Ecological Processes

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Assessment of land use change and its effect on soil carbon stock using multitemporal satellite data in semiarid region of Rajasthan, India

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Abstract

Background: Land use change plays a vital role in global carbon dynamics. Understanding land use change impact on soil carbon stock is crucial for implementing land use management to increase carbon stock and reducing carbon emission. Therefore, the objective of our study was to determine land use change and to assess its effect on soil carbon stock in semi-arid part of Rajasthan, India. Landsat temporal satellite data of Pushkar valley region of Rajasthan acquired on 1993, 2003, and 2014 were analyzed to assess land use change. Internal trading of land use was depicted through matrices. Soil organic carbon (SOC) stock was calculated for soil to a depth of 30 cm in each land use type in 2014 using field data collection. The SOC stock for previous years was estimated using stock change factor. The effect of land use change on SOC stock was determined by calculating change in SOC stock (t/ha) by deducting the base-year SOC stock from the final year stock of a particular land use conversion.

Results: The total area under agricultural lands was increased by 32.14% while that under forest was decreased by 23.14% during the time period of 1993–2014. Overall land use change shows that in both the periods (1993–2003 and 2003–2014), 7% of forest area was converted to agricultural land and about 15% changes occurred among agricultural land. In 1993–2003, changes among agricultural land led to maximum loss of soil carbon, i.e., 4.88 Mt C and during 2003–2014, conversion of forest to agricultural land led to loss in 3.16 Mt C.

Conclusion: There was a continuous decrease in forest area and increase in cultivated area in each time period. Land use change led to alteration in carbon equity in soil due to change or loss in vegetation. Overall, we can conclude that the internal trading of land use area during the 10-year period (1993–2003) led to net loss of SOC stock by 8.29 Mt C. Similarly, land use change during 11-year period (2003–2014) caused net loss of SOC by 2.76 Mt C. Efforts should be made to implement proper land use management practices to enhance the SOC content.

Keywords: Multitemporal satellite data, Land use change dynamics, Internal trading of land use, SOC stock, Stock change factor, Change in SOC pool, Land use management

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Background

Land use can be define as "The set of anthropogenic activities and arrangements (e.g., cultivation, grazing, timber extraction) in a piece of land for economic and social welfare" (IPCC 2000). Land use change has been recognized as a global concern as it is one of the main reasons for environmental change. Land use patterns, controlled by various social activities, lead to change in land use that has adverse effect on global climate and biosphere through emission of greenhouse gases (GHGs) and alteration in biodiversity (Schreier 1994; Bajracharya 2004). Land use change from forest to agricultural land (deforestation) is supposed to be one of the anthropogenic activities culprit for increased atmospheric level of carbon dioxide (Shrestha et al. 2004; Houghton and Hackler 1999; Lal 2004a). Thus, globally, the rate of emission of carbon from change in land use has been gradually rising over the last 150 years (1850–2000), which reached to about 2 Pg C per year (Houghton and Hackler, 2002). Also, the net emissions of carbon dioxide in the last 150 years (1850–2000) due to land use change is about 156 Pg C (Houghton 2003). The CO_2 emission from land use change was estimated to be 1.7 Pg C year^{-1} in 1980–1989, 1.6 Pg C year^{-1} in 1989–1998 (IPCC 2000), and 1.1 Pg C year^{-1} in 2000–2009 (Friedlingstein et al. 2010).

Land cover and land use change has a very prominent effect on soil carbon stock and its spread in ecosystem, and therefore plays a vital role in relation to global carbon dynamics. In particular, land cover and land use change result in loss in natural vegetation and alteration in equity between input and output of carbon from soil which leads to decrease in soil carbon stock (Ostle et al. 2009). Soil is the major carbon reservoir and has maximum carbon sequestration potential (Batjes 1996; Lal 2004; Lal 2005). The amount of carbon in soil (1500 Pg of carbon) is about two times more than present in the atmosphere (750 Pg of carbon) and thrice the amount stored in vegetation (650 Pg of carbon) (Powlson et al. 2011; Eswaran et al. 1993; Batjes and Sombroek 1997). Soil organic carbon is vital for increasing soil quality and its productivity and thus enhancing food production (Eswaran et al. 1993). Also increasing soil carbon storage is an effective method to mitigate increased level of carbon dioxide in atmosphere.

Many factors such as change in land use, land use management, climate change, etc. are responsible to control soil carbon stock (Xia et al. 2010). Land use change is a critical factor affecting soil carbon stock (Xia et al. 2011; Leifeld 2013). Land use change such as conversion from forest land to agricultural land leads to loss in soil carbon (Noordwijk et al. 1997; Lal 2001; Lal 2003; Lal 2004). Houghton (2003) observed that 156 Pg of soil carbon is released into the atmosphere due to land use changes globally since 1850. There is loss in soil organic carbon (SOC) by 20–50% when forest land is converted into cultivated land (Sombroek et al. 1993; Davidson and Ackerman 1993; Post and Kwon 2000; Amundson 2001; Murty et al. 2002; Don et al. 2011). Guo and Gifford (2002) reviewed previous literature and concluded that soil carbon stocks reduce when land is converted from grassland to cropland (− 59%), forest land to cropland (− 42%), forest to plantation (− 13%), and grassland to plantation (− 10%), whereas soil carbon stocks increase after land use changes from cropland to forest (+ 53%), cropland to grassland (+ 19%), cropland to plantation (+ 18%), and forest to grassland (+ 8%). Intensive cultivation change the natural ecosystems and disturbed the soil environment, leading to a significant loss of soil carbon (Detwiler 1986; Lou et al. 2010). Reduction in soil carbon stock also leads to poor soil quality and low plant productivity. Assessment of impact of land use change on soil carbon stock using multitemporal satellite data is studied by various researchers. Xia et al. (2010) revealed that land use changes had caused decrease in soil carbon by 30.7 Tg. Similarly, Dhakal et al. (2010) concluded that conversion of forest to cropland and other land uses has caused decrease in SOC, whereas vice versa has increased the SOC stock.

Detection of land use change is necessary to know its potential effect on soil carbon stock at regional level. Interpretation of satellite images obtained at different time and of the similar area has been the most used method to determine the temporal change in land use (Mulders 2001), and this method detect changes in land use with better accuracy, take short time, and also it is inexpensive (Kachhwala 1985). Mapping land use classification and detection of land use dynamics using satellite data has been executed since 1972. The most recent Landsat 8 was launched in 2013. The complete archive of Landsat is now freely accessible to the researcher and scientist for determining and examining manmade changes (Chander et al. 2009; Bastawesy 2014). Several international researchers (Dimyati et al. 1996; Lambin and Ehrlich 1997; Rembold et al. 2000; Li and Yeh, 2004; Yuan et al. 2005; Dewan and Yamaguchi, 2009; Gammal et al. 2010) and national researchers (Ram and Kolarkar 1993; Sharma et al. 2012; Pooja et al. 2012; Amin and Singh, 2012; Mehta et al. 2012; Singh et al. 2014) made exhaustive research efforts for detection of land use/land cover change using remote sensing data.

