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Assessment of Soil Organic Carbon Storage in Urmodi Basin of Krishna River using Geographic Information System

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Abstract: Soil is a basic source to produce food, fodder, fuel and fiber and other necessities of the human being. Soil organic carbon (SOC) is one of the most important indicators of soil fertility, productivity and quality. SOC storage has been widely considered as a measure for mitigating global climate change through C sequestration in soils. Severe depletion of the SOC pool from watershed degrades soil quality, reduces biomass productivity, and adversely impacts water quality, and the depletion may be exacerbated by projected global warming. Hence assessment of carbon sequestration has become need of the hour for sustainable planning to mitigate climate change. In KR 14 watershed (Urmodi basin), SOC densities were estimated from the SOC contents, bulk density values and the soil depth (up to 30 cm). Carbon stock in the soil was calculated from SOC density and micro watershed area. SOC value ranged between 0.26 to 1.7% for watershed. Increase in SOC value increases the soil carbon density. Soil Carbon Density value for KR 14 watershed varied between 7.7 to 50.49 Mg/ha. SOC storage value for the study watershed was ranged between 1056.41 to 23504.97 Mg. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands.

Key words: *Carbon sequestration, GIS, soil organic carbon storage*

Introduction

Soil is a basic source to produce food, fodder, fuel and fiber and other necessities of the human being. It is made up of three main components- minerals that come from rocks below or nearby, organic matter (OM) and the living organisms that reside in the soil. Soils are critically important in determining global carbon cycle dynamics because they serve as the link between the atmosphere, vegetation and oceans. Soil organic carbon (SOC) is the main constituent of soil organic matter. The SOC plays an important role in the global C cycle. It is one of the most important indicators of soil fertility, productivity and quality.

Globally, the soil carbon pool (also referred to as the pedologic pool) is estimated at 2,500 Gt (Gt= 1 billion tons) up to a 2-m depth (The world bank 2012). Out of this, the soil organic carbon pool comprises 1,550 Gt, while the SOC and elemental pools make up the remaining 950 Gt (Batjes 1996). The soil carbon pool is more than 3 times the size of the atmospheric pool (760 Gt) and about 4.5 times the size of the biotic pool (560 Gt).

In India total land area is 329 million hectares (m ha) comprising 162 m ha of arable land (Lal R. 2004), 69 m ha of forest and woodland, 11 m ha of permanent pasture, 8 m ha of permanent crops and 58 m ha is other land uses. The first estimation of organic carbon (OC) stock in Indian soils was 24.3 Pg (1 Pg = 10^{15}g) based on 48 soil series taking into account of a few major soils (Bhattacharyya *et al.* 2000). The present OC stock has been estimated as 63 Pg in the first 150 cm depth of soils (Bhattacharyya *et al.* 2000). The SOC concentration in most cultivated soils is less than 5 g/kg compared with 15 to 20 g/kg in uncultivated soils (Lal R. 2004).

SOC storage has been widely considered as a measure for mitigating global climate change through C sequestration in soils (Huang *et al*. 2010). Carbon sequestration implies transferring atmospheric CO_2 into long-lived pools and storing it securely so it is not immediately reemitted. Promoting soil carbon sequestration is an effective strategy for reducing atmospheric CO_2 and improving soil quality (Lal *et al*. 1998, 1999). The build-up of each ton of soil organic matter removes 3.667 tons of CO_2 from the atmosphere (Bowen and Rovira 1999).

Watershed is an area covering all the land that contributes runoff water to a common point. The SOC is preferentially removed from soil by wind and water borne sediments through erosional processes. Severe depletion of the SOC pool from watershed degrades soil quality, reduces biomass productivity, and adversely impacts water quality,

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and the depletion may be exacerbated by projected global warming. Hence assessment of carbon sequestration has become necessary for sustainable planning to mitigate climate change.

Remote Sensing (RS) and Geographic Information System (GIS) techniques are advanced tools which can be effectively used to manage spatial and non spatial database that represent the hydrologic characteristics of the watershed. The knowledge on soil physical properties is essential for land use planning, water resources management (Saikia and Singh 2003) and development of water harvesting structures in watersheds. Decline in SOC creates an array of negative effects on land productivity. Hence maintaining and improving its level is a pre-requisite to ensure soil quality, crop productivity and sustainability of agricultural ecosystems. Estimates of topsoil soil organic carbon (SOC) pool may be crucial for understanding soil C dynamics under human land uses and soil potential of mitigating the increasing atmospheric CO_2 by soil C sequestration (Song *et al*. 2005). To sustain the quality and productivity of soils, knowledge of SOC in terms of its amount and quality is essential. Therefore, a study was undertaken to estimate the SOC pool in KR -14 watershed of Satara district in Maharashtra state.

