGH transact with mild slope, less affected the CEC compared to other two transacts. Cation Exchange Capacity was 10.47 cmol kg⁻¹ in BGH-1 of upland and 11.24 cmol kg⁻¹ in BGH-2 (lowland). Lower CEC in upland soil was observed and it was 7% compared to lowland pedon. Though there was much difference in clay content between upland and lowland pedon soils, contribution of organic matter is poor for CEC due to severe loss of organic carbon by water erosion (Rajan *et al.* 2010). The study area is under semi-arid tropical climate with an annual rainfall of around 700 mm and rainy season is succeeded by hot dry season, allowing to mineralize and decompose all the organic matter contributed through biomass accumulation and removal through the water erosion during next rainy season before getting absorbed by plants or accumulating through biological activity in surface soil. Organic carbon on surface horizon is less unless under thick

vegetation canopy, that is very rare in this climate except in groves or reserved/protected natural forests with good canopy and ground cover.

Base saturation percentage (BS)

Degradation and aggradation take place simultaneously in the topo-sequence due to erosion-deposition process, which has affected the CEC at different depths of profiles (Fig.5d). Hence removal of bases in upland and their deposition in lowland is naturally occurring process. The Base Saturation ranged from 2.87 to 67.10 per cent in soils of different horizons (Table 2). The least BS was recorded in severely eroded land and highest was recorded with soils of valley pedon. In JKT, the highest BS was recorded in soil of valley pedon (mean 42.76 per cent), where the BS increased with depth owing to continues deposition of bases by leaching (Hendershot *et al.* 1992). Among upland pedons, the highest BS was recorded with natural forest (29.05 %) might be with less leaching due to permanent vegetation cover and BS was increased with depth. The highest BS in the pedon was supported by high EC, clay content and bases. JKT-1 in cultivable fallow had 16.87 % while JKT-4 pedon at toe land possessed 12.70 % base saturation. The least BS was recorded in the pedon with severely eroded slopy land (6.65 per cent), where least clay content, lower EC and bases were mainly due to leaching (Sharma *et al.* 2011). Among the two pedons of eroded land at BKH transacts, the highest BS (35.96 %) was recorded at BKH-1 followed by 28.42 per cent in BKH-2 pedon located at the slope of severely eroded land. It was evident that the supporting parameters of BS such as clay content, CEC, EC and bases are higher in BKH-1 compared to BKH-2. In BGH transact of red soil land the difference in BS was less among the pedons and its mean BS were 29.49 per cent and 30.73 per cent at BGH-1 and BGH-2 respectively.

