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Carbon Sequestration Mapping of Ratnagiri District in India Using Geospatial Technology

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Abstract: Soil plays a crucial role in combating climate change and ecological restoration through controlling the global carbon cycle. Therefore, mapping of the carbon stock and spatial distribution of soil carbon in soils are essentially needed as it will be helpful for stakeholders and managers in land management decisions and for soil carbon sequestration. The average carbon stock was found to be 16.15 t C ha^{-1} and 14.71 t C ha^{-1} for 0-15 cm and 15-30 cm depths, respectively, in the soils of Ratnagiri district in the Konkan region. Total soil carbon sequestration value for the whole Ratnagiri district was 49.29 megatonnes of CO_2 up to 15 cm depth and 45.62 megatonnes of CO_2 for the next 15-30 cm depth. Thus, soils can store a greater quantity of atmospheric CO_2 and play a vital role in the mitigation of climate change impacts.

Key words: *Carbon sinker, carbon stock, organic carbon, GIS*

Introduction

Soil, forest and atmosphere are potential carbon sinks in the terrestrial ecosystem and play a key role in the carbon cycle. Anthropogenic greenhouse gases (GHGs) emissions since the pre-industrial era have driven the global rise in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 Gt CO_2 out of which about half of an anthropogenic emission has occurred in the last 40 years (IPCC 2014). Global climate change and the warming of earth have adverse impacts on humans and natural systems.

The soil is the largest terrestrial pool of organic carbon and plays an important role in carbon capture and storage. Soil organic carbon was estimated to be 684–724 Pg (1 Pg = $1x10^{12}$ kg) of C in the upper 30 cm depth of soil, 1462–1548 Pg of C in the upper 100 cm depth of soil, and 2376–2456 Pg of C in the upper 200 cm depth of soil (Batjes 1996). Soils have a finite capacity to sequester organic carbon from the atmosphere and can be an important mitigation option of climate change.

Soil carbon, both soil organic carbon (SOC) and soil inorganic carbon (SIC) is important as it determines ecosystem and agro-ecosystem functions, influencing soil fertility, water-holding capacity and other soil parameters. Knowledge of soil carbon stock in terms of its amount and quality is essential to sustain the quality and productivity of soils. Carbon sequestration has been found to be an important option to reduce the emission of CO_2.

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Carbon sequestration is fixing atmospheric CO_2 by physical, chemical or biological processes into long-lived carbon pools such as the ocean, soil, vegetation (especially forests) and geologic formation in a manner that it is not re-emitted into the atmosphere in the near future (Srinivasarao *et al.* 2013). Thus, soil carbon sequestration enhances both soil organic and inorganic carbon stocks through judicious land use and recommended soil management practices. Remote Sensing (RS) and Geographic Information System (GIS) had great potential in current estimation, future prediction and management of carbon sequestration potential in terrestrial ecosystems.

The soils of Ratnagiri district mostly belong to laterite and lateritic types, derived from gneissic basaltic, granite and gneiss rocks. The determination of carbon stock from top soils of Ratnagiri district will give on information on carbon status of the district that could help in estimating and mapping carbon sequestration potential for fragile ecosystem of Konkan region of Maharashtra state, India. The information generated in this study will be useful for policy-makers and environmentalists for undertaking appropriate conservation plans.

Materials and Methods

Ratnagiri district (15°40' and 18°5' N; 73°5' and 73°55' E) and cover an area of 8,461 sq. km.

For effective data collection, the district was divided into smaller areas of grid size of 5 km × 5 km on using ArcGIS software. 242 villages were selected for data collection. Soil samples were collected at 0-15 and 15-30 cm depth from each sampling village with the help of a soil auger for the estimation of soil organic carbon stock from the study area (Fig. 1). The soil parameters such as sand (%), silt (%), clay (%), organic carbon (%) and bulk density (Mg m^{-3}) were determined in the soil organic carbon (%), bulk density (Mg m^{-3}) and sand (%) were used for the estimation of total carbon stock of soil.