Materials and Methods

Study area

The study was conducted in Urmodi basin of Krishna River of Satara district of Maharashtra State (Fig. 1). It lies between 17°30' N to 17°45' N latitude and 73°45' E to 74°00' E longitude. The total valley area covered by KR-14 watershed is 43,719 ha. Out of this 4,624 ha is under forest area, 4,261 ha permanent pastures, 6,048 ha open scrub, 5,629ha urban area and 23,157 ha rainfed agriculture area. Urmodi River is one of the tributary of Krishna River. Urmodi Basin experiences heavy rainfall during June to September (monsoon). Mean annual rainfall in the basin is of the order of 1250-1800 mm. Urmodi Basin has an undulating topography with slope ranging between 4 to 33%. There are 71 villages and 72 micro watersheds in Urmodi Basin.

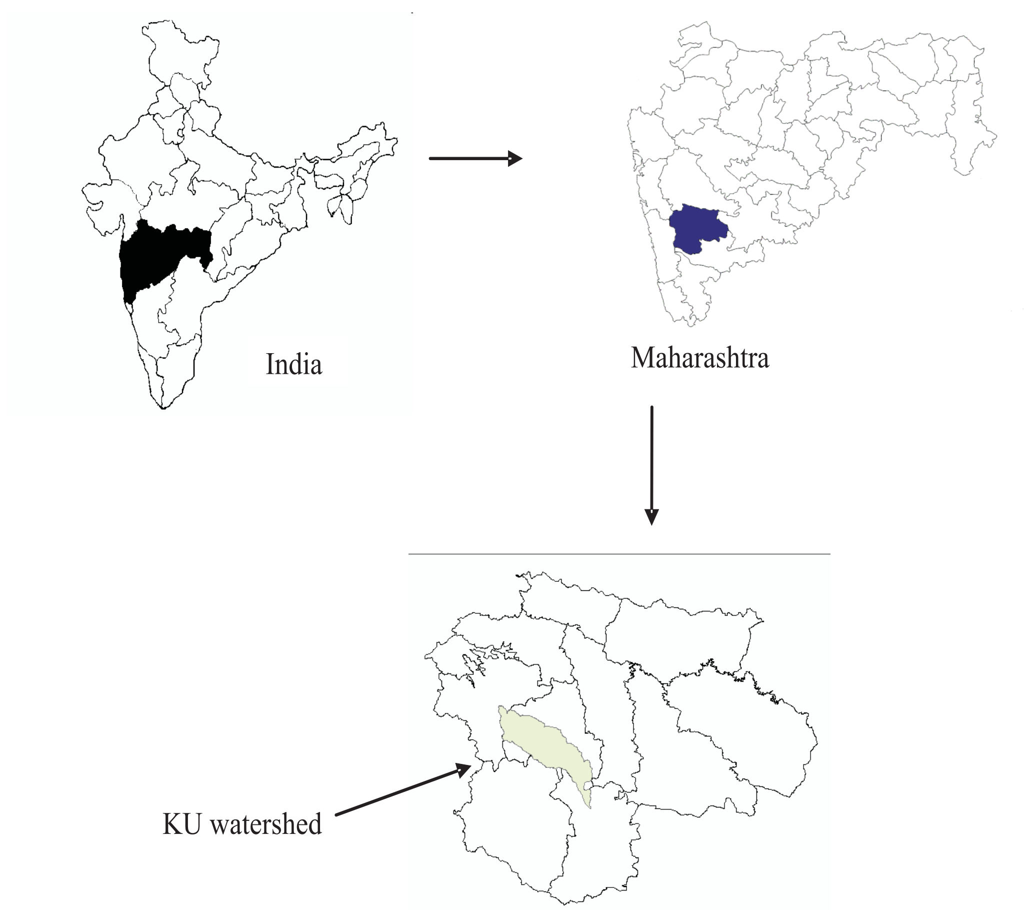

Fig. 1 Location map of study area

Data Collection

Soil sample data such as percentage of coarse fractions, organic carbon and bulk density were collected for each village of Urmodi Basin from District Soil Testing Laboratory, Satara. Standard protocol of data collection and analysis approved by Government of Maharashtra has been followed at all District Soil Testing Laboratories including Satara district. Soil organic matter tends to concentrate in the upper soil horizons with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer (IPCC 2003). Therefore, the soil samples from 30 cm depth were collected.

