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Geospatial assessment of long-term changes in carbon stocks and fluxes in forests of India (1930–2013)

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ABSTRACT

The present study has estimated spatial distribution of biomass carbon density from satellite remote sensing data, historical archives and collateral data from 1930 to 2013. The spatial forest canopy density datasets for 1930, 1975, 1985, 1995, 2005 and 2013 were analysed to obtain biomass carbon pools at 5 km grid level. The overall loss of forest cover was 28% from 1930 to 2013. Analysis of change in the forest canopy density indicates that the dense forest cover reduced from 419,175 km^2 in 1975 to 390,966 km^2 in 2013. The total above ground biomass carbon stock of Indian forest was calculated as 3070.27 Tg C in 2013. Standing biomass carbon stocks varied significantly during different steps of time periods. There are a total 67,184 grid cells with loss of carbon stocks during 1930–1975 followed by 55,742 cells during 1975–1985. The annual carbon loss in the above ground biomass showed the highest decrease during the period of 1930 to 1975 and estimated as 2168.50 Tg C while the net annual loss of carbon is 48.19 Tg C. The maximum observed net annual loss of carbon stocks was 53.97 Tg C during 2005 to 2013. Carbon content for various states shows that maximum carbon stocks were stored in the forests of Arunachal Pradesh (11.27%) in 2013. State-wise change analysis indicates the highest loss of carbon stocks in Tripura (80.99%) from 1930 to 2013. Overall reduction in carbon stock in Indian forests has been estimated as 3079.98 Tg C (50.08%) from 1930 to 2013. The spatial characterization of distribution and changes in carbon stocks can provide useful information for planning and strategic management of resources and fulfilling global initiatives to conserve forest biodiversity.

1. Introduction

Forests play a significant role in the carbon cycle because they store large quantities of carbon, exchange large quantities of carbon with the atmosphere through photosynthesis and respiration, and can be managed to alter the magnitude and direction of carbon fluxes (Brown and Schroeder, 1999). Houghton et al. (1987) reported that forests hold more carbon per unit area in vegetation and soils than any other ecosystem, therefore conversion of forests into another land use accompanies loss of biomass and carbon. Droughts make tropical forests more susceptible to biomass burning (Randerson et al., 2005). Threat of global warming due to increased levels of Green House Gases in the atmosphere due to fossil fuel burning, industrialization, deforestation and degradation in last 150 years have spurred research interest in forest carbon cycle. Ocean, soil, atmosphere and the biosphere can act as sink or sources of carbon, depending upon the temporal scale and location. The amount of carbon stock and emission varies with land use practices and land use changes (Dadhwal et al., 2009). The world's population of nearly one billion in 1800 has grown to approximately 6.9 billion today and population projections suggest that the world population will fall somewhere between 7.5 and 10.5 billion by 2050 (UNPD, United Nations Population Division, 2009). India has the second largest population in the world and accounts for 17.5% of the global population. The population of India was only 238.4 million in 1901 having increased by more than four times to reach 1277 million in 2013 (http://censusindia.gov.in).

Tropical deforestation currently accounts for over 90% of net carbon emissions resulting from global land-use change (Houghton, 2003). Emissions from deforestation and degradation remain a significant (ca. 20%) source of annual greenhouse gas emissions into the atmosphere (IPCC, 2007). Avoided tropical deforestation reduces anthropogenic carbon emissions from land use change. Therefore, spatial data on long-term forest change is needed to model net carbon emissions. Net carbon emissions from deforestation during the past decade are estimated at 3.3 billion tonnes of CO_2 emissions annually (http://www.ipcc.ch). The majority of biomass assessments are performed for the above-ground biomass of trees which represents the greatest fraction of the total living biomass in a forest and does not pose significant logistical problems during field measurements (IPCC, 2007). Estimating above ground