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Assessment of some soil physical indicators in severely eroded lands of southern Karnataka

K. Rajan[1], A. Natarajan[2], K.S. Anil Kumar[2], R.C. Gowda[3] and A. Abdul Haris[4]

[1]Central Soil and Water Conservation Research and Training Institute, Research Centre, Udhagamandalam-643004, Tamil Nadu; [2]National Bureau of Soil Survey and Land Use Planning, RC, Bangalore-560024, Karnataka; [3]Department of Soil Science and Agricultural Chemistry, GKVK, UAS, Bangalore-560065, Karnataka; [4]ICAR Research Complex for Eastern Region, Patna-800 014.
[1]E-mail: krajanars@gmail.com

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ABSTRACT

Water erosion is the major type of land degradation in Karnataka affecting 30.9% geographical area in the state in which Kolar is the most severely affected district in Southern Karnataka. Remote sensing technique was used to identify the hot spots. Seven profiles were opened in two transects, one near Jankamakote village (named as JKT with five profiles) and another one at Bhaktarahalli village (named as BHT with two profiles) and investigated the impact of water erosion on soil physical indicators. Pedon 2 of JKT under natural scrub forest recorded highest infiltration rate and Pedon-3 recorded the lowest infiltration rate because the soil was crusted and compacted. Highest bulk density (1.7 Mg m^{-3}) was observed in Pedon 4 in JKT. The texture of surface horizons in all the pedons were sandy clay or sandy clay loam. Available soil water in different Pedons varied from 67.4 to 288.4 mm. Pedon- 4 of JKT retained only 67.4 mm water because of severe erosion, shallow depth and higher bulk density. Pedon-1 of BHT retained maximum water (132.1 mm) compared to Pedon-2 (96.1 mm).The highest amount of micro-aggregates observed under natural forest soil and the least was in severely eroded lands. Porosity of the soil in different Pedons varied from 33.6 to 44.7%. Clay dispersion in different Pedons ranged from 2.9 to 14.4%. Clay dispersion was highest in the lowland soil (Pedon-5). The differences in soil physical qualities at various degrees are attributed to the impact of soil erosion coupled with incorrect land use. Soil and water conservation measures are highly needed in sloping areas to restore the soil physical quality.

1. INTRODUCTION

Land degradation due to soil erosion reduces the agricultural production and productivity. In India, about 188.0 m ha (57%) of land is under different forms of degradation in which about 162 m ha is due to the displacement of soil materials by water and wind erosion (Sehgal and Abrol, 1994). In Karnataka, 7.7 m ha of land, out of the 19.1 m ha of total geographic area, is under soil degradation problems. Water erosion is the major problem in 5.9 m ha (30.9%) of land area (Shivaprasad *et al.*, 1998) and considerable area has been reported in Southern Karnataka with severely disturbed soil physical qualities by virtue of soil erosion. Investigations have been conducted in the lateritic belt of southern Karnataka to study the impact of erosion on soil physical properties. Land forms are created by the continuous geo-morphological processes like denudation and deposition. Hence it is the elevated lands, which undergo denudation process first and lowlands undergo the deposition process. In sloping land, the denudation process appears very fast. Land uses vary based on the topography, climate conditions and market demand. High intensity rainfall in undulating land form and improper land use for agriculture production result in severe leaching of bases and removal of fertile top soil. Inadequate attention is paid on soil conservation, which leads to land degradation by soil erosion. Land degradation due to soil erosion reduces the agricultural production and productivity through deterioration of physical land qualities and land degradation. Soil physical properties are changed gradually under crop cultivation. Changes in physical land quality may vary depending upon the nature of crop and intensity of its cultivation. Accelerated soil erosion is the most destructive process and makes the land unproductive in contrast to natural geological erosion. Based on the information and reports available (NBSS&LUP and NRSA), it was confirmed that large tracts of degraded lands, due to erosion, exist in the Southern parts of Karnataka. The main objective of the present study was to assess the status of soil physical indicators in the eroded land.

2. MATERIALS AND METHODS

Karnataka State Remote Sensing Application Center, Bangalore has published natural resource reports for entire Karnataka. According to the report, the Kolar district is severely affected by erosion which was selected for this investigation.

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 months of very high temperature whereas December and January are the coolest months.

Imageries of entire district of Kolar of 1:50000 scales (57G/15, 57G/16, 57K/03, 57K/04 and 57K/08) were interpreted in conjunction with respective toposheets, based on the tonal variations, texture and pattern. Permanent structures like roads, settlements, railway lines, and lakes were marked first in the trace sheet mounted on the imagery. Lowlands were demarcated along the water bodies, since they were clearly visible on the imageries. The uplands seen with dark brown colour with light patches were demarcated on the imageries. Based on the tonal variations and pattern, the upland areas were further divided into summits and midlands. Most of the uplands in Kolar district were observed to have dark red colour with uniform texture due to the presence of plantations, either *Eucalyptus* or Mango.

Gullies were observed with light tones in irregular patches in the midlands. The other areas showed regular pattern of either increasing or decreasing tones. Very pale yellow tones and same tones with streaks were demarcated as severely eroded land; Yellow to light brown tones were demarcated as moderately eroded land and light brown to brown tones demarcated as slightly eroded land. 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 bouldered 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, one imagery namely 57G/15 representing different intensities of erosion were selected for the characterization of erosion status in the district. The imagery covers major areas of Sidlaghatta, Chintamani and Srinivaspur taluks of Kolar district. Based on the variation in tone and pattern, two transects were selected covering both uplands and lowlands.

Transects were marked at the time of interpretations and the areas were traversed in detail in the field to study the landform and soil relationship. In areas affected by erosion, two transects were demarcated. Both transects were traversed in detail in the field. The first transect was located in Sidlaghatta taluk near Jangamakote village, hence named as Jangamakote Transect (JKT). Elevation of this transect ranged from 880 to 920 m above msl. This transect is in the lateritic landform. It consisted of uplands and low lands. Lowland is nearly level and intensively cultivated. The soils are very deep and not much gravels observed on the surface. Upland consisted of summit and midlands, which are under different land uses such as reserve forest (*Eucalyptus*), natural scrub forest and crop cultivation. Surface cover was observed with rock fragments and the soil is moderately shallow. Exposed cemented iron stone materials were also observed in these transects. 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 is also located in Sidlaghatta taluk near Bhaktarahalli village and named as Bhaktarahalli transect (BKH). This transect is also in the lateritic landform but with different image characteristics. Elevation of this transect ranged from 880 to 900 m above msl. The upland is under different land uses. Summit areas were cultivated with field crops and mulberry, gravels were less in the surface and the soil is deep, Midland areas are having Eucalyptus plantations. The soils are deep with gravels exposed 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.