Estimation of Carbon stock in soil

Soil samples were collected for each village of KR 14 watershed. Data on organic carbon (%), coarse fraction (%) and bulk density (g/cm^3) for different depths were collected from the District Soil Testing Laboratory.

SOC densities were estimated from the SOC contents, bulk density values and the corresponding soil depth by using equation 1. Carbon stock in the soil was calculated using equation 1, 2 and 3 (Ramachandran *et.al* 2007);

$$\text{SOC density} = \frac{\text{soc}}{100} \text{ X corrected bulk density x layer depth x } 10^4 \quad .... \quad (1)$$

$$\text{Corrected bulk density} = \text{Bulk density X} \frac{\{(100\text{-\% coarse fraction})\}}{100} \quad .... \quad (2)$$

$$\text{Total SOC storage} = \text{SOC density X micro watershed area} \quad .... \quad (3)$$

where, soil organic carbon in %, corrected bulk density in Mg/m^3, layer depth in m, bulk density in Mg/m^3, soil organic carbon density in Mg/ha, micro watershed area in ha. Carbon stock values were estimated based on samples from all 72 micro watersheds of Urmodi basin.

Generation of carbon stock map (Soil)

Weighted value of SOC storage was calculated for each micro watershed area. This value was assigned in attribute table to each micro watershed in Arc GIS 9.3 and carbon stock map for soil was generated.

Results and Discussion

SOC content up to 30 cm depth covering both arable and non-arable lands varied considerably across the study area. SOC value ranged between 0.26 to 1.7% for KR 14 watershed. Increase in SOC value increases the soil carbon density. Soil Carbon Density value for Urmodi Basin varied between 7.7 to 50.49 Mg/ha (Table 1). SOC Storage value for the basin ranged between 1056.41 to 23504.97 Mg (Table 2). Total area covered by Urmodi basin was 43,719 ha out of that SOC storage value was higher (>15,000 Mg) in 6557.44 ha area and it was lower (<5000 Mg) in 4407.56 ha area. High SOC storage value was on south east portion of watershed and low SOC storage value on middle part of watershed (Fig.2). There was high variability in SOC storage value across the different land use types. The SOC storage value for forest was the highest amongst all the land use types. SOC storage value was lowest for barren land and open scrub area of the basin may be due to soil erosion and runoff. Soils with higher clay content have high SOC storage value. Low concentration of SOC is due to coarse texture of soil. SOC is concentrated in the upper 12 inches of the soil. It is readily depleted by anthropogenic (human-induced) disturbances such as land use changes and cultivation. Low concentration of SOC storage is attributed to deforestation, erosion, land use changes, burning of biomass, cultivation, ploughing, removal of crop residue and mining of soil fertility.

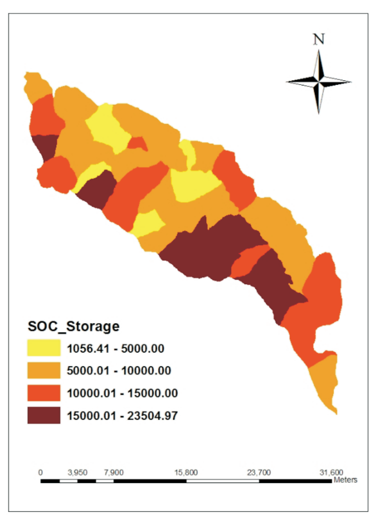

Fig. 2 Carbon stock map (soil) of watershed

Table 1. SOC, Coarse fraction, Bulk density and SOC density of Villages in Urmodi Basin of Krishna River