Understanding land-use change impact on soil carbon stock is crucial for implementing land use management to increase carbon stock and reducing carbon emission. Study on land use change analysis and its relationship to soil carbon stock in Pushkar valley region is not yet done. Pushkar valley of Rajasthan comes under semi-arid region. Semi-arid region is severely degraded ecosystems around the world and has the great capacity for increasing soil carbon content. Improvements in land use management can increase the sequestration of carbon in the soil. Therefore, the objective of our study

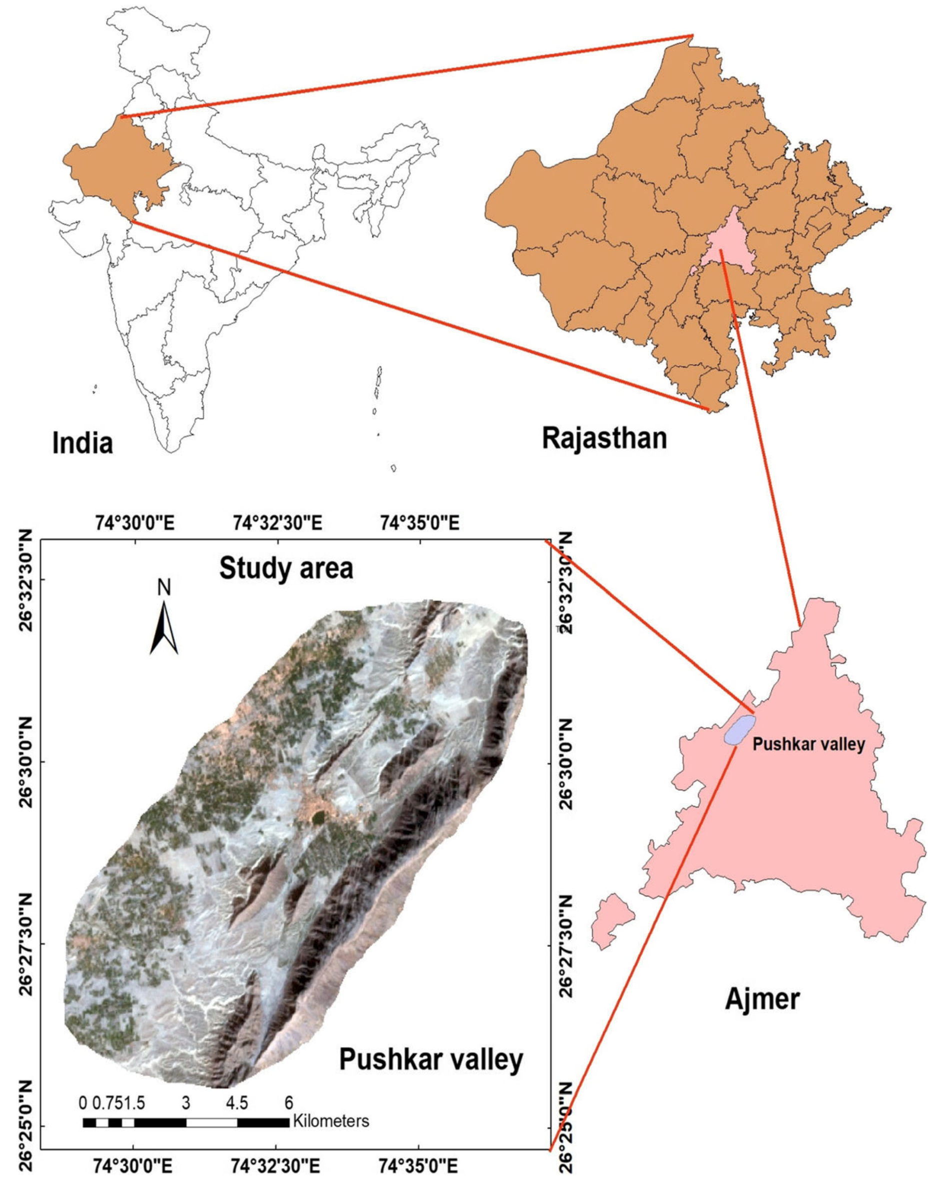

Fig. 1 Location map of Pushkar valley

was to determine land use change dynamics by using satellite images from 1993 to 2014, and to assess effect of land use changes on soil carbon stock in Pushkar valley region of Rajasthan.

Materials and methods

Description of study site

The study was carried in the Pushkar valley region (26° 24′ to 26° 33′ N and 74° 27′ to 74° 40′ E) located in the center of Rajasthan State at a distance of 10 km north-west to Ajmer. Area covered by the Pushkar valley is about 97.93 km^2. Location map of Pushkar valley is shown in Fig. 1. The valley is situated at an altitude of 500 m above sea level. The average maximum temperature in summer ranges from 30.8 to 39.5 °C and average minimum temperature in summer ranges from 15.7 to 27.6 °C. The average maximum temperature in winter ranges from 22.3 to 25.4 °C and average minimum temperature in winter ranges from 7.4 to 9.9 °C. The mean annual rainfall is 450–527 mm. Average precipitation is minimum in February (1 mm) and average precipitation is maximum in July (195 mm). The Pushkar Valley represents different soil types ranging from sandy clay to sandy loam. Soil has sand as major fraction and poor organic matter. pH values for all soils are on alkaline side (7.4 to 8).

The Pushkar Valley region forms the main part of Central Aravallis and represents an ecotone between North-West arid and South-East semi-arid agroclimatic zone of Rajasthan. The area of Pushkar Valley is represented by a long track of dense forest commonly known as "Nagpahar". The area represents a wide spectrum of habitats such as Aravalli hillocks, sand dunes, sandy plains, scrub forest, dense forest of Nagphar, agricultural fields, fresh water bodies (amphibious to perennial), rural to urban settlement, and mining land. Land use pattern observed in the study area are dry deciduous forest, tropical thorn forest, scrubland, agricultural cropland, agricultural plantation, agricultural fallow land, water body, settlement, and wasteland. The major ecological problems of Pushkar Valley region includes degradation of landscape and loss of natural soil surface due to deforestation of dense stands of nagpahar, intense agricultural activities, and mining excavations.

Data acquisition and collection

A Landsat thematic mapper (TM), enhanced thematic mapper plus (ETM+), and OLI/TIRS satellite image of Pushkar Valley region acquired in 1993, 2003, and 2014 respectively were obtained from the U.S. Geological Survey (USGS earth explorer). Characteristics of Landsat data are shown in Table 1. Images were downloaded in Geo-TIFF format with the different spectral bands as separate files. Topographic data in the form of maps (scale 1:50000) published by the Survey Department of the Government of India, were used as a geographical reference.

Ancillary data include ground reference data (often called ground truth data) collected from actual ground surveys collected independently. A Garmin global positioning system (GPS) V unit was used to verify the ground truth information collected during the field work in 2014 and recorded visible and other physical characteristics of the terrain for mapping purposes. Secondary data collected from local area and provided information on land use and land use conversion was also utilized in the study.

Image pre-processing

The datasets were imported into ArcMap 10.2 and individual bands of each of the three images (Landsat TM and Landsat ETM+, and Landsat OLI/TIRS) were combined into single composite image using the composite Bands tool in the Raster processing toolbar of ArcGIS 10.2. In Landsat TM and ETM+ images, all the bands were stacked together and band 6 which signifies thermal reflectance having spatial resolution of 120 m was excluded. Due to various external and internal conditions, some errors are caused in data. The pre-processing steps enhance the quality of data by removing or rectifying these errors. This is also known as data correction. There are two processes in data correction, i.e., geometric correction and radiometric condition.

Table 1 Characteristics of remote sensing images

Year	Satellite	Sensor	Date acquired
1993	Landsat 4–5	TM	30/12/1993
2003	Landsat 7	ETM+	16/01/2003
2014	Landsat 8	OLI/TIRS	24/12/2014

Geometric correction and area of interest extraction

Geometric correction also known as geo-referencing means to give satellite images an actual coordinated system by eliminating the geometric distortions visible on the original remotely sensed images. Generally, satellite databases have different coordinate systems and therefore, it is necessary to geometrically correct the data and fit it into the original coordinate system. All the datasets (Landsat TM and Landsat ETM+, and Landsat OLI/TIRS) were georeferenced (Universal Transverse Mercator-UTM, WGS84) using linear transformation based on ground control points (GCPs) of the digital topographic maps. The outline of the Pushkar valley region was digitized on the basis of topographic map sheet and subset of image or area of interest delineated from the whole individual images for the respective years using extract by mask tool in the spatial analyst toolbar.

Image classification and accuracy assessment

The images were classified using the technique of supervised classification. Training samples is created in training sample manager and the definition of the training areas was supported by the topographic map sheet, visual interpretation of the satellite images in Google earth and by ground truthing. Firstly, 5–6 training samples were defined for sub-classes of each main land use type. The training samples were then merged of each land use category. Signature file of training sample is then created and finally classification is done by maximum likelihood classification. Accuracy has been assessed from ground truth data by generating random points and comparing it to classified map by developing confusion matrix. Overall accuracy was 87.81%, 93.3%, and 95.4% for the classified images of the year 1993, 2003, and 2014 respectively (Table 5).