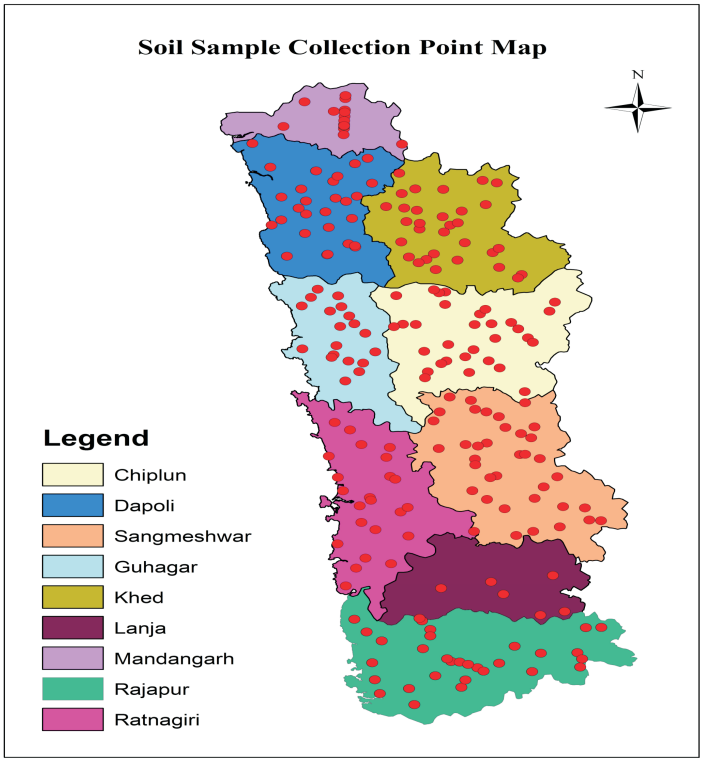

Fig. 1. Soil Sample Collection Point Map of Ratnagiri District

The organic carbon (OC) content of soil samples was determined by using the wet oxidation method of Walkley and Black. It is the most suitable method to calculate OC from the terrestrial biosphere due to high recovery rates, low cost and less time consuming (Kumar and Sharma 2015).

The bulk density was determined using the following (Alexander 1980):

$BD=1.66-0.308\ (OC^{0.5})$

Where BD is bulk density of soil (Mg m^{-3}), OC is organic carbon, (%)

The SOC stock was calculated for two depths, *viz.* (0-15 cm and 15-30 cm). Soil carbon stocks were considered up to 30 cm soil depth only as per the guide lines of IPCC (Guleria *et al*. 2014). SOC stock was calculated using following equations (Ramachandran *et al*. 2007)

$$\text{SOC stock} = \frac{\text{soc}}{100} \times \text{Corrected bulk density} \times \text{layer depth} \times 10^4 \quad \ldots\ldots (1)$$

$$\text{Corrected bulk density} = \text{Bulk density} \times \frac{(100-\text{coarse fraction})}{100} \quad \ldots\ldots (2)$$

$$\text{Total SOC stock} = \text{SOC stock} \times \text{Area} \quad \ldots\ldots (3)$$

Where SOC is soil organic carbon in %, corrected bulk density is in Mg m^{-3}, layer depth in m, bulk density is in Mg m^{-3}, SOC stock is soil organic carbon stock in Mg ha^{-1}, area in ha.

After estimating the weighted value of SOC stock for each sampling village of Ratnagiri district, a SOC stock map was generated using ArcGIS.

The amount of carbon dioxide CO_2 that is released into the atmosphere is expressed in tonnes of CO_2 equivalent per year (t CO_2). Sequestration on the other hand concerns itself with how much carbon is being removed from the atmosphere and then stored, and is expressed in tonnes of Carbon equivalent per year. To convert from carbon equivalent to CO_2, multiplied by 44/12 (EPA 2005).

1 metric tonne carbon equivalent = 3.667 metric tonnes of CO_2 equivalent

Thus, amount of CO_2 sequestered by soil was calculated from soil carbon stock values for each sampling village of Ratnagiri district. These values were assigned in attribute table in ArcGIS to get map of amount of CO_2 sequestered by soil from each sampling village of Ratnagiri district.

