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Soil Organic Carbon Stocks: A Potential Land Quality Indicator for Soils of Western Karnataka

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Abstract: Tropical soils have an important role in sustaining and regulating carbon cycle as they are characterized by high risk of soil degradation owing to rapid decomposition of soil organic matter under changing climatic situations. A study was undertaken in West coastal and Western Ghats of Karnataka to estimate horizon-wise soil organic carbon stocks to understand its impact on land quality. Soils were collected from different land uses under varying agro-climatic conditions. Soil organic carbon (SOC) stocks were estimated at different depths applying correction factor of bulk density and coarse fragments. The SOC estimates under different land use systems varied with type of land use, climatic conditions, erosional status, thickness of the horizon and bulk density of the soil. SOC stocks at different depths were higher in Kollur (14.29 kg m^{-2} at 0-150 cm depth) indicating better land quality, followed by Beltangadi (9.54 kg m^{-2}) and Brahmavar (9.17 kg m^{-2}) with moderate land quality. Murdeshwar and Molahalli soils were categorized as low and very low quality status, respectively, due to low SOC stocks (5.89 kg m^{-2} and 1.77 kg m^{-2} respectively). It was concluded that SOC is a reliable land quality indicator that could corroborate with the land use.

Key words: *Soil Organic Carbon, Land quality, Land degradation, Soil acidification, Soil erosion, Vegetative degradation*

Introduction

Soil carbon is an important attribute of soil quality and its productivity. Doran and Parkin (1994) defined soil quality as the capacity of a soil to function, within ecosystem boundaries, to sustain biological productivity, improve environmental quality and support human and plant health. Soil quality cannot be measured directly but inferred indirectly by measuring soil physical and chemical properties, which serve as quality indicators (Diack and Stott 2001). However, soil properties do have different degrees of influence on soil quality. In Coastal and in the Western Ghats of the study area, the main degradational processes are soil acidification, removal of bases, low cation exchange capacity (CEC), soil erosion and vegetative degradation (Sharda 2011). In addition, soil erosion is another major contributor to land degradation due to mismanagement and indiscriminate use of land resources and it is estimated that about 73 km of coastal Karnataka is affected by soil erosion (Joshi 1995). Land degradation due to erosion, salinity, water logging, and acidification reduces the quality of land in the area. Monitoring of land quality is essential for appropriate management of land resources. Among many land quality indicators, soil organic carbon (SOC) stocks is the most reliable indicator for monitoring land degradation (Larson and Pierce 1994) and mainly by soil erosion (Rajan *et al.* 2010). Soil is the largest pool of organic carbon with 1115 to 2200 Pg in the world (Batjes 1996) and 9 Pg in India (Bhattacharrya *et al*. 2000). Studies found that conversion of forests into farming systems will lead to land degradation and conversion of natural vegetation to annual crops leads to the greatest soil C losses (Kamoni *et al*. 2007). In tropical climate like in India, soil is the major carbon reservoir with 36 to 60% of ecosystem carbon being stored in forest soils (Malhi *et al*. 1999). Tropical soils are estimated to emit 0.2 Gt C yr^{-1} due to land use change, which accounts for 10 to 30% of the total C emissions from deforestation (Achard *et al*. 2004). Hence a study was undertaken to estimate horizon-wise SOC stocks along with other physical and chemical parameters to study its impact on land quality under different land use and agro climatic regions.

Materials and Methods

The Western coastal and the Western Ghats of Southern Karnataka represent humid tropical climate

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characterised by heavy rainfall and high temperature inducing intense leaching of bases. Hence, these areas are predominant with deep, well drained, acidic, red and lateritic soils. Physiographically it ranges from steep hills of Western Ghats to nearly level lower lateritic terrace with the slope ranges of 1-33%. The area receives very good amount of rainfall ranged from 3200 to 4485 mm (Table 1). Elevation of the location ranges from 7 to 252 m above mean sea level (MSL) and the study area falls in two classes *viz*. 0-25 m where the field crops or banana are being cultivated and 25-600 m where the rubber, cashew, coconut or arecanut plantations and forests are common. The erosion is slight to severe where the rainfall coupled with elevation is high. Seven representative sites were selected for study in Western coastal and the Western Ghats of Southern Karnataka *viz.* Sullya, Beltangadi, Kollur, Molahalli, Brahmavar, Murdeshwar and Ullal (Table 1 & Fig. 1).