Land use change analysis

To assess the internal trading of land use classes, the vector datasets of these 3 years were intersected using intersect tool of ArcMap 10.2. The datasets obtained in this way were then exported in Excel and land use change matrix is prepared using pivot table and datasets were recorded into stable or converted land areas. Steps for land use change detection are presented in Fig. 2.

Soil sampling and analysis

In October 2014, three replicate sampling plots of dimension 5 × 5 m were selected in each land-use type namely dry deciduous forest, tropical thorn forest, scrubland, agricultural crop land, agricultural plantation, and agricultural fallow land. Soil samples were collected at 0–10 cm, 10–20 cm, and 20–30 cm depths from each corner of plot using auger and composite were made for each depth. Total number of composite samples collected from six land use and three soil depth was 54. Samples were then dried and sieved for analysis in the laboratory. Bulk density was estimated using core sampler (auger) (Blake and Harte 1986) and soil organic carbon determined by Walkley and Blake method (Allison 1975).

Soil carbon stock calculation and effect of land use changes

Following the Intergovernmental Panel on Climate Change (IPCC) guidelines, the SOC stock was calculated for soil to a depth of 30 cm. Data collected from field survey in 2014 was used to calculate SOC stock for 2014. To calculate SOC stock for each sampling depth, i.e., 0–10, 10–20, and 10–20 cm, Eq. 1 was used given by Wairiu and Lal 2003.

$$SOC = (C\ content) \times BD \times 100 \quad (1)$$

Where, SOC = soil organic carbon stock (g m^{-2})
C content = soil organic carbon (%)
BD = soil bulk density (g cm^{-3})
d = soil layer thickness (cm)

Summation of carbon stock in each soil depth gives the total C pool in each land use type of the region. The carbon pool (Mt C) in all land use types was calculated

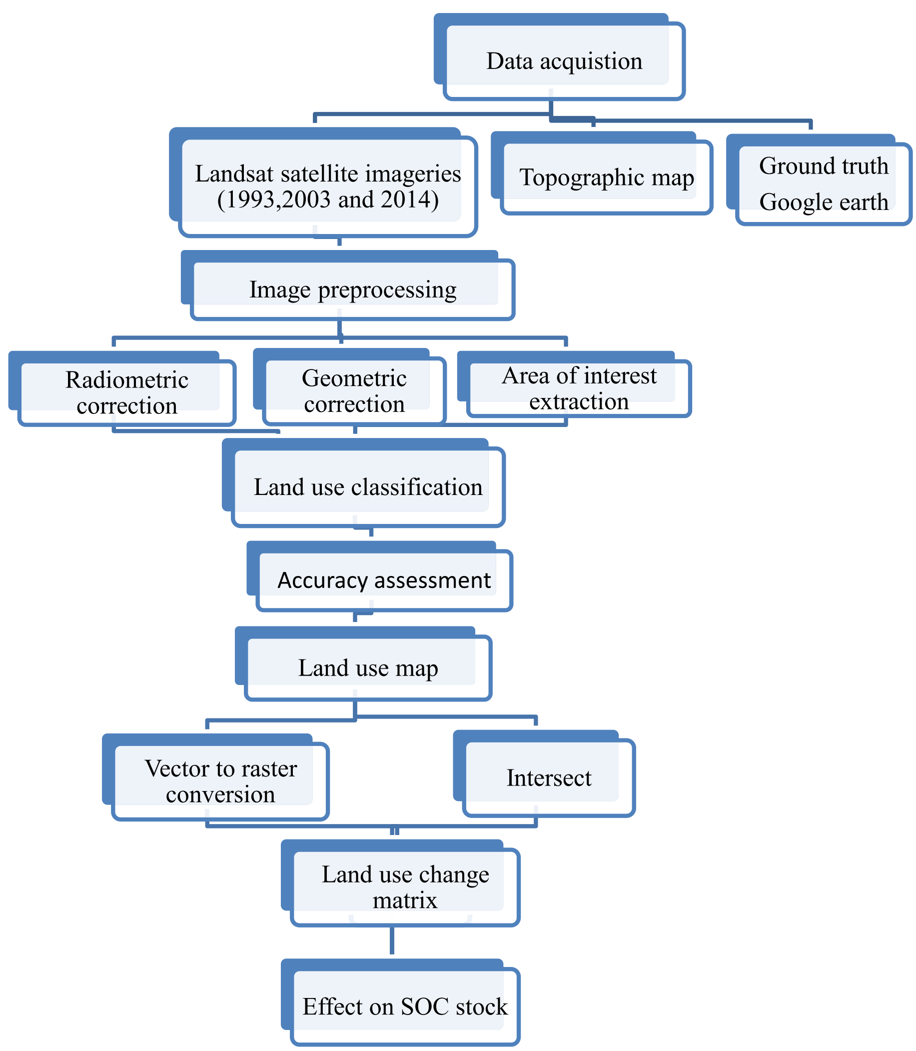

Fig. 2 Scheme for detection of land use change

by multiplication of the carbon stock in each unit area (t/ha) with the total area covered by a specific land use. The SOC stock for previous year 1993 and 2003 were estimated using equation given by IPCC 2003.

$$SOC = SOC_{REF} \times EF = \text{land u} \quad (2)$$

SOC_{REF} = default reference carbon stock (t/ha)

FLU = stock change factor for a specific land-use pattern (dimensionless)

FMG = stock change factor for management practice (dimensionless)

FI = stock change factor for organic matter input (dimensionless)

SOC_{REF} default value for the tropical dry area is 38 t C ha^{-1}. The SOC stock estimated for forest types (dry deciduous forest, thorn forest, and scrubland) in our study region varied from 24.91 to 37.78 t C ha^{-1} which is lower than the SOC_{REF} default value of IPCC (Table 2). Thus, we used our estimated values as the SOC_{REF} for the forest area. Default reference soil organic carbon (SOC_{REF}) for agricultural land (cropland, plantation, and fallow land) was determined by calculating mean value of the default SOC_{REF} for three types of forest. The SOC stock change factors (FLU, FMG, and FI) were used from IPCC 2006 (Table 3), depending on land use management practices as mentioned by farmers and local people during field visit. The effect of internal trading of land uses on SOC stock was determined by calculating change in SOC stock (t/ha) by deducting the base-year SOC stock from the final year stock of a particular land use conversion. Change in SOC stock (MTC) was determined by multiplying change in area (ha) with the change in SOC stock (t/ha) of each land use conversion. Scheme to determine effect of land use change on SOC stock is shown in Fig. 3.

Results

Land use/land cover change pattern analysis

Subset of satellite imageries and land use maps for 1993, 2003, and 2014 are presented in Fig. 4 and Fig. 5 respectively and land use/land use change pattern is shown in Table 4. During the period of 1993–2003, dry deciduous forest and tropical thorn forest was decreased by 1.34% and 28.94% respectively. Dry deciduous forest and tropical thorn forest decreased again during 2003–2014 by 4.15% and 15.82% respectively, accounting for the total decrease of 5.43% and 40.19% respectively in 2014 as compared to the area in 1993. Scrubland was increased in the first half (1993–2003) by 12.89% and decreased in second half (2003–2014) by 39.44% resulting in total decrease of 31.63% in 2014 from 1993 (Table 4).

Among the agriculture land, cropland increased significantly (254.56%) in the period 1993–2003 and again increased by 2.49% during 2003–2014, accounting for the total significant increase of 263.39% in 2014 as compared to the area in 1993. Agricultural plantation increased steadily in each time period of 1993–2003 and 2003–2014 by 14.46% and 65.07% respectively, accounting for the total significant increase of 88.94% in 2014 as compared to the area in 1993. While fallow land was decreased in the first half (1976–1989) by 31.66% and increased in second half (1989–2003) by 11.66%, thus there was a net decrease of 23.69% during 1993–2014. It is interesting to note that the area under settlement increased in each time period and significant increase (345.67%) was observed in 1993–2014. Wasteland also increased significantly by 99.54% during 1993–2014. Overall, the result showed that the total area under agricultural lands was increased by 32.14% while that under forest was decreased by 23.14% during the time period of 1993-2014 (Table 4).