Results and Discussion

Soil organic carbon

Soil organic carbon (SOC) in the soils of Ratnagiri district ranged from 0.08 to 5.56 % with an average value of 2.13 % for 0-15 cm depth. For 15-30 cm soil depth, SOC ranged from 0.12 to 4.45 % with an average value of 1.95 %. The average soil organic carbon values for the selected tehsils of Ratnagiri district are given in table 1. All the values of soil organic carbon were entered into the attribute table in ArcGIS to generate the soil organic map of district for 0-15 cm and 15-30 cm soil depths (Fig. 2 and Fig. 3). High soil organic carbon values were observed in forest lands followed by horticulture and agricultural lands. The low organic carbon values were observed in barren/degraded lands. Most agricultural soils had lower soil organic carbon pool due to various tillage operations and it was found that loss of organic carbon is proportional to intensity of tillage. In, general amount of organic carbon stored in soil is varying depending on the soil groups, agro-ecological zones, human interference, natural vegetation, soil ecosystems and poor soil management interventions (Batjes 1999).

Table 1. Tehsil-wise average soil organic carbon in Ratnagiri district

	Tehsils	0-15 cm		15-30 cm	
		SOC (%)	Avg. SOC (%)	SOC (%)	Avg. SOC (%)
1	Dapoli	0.59 - 4.78	2.35	0.78 - 4.37	2.29
2	Guhaghar	0.66 - 4.37	2.38	0.78 - 4.29	2.48
3	Mandangad	0.82 - 4.41	2.38	0.51 - 4.45	1.83
4	Chiplun	0.20 - 3.24	1.93	0.39 - 3.12	1.72
5	Khed	0.59 - 5.56	2.30	0.59 - 4.31	2.08
6	Ratnagiri	0.12 - 3.98	1.82	0.35 - 4.06	1.80
7	Sangameshwar	0.08 - 4.47	2.07	0.39 - 3.16	1.83
8	Lanja	0.51 - 4.29	1.89	0.70 - 3.90	1.69
9	Rajapur	0.16 - 5.03	2.01	0.12 - 4.10	1.82

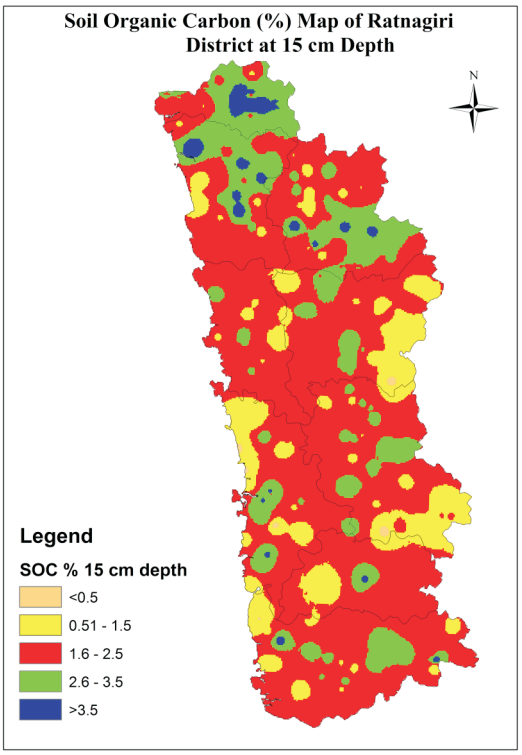

Fig. 2. Soil organic carbon (%) map of Ratnagiri district (0-15 cm)