Details of the land form and pedon locations are furnished in Table 1. Infiltration rate was measured adjacent to profile spot with double ring infiltrometer using falling head method (Jackson, 1973). Profiles were opened in different physiographic units consisted of summit, midland and lowland in each transect. In shallow soils, the profile was opened up to hard substratum and in deep soils more than 150 cm. Horizons were marked and soil samples collected from each horizon. Soil texture was estimated by international pipette method (Richards, 1954). Available soil water (ASW) was estimated by pressure plate apparatus (Jackson, 1973), micro-aggregates as per the procedure of Sarma and Das (1996) and clay dispersion following Rengasamy *et al.* (1984) procedure.

Table: 1
Pedons location and site characteristics of transects in Sidlaghatta taluk of Kolar district

Transect location	Pedon no.	Location of pedons	Land forms	Land use	Slope (%)	Run-off	Erosion status
Jangamakote	1	Latitude: 13° 16' 36. 71" N Longitude:77°51' 26.79" E	Very gently sloping upland	Current fallow	1-3	Medium	Moderate
	2	Latitude:13° 16' 53.49" N Longitude:77° 52' 02. 71" E	Very gently sloping upland	Scrub forest	1-3	Slow	Slight
	3	Latitude:13° 17' 08.49" N Longitude:77° 52' 00.20" E	Very gently sloping upland	Eucalyptus forest	3-5	Medium	Moderate
	4	Latitude:13° 17' 13.17" N Longitude: 77° 51' 59.84" E	Moderately sloping upland	Eucalyptus forest	10-15	Very rapid	Severe
	5	Latitude:13° 17' 17.89" N Longitude:77° 52' 04.94" E	Very gently sloping lowland	Cultivable land	1-2	Slow	Slight
Bhaktarahalli	1	Latitude:13° 19' 47.88" N Longitude:77° 50' 57.07" E	Very gently sloping upland	Cultivable land	1-2	Slow	Moderate
	2	Latitude:13° 19' 51.41" N Longitude:77° 50' 50.46" E	Gently sloping upland	Eucalyptus forest	5-10	Rapid	Moderate

3. RESULTS AND DISCUSSION

Soil Depth

Soil solum depth was varying from 55 to more than 150 cm (Fig. 1). Pedon-2 in JKT was in undisturbed scrub forestland and the soil was very deep (>150 cm) with nearly level surface (Table 2). The depth of Pedon-1 at the summit was 80 cm only which falls under the category of moderately deep. The intermittent cultivation and fallowing of the land without soil and water conservation measures might have reduced the soil depth and the reduction in soil depth is 47% compared to forest land. Pedon- 4 of JKT under moderately sloping land has affected with very severe erosion and the soil depth was moderately shallow (55 cm). Reduction in soil depth under Pedon-4 compared to forest land is 63% per cent. Similar observation was made by

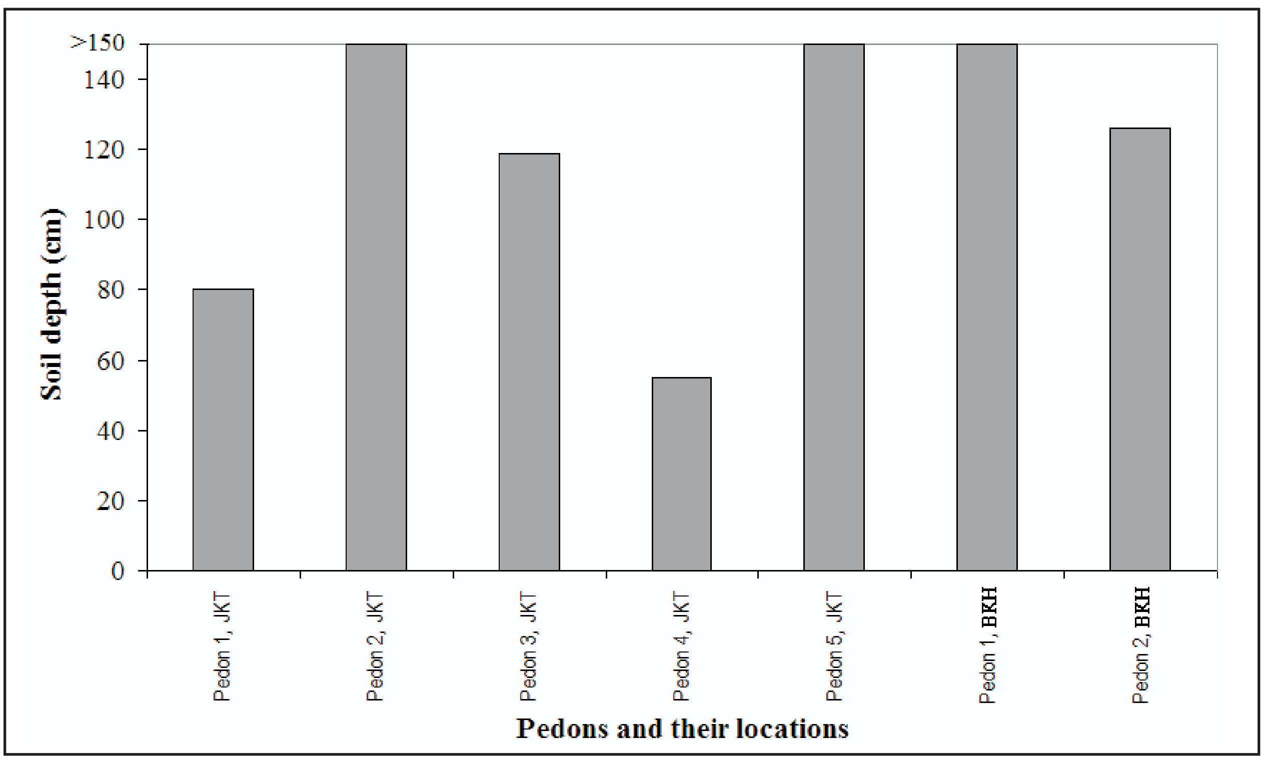

Fig.1. Soil depth of pedons at different transects (cm)