Internal trading of land uses (1993–2003)

Dry deciduous forest remained the same during 10 years (1993–2003) by 2507.49 ha. Similarly, thorn forest, scrubland, cropland, and plantation remained the same by 772.41 ha, 596.19 ha, 211.45 ha, and 286.66 ha respectively. The land use conversion matrix has been shown in Table 6. Dry deciduous forest changed to thorn forest by 182.64 ha. To some extent, dry deciduous forest was changed to fallow land (21.68 ha),

Table 2 Default reference soil organic carbon stocks (SOC_{REF}) in different forest types at 0–30 cm depth (t/ha)

Region	HAC soils	LAC soils	Sandy soils	Spodic soils	Volcanic soils	Wetland soils
Boreal	68	NA	10	117	20	146
Cold temperate, dry	50	33	34	NA	20	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70	88
Warm temperate, Moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50	86
Tropical, moist	65	47	39	NA	70	
Tropical, wet	44	60	66	NA	130	

Source: IPCC (2006)

Table 3 Relative stock change factors (FLU, FMG, and FI) (over 20 years) for different management activities on cropland

Factor value type	Level	Temperature regime	Moisture regime	GPG revised default
Land use (FLU)	Long-term cultivated	Temperate	Dry	0.82
			Wet	0.71
		Tropical	Dry	0.69
			Wet	0.58
Land use (FLU)	Paddy rice	Temperate and tropical	Dry and wet	1.1
Land use (FLU)	Set aside (< 20 years)	Temperate and tropical	Dry	0.93
			Wet	0.82
Tillage (FMG)	Full	Temperate	Dry and wet	1.0
		Tropical	Dry and wet	1.0
Tillage (FMG)	Reduced	Temperate	Dry	1.03
			Wet	1.09
		Tropical	Dry	1.10
			Wet	1.16
Tillage (FMG)	No-till	Temperate	Dry	1.10
			Wet	1.16
		Tropical	Dry	1.17
			Wet	1.23
Input (FI)	Low	Temperate	Dry	0.92
			Wet	0.91
		Tropical	Dry	0.92
			Wet	0.91
Input (FI)	Medium	Temperate	Dry and wet	1.0
		Tropical	Dry and wet	1.0
Input (FI)	High–without manure	Temperate and tropical	Dry	1.07
			Wet	1.11
Input (FI)	High–with manure	Temperate and tropical	Dry	1.34
			Wet	1.38

Source: IPCC Good Practice Guidance for LULUCF, 2003

scrubland (8.39 ha), plantation (2.51 ha), and cropland (0.43 ha). Thorn forest change remarkably to scrubland by 826.30 ha. Also, thorn forest converted to cropland (169.80 ha), fallow land (259.55 ha), wasteland (66.76 ha), and plantation (6.98 ha). Scrubland was changed to thorn forest contributing area of 415.45 ha and also scrubland converted to fallow (178.18 ha), wasteland (92.77 ha), dry deciduous (30.72 ha), and cropland (40.33 ha). Cropland was changed to plantation and fallow land contributing area of 101.64 ha and 80.64 ha respectively, whereas plantation was changed to cropland and fallow land contributing area of 144.91 ha and 100.18 ha respectively. The remarkable change on fallow land was seen which was converted to cropland contributing area of 919.85 ha. Also, fallow land converted to plantation (180.84 ha), thorn forest (121.32 ha), dry deciduous forest (89.06 ha), scrubland (66.81 ha), and settlement (21.80).

Internal trading of land uses (2003–2014)

Land under dry deciduous forest remained consistent during 10 years (2003–2014) by 2493.35 ha. Similarly, land under thorn forest, scrubland, cropland, and plantation remained the same by 912.73 ha, 608.34 ha, 762.40 ha, and 361.83 ha respectively. Dry deciduous forest changed to thorn forest by 74.65 ha. The remarkable change on thorn forest to scrubland was seen which contributed by 255.93 ha. The land use conversion matrix has been shown in Table 7. Dry deciduous forest was changed to fallow land (60.09 ha), scrubland (21.29 ha), plantation (17.22 ha), and cropland (14.32 ha). Thorn forest was converted to wasteland (129.96 ha), fallow land (108.80 ha), dry deciduous forest (58.05 ha), and cropland (24.53 ha). The remarkable change on scrubland was seen which was converted to thorn forest contributing an area of

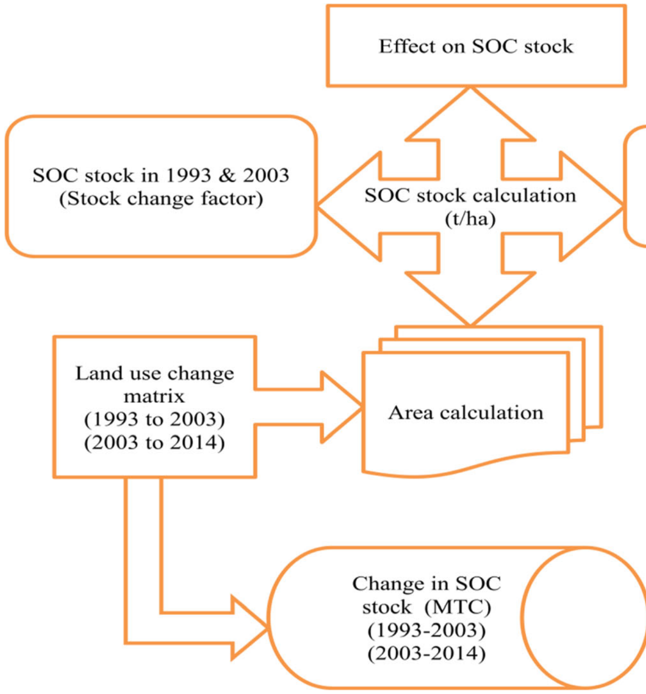

Fig. 3 Scheme to determine effect of Land use change on SOC stock

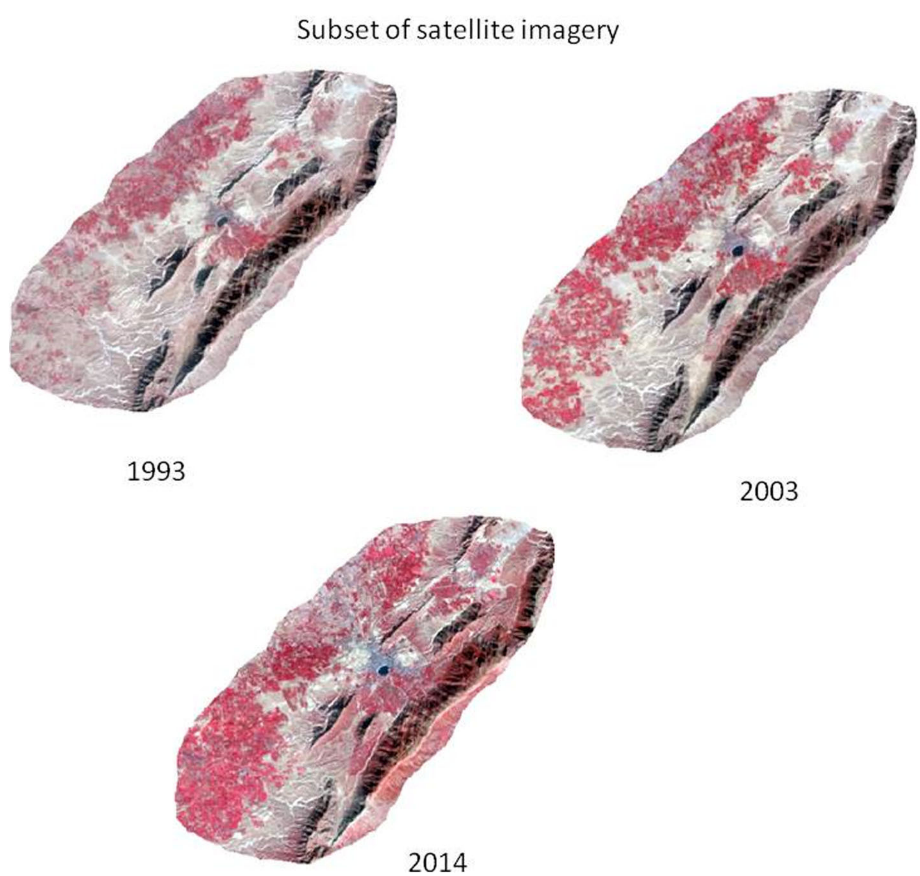

Fig. 4 Subset of multispectral satellite imageries (1993–2014)