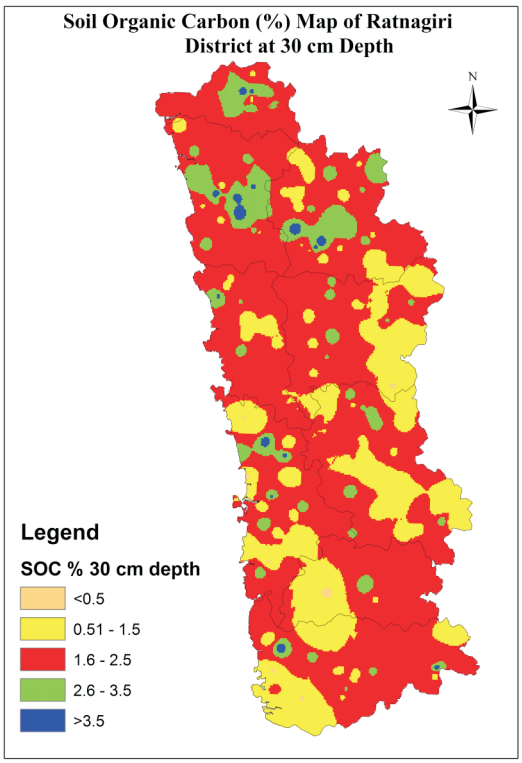

Fig. 3. Soil organic carbon (%) map of Ratnagiri district (15-30 cm)

Bulk density

The bulk density of the soils for the tehsils of district ranged from 0.93 to 2.42 Mg m^{-3} with an average value of 1.23 Mg m^{-3} for 0-15 cm depth. Similarly, the bulk density values for 15-30 cm soil depth ranged from 1.01 to 2.89 Mg m^{-3} with an average of 1.26 Mg m^{-3}. The bulk density for the tehsils of district are given in table 2. All the values of bulk density were entered into the attribute table in ArcGIS to generate the bulk density map of district for 0-15 cm and 15-30 cm soil depths (Fig. 4 and fig. 5).

Table 2. Tehsil-wise average bulk density (Mg m^{-3}) of Ratnagiri district

Tehsils	0-15 cm		15-30 cm	
	Bulk density (Range)	Avg. Bulk density (Mean)	Avg. Bulk density (Range)	Avg. Bulk density (Mean)
Dapoli	0.99 - 1.42	1.20	1.02 - 1.39	1.20
Guhaghar	1.02 - 1.41	1.20	1.02 - 1.39	1.19
Mandangad	1.01 - 1.38	1.20	1.01 - 1.44	1.26
Chiplun	1.11 - 1.52	1.24	1.12 - 1.47	1.27
Khed	0.93 - 1.42	1.21	1.02 - 1.42	1.23
Ratnagiri	1.05 - 2.42	1.35	1.04 - 2.89	1.37
Sangameshwar	1.08 - 1.57	1.24	1.11 - 1.42	1.27
Lanja	1.02 - 1.40	1.23	1.05 - 1.44	1.26
Rajapur	0.97 - 1.54	1.24	1.04 - 2.89	1.28

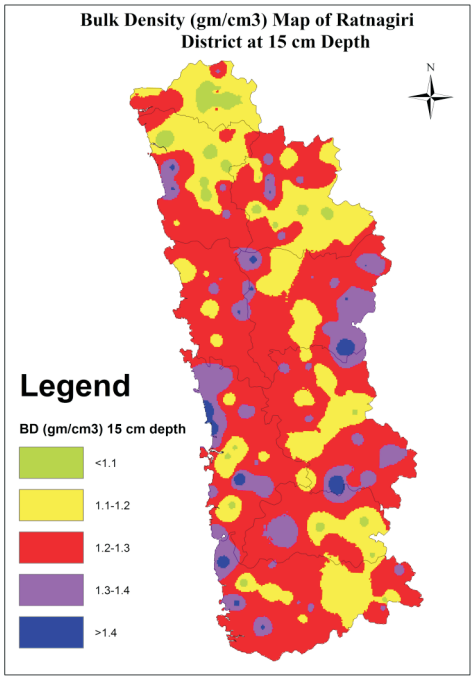

Fig. 4. Bulk density map of Ratnagiri district (0-15 cm)