Bhaskar and Subbaiah (1995) in Andhra Pradesh and Mahapatra *et al.* (2000) in the sub-humid region of Kashmir. Hard laterite was exposed in many places. Pedon-1 of BHT was in summit and hence the soil was very deep due to less erosion (> 150 cm). Nearly level land, low soil erosion and the loose soil due to continuous cultivation might have reduced the runoff by increasing the infiltration rate. Soil depth of Pedon-2 of BHT was 126 cm due to erosion compared to Pedon-1 in the same transect and the soil depth reduction was 16% compared to Pedon-1 of BHT. The land might have not been protected well in the past and the topsoil got eroded. Presently the land is brought under Eucalyptus plantation. Soil depth of Pedon-5 under JKT was also very deep (>150 cm) and it is located at valley portion of transect. The soil is very fine in the entire profile which might be due to deposition of finer particles by the erosion.

Bulk Density

It was observed that the bulk density decreased with depth in both in the upland as well as midland (Fig. 2) except in lowland soils (Pedon-5) where deposit of fine particle and intensive cultivation with high organic input might be reduced the bulk density at the surface layers and also continuous cultivation of field crops (Mehta *et al*., 2005). Among the three pedons in the summit of JKT, Pedon 3 is in gentle slope showed higher bulk density in the surface horizon, which is 126% more than the lower most layer (Bt4). Due to wide variation in bulk density among horizons, the standard deviation was very high in Pedon-3 compared to other pedons in the same transect. Pedon-1 in the summit, the bulk density was low due to cultivation. The value of bulk density of Pedon-2 of JKT was between the above two pedons. Highest mean bulk density (1.7 Mg m^{-3}) was observed in Pedon-4 in JKT, which is located in the midland with moderate slope. Heavy sand particles in the surface layer due to erosion of clay and silt particles might be the reason for high bulk density in the surface layers. Due to the severity of erosion, most of the soil materials have been removed leaving only the compacted layer below. Bulk density increased with depth in lowland soil (Pedon-5). Highest standard deviation in bulk density was observed in Pedon-2 of BHT followed by Pedon-3 of JKT and Pedon-2, BHT. This may be due to the formation of more compacted layer at the surface horizon and less compaction at lower horizons. At low intensity and low rainfall conditions, the dispersed soil particle forms hard crust on the surface.

Soil Texture

The texture of horizons in all the pedons falls under clay, sandy clay or sandy clay loam. Surface horizons were lighter in texture compared to sub-surfaces and deeper horizons consisted of high quality of clay (Table 2).