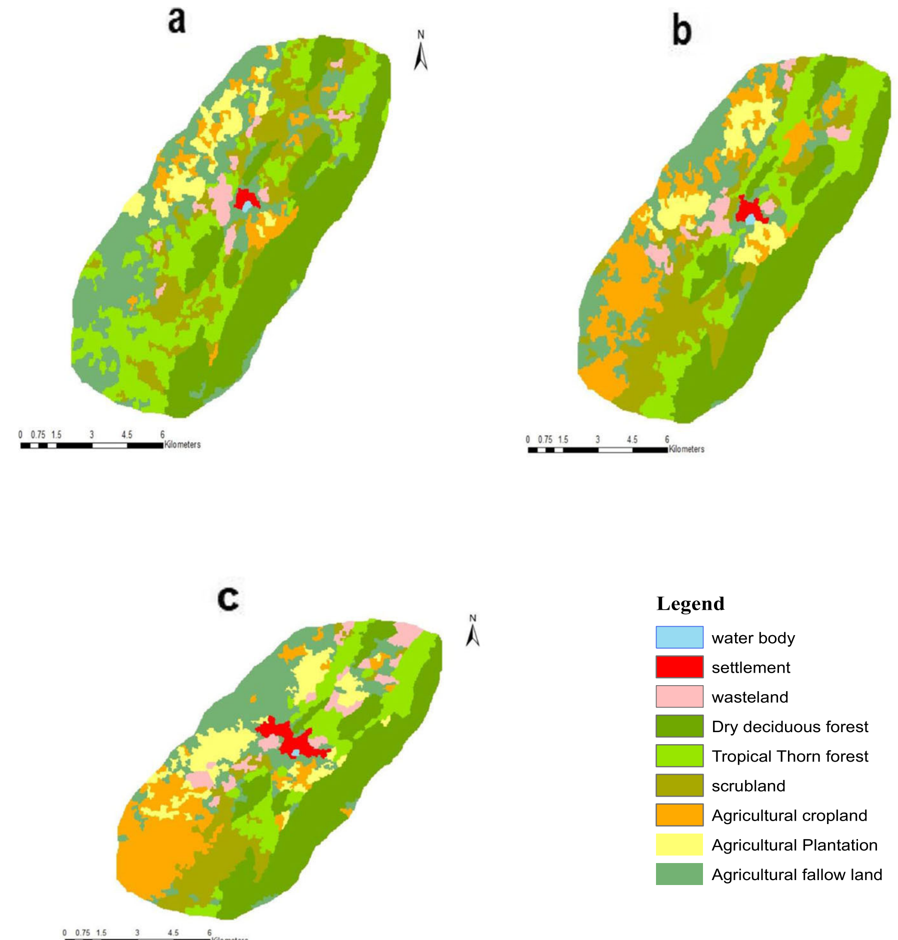

Fig. 5 Land use land cover maps of **a** 1993, **b** 2003, and **c** 2014

254.15 ha, cropland (242.97 ha), wasteland (204.73 ha), fallow land (163.35 ha), and plantation (48.69 ha). The major change was the conversion of cropland to plantation and fallow land contributing an area of 370.95 ha and 330.59 ha respectively, whereas plantation was changed to fallow and crop land contributing an area of 191.43 ha and 52.52 ha respectively. Fallow land changed remarkably to cropland contributing an area of 416.58 ha. Also, fallow land was converted to plantation (181.99 ha), wasteland (73.78 ha), thorn forest (28.88 ha), dry deciduous forest (16.57 ha), and wasteland (14.55 ha).

Table 4 Land use/land use change patterns (1993–2014)

Land use type	1993	2003	2014	Change in area (ha)		
	Area (ha)	Area (ha)	Area (ha)	1993–2003	2003–2014	1993–2014
Water body	10.08	12.24	7.65	2.16	− 4.59	− 2.43
Settlement	44.73	69.48	199.35	24.75	129.87	154.62
Wasteland	254.7	284.76	508.23	30.06	223.47	253.53
Dry deciduous	2725.2	2688.75	2577.15	− 36.45	− 111.6	− 148.05
Tropical thorn	2149.92	1527.66	1285.92	− 622.26	− 241.74	− 864
Scrubland	1372.14	1548.99	938.07	176.85	− 610.92	− 434.07
Cropland	420.66	1491.48	1528.65	1070.82	37.17	1107.99
Plantation	532.17	609.12	1005.48	76.95	396.36	473.31
Fallow land	2283.57	1560.69	1742.67	− 722.88	181.98	− 540.9

Table 5 Accuracy assessment of classified map of 3 years

Land use types	1993		2003		2014	
	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)
Water body	100	100	100	100	100	100
Settlement	100	100	100	100	100	100
Wasteland	97	95.09	95	96.3	96	96.8
Dry deciduous	94	98.94	96	98.9	97.4	99
Tropical thorn	72	94.73	82	95.6	83.7	96.4
Scrubland	94	79.66	95	84.7	96.2	86.9
Cropland	66.3	79.77	78	88.6	79.6	89.4
Plantation	93.6	66.07	92.3	74.5	94.5	78.7
Fallow	78.4	82.35	79.4	79.4	81.3	85.9
Overall accuracy (%)	87.81		93.3		95.4	
Kappa coefficient	0.85		0.89		0.91	

Land use change dynamics

Major land use change dynamics in 1993–2003, 2003–2014, and 1993–2014 is shown in the map in Fig. 6. Also, major land use change dynamics in percentage is presented in Table 8. Changes between forest types in 1993–2003 and 2003–2014 are 14.14% and 6.84% respectively. Changes from agricultural land to forest are 4.98% and 0.86% during 1993–2003 and 2003–2014 respectively. In both the periods (1993–2003 and 2003–2014), 7% of forest area is converted to agricultural land and about 15% changes occurred among agricultural land. About 60% of the area remains the same in both the periods.

Change in soil organic carbon stock

Net change in SOC pool within 21 years from 1993–2014 is shown in Table 9. SOC stock in forest land was found higher than agricultural land based on field data collected in 2014. Among different forest types, maximum soil carbon stock is found in dry deciduous forest (37.78 t/ha) followed by thorn forest (28.41 t/ha), and minimum in scrubland (24.91 t/ha). Our results revealed that there is significant temporal change in the SOC stock under agricultural lands (cropland, plantation, and fallow land) during 1993–2014 period. Changes in SOC stock were highest in the fallow land, with decrease of 8.41 t/ha in the periods 1993–2014 (Table 9). Also, there is increase of SOC pool by 2.27 t/ha and 4.05 t/ha in cropland and plantation respectively in the period 1993–2014. There is a net decrease in SOC from 1993 to 2014. In 1993, total SOC of all land use types was 287.16 Mt C and in 2003 total SOC was 276.04 Mt C, and in 2014 total SOC was 260.08 Mt C (Table 9).

In the period 1993–2003, SOC pool changes were highest in fallow land and cropland with decrease of 24.71 Mt C under fallow land and increase of 24.63 Mt C under cropland (Table 9). In the period 2003–2014, SOC pool changes were observed remarkably in fallow land (– 30.12 Mt C), cropland (26.68 Mt C), and thorn forest (– 24.55 Mt C).