Table 1. Details about the study area of west coast of southern Karnataka

Profile no	Physiographic division	Location	Land use	Elevation m above MSL	Rainfall (mm)	Soil classification	Erosion	Slope of pedon location
1	Steep hill ranges	Sullya (Hot humid tropics)	Rubber	252	3738	Fine, kaolinitic, iso-hyperthermic, *Ustic Kandihumults*	Severe	5-10%
2	Steep low hill ranges, isolated hills and dissected hills and valleys	Beltangadi (Humid tropics)	Rubber	148	4485	Fine-loamy, kaolinitic, iso-hyperthermic, *Ustic Kanhaplohumults*	Slight	1-3%
3	Elongated ridges and foot hill slopes	Kollur (Humid tropics)	Rubber	141	3844	Fine, mixed, iso-hyperthermic, *Kandic Palehumults*	Slight	1-3%
4	Undulating uplands	Molahalli (Hot Humid tropics)	Forest	25	3844	Loamy, kaolinitic, iso-hyperthermic, *Kanhaplic Haplustults*	Moderate	3-5%
5	Lateritic plateau and lateritic monds	Brahmavar (Humid tropics)	Rubber	38	3887	Fine loamy, kaolinitic, iso-hyperthermic, *Typic-Kanhaplustults*	Slight	3-5%
6	Coastal plateau summits	Murdeshwar (Hot humid tropics)	Cashew	8	3200	Clayey-skeletal, kaolinitic, iso-hyperthermic, *Typic-Kandiustults*	Moderate	3-5%
7	Valleys, bars and ridges and beaches and marshes (lower laterite terrace)	Ullal (Hot humid tropics)	Paddy	7	3769	Fine, kaolinitic, iso-hyperthermic, *Typic-Kanhaplustults*	Slight	3-5%