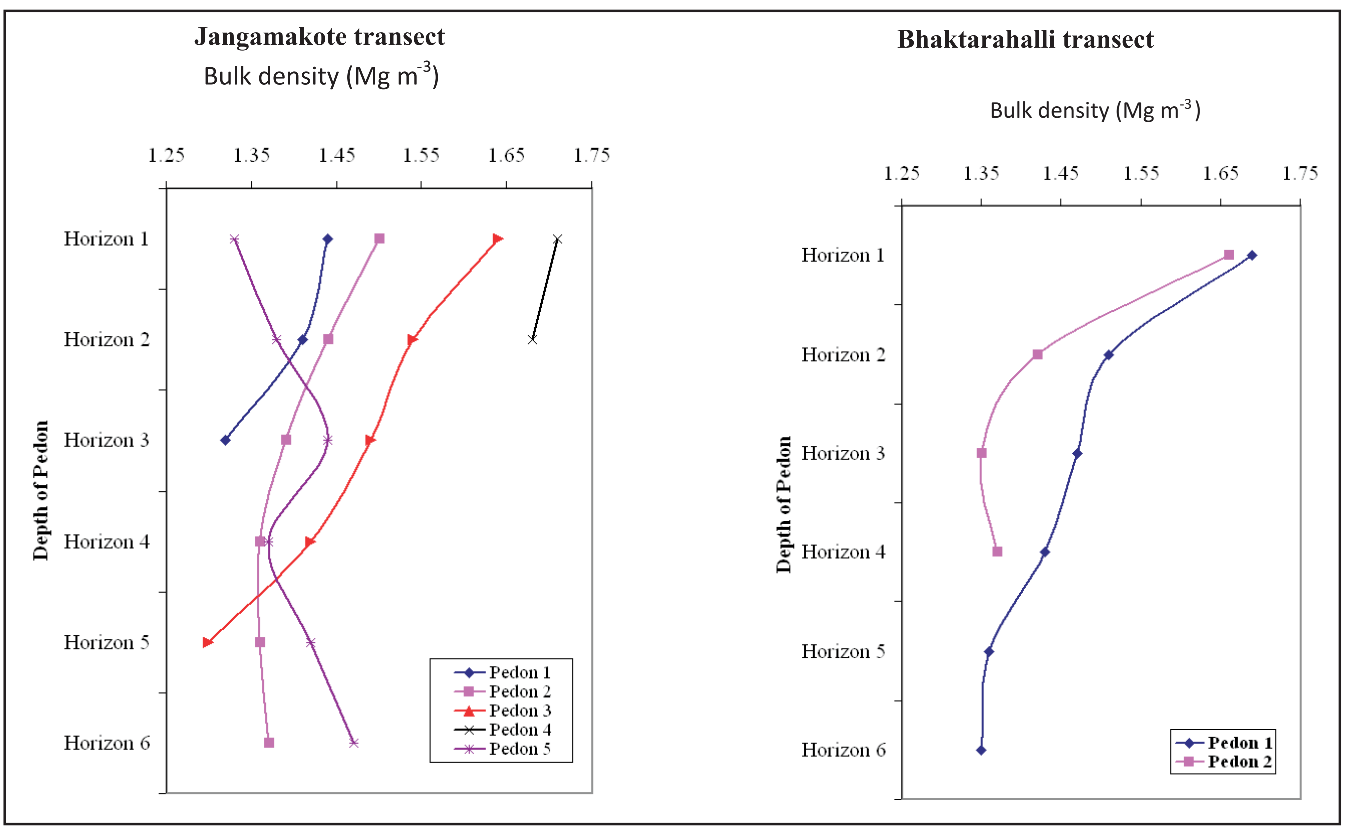

Fig. 2. Depth-wise bulk density (Mg m^{-3}) in pedons at different transects

Dispersion of clay in surface horizons resulted in lower clay content in surface horizons (sandy clay). Clay content was increasing with depth as observed by Rajamannar and Krishnamoorthy (1978). There is an evidence of illuviation of clay and formation of argillic horizons in the subsurface layer (Sitanggang *et al.,* 2006). In Pedon-5, the soil texture was mostly clay except in the surface horizon and the highest average clay content of the profile was recorded in the profile (50.6%) followed by forest soil (44.7%). The clay content in Pedon-5 is more than the upland pedons due to deposition of soil materials from the upland (Dadhwal *et. al.,* 2012). The mean sand content of the profile was increasing with increasing severity of erosion. Pedon-5 of JKT recorded the lowest sand content of 38.5% and the highest sand content was in Pedon-4 of severely eroded slopy land. Clay content of Pedon-2 of BHT was similar in all the horizons and the quantity of clay was lower than Pedon-1, because the Pedon-2 is in moderate slope position. Moderate runoff and percolating water might have displaced the clay particles from the surface and sub-surface soils.

Pedons of summit and midlands under different land uses were observed with rock fragments. Rock fragments quantity varied among pedons and increased with depth. It varied from gravel to extremely gravel. Under JKT, there were no gravels in the soils under forest and lowland where as in other pedons gravels were observed in all the horizons which varied from 15 to 75%. Pedon-1 of JKT the rock fragments were observed more in subsurface layers and during lateritization process, when the soil is brought under saturation, iron nodules are formed with different sizes in the sub-surface which might be the reason for the gravelly nature of sub-soils.

Table: 2
Soil physical indicators of pedons of Jangamakotte and Bhaktharahalli transects

Pedons and location	Horizons with designation	Horizon width (cm)	Depth of Pedon (cm)	Bulk density (Mg m^{-3})	Particle size distribution Sand (%)	Silt (%)	Clay (%)	USDA Textural classes	Rock Frag. (%)	Avail. Soil water (mm)	Micro-aggregate (%)	Total porosity (%)	Clay dispersion (%)
P1 Jangamakotte (Pedon 1)	0-13 A	13	80	1.44	48.75	14.56	36.69	g sandy clay	20	24.9	16.40	36.27	2.88
	13-36 Bt1	23		1.41	38.90	24.95	36.15	eg clay loam	65	38.6	21.05	40.00	2.88
	36-80 Bt2	44		1.32	55.39	16.23	28.38	vg sandy clay loam	60	64.8	25.70	40.55	5.75
P2 Jangamakotte (Pedon 2)	0-15 A	15	150	1.50	58.97	10.91	30.12	sandy clay loam	<5	29. 9	15.10	36.41	2.87
	15-35 Bt1	20		1.44	50.33	3.71	45.96	sandy clay	<5	40.6	21.58	37.67	5.75
	35-65 Bt2	30		1.39	46.10	4.96	48.94	sandy clay	<5	62.3	26.20	39.27	8.63
	65-96 Bt3	31		1.36	45.74	8.52	45.74	clay	<5	69.8	28.69	40.70	8.63
	96-115 Bt4	19		1.36	42.90	8.11	48.99	clay	<5	31.7	28.48	41.42	5.75
	115-150 Bt5	35		1.37	43.96	7.78	48.25	vg clay	45	54.1	29.20	41.34	5.75
P3 Jangamakotte (Pedon 3)	0-13 A	13	119	1.64	68.19	6.66	25.15	g sandy clay loam	15	21.8	10.40	38.56	11.50
	13-39 Bt1	26		1.54	68.76	5.24	26.00	g sandy clay loam	20	493.	15.69	40.77	8.63
	39-60 Bt2	21		1.49	51.01	11.89	37.10	vg sandy clay	50	38.0	18.20	49.60	5.75
	60-91 Bt3	31		1.42	39.76	20.58	39.66	eg clay loam	65	47.9	21.59	38.52	8.63
	91-119 Bt4	28		1.3	51.95	17.03	31.02	eg sandy clay	75	35.8	22.80	37.63	11.50
P4 Jangamakotte (Pedon 4)	0-16 A	16	55	1.71	66.42	0.90	32.68	vg sandy clay loam	50	18.5	8.10	46.48	11.50
	16-55 Bw	39		1.68	48.28	7.35	44.37	eg sandy clay	65	48.9	13.80	42.93	5.75
P5 Jangamakotte (Pedon 5)	0-15 Ap	15	136	1.33	52.20	8.27	39.53	sandy clay	<5	17.0	13.40	40.04	11.50
	15-32 Bt1	17		1.38	39.60	3.62	56.78	clay	<5	26.9	16.58	41.27	11.50
	32-60 Bt2	28		1.44	33.68	10.48	55.84	clay	<5	47.4	17.80	42.28	14.37
	60-84 Bt3	24		1.37	33.30	9.57	57.14	clay	<5	28.1	19.25	42.92	14.38
	84-105 Bt4	21		1.42	34.43	16.34	49.23	clay	<5	22.4	15.69	44.36	17.25
	105-136 BC	31		1.47	37.85	17.34	44.81	clay loam	<5	34.4	11.50	41.58	17.25
P1 Bhaktarahalli (Pedon 1)	0-16 Ap	16	158	1.69	33.12	38.62	28.25	g clay loam	30	7.5	2.90	34.39	2.88
	16-38 Bt1	22		1.51	45.52	22.75	31.72	vg clay loam	50	14.5	7.99	34.77	2.88
	38-71 Bt2	33		1.47	40.91	10.05	49.04	vg clay	50	27.4	12.00	41.91	2.87
	71-105 Bt3	34		1.43	38.07	19.07	42.86	vg clay	50	31.3	10.25	43.25	2.88
	105-127 Bt4	22		1.36	40.23	14.60	45.17	vg clay	60	20.0	13.25	43.84	2.88
	127-158 Bt5	31		1.35	43.72	15.48	40.80	vg clay	60	31.4	7.50	42.41	2.88
P2 Bhaktarahalli (Pedon 2)	0-17 A	17	126	1.66	35.51	34.69	29.80	vg clay loam	35	13.0	2.70	22.26	2.88
	17-49 Bt1	32		1.42	45.65	18.76	35.59	vg clay loam	55	23.7	4.88	35.69	2.88
	49-82 Bt2	33		1.35	37.67	29.79	32.54	vg clay	40	25.3	8.00	39.83	2.88
	82-126 Bt3	44		1.37	35.30	29.70	35.00	eg clay	65	34.1	13.58	40.74	2.88
Descriptive statistics													
Mean	-	-	-	1.45	45.38	14.64	39.98	-	-	33.79	15.63	39.99	7.10
Standard Error	-	-	-	0.02	1.75	1.64	1.62	-	-	2.71	1.31	0.81	0.82
Standard Deviation	-	-	-	0.11	9.91	9.30	9.15	-	-	15.35	7.40	4.60	4.62
Variance	-	-	-	0.01	98.29	86.40	83.77	-	-	235.76	54.83	21.12	21.31
Range	-	-	-	0.41	35.64	37.72	31.99	-	-	62.30	26.50	27.34	14.38
Minimum	-	-	-	1.30	33.12	0.90	25.15	-	-	7.50	2.70	22.26	2.87
Maximum	-	-	-	1.71	68.76	38.62	57.14	-	-	69.80	29.20	49.60	17.25