Village	SOC (%)	Coarse Fraction (%)	BD (gm/cm^3)	SOC density (Mg/ha)	SOC Storage (Mg)
Ghatwan	0.99	11.68	1.15	30.17	4356.83
		1.16			
Pateghar	0.87	13.38	1.28	28.94	15532.48
Ghawali	1.48	13.08	1.04	40.14	16762.47
Nawali	1.05	11.33	1.2	33.52	14567.27
Kurul tijai	1.18	13	1.26	38.81	3074.95
Sawali	0.55	17.97	1.19	16.11	4276.78
Petri	0.92	14	1.17	27.77	2825.71
Sayali	0.52	15.6	1.19	15.67	3306.42
Lumne khot	0.43	12.5	1.23	13.88	2053.39
Katwadi khurd	0.89	19		25.09	6580.40
Kelwali	0.71	11.83	1.12	21.03	11876.76
Kus khurd	1.25	11	1.18	39.38	3327.43
Palsawade	1.7	10	1.1	50.49	15910.91
Sandwali	0.88	13.08	1.14	26.16	14764.65
Dhidawale	1.43	16.5	1.14	40.84	7237.45
Kurun	0.54	10.83	1.17	16.90	2602.29
Takwali	0.5	10	1.21	16.34	4499.48
Lavnghar	0.52	15.68	1.36	17.89	4209.00
Dare tarf Parali	0.69	15.63	1.24	21.66	7874.37
Vavdare	1.52	9.63	1.16	47.80	10677.08
Parmale	0.77	15	1.06	20.81	6098.86
Ambale	0.91	11.43	1.21	29.26	8234.18
Raighar	1.32	14.75	1.09	36.80	3620.49
Kus buk	1.03	14.15	1.26	33.42	10863.07
Rajapuri	1.48	11.63	1.01	39.63	19329.66
Bhodawade	0.5	17.63	1.21	14.95	3341.06
Gajawadi	0.63	15.75	1.23	19.59	4603.40
Kaloshi	0.59	10.19	1.26	20.03	7612.58
Ambawade Bk	0.7	7.25	1.27	24.74	13236.21
Parali	0.56	12.88	1.26	18.44	7419.41
Pangare	1.7	11.63	1.09	49.12	26043.07
Ufali	0.38	10.25	1.24	12.69	2455.71
Shelakewadi	0.43	15.69	1.46	15.88	6311.09
Pogarwadi	0.55	12.13	1.2	17.40	4164.27
Are	0.59	12.5	1.8	27.88	8657.64
Sonwadi	0.76	8.81	1.17	24.33	4579.34
Ambawade khurd	0.44	12.69	1.26	14.52	5149.00
Karandi	0.26	18.63	1.22	7.74	4574.43
Rewande	0.98	14.25	1.16	29.24	7102.24
Pilani	0.56	10.58	1.26	18.93	5766.92
Asangaon	0.53	15.96	1.21	16.17	2045.79
Shendre	0.66	13.56	1.24	21.22	14568.36
Valase	0.94	5	1.14	30.54	14804.25

Vechale	0.37	14.31	1.31	12.46	4630.08
Dolegaon	0.8	12.44	1.17	24.59	6825.31
Kumathe	0.68	12.75	1.19	21.18	6226.52
Bhatamarali	0.42	12.25	1.23	13.60	7364.81
Mandave	0.81	12.03	1.28	27.36	20214.91
Ninam	0.61	8.63	1.19	19.90	18202.17
Bharatgaon	0.52	15.79	1.35	17.73	4325.65
Padali	0.59	8.38	1.31	21.24	24156.47
Nagthane	0.5	9.75	1.21	16.38	20133.77
Khodad	0.77	8.94	1.26	26.50	11979.77
Anawale	0.93	16.88	1.26	29.22	4475.34
Kusawde	0.54	12.33	1.26	17.90	18327.55
Songaon	0.42	17.75	1.2	12.44	11656.33
Shahapur	0.47	11.05	1.24	15.55	3501.23
Nigudmal	0.72	11.63	1.21	23.10	2180.07
Nitral	0.45	10	1.3	15.80	7652.05
Katwadi bk	0.57	12.63	1.22	18.23	4780.98
Kari	0.66	15.35	1.25	20.95	16765.94
Rohat	0.63	11.13	1.22	20.49	8058.54
Venekhot	1.04	14.69	1.21	32.21	8029.66
Alawadi	1.26	18.5	1.17	36.04	6596.09
Ashte	0.47	8.5	1.34	17.29	4165.37
Punwadi	0.38	7.5	1.25	13.18	2844.25
Rewali	0.36	6.5	1.24	12.52	2208.42
Atali	1.08	12.6	1.23	34.83	9760.03
Dhawali	1.44	15.11	1.17	42.91	17919.71
Kasani	1.11	14.6	1.21	34.41	8620.53
Kurul baji	0.92	16	1.12	25.97	4370.35