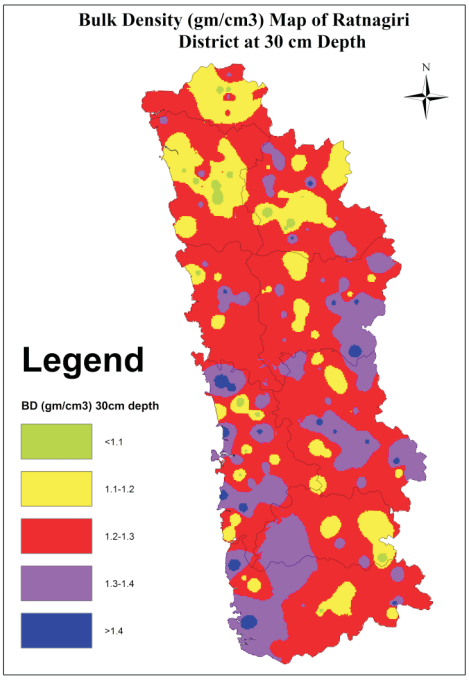

Fig. 5. Bulk density map of Ratnagiri district (15-30 cm)

Determination of soil carbon stock

Total soil organic carbon stock in district was 13.44 megatonnes for 0-15 cm depth and 12.35 megatonnes for 15-30 cm depth. The average carbon stock was found to be 16.15 t C ha^{-1} and 14.71 t C ha^{-1} for 0-15 cm and 15-30 cm depths, respectively. The highest SOC stock was observed in Khed tehsil (20.46 t C ha^{-1}) whereas the lowest SOC stock (12.35 t C ha^{-1}) was observed in Lanja tehsil for 0-15 cm depth. Similarly, the highest SOC stock (19.21 t C ha^{-1}) was observed in Guhaghar tehsil and the lowest (10.84 t C ha^{-1}) in Rajapur tehsil for 15-30 cm depth. The soil organic carbon stock map of district was prepared for 0-15 cm and 15-30 cm soil depths using the soil organic carbon and bulk density layers in raster calculator of ArcGIS (Fig. 6 and Fig. 7). The SOC stocks for the selected tehsils of Ratnagiri district are given in table 3.

The soil organic carbon stocks for 0-15 cm, 15-30 cm and 0-30 cm soil depths in the selected tehsils of

Ratnagiri district are given in table 4. Soil carbon stock map of district was prepared by using the SOC stock map (Fig. 8, Fig. 9, Fig. 10). Soil carbon stocks were found to be more in forest system due to higher leaf litter and the extensive root system of forest trees. The occurrence of higher SOC content in both forest and grassland/open-scrub can be attributed to the addition of litter-fall from trees and shrubs to the surface soil (Nsabimana *et al.* 2008; Worku *et al.* 2014 and Yimer *et al.* 2015). The forest and grassland/open-scrub possess a higher organic carbon; through dead fine tree and shrub roots and the mycorrhizal fungi contribution of organic matter (Lemma *et al.* 2006 and Yimer *et al.* 2007). Low soil carbon stock values were observed in the tehsils having a large portion of degraded land. Low carbon stock values were also observed in some tehsils having a large area under agricultured land and limited areas under forest. The loss of SOC, is due to frequent soil disturbance, crop uptake, leaching and surface erosion losses, and inadequate land management.

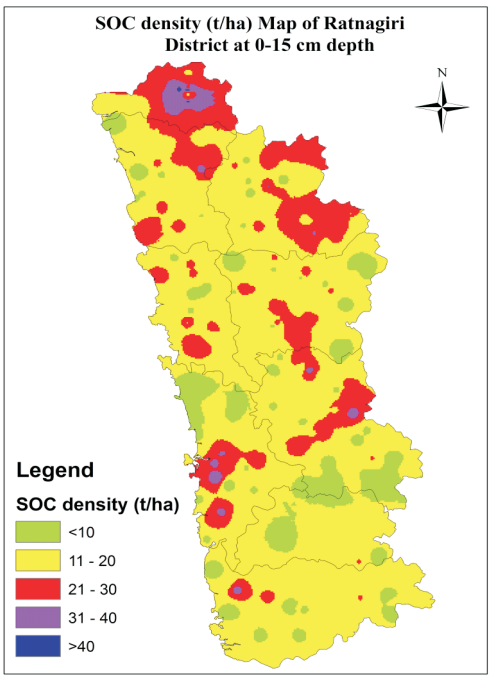

Fig.6. SOC stock (t ha^{-1}) map of Ratnagiri district (0-15 cm)