Available Soil Water

Available soil water showed an increasing trend with increase in depth from 17 to 70 mm in JKT and 7.5 to 34.1 mm in BHT, because of heaviness in texture consequent to clay eluviation and exposure of more surface area with finer textures (Fig. 3). Available soil water in different Pedons varied from 67.4 to 288.4 mm. The difference was due to depth of soil, organic matter, clay content, coarse fragments, bulk density and aggregates. Reduction in soil depth reduced the available soil water capacity in Pedon 1, 3, 4 of JKT and Pedon-2 of BHT. The variation in ASW in horizons was minimum in Pedon-5 (s = 10.58) due to reduced erosion and deposition of clay and silt from the uplands. Similar results were observed by Saha and Mishra (2007) on available soil water under different land use systems.

Microaggregates

Average per cent of microaggregates in the pedon varied from 2.1 to 24.9%. The highest amount of micro-aggregates was observed under natural forest soil and the lowest in severely eroded lands (Fig. 4). In forest, the nearly level land covered with natural vegetation like shrubs and grasses, the micro-aggregates have been protected from the impact of raindrops and which might have reduced the runoff and removal of fine particles from the soils. This might be the reason for retention of higher percentage of microaggregates in the soil. At the same time, the unprotected land might have been relieved off micro-aggregates from the soil with intense rain and runoff forces. Opera (2009) found similar result of highest amount of microaggregates under soils of natural forest compared to soils under oil palm, cassava, bush plants and rubber plantations. Pedon-2 recorded higher per cent of micro-aggregates than any other pedon in JKT due to the presence of natural forest vegetation. The humid substances present in higher amounts under natural forest vegetation compared to eroded land, might have stabilized the microaggregates over a long period of time (Chaney and Swift, 1986). In this pedon, the activity of termites and ants were more in the sub-soil that might have helped in the aggregation. Least amount of mean microaggregates were measured in Pedon-4 (11.0%), because of the pedon is located on the moderately sloping land and hence, the erosion is severe. Removal of clay and silt due to heavy runoff might have not supported the formation microaggregates and also the microaggregates formed might have been eroded down to lowland due to higher slope. Pedons of BHT recorded less than 10% mean average microaggregates. Higher per cent of microaggregates was observed in sub-surface horizons. Pedon-1is in upland under the cultivation of annual crops like ragi, sorghum and mulberry. Average content of micro-aggregates in this pedon was higher (9.0 %) than Pedon-2 (7.3%), which is located in sloping land. Presently, *Eucalyptus* trees are grown on this land but many years back there might not have been any protection, which have caused severe erosion in the sloping land. Rain drops might have destroyed the soil aggregates and most part of the surface horizon might have been removed.

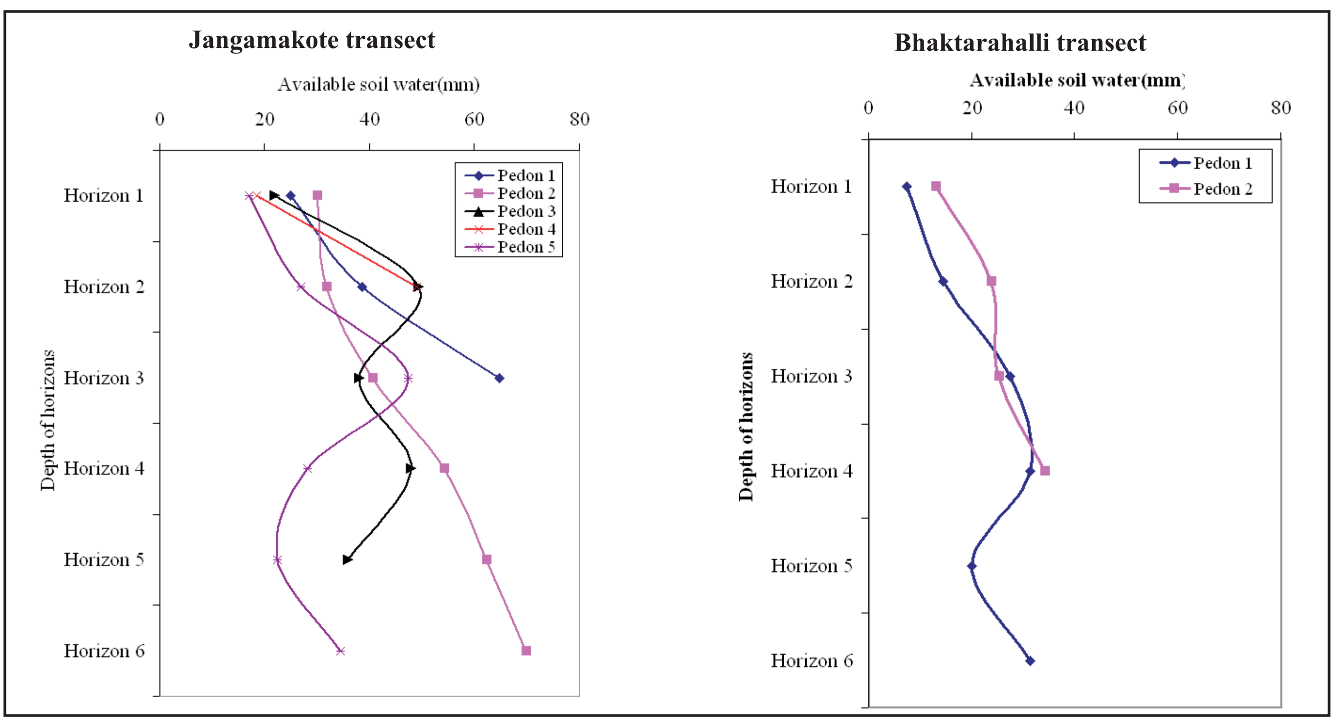

Fig. 3. Depth-wise available soil water in pedons at different transects (mm)