Table 6 Land use change matrix (1993–2003)

Land use	Water	Settlement	Wasteland	Dry deciduous	Thorn	Scrubland	Cropland	Plantation	Fallow	Total area in 1993 (ha)
Water	9.44	0.40							0.09	9.93
Settlement	0.17	44.23							0.37	44.77
Wasteland			114.81	5.27	28.73	38.84	2.70	15.72	48.07	254.14
Dry deciduous				2507.49	182.64	8.39	0.43	2.51	21.68	272.15
Thorn		1.71	66.76	44.74	772.41	826.30	169.80	6.98	259.55	2148.23
Scrubland		1.47	92.77	30.72	415.45	596.19	40.33	15.93	178.18	1371.05
Cropland				10.53	6.83	9.25	211.45	101.64	80.64	420.34
Plantation						0.98	144.91	286.66	100.18	532.74
Fallow	2.61	21.80	10.70	89.06	121.32	66.81	919.85	180.84	868.25	2281.25
Total area in 2003(ha)	12.22	69.61	285.04	2687.81	1527.38	1546.76	1489.47	610.28	1557.01	9785.6

Table 7 Land use change matrix (2003–2014)

Land use	Water	Settlement	Wasteland	Dry deciduous	Thorn	Scrubland	Cropland	Plantation	Fallow	Total area in 2003 (ha)
Water	7.09	3.57							0.16	12.23
Settlement	0.16	67.32							2.13	69.61
Wasteland		11.88	136.83		5.77	44.86	13.22	8.26	64.14	284.97
Dry deciduous		1.33	6.82	2493.35	74.65	21.29	14.32	17.22	60.09	2689.07
Thorn		21.11	129.96	58.05	912.73	255.93	24.53	16.25	108.80	1527.35
Scrubland		18.89	204.73	5.55	254.15	608.34	242.97	48.69	163.35	1546.67
Cropland			13.80	1.27	9.23	0.82	762.40	370.95	330.59	1489.08
Plantation		1.92	0.11	2.14	0.12	0.19	52.52	361.83	191.43	610.28
Fallow land		73.78	14.55	16.57	28.88	8.03	416.58	181.99	816.37	1556.75
Total area in 2014(ha)	7.25	199.81	506.80	2576.93	1285.52	939.46	1526.55	1005.21	1738.47	9786.01

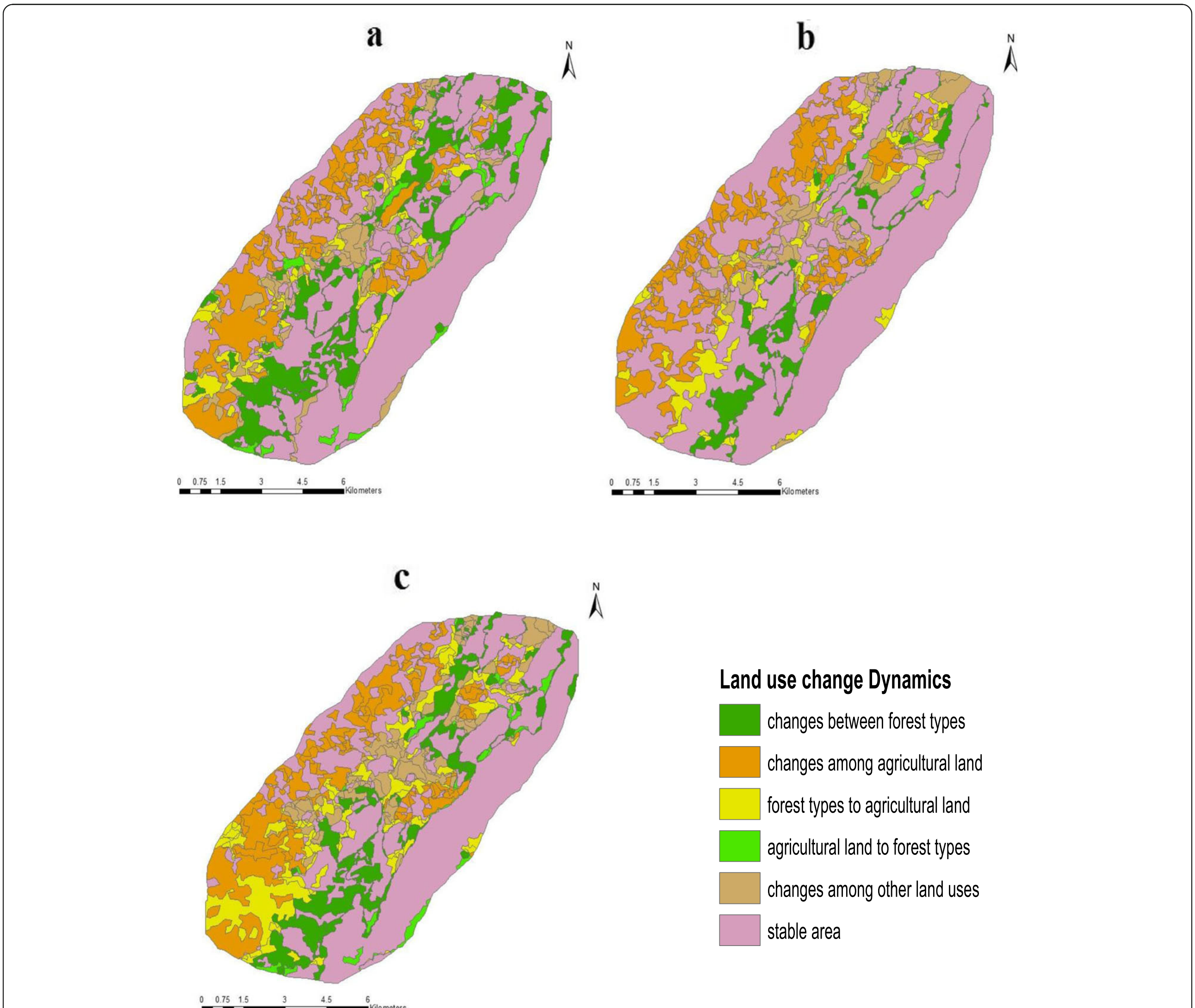

Fig. 6 Land use change dynamics in **a** 1993–2003, **b** 2003–2014, **c** 1993–2014

Table 8 Land use change dynamics in 1993–2003 and 2003–2014

Land use change dynamics	1993–2003		2003–2014	
	Area (ha)	% of total	Area (ha)	% of total
Changes between forest types	1384.19	14.14	669.62	6.84
Changes among agricultural land	1528.06	15.61	1544.06	15.78
Changes from forest to agricultural land	695.39	7.11	696.22	7.11
Changes from agricultural land to forest	487.06	4.98	83.8	0.86
Changes among other land uses	279.97	2.86	626.05	6.39
Stable area	5410.93	55.29	6166.26	63.01

Effect of internal trading of land use on SOC stock

Changes in the SOC pools were observed due to changes in land use or land management practices. Change in SOC stock due internal trading of land use is presented in Table 10. During the period of 1993–2003, the rate of loss in SOC was observed higher when dry deciduous forest was changed to other land types, i.e., cropland (15.33 t/ha), scrubland (12.87 t/ha), fallow land (11.8 t/ha), and thorn forest (9.37 t/ha). Conversion of thorn to scrubland results in loss of 2.89 Mt C soil carbon and conversion of dry deciduous forest to thorn forest results in 1.71 Mt C soil carbon loss during the period 1993–2003. The maximum rate of gain in SOC during 1993–2003 was observed when cropland converted to dry deciduous forest (16.83 t/ha) followed by conversion of scrubland to dry deciduous (12.87 t/ha), cropland to plantation (9.42 t/ha), and conversion of thorn to dry deciduous (9.37 t/ha). Conversion of scrubland to thorn forest leads to maximum gain of 1.45 Mt C in 1993–2003. Effect of major land use change dynamics on SOC stock in 1993–2003 is shown in Figs. 7a and 8a, and it shows that changes among agricultural land leads to maximum loss of soil carbon, i.e., 4.88 Mt C.