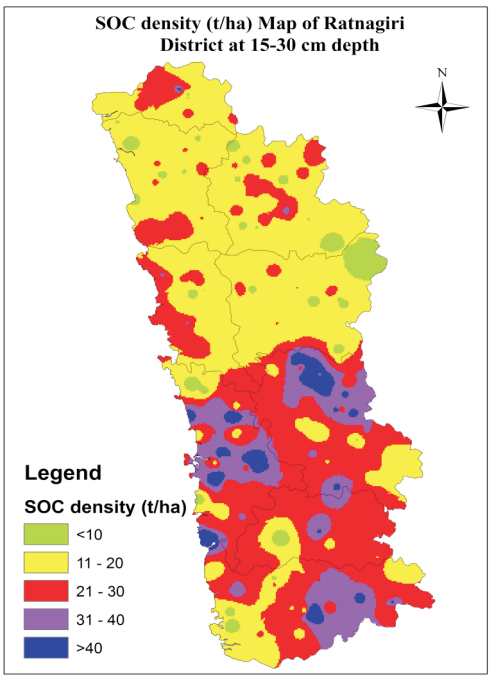

Fig.7. SOC stock (t ha^{-1}) map of Ratnagiri district (15-30 cm)

Table 3. Tehsil-wise average SOC stock (t C ha^{-1}) in Ratnagiri district

Tehsils	0-15 cm		15-30 cm	
	SOC stock range	Average SOC stock	SOC stock range	Average SOC stock
Dapoli	4.15 - 29.44	15.31	3.94 - 24.11	14.38
Guhaghar	6.46 - 34.94	17.69	6.51 - 33.63	19.21
Mandangad	2.02 - 30.76	19.41	1.49 - 23.84	13.55
Chiplun	1.82 - 29.80	15.34	3.02 - 30.70	14.91
Khed	1.94 - 56.06	20.46	3.72 - 44.39	18.43
Ratnagiri	1.10 - 40.23	16.09	2.22 - 41.24	15.00
Sangameshwar	0.73 - 37.41	15.79	4.72 - 34.95	14.27
Lanja	1.43 - 20.00	12.35	1.95 - 18.14	11.83
Rajapur	1.33 - 35.09	12.90	0.26 - 31.93	10.84

Table 4. Tehsil wise soil organic carbon stock in Ratnagiri district

Tehsil	Geographical Area (ha)	Soil organic carbon (tonnes)		
		0-15 cm	15 - 30 cm	0 - 30 cm
Dapoli	91040.47	1393830	1309162	2702992
Guhaghar	69490.4	1229285	1334911	2564196
Mandangad	44667.64	866998.9	605246.5	1472245
Chiplun	111995.3	1718008	1669850	3387858
Khed	102582	2098828	1890586	3989414
Ratnagiri	97700	1571993	1465500	3037493
Sangameshwar	126800	2002172	1809436	3811608
Lanja	75400	931190	891982	1823172
Rajapur	126500	1631850	1371260	3003110

Estimation of amount of CO_2 sequestered by soil

Amount of CO_2 sequestered by the soil in the selected tehsils of district ranged from 3.18 to 7.70 megatonnes of CO_2 for 0-15 cm depth and 2.22 to 6.93 megatonnes of CO_2 for 15-30 cm depth. Total soil carbon sequestration for district was 49.29 megatonnes of CO_2 for 0-15 cm depth and 45.62 megatonnes of CO_2 at 15-30 cm depth. Thus, the soils are a large sink of carbon due to a relatively large area and long residence time of organic carbon in the soil. High values of soil carbon sequestration were observed in those tehsils having relatively large geographical areas and high carbon sequestration rates. Tehsil-wise soil carbon sequestration rate and soil carbon sequestration for district are given in tables 5 and 6, respectively. Soil CO_2 Sequestration maps of district for 0-15 cm and for 15 -30 cm depth are shown in fig. 11 and fig. 12