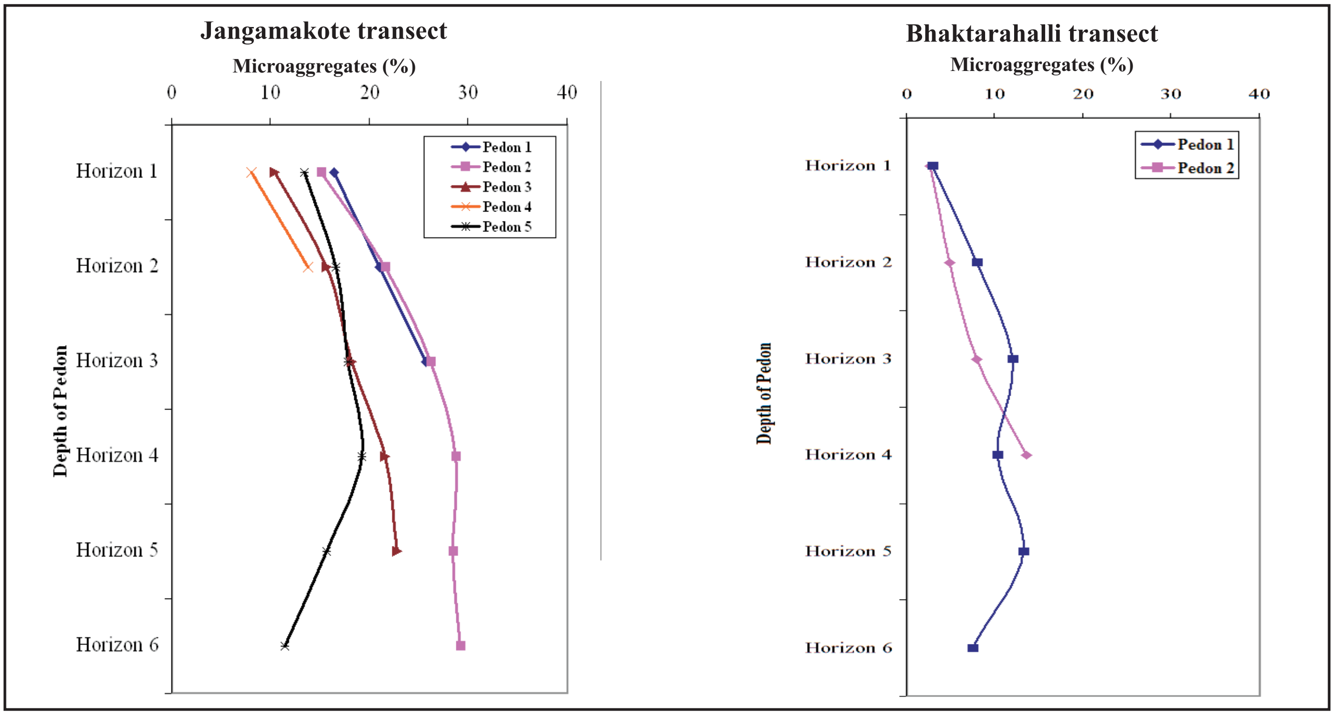

Fig. 4. Depth-wise soil microaggregates in pedons at different transects (%)

Total Porosity

Porosity of the soil in different pedons varied from 22.26 to 49.6%. Maximum samples in the study area fall under 40-45% porosity followed by 35-40% (Fig. 5). Mean porosity of the study area is 40.0% and the variance is 21. Jankauskas *et al.* (2008) observed the decreased porosity with increasing the severity of erosion under undulating slopes of Lithuanian Eutric Albeluvisol. Management practices in different land uses without adequate attention to soil and water conservation measures influences the soil porosity. Soil texture affects the porosity significantly and texture in turn is altered by erosion process. Highest porosity was observed in Pedon-3 of JKT (49.6%). The soil is gravelly in nature due to severe erosion. Pedon-2 is under natural scrub forest and recorded less variation in porosity among different horizons (sd = 2.07) where as Pedon-3 recorded maximum variation (sd = 4.94). This is because of the high compaction observed in the surface horizon (BD-