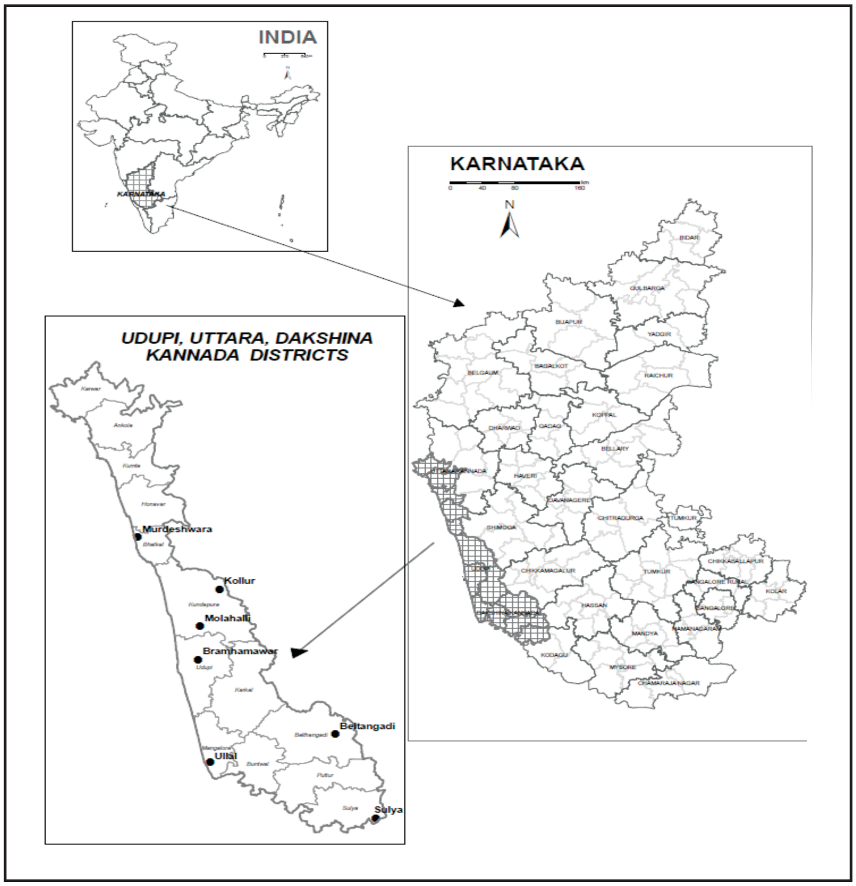

Fig. 1 Location map showing study area and pedons

A profile of dimensions of 1.5 X 1.5 X 2 m was dug at each site. Horizon wise samples were collected for laboratory study. The organic carbon was estimated by wet digestion method (Walkley and Black 1934) and SOC stocks were calculated using Grossman equation (Grossman *et al.* 2001) for top 30 cm, 30-50 cm, 30-100 cm, 100-150 cm and 0-50 cm, 0-100 cm and 0-150 cm layers.

For each of the soil profile SOC stocks were calculated for 150 cm by summing the stocks of different layers in proportion of their occurrence within this reference thickness. The total organic carbon stock in kg m^{-2} soil for each pedon was estimated using the general equation presented below (Grossman *et al*. 2001).

$$SOC = \frac{L_1 \text{ x } SOCP_1 \text{ x } \rho 33_1 \frac{(1 - V{>}2_1)}{100} + L_2 \text{ x } SOCP_1 \text{ x } \rho 332 \frac{(1 - V{>}2_2)}{100} + ...)}{10}$$

Where

SOC	=	soil organic carbon in kg m $^{-3}$
SOCP	=	soil organic carbon per cent
L	=	thickness of the layer in cm (if only surface 15 cm; L_1= 15cm; ignore L_2, L_3…).
ρ	=	bulk density (oven dry)
V>2	=	volume per cent of > 2 mm (gravel)

Results and Discussion

The soils studied were classified under Ultisol order owing to low per cent base saturation and low cation exchange capacity (CEC) clay ratio. The soil depth ranged from deep to very deep in nature (Table 2).