During the period of 2003–2014, the rate of loss in SOC was observed remarkably due to conversion of dry deciduous forest to other land use types, i.e., fallow (17.61 t/ha), cropland (14.56 t/ha), scrubland (12.87 t/ha), and thorn forest (9.37 t/ha). Conversion of dry deciduous and plantation to fallow land leads to loss of 1.06 Mt C and 1.95 Mt C. Also, there was a loss of 1.15 Mt C soil carbon when fallow land was changed to cropland. Prominent rate of SOC gain in 2003–2014 was found due to conversion of cropland to dry deciduous forest (15.36 t/ha), scrubland to dry deciduous forest (12.87 t/ha), fallow to dry deciduous forest (11.8 t/ha), cropland to plantation (9.57 t/ha), and thorn forest to dry deciduous forest (9.37 t/ha). Conversion of cropland and fallow land to plantation results in gain of SOC by 3.55 and 1.09 Mt C respectively. The estimated effects of other internal trading of land use changes are shown in Table 8. Effect of major land use change on SOC stock in 2003–2014 is shown in Figs. 7b and 8b, and it shows that conversion of forest to agricultural land leads to loss in 3.16 Mt C soil carbon.

Discussion

The total area under cultivated land was increased, while that under forest was decreased during the time periods under study (1993–2014). During this period, increase in human population leads to increase in demand of crop cultivation which results in deforestation. Also, this demand leads to the major conversion of fallow land to cropland during the period 1993–2014. During both the period, thorn forest change remarkably to scrubland.

Table 9 Net change in SOC pool within 21 years from 1993 to 2014

Land use	[a]1993		[a]2003		[b]2014	
	SOC (t/ha)	SOC (Mt C)	SOC (t/ha)	SOC (Mt C)	SOC (t/ha)	SOC (Mt C)
Dry deciduous forest	37.78	102.96	37.78	101.58	37.78	97.36
Tropical thorn forest	28.41	61.08	28.41	43.40	28.41	36.53
Scrubland	24.91	34.18	24.91	38.58	24.91	23.37
Agricultural cropland	20.95	8.81	22.42	33.44	23.22	35.49
Agricultural Plantation	27.94	14.87	30.37	18.49	31.99	32.16
Agricultural fallow land	28.58	65.26	25.98	40.55	20.17	35.14
Total		287.16		276.04		260.05

[a]Based on IPCC guideline
[b]Based on field data

Table 10 Effect of internal trading of land use on SOC stock

Land use change	1993–2003			2003–2014		
	Change in area (ha)	Change in SOC stock (t/ha)	Change in SOC stock (Mt C)	Change in area (ha)	Change in SOC stock (t/ha)	Change in SOC stock (Mt C)
Dry deciduous to thorn forest	182.64	− 9.37	− 1.71	74.65	− 9.37	− 0.69
Dry deciduous to scrubland	8.39	− 12.87	− 0.11	21.29	− 12.87	− 0.27
Dry deciduous to cropland	0.43	− 15.33	− 0.007	14.32	− 14.56	− 0.21
Dry deciduous to plantation	2.51	− 7.41	− 0.02	17.22	− 5.79	− 0.09
Dry deciduous to fallow	21.68	− 11.8	− 0.25	60.09	− 17.61	− 1.06
Thorn to dry deciduous	44.74	9.37	0.42	58.05	9.37	0.54
Thorn to scrubland	826.30	− 3.5	− 2.89	255.93	− 3.5	− 0.89
Thorn to cropland	169.80	− 5.99	− 1.02	24.53	− 5.19	− 0.13
Thorn to plantation	6.98	1.96	0.01	16.25	3.58	0.06
Thorn to fallow land	259.55	− 2.43	− 0.63	108.80	− 8.24	− 0.89
Scrubland to dry deciduous	30.72	12.87	0.39	5.55	12.87	0.07
Scrubland to thorn forest	415.45	3.5	1.45	254.15	3.5	0.89
Scrubland to cropland	40.33	− 2.49	− 0.07	242.97	− 1.69	− .41
Scrubland to plantation	15.93	5.46	0.10	48.69	7.08	0.34
Scrubland to fallow land	178.18	1.07	0.19	163.35	− 4.74	− 0.77
Cropland to dry deciduous	10.53	16.83	0.18	1.27	15.36	0.02
Cropland to thorn forest	6.83	7.46	0.05	9.23	5.99	0.05
Cropland to scrubland	9.25	3.96	0.04	0.82	2.49	0.002
Cropland to plantation	101.64	9.42	0.96	370.95	9.57	3.55
Cropland to fallow land	80.64	5.03	0.40	330.59	− 2.25	− 0.74
Plantation to scrubland	0.98	− 3.03	− 0.003	0.19	− 5.46	− 0.001
Plantation to cropland	144.91	− 5.52	− 0.79	52.52	− 7.15	− 0.37
Plantation to fallow land	100.18	− 1.96	− 0.19	191.43	− 10.2	− 1.95
Fallow to dry deciduous forest	89.06	9.2	0.82	16.57	11.8	0.19
Fallow to thorn forest	121.32	− 0.17	− 0.02	28.88	2.43	0.07
Fallow to scrubland	66.81	− 3.67	− 0.24	8.03	− 1.07	− 0.008
Fallow to cropland	919.85	− 6.16	− 5.67	416.58	− 2.76	− 1.15
Fallow to plantation	180.84	1.79	0.32	181.99	6.01	1.09
Total			− 8.29			− 2.76

The reason might be low rainfall during that period which leads to land degradation. During 2003–2014, it was also observed that in some area scrubland is converted to thorn forest which indicated an altogether positive effect of forest management by the local people since 2003.

SOC stock in forest land was found higher than agricultural land based on field data collected in 2014. The