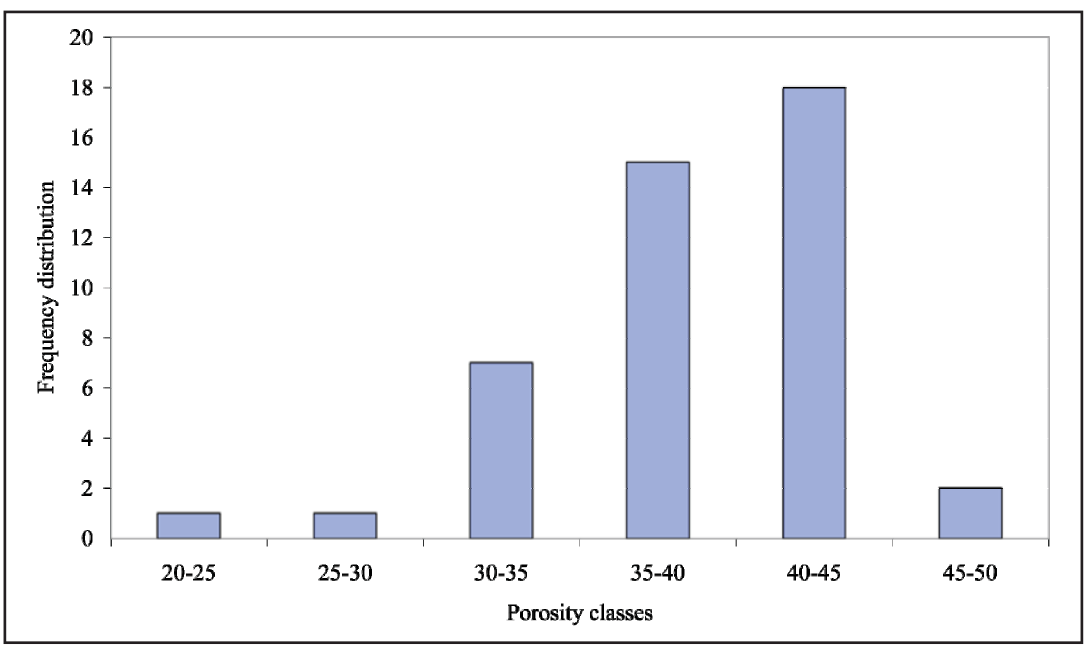

Fig. 5. Distribution of total soil porosity in the pedons of study area

1.6 Mg m^{-3}) and less compaction in the sub-surface horizons (BD-1.3 Mg m^{-3}) in Pedon-3. Pedon-5 under lowland showed uniform porosity with minimum variation among the horizons (sd = 1.48). Pedon-1 of BHT is in summit of the upland and the land is under cultivation. Average porosity of this pedon is higher (43.2%) than Pedon 2 (39.8%). Soil is very deep and clay content increased with depth, hence the porosity also increased with depth. Pedon 2 of BHT showed lower amount of average porosity with highest variations (sd = 8.53). Very low amount of porosity in the surface horizon of this Pedon is due to the severe surface sealing and loss of clay particles.

Clay Dispersion

Clay dispersion in different Pedons ranged from 2.88 to 14.4%. Clay dispersion was high in the lowland pedon (Pedon 5) because the soil itself contained higher clay, which might be due to deposition by runoff water from upland, frequent tillage and loosening of soil might have separated the clay particle from the aggregates. More clay particles might have been released from macro-aggregates into water at the time of mechanical shaking. The above processes make sure the higher clay dispersion in Pedon 5 of JKT. In case of upland and midland soils the clay dispersion was very less. Impact of raindrops and erosion due to high per cent slope might have dispersed and destroyed the soil aggregates. Due to this, most of the dispersed clay might have been easily removed from the upland by erosion and less clay was recorded here compared to lowland soils. Also, higher the erosion in upland, higher will be the leaching of bases, which in turn increases the absolute accumulation of iron and aluminum oxides in the soil. This might have caused higher aggregate stability in the remaining soil particles and lower clay dispersion(Goldberg, 1989).

Infiltration Rate

Water transmission characteristics affects severely by soil degradation processes like erosion and sodiciy. Disturbance in soil structure, pore size and volumes, clay dispersion etc are some of the important properties affected by soil erosion. Surface crusting by splashing of soil by raindrop affects the water entry into the soil. Pedon-2 of JKT under natural scrub forest recorded highest infiltration rate (Fig. 6). The standard error was varying from 0.45 to 1.35 at different profile sites of study area. Peng and Wang (2012) observed that when the soil is covered with more and long term vegetation cover respond high infiltration rate. Very deep soil and favourable structure (microaggregate = 25%) was found to be responsible for the higher infiltration rate which is in accordance with the findings of Hur and Letey (1989). The least infiltration rate was recorded in Pedon-3, where the soil was more compacted (BD=1.64 Mg m^{-3}) which might have reduced the infiltration rate (Shinde *et al.,* 1983) and also the severely eroded land with surface hardness might have created macropore discontinuity from surface to subsurface layer as observed by Sharma *et al.* (2013). Pedon-1 of BHT showed higher infiltration rate which might be due to nearly leveled land and loose soil and increased pore space due to ploughing and addition of organics could have contributed to the higher infiltration rate observed in this pedon (Total porosity = 40%). Pedon-2 in the same transect recorded lower rate of infiltration,

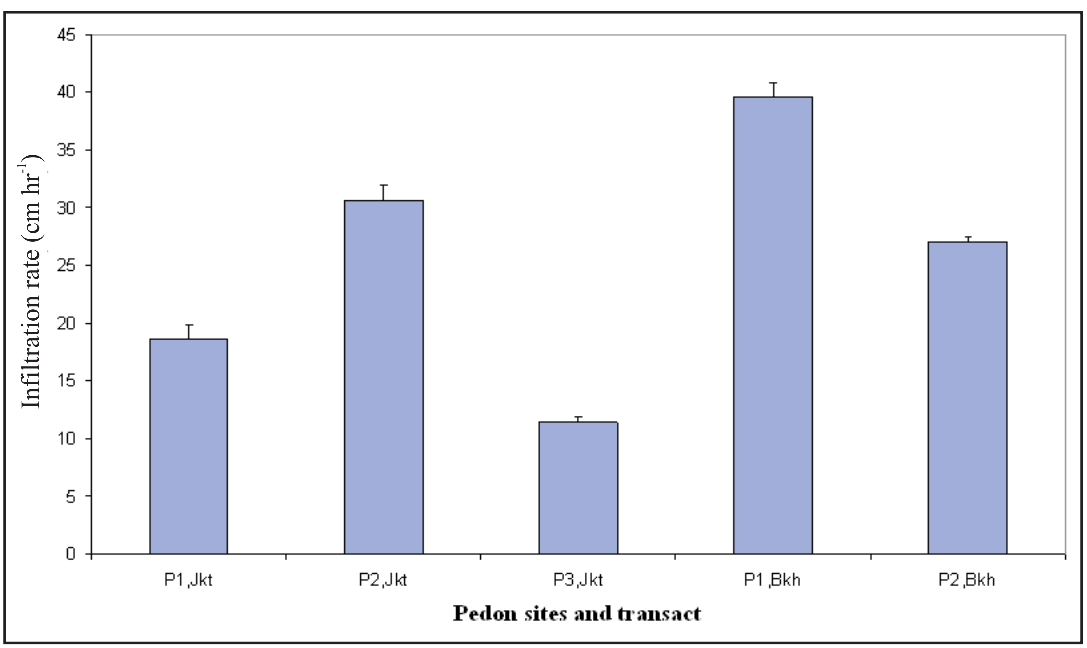

Fig. 6. Infiltration rate at pedon locations at two transects (cm ha^{-1})

which was only 63% of Pedon-1. This area might have brought under Eucalyptus plantation recently after keeping the land barren for long period. This pedon was located in the slope and the erosion was severe. Due to higher silt content, surface sealing was common. All these reasons might have contributed for the low rate of infiltration in Pedon-2. This inference is supported by sub-montane soils of Punjab under forest land, which recorded the highest infiltration rate followed by grass land, arable soil and bare land (Khera and Kahlon, 2005).