Table 2. Horizon wise soil parameters of different soil profiles

Pedons and locations	Horizons	Horizon width (cm)	Gravelliness (%)	Texture	pH	OC (%)	CEC/ Clay	CEC [cmol (p+) kg^{-1}]	BS (%)	BD (Mg m^{-3})
Sullya	Ap	0-10	15.9	gscl	5.4	0.94	0.30	18.9	10.4	1.08
	Bt1	10-33	11.9	scl	5.2	1.22	0.20	16.1	10.3	1.04
	Bt2	33-54	7.9	c	5.1	0.59	0.12	12.0	13.0	1.05
	Bt3	54-90	15.9	gc	4.8	0.09	0.10	13.2	9.9	1.14
	Bt4	90-121	23.8	gc	5.2	0.09	0.09	8.5	17.7	1.23
	Bt5	121-150	15.9	gc	5.1	0.09	0.07	10.1	16.5	1.20
Beltangadi	Ap	0-18	27.4	gscl	5.2	2.3	0.37	24.4	3.8	1.22
	AB	18-41	21.4	gsl	5.0	0.9	0.44	15.1	7.3	1.19
	Bt1	41-62	23.0	gsc	5.3	0.46	0.13	12.3	10.6	1.22
	Bt2	62-82	25.4	gsc	5.4	0.13	0.15	9.5	21.4	1.28
	Bt3C	82-119	15.2	gscl	5.4	0.16	0.16	9.8	19.0	1.24
	BC1	119-139	15.1	gcl	5.3	0.16	0.09	6.7	18.2	1.42
	BC2	139-153	13.5	sc	5.4	0.09	0.05	6.5	16.4	1.33
Kollur	Ap	0-10	27.8	gsl	5.3	5.49	0.73	28.2	23.9	1.13
	Bt1	10-27	28.8	gcl	5.5	2.8	0.32	22.5	14.8	1.12
	Bt2	27-53	31.0	gsl	5.3	1.22	0.20	22.1	20.8	1.22
	Bt3	53-88	32.4	gl	5.4	0.99	0.21	14.6	14.7	1.21
	Bt4	88-130	38.6	vgcl	5.6	0.03	0.08	11.4	10.8	1.33
Molahalli	Ap	0-10	31.0	gsl	5.7	0.66	0.27	9.4	20.5	1.21
	Bt1	10-28	32.2	gcl	5.6	0.13	0.09	9.4	20.3	1.21
	Bt2C	28-50	32.6	gsl	5.5	0.13	0.21	8.4	17.5	1.26
	BC1	50-78	34.2	gl	5.7	0.10	0.13	6.0	25.7	1.26
	BC2	78-109	37.0	vgcl	5.5	0.06	0.12	8.5	11.7	1.34
Brahmavar	Ap	0-10	21.4	gc	5.8	2.48	0.20	18.2	23.2	1.17
	BA	10-38	19.5	gcl	5.4	0.46	0.14	13.7	20.0	1.23
	Bt1	38-59	19.1	gc	5.2	0.49	0.08	13.9	4.9	1.22
	Bt2C	59-79	13.9	cl	5.2	0.46	0.14	15.4	9.3	1.19
	BC1	79-113	22.2	gcl	5.3	0.39	0.15	9.7	7.8	1.25
	BC2	113-148	24.2	gcl	5.2	0.13	0.11	13.2	16.9	1.29
Murdeshwar	Ap	0-20	28	gcl	5.7	1.45	0.18	18.0	8.6	1.24
	Bt1	20-47	35	gsc	5.6	0.46	0.10	13.7	12.9	1.23
	Bt2	47-82	60	vgsc	5.5	0.62	0.11	14.0	14.7	1.26
	Bt3	82-112	60	vgc	5.7	0.13	0.12	11.9	22.8	1.28
	Bt4C	112-155	70	egc	5.5	0.06	0.11	12.4	17.8	1.32
Ullal	Ap	0-10	3	scl	5.2	15.9	0.21	22.3	12.3	1.12
	AB	10-20	5	Scl	5.5	11.7	0.17	20.8	13.5	1.52
	Bt1C	20-47	14	c	5.4	3.0	0.12	19.0	14.8	1.32
	Bt2C	47-78	27	gcl	5.4	2.6	0.09	16.9	14.4	1.28
	Bt3C	78-103	14	c	5.4	3.0	0.09	18.2	14.7	1.43
	BC	103-133	15	gcl	5.4	2.4	0.10	19.6	10.5	1.45
	CB	133-151	15	gcl	5.7	2.6	0.14	14.7	15.1	1.42

The SOC content was high in surface soils and ranged from 0.66 to 5.4% and it decreased with depth, irrespective of land use and agro climatic region. The high organic carbon content in the surface layer might be due to slow decomposition rate and high biomass addition under closed rubber plantation of foot hill areas where the rainfall is high and temperature is low (Kharche *et al*. 1999). Low organic carbon content in the surface layer was noticed in undulating uplands represented by Molahalli (0.66%) and steep hill ranges represented by Sullya (0.94%) pedon with similar climatic conditions. The open forest land use system (crown density of 10 to <40%) coupled with hot humid tropical climate triggered the organic carbon decomposition rate of subsequent pedons (Chiti *et al*. 2014). The SOC stock in upper 30 cm soils (Table 3) ranged from 0.99 to 10.85 kg m^{-2}.