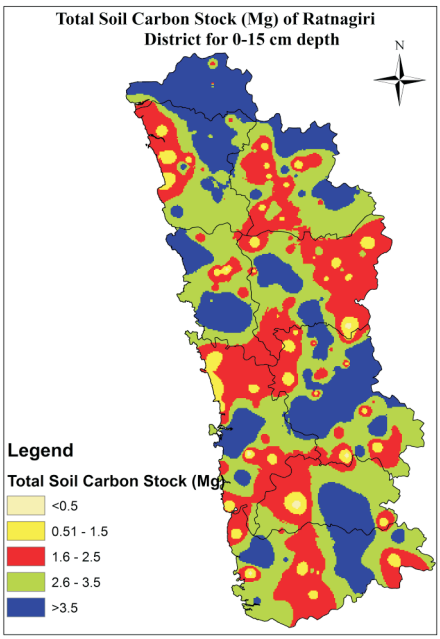

Fig. 8. Total soil carbon stock (0-15 cm) of Ratnagiri district

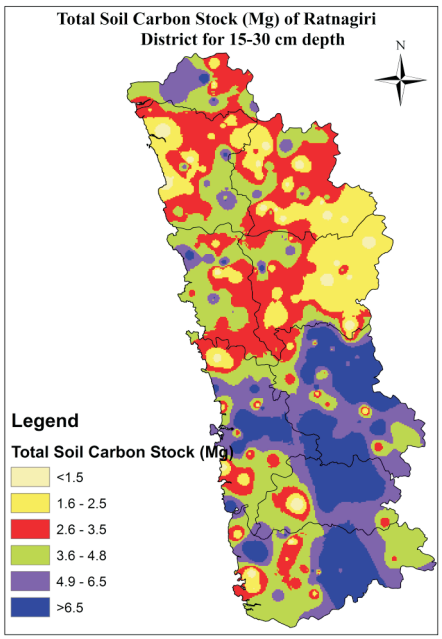

Fig. 9. Total soil carbon stock (15 -30 cm) of Ratnagiri district

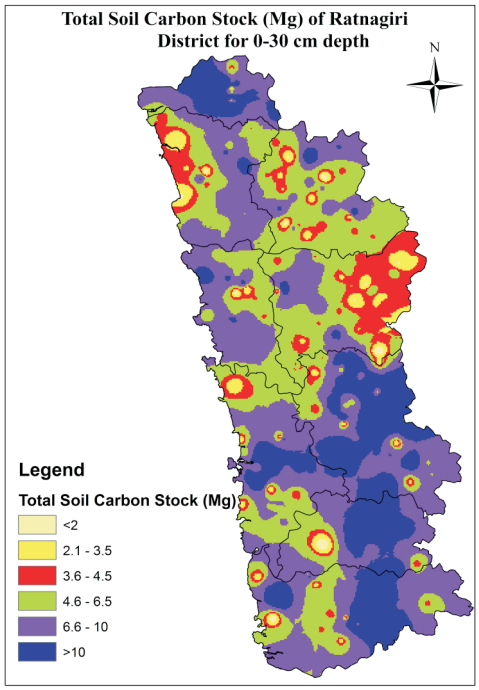

Fig. 10. Total soil carbon stock (0-30 cm) of Ratnagiri district

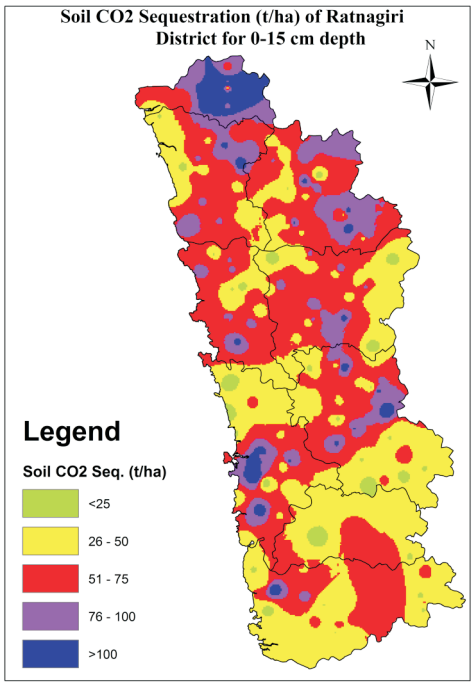

Fig. 11. Soil CO_2 Sequestration map of Ratnagiri district at 0-15 cm

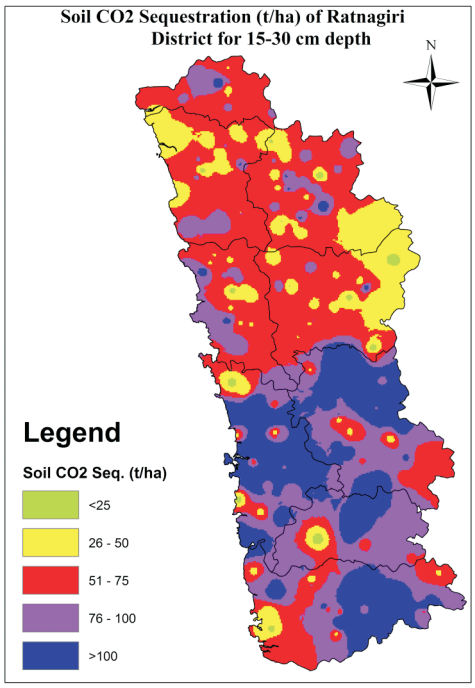

Fig. 12. Soil CO_2 Sequestration map of Ratnagiri district at 15 -30 cm

Table 5. Tehsil-wise average soil carbon sequestration (t CO_2 ha^{-1}) stock in Ratnagiri district

Tehsils	0-15 cm		15-30 cm	
	Carbon sequestration range	Average carbon sequestered	Carbon sequestration range	Average carbon sequestered
Dapoli	15.20 - 107.96	56.13	14.34-88.42	52.74
Guhaghar	23.70 - 128.14	64.85	23.87-123.31	70.73
Mandangad	7.41 - 112.78	71.16	5.46-87.42	49.69
Chiplun	6.67 - 109.29	56.25	11.06-112.58	54.66
Khed	7.10 - 205.56	75.02	13.67-162.78	67.57
Ratnagiri	4.02 - 147.54	59.00	8.13 - 153..24	58.33
Sangameshwar	2.68 - 137.16	57.90	17.31 - 128.16	52.32
Lanja	5.24 - 73.35	45.28	7.15 - 67.54	43.39
Rajapur	4.88 - 128.67	47.29	3.97 - 117.12	39.78