Association of Soil Physical Indicators

Soil physical indicators showed varied levels of association or correlation among themselves (Table 3). Sand showed negative relationship with silt and clay which are highly significant and could not establish any relationship with other indicators. Silt showed negative relationship with all the physical properties except bulk density. The highest relationship was recorded with total porosity followed by micro-aggregates, clay and clay dispersion which are highly significant. Clay showed significantly positive relationship with available soil water, micro-aggregates, total porosity and clay dispersion and highly significant negative relationship was observed with bulk density. Negative relationship of bulk density was observed with clay, available soil water, micro-aggregates and total porosity. Similar result was observed by Nkongolo and Plassmeyer (2010) and Dutta *et al.* (2014) in the forest soils of Missouri State of USA. Available soil water showed significant and positive association with micro-aggregates which contributes up to 54% for water retention (Fig. 7). Silt and bulk density were found with negative relationship with available soil water. Total porosity was recorded with highly significant negative relationship with silt and clay. Clay dispersion was found negative and highly significant relationship with silt and significantly positive relationship with total porosity and clay.

Table: 3
Pearson's correlation matrix of soil physical properties in eroded land of southern Karnataka

Soil physical indicators	Sand	Silt	Clay	Bulk density	Avail. Soil Water	Micro-aggregates	Total porosity	Clay dispersion
Sand	1.00							
Silt	-0.55**	1.00						
Clay	-0.52**	-0.42**	1.00					
Bulk density	0.28	0.08	-0.39**	1.00				
Avail. Soil Water	0.14	-0.38*	0.23	-0.35*	1.00			
Micro-aggregates	0.08	-0.47**	0.40**	-0.55**	0.77**	1.00		
Total porosity	0.11	-0.52**	0.41**	-0.24	0.28	0.31*	1.00	
Clay dispersion	0.05	-0.42**	0.38*	-0.05	0.12	0.23	0.33*	1.00

* Significant **highly significant

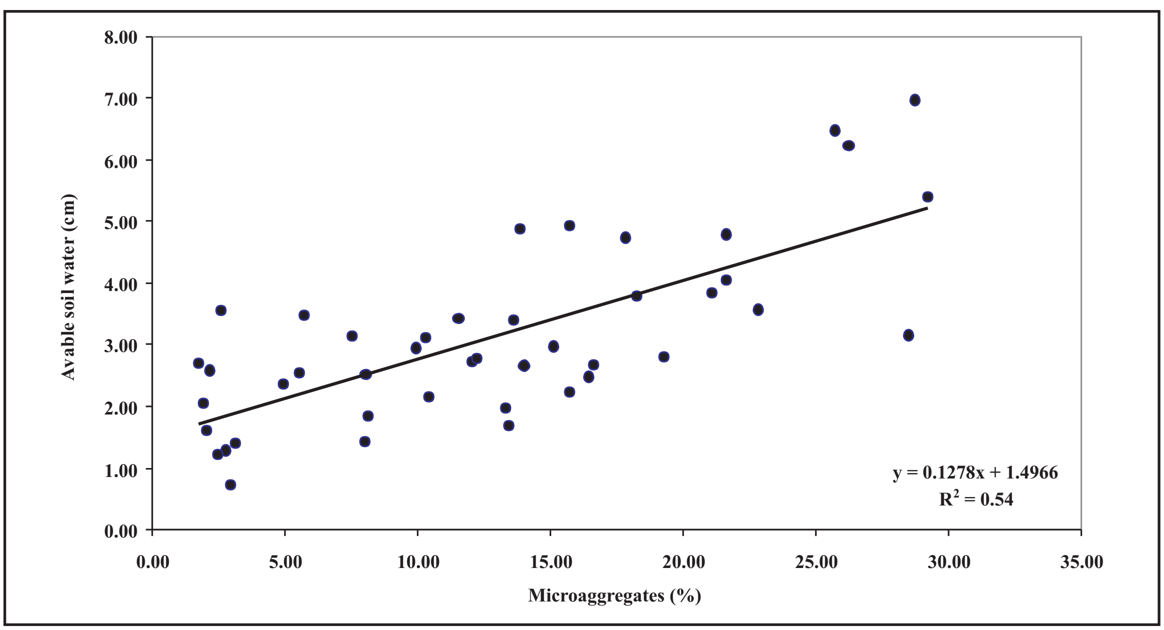

Fig. 7. Correlation between micro aggregates and available soil water in eroded land

4. CONCLUSIONS

Soil erosion affected the physical land qualities at various degrees. Sloping land without protection for soil conservation has severely affected the soil physical indicators especially the soil depth, bulk density, available soil water and micro-aggregates. Soil depth of Pedon-5 in 10-15% slope of Jangamakote transect was found only 55 cm with heavy gravels and boulders. Other soil properties were also severely affected by erosion process. Though, soil depth of Pedon-3 of Jangamakote and Pedon-2 of Bhaktarahalli transects are very deep (>150 cm) and deep, respectively, the soil become very hard in surface and also subsurface which lead to low infiltration and sheet erosion. Whether the soil is deep or shallow, adoption of soil and water conservation measures in the slopy lands has to be done immediately after demarcating the similar places. Pedon-1 is in summit of Jangamakote transect with 1-2% slope and soil depth is only 80 cm. Cultivation of fingermillet for two years and fallowing the land for 4-5 year induced the erosion and reduced the soil depth. Though, Pedon 1 is near to Pedon-2 which is in forest, soil physical indicators like available soil water and micro-aggregates are lesser because after the cultivation of land for two years, the land is left unattended. Proper conservation measures like growing cover crop have to be followed. The soils protected under natural forest cover (Pedon 2 of JKT transact) against erosive forces were observed with better soil physical properties. Land form specific soil and water conservation measures need to be followed in the fragile ecosystems like undulating lateritic terrains, involving mechanical measures as well as vegetative barriers.

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