Table 3. Soil Organic Carbon Stocks of pedons

Depth (cm)	Horizon	OC (%)	Horizon	Soil Organic Carbon Stocks (kg m^{-2})						
				0-30	30-100	30-50	100-150	0-50	0-100	0-150
				(cm)						
Pedon 1 (Sullya): Clayey, kaolinitic, iso -hyperthermic, *Ustic Kandihumults*										
0-10	Ap	0.94	1.00	1.00						
10-33	Bt1	1.22	3.25	2.83	0.42	0.42				
33-54	Bt2	0.59	1.47		1.47	1.19				
54-90	Bt3	0.09	0.33		0.33					
90-121	Bt4	0.09	0.30		0.09		0.20			
121-150	Bt5	0.09	0.33				0.33			
				3.83	2.31	1.61	0.53	5.44	6.14	6.67
Pedon 2 (Beltangadi): Loamy, kaolinitic, iso -hyperthermic, *Ustic Kanhaplohumults*										
0-18	Ap	2.3	4.28	4.28						
18-41	AB	0.99	2.57	1.34	1.29	1.23				
41-62	Bt1	0.46	1.1		1.00	0.47				
62-82	Bt2	0.13	0.29		0.29					
82-119	Bt3C	0.16	0.75		0.36		0.39			
119-139	BC1	0.16	0.46				0.46			
139-153	BC2	0.09	0.17				0.13			
				5.62	2.94	1.70	0.98	7.32	8.56	9.54
Pedon 3 (Kollur): Clayey, mixed, iso -hyperthermic, *Kandic Palehumults*										
0-10	Ap	5.4	5.69	5.69						
10-27	Bt1	2.8	4.77	4.77						
27-53	Bt2	1.22	3.43	0.39	2.99	3.03				
53-88	Bt3	0.99	3.63		0.35					
88-130	Bt4	0.03	0.12		0.03		0.09			
				10.85	3.38	3.03	0.09	13.88	14.20	14.29
Pedon 4 (Molahalli): Loamy, kaolinitic, iso -hyperthermic, *Kanhaplic Haplustults*										
0-10	Ap	0.66	0.77	0.77						
10-28	Bt1	0.13	0.24	0.20						
28-50	Bt2C	0.13	0.30	0.02	0.28	0.27				
50-78	BC1	0.10	0.30		0.30					
78-109	BC2	0.06	0.20		0.14		0.06			
				0.99	0.72	0.27	0.06	1.26	1.71	1.77
Pedon 5 (Brahmavar): Loamy, kaolinitic, iso -hyperthermic, *Typic Kanhaplustults*										
0-10	Ap	2.48	3.02	3.02						
10-38	BA	0.46	1.52	1.08	0.43	0.43				
38-59	Bt1	0.49	1.28		1.28	0.73				
59-79	Bt2C	0.46	1.2		1.20					
79-113	BC1	0.39	1.63		1.00		0.62			
113-148	BC2	0.13	0.53				0.53			
				4.10	3.91	1.16	1.15	5.26	8.01	9.17
Pedon 6 (Murdeshwar): Clayey-skeletal, kaolinitic, iso-hyperthermic, *Typic Kandiustults*										
0-20	Ap	1.45	2.88	2.84						
20-47	Bt1	0.46	1.20	0.45	0.74	0.75				
47-82	Bt2	0.62	1.36		1.36	0.12				
82-112	Bt3	0.13	0.24		0.14		0.10			
112-155	Bt4C	0.06	0.28				0.25			
				3.30	2.24	0.87	0.35	4.17	5.54	5.89

Pedon 7 (Ullal): Clayey, kaolinitic, iso-hyperthermic, *Typic Kanhaplustults*										
0-10	Ap	1.59	2.13	2.13						
10-21	AB	1.17	1.62	3.40	0.16					
21-47	Bt1C	0.3	1.09	0.38	1.03	0.65				
47-78	Bt2C	0.26	0.95		0.54	0.09				
78-103	Bt3C	0.3	1.11							
103-133	BC	0.34	1.54				0.09			
133-151	CB	0.26	0.63				0.15			
				5.91	2.23	0.74	0.24	6.65	8.14	8.34