Table 6. Tehsil wise carbon sequestered (tonnes of CO_2) by soils in Ratnagiri district

Sr. No.	Tehsil	Geographical area (ha)	Carbon sequestered by soil		
			0-15 cm	15-30 cm	0-30 cm
1	Dapoli	91040.47	5110101.58	4801474.38	9911575.96
2	Guhaghar	69490.4	4506452.44	4915055.99	9421508.43
3	Mandangad	44667.64	3178549.26	2219535.03	5398084.29
4	Chiplun	111995.30	6299735.62	6121663.09	12421398.72
5	Khed	102582.00	7695701.64	6931465.74	14627167.38
6	Ratnagiri	97700	5764498.33	5698841	11463339.33
7	Sangameshwar	126800	7341964.72	6634176	13976140.72
8	Lanja	75400	3414673.73	3271606	6686279.73
9	Rajapur	126500	5983993.95	5032170	5398084.29

Conclusion

Total carbon stock in the soil is 13.44 megatonnes for 0-15 cm depth and 12.35 megatonnes for 15-30 cm depth in district. The amount of CO_2 sequestered by soil is 49.29 megatonnes of CO_2 at 0-15 cm depth and 45.62 megatonnes of CO_2 at 15-30 cm depth. Significant variations were observed in organic carbon content among samples collected from different places and soil depths. The results indicated that soils are an important sink of atmospheric carbon dioxide and can play an important role in mitigating the climate change if protected with suited conservation measures.

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