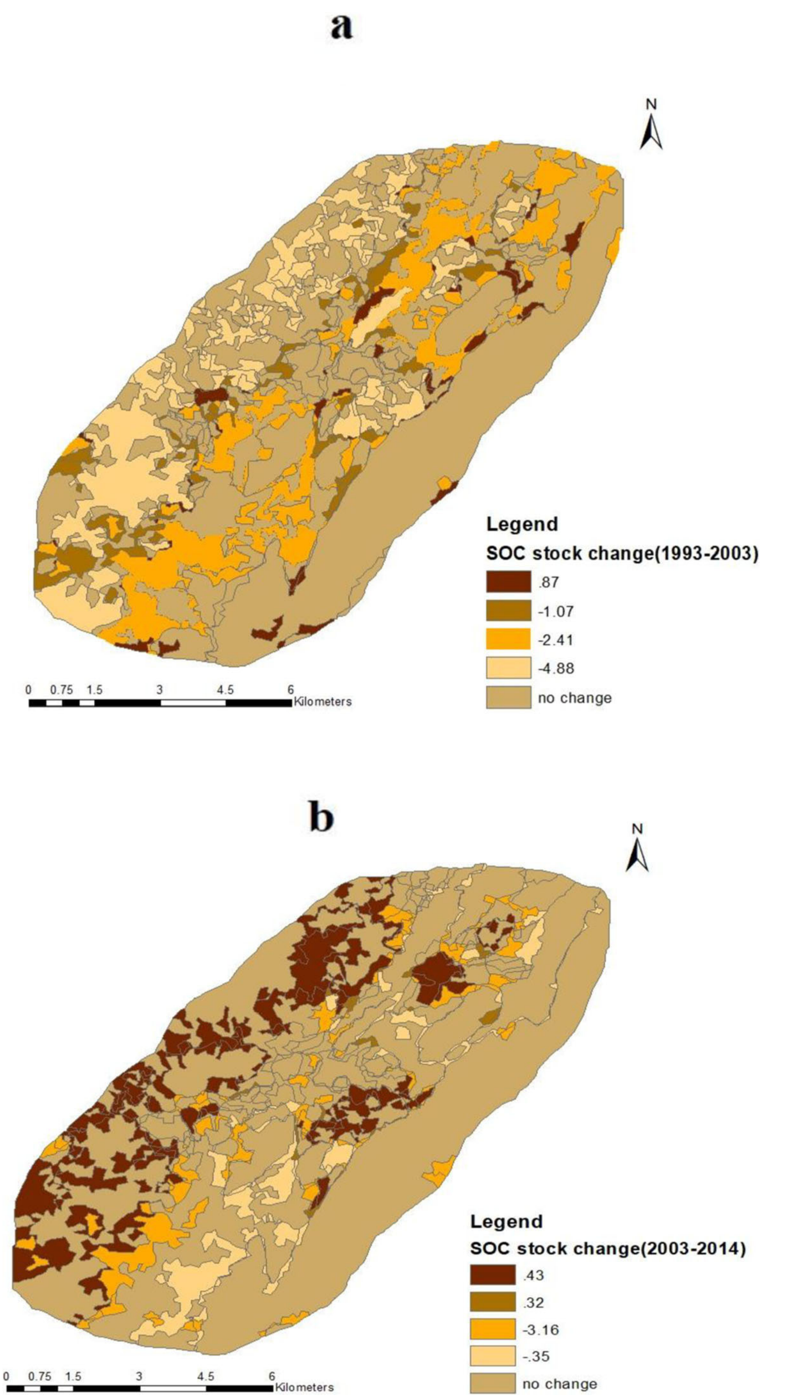

Fig. 7 Change in soil organic carbon stock (Mt C) in 0–30 cm depth due to land use change in **a** 1993–2003 and **b** 2003–2014

result is in harmony with findings from previous studies (Davidson and Ackerman 1993; Amundson 2001; Murty et al. 2002; Don et al. 2011). The reason for more soil carbon stock in the soil of forest is due to the minimum disturbance in soil and a slow rate of SOC decomposition which result in higher carbon accumulation, whereas low SOC stock in agricultural land is due to intensive cultivation practices which results in greater soil disturbance, and increase rate of SOC decomposition (Mancinelli et al. 2010; Sainju et al. 2008; Yimer et al. 2007). Among different forest types, maximum soil carbon stock is found in dry deciduous forest followed by thorn forest and minimum in scrubland. The reason is soil carbon pool of forest differ according to climate,

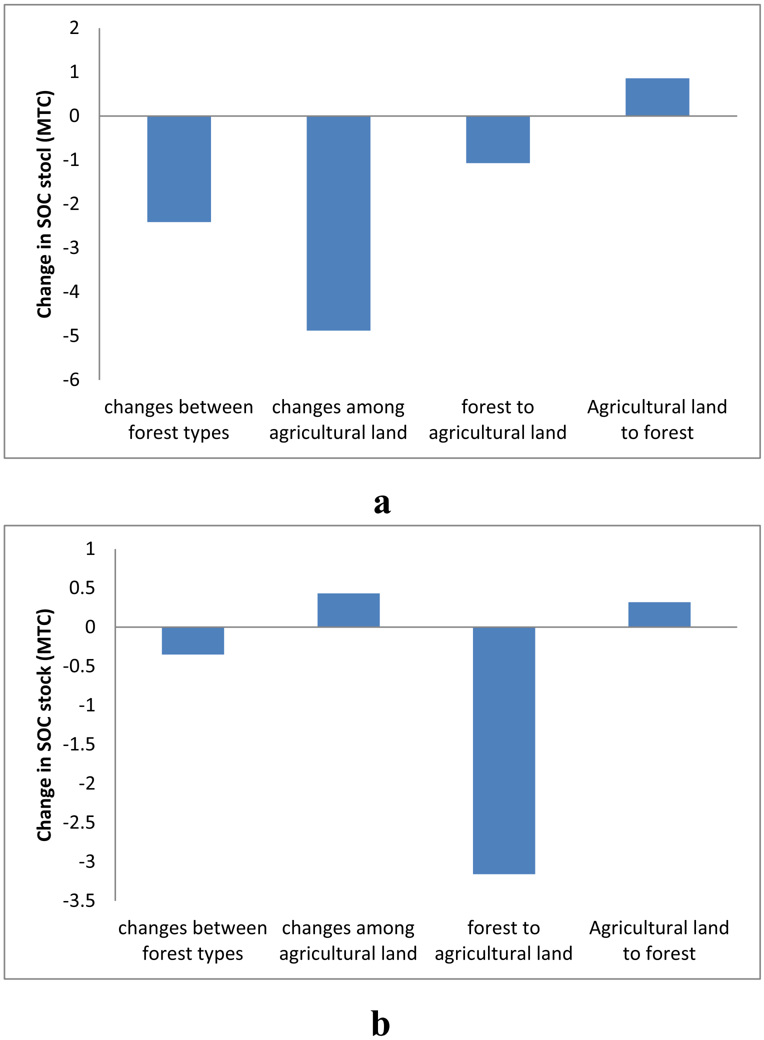

Fig. 8 Effect of major land use change on soil carbon stock (Mt C) in **a** 1993–2003 and **b** 2003–2014

location, age of the forest stand, and type of plant species (Noordwijk et al. 1997).

During 1993–2014, there is remarkable change in the SOC stock under agricultural lands. These results reflect the fact that the SOC pool in the cultivated lands is affected directly by the management practices adopted by the farmers. Interviews with farmers revealed that there was lower input of manure and fertilizer in cropland and plantation in 1993. After 1993, the farmers increased the input of fertilizer. During both the period, maximum loss in SOC was observed when dry deciduous forest was converted to other land types, i.e., cropland, scrubland, fallow land, and thorn forest. It is revealed that the change in forest land to other land causes oxidation of organic carbon in soil which leads to loss in SOC (Lal 2003; Lal 2004). The maximum rate of gain in SOC was observed when cropland was converted to dry deciduous forest.

Conclusion

To determine the dynamics of land use change, interpretation of multitemporal satellite imagery was found to be a practical method. The results showed that there was a continuous decrease in forest area, whereas area under agriculture increased steadily in each time period of 1993–2014. Matrices of land use change shows that in 1993–2003, highest internal trading occurred between forest types. In both the periods (1993–2003 and 2003–2014), maximum internal trading occurred among agricultural land followed by conversion of forest area to agricultural land.

This study also investigated the effect of land use change dynamics on SOC stock. Changes in the SOC pools were observed due to changes in land use or land management practices. In 1993–2003, changes among agricultural land leads to maximum loss of soil carbon and during 2003–2014 conversion of forest to agricultural land leads to maximum loss in soil carbon. There is gain in SOC stock in both the periods due to conversion of forest types to agricultural land. Overall, we can conclude that the internal trading of land use area during the 10-year period (1993–2003) leads to net loss of SOC stock by 8.29 Mt C. Similarly, land use change during the 11-year period (2003–2014) caused a net loss of SOC by 2.76 Mt C.

This study concluded that land use change has a potential impact on soil carbon storage due to change or loss in vegetation which leads to alteration in input and output of carbon in soil. Efforts should be made to implement proper land use management practices, such as application of biofertlizers and organic manure to enhance the SOC content. Conversion of land use from cultivated to managed perennial plantation can enhance soil carbon stock. Land use management is an essential step for preserving existing soil carbon and also aids in increasing soil carbon. Semi-arid region has a great capacity to sequester carbon and this capacity can be enlarged if proper land use management is implemented. Also, these regions can contribute to mitigating carbon dioxide from the atmosphere.

Abbreviations
BD: Bulk density; ETM+: Enhanced thematic mapper plus; FI: Stock change factor for organic matter input; FLU: Stock change factor for a specific land use pattern; FMG: Stock change factor for management practice; IPCC: Intergovernmental Panel on Climate Change; MTC: Metric ton carbon; OLI: Operational land imager; SOC: Soil organic carbon; SOCref: Default reference soil organic carbon; TM: Thematic mapper

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GS collected, interpreted, and analyzed the data and found the results and conclusion and was a major contributor in writing the manuscript. LK guided regarding spatial data analysis, KC guided regarding assessment of soil carbon stock. All authors read and approved the final manuscript.

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The authors declare that they have no competing interests.

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