The highest SOC stock was observed in foot hill region represented by Kollur (10.85 kg m^{-2}) followed by low hills represented by Beltangadi (5.62 kg m^{-2}) pedons. These pedons are located in rubber plantation area with humid tropical climate at little higher altitude and moderate slopes. The two groups of processes which reduce the SOC stocks after the land use (modification of the SOC turnover rate by increasing SOC decomposition and erosion of the C rich surface layer) were low in these pedons (Lal 2001; Don *et al*. 2011). Similar pattern was observed in SOC stock under 0-50 cm depth and 30-50 cm depth. The open forest system in the same area however has very low SOC stock in the upper layer (0.99, 1.26 and 0.27 kg m^{-2}) compared to rubber plantation at 0-30, 0-50 and 30-50 cm, respectively due to high decomposition rate. It is evident that conversion of open forest to rubber plantation can cause higher SOC stocks in the surface layer (Yang *et al*. 2005 and Frazao *et al*. 2013). Similarly the highest SOC stock (3.91 kg m^{-2}) was reported in Brahmavar at 30-100 cm soil depth followed by Kollur (3.38 kg m^{-2}) where rubber rooting activity will be more. Further in the rubber plantations, the SOC stocks amongst 0-30, 30-50, 0-50 and 30-100 cm, layers was higher in Kollur, Brahmavar and Beltangadi pedons compared to Sullya. The factor which causes this reduction is age of the plantation in Sullya which is around 11 years old after its first replanting. The sparse vegetation in the young plantation which reduces the biomass addition and may change the microclimatic conditions, the latter could in turn result in enhanced soil decomposition rate. The reduced soil carbon loss in older plantations may be explained by the dense vegetation cover and thereby increased soil carbon input and soil stability (Marleen *et al*. 2013). The changes in carbon concentration in the surface are attributed to the decrease in bulk density observed in different land uses (Lal and Kimble 2001). If we consider the SOC stock in 100-150 cm depth, it was high in Brahmavar (1.15 kg m^{-2}) because of lateritic plateau (Ter Steege *et al*. 2003). Overall, the large amount of SOC stocks in 0-100 cm and 0-150 cm depth despite the low C concentrations in the subsoil can be ascribed to the large volume of soil (Veldkamp *et al*. 2003). SOC stocks in paddy fields was also found at par with rubber plantations because of better management practices and addition of biomass (Bhattacharyya *et al*. 2007).

Land quality based on SOC status for the study area is given in Table 4.

Table 4. Criteria for land quality based on Soil Organic Carbon Stock (kg m^{-2}) and respective pedons

SOC (kg m^{-2})	Land quality	Pedon Location
<3	Very low	Molahalli
3-6	Low	Murudeshwar
6-9	Medium	Sullya, Ullal
9-12	Moderate	Brahmavar, Belthangadi
12-15	High	Kollur
>15	Very High	-

Criteria modified and adapted from Shalima Devi (2006).

The Kollur pedon has registered high land quality index followed by Belthangadi and Brahmavar which has moderate land quality status. Ullal and Sullya soils fall under medium land quality. Murdeshwar and Molahalli soils are categorized as low and very low quality, respectively. Under a given agro-climatic condition, three principal mechanisms accounting for SOC stocks decline are-reduced organic matter input, increased erosion and increased oxidation as a result of tillage irrespective of climate or land use apart from the change in micro climate induced by land use change (Shalima Devi and Anil Kumar 2009). Among many physical and chemical soil quality indicators, SOC is more reliable due to its relationship with water infiltration, water holding capacity, bulk density and chelation of nutrients. SOC stocks have been chosen as the most valuable land quality indicator in degraded saline sodic agro- ecosystems of Tungabhadra irrigated areas (Gangadharappa et al. 2008), coffee production systems with a range of factors determining stabilization of carbon in soils with key variables of clay content and type, pH, hydrology, climate and organic inputs (Anil Kumar and Shalima Devi 2009) and also in eroded semi-arid systems through principal component analysis after soil characterization (Rajan et al. 2010).

Conclusions

The variation in estimated SOC stocks was due to difference in land use, erosion and the thickness of the horizons having high organic carbon content and low bulk density, which is controlled by climatic conditions. The highest SOC stocks and better land quality was observed where dense rubber cultivation and the practice of allowing the litter to remain in situ and decompose with less erosion status were observed. The lowest land quality was found where the organic carbon status was low due to high erosion, steep slope and light soil texture. It was concluded that the SOC is the most differentiating and reliable land quality indicator which can be used singly or in combination with other parameters for monitoring the status of land degradation and land quality.

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