Table 2. Carbon stock for each micro watershed in Urmodi Basin of Krishna River

Micro watershed	Soil Organic Carbon Storage (Mg)	Micro watershed	Soil Organic Carbon Storage (Mg)
KR14/01/01	9634.89	KR14/02/01	13707.36
KR14/01/02	12914.22	KR14/02/02	10839.94
KR14/01/03	15795.08	KR14/02/03	13349.69
KR14/01/04	9296.42	KR14/02/04	7824.10
KR14/01/05	6892.08	KR14/02/05	7069.99
KR14/01/06	5137.32	KR14/02/06	6808.89
KR14/01/07	3679.58	KR14/02/07	5060.99
KR14/01/08	12730.64	KR14/02/08	4261.82
KR14/01/09	11741.41	KR14/02/09	7806.79
KR14/01/10	6110.05	KR14/02/10	11654.28
KR14/01/11	6206.35	KR14/02/11	11656.43
KR14/01/12	4327.64	KR14/02/12	13804.87
KR14/01/13	18796.85	KR14/02/13	14705.29
KR14/01/14	8088.76	KR14/02/14	12437.83
KR14/01/15	1056.41	KR14/02/15	7702.72
KR14/01/16	10709.80	KR14/02/16	4880.89
KR14/01/17	5418.00	KR14/02/17	4587.26
KR14/01/18	7497.43	KR14/02/18	4891.39
		KR14/02/19	5077.47

Micro watershed	Soil Organic Carbon Storage (Mg)	Micro watershed	Soil Organic Carbon Storage (Mg)
KR14/03/01	5660.22	KR14/04/01	8497.33
KR14/03/02	4871.07	KR14/04/02	10782.94
KR14/03/03	6587.19	KR14/04/03	10690.84
KR14/03/04	18328.05	KR14/04/04	10694.46
KR14/03/05	8575.13	KR14/04/05	10807.14
KR14/03/06	15188.30	KR14/04/06	16782.25
KR14/03/07	6474.86	KR14/04/07	16782.24
KR14/03/08	19302.05	KR14/04/08	15984.51
KR14/03/09	18403.57	KR14/04/09	13703.86
KR14/03/10	19392.26	KR14/04/10	11101.90
KR14/03/11	23504.97	KR14/04/11	10789.37
KR14/03/12	18267.33	KR14/04/12	10789.42
KR14/03/13	14513.99	KR14/04/13	10789.48
KR14/03/14	20127.84	KR14/04/14	8620.93
KR14/03/15	15369.18	KR14/04/15	7659.00
KR14/03/16	7704.34		
KR14/03/17	6431.98		
KR14/03/18	8499.25		
KR14/03/19	7194.00		
KR14/03/20	7155.01		

Generation of carbon stock map (Soil)

Carbon stock present in soil of each village was calculated by using above equations. Weighted soil organic carbon was calculated for each micro watershed. This value was assigned in attribute table to each micro watershed in Arc GIS 9.3 and carbon stock map for soil was generated.

Soil organic carbon storage value was highest (more than 15,000) in KR14/01/03, KR 14/03/06, KR 14/03/08, KR 14/03/09, KR 14/03/10, KR 14/03/11, KR 14/03/12, KR 14/03/14, KR 14/03/15, KR 14/04/06, KR 14/04/07 and KR 14/03/08. SOC Storage value was lowest (less than 5,000) in KR 14/01/07, KR 14/01/12, KR 14/01/15 KR 14/02/08, KR 14/02/16, KR 14/02/17, KR 14/02/18 and KR 14/03/02.

Conclusions

Soil Carbon Storage was estimated for soils of the Urmodi basin. It ranged between 0.26 to 1.7%. Soil Carbon Density value for the basin varied between 7.7 to 50.49 Mg/ha. While SOC Storage values ranged between 1056.41 to 23504.97 Mg. SOC storage value was higher (>15,000) in 12 watersheds while it was lower (<5000) in 8 watershed covering 6557.44 ha & 4407.56 ha area, respectively. SOC storage value was higher for forest area. Lowest SOC storage value was observed in open scrub area. The Information will help in managing the soil carbon pool.

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