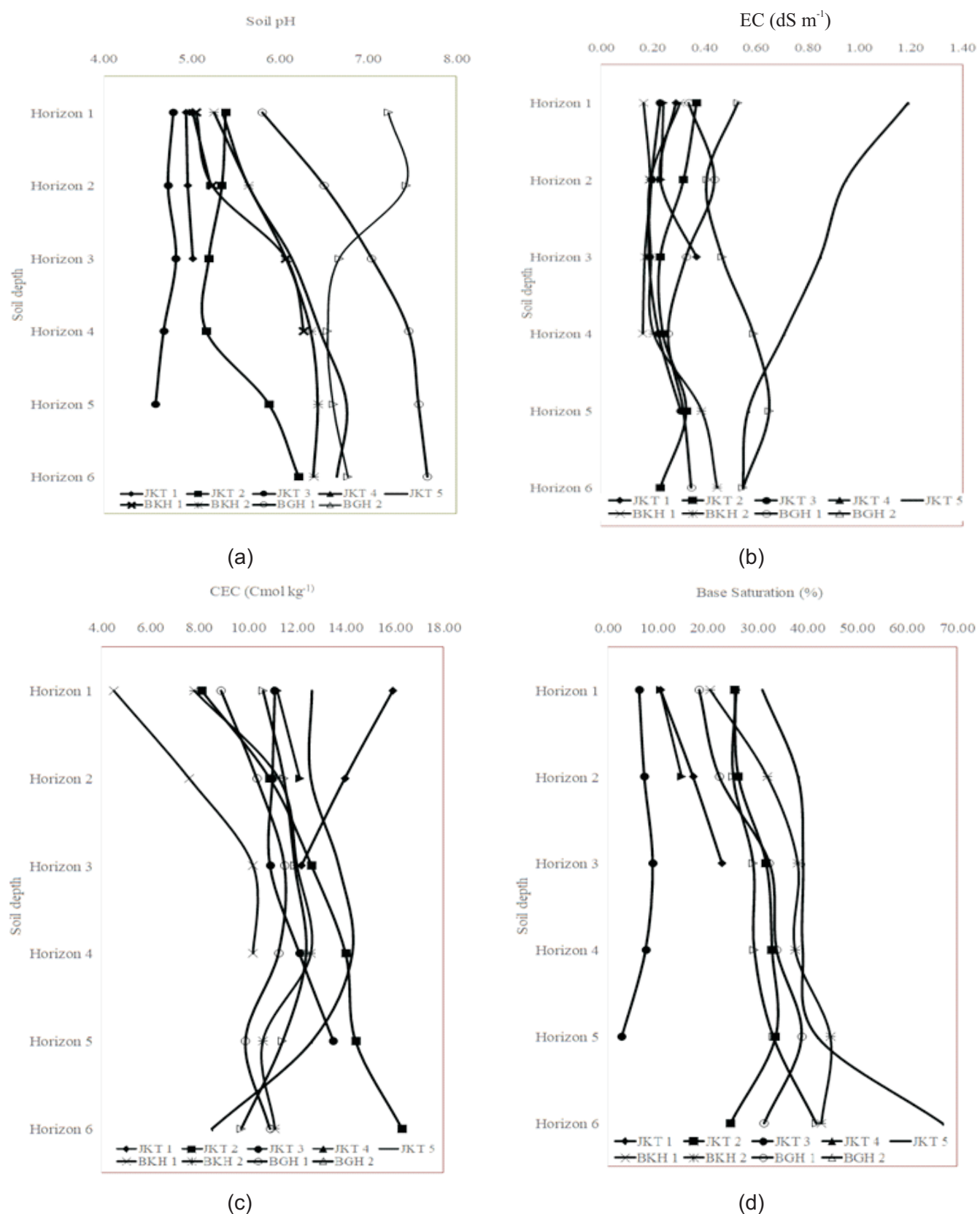


Fig. 5. Distribution of pH (a), EC (b), CEC (c) and BS (d) in Profiles of three transects

Correlation of soil quality indicators

The soil quality indicators such as pH, EC, CEC, and BS observed significant association among themselves and other relevant properties in eroded land. Erosion, exclusively of clay particles and leaching of solutes due to water had tremendous influence on sloppy lands and their acidity. The clay in eroded land recorded positive and significant relationship with soil pH (0.29*), which might be due to retention of bases (Table 3). The high base status has strong positive and significant relation with pH (0.62**) and with EC (0.27*). Among bases, calcium and magnesium have contributed more with strong positive correlation of 0.61** and 0.37* respectively with soil pH. Electrical conductivity showed positive correlations with clay percentage (0.42**) and BS (0.39**). Among bases, sodium content recorded strong and positive correlation (0.59**) with EC than other bases. Cation exchange capacity was very high with higher quantity of finer particles like clay, which is evident in this eroded land. The clay content strongly and positively correlated with CEC (0.36*) and microaggregates (0.60**). (Jones *et al.* 2021) observed positive correlation between clay content and CEC of soil in different soil profile. Transportation of finer particles and disruption of microaggregates in erosion process might have affected

CEC in eroded land more compared to non-eroded lands. Base saturation had strong and positive correlation with clay (0.57**), pH (0.62**), EC (0.39**), Ca (0.91**) and Mg (0.70**). (Gaspar and Laboski 2016) also reported positive correlation between base saturation and pH, Ca and Mg content of soil. The pH, EC, CEC, and BS got severely affected by water erosion in the sloppy land of red ferruginous soils due to run-off, leaching and translocation of solutes. The severely affected soil qualities indicate that the soil is heading towards complete degradation.

Conclusion

The soil chemical quality indicators of pH, EC, CEC and BS were severely affected by water erosion. The ranges of soil pH, EC, CEC, and BS were 3.08, 1.03 dS m⁻¹, 11.08 cmol kg⁻¹ and 64.23 per cent which indicate that the upland soils with severe erosion are leading to soil degradation. The base saturation had highest variance of 169.56 followed by CEC (4.82), pH (0.78) and EC (0.05). These quality indicators are efficient to judge the severity of soil erosion because of its high range values and could be used as Minimum Data Set (MDS). Implementation of soil and water conservation measures and liming are needed to improve the soil quality and arrest the degradation process.

Table 3. Correlation metrics among soil physico-chemical properties of eroded land

	Sand	Silt	Clay	Micro aggregate	pH	EC	CEC	BS	OC	K	Na	Ca	Mg
Sand	1.00												
Silt	-0.55**	1.00											
Clay	-0.52**	-0.43*	1.00										
Micro-aggre	-0.06	-0.30*	0.37*	1.00									
pH	-0.19	-0.08	0.29*	-0.50**	1.00								
EC	-0.09	-0.31*	0.42**	-0.01	0.27*	1.00							
CEC	0.06	-0.41**	0.36*	0.60**	-0.05	0.20	1.00						
BS	-0.52**	-0.01	0.57**	-0.11	0.62**	0.39**	-0.12	1.00					
OC	0.13	-0.10	-0.04	0.49**	0.61**	0.00	0.08	-0.28*	1.00				
K	0.37*	-0.26*	-0.13	0.01	-0.25*	0.35*	0.16	-0.17	0.31*	1.00			
Na	-0.15	-0.27*	0.44**	0.31*	0.03	0.59**	0.28*	0.20	0.05	0.19	1.00		
Ca	-0.49**	-0.17	0.70**	0.10	0.61**	0.45**	0.26*	0.91**	-0.22*	-0.16	0.26*	1.00	
Mg	-0.42**	-0.12	0.58**	0.21	0.37*	0.54**	0.31*	0.70**	-0.03	0.12	0.36*	0.80**	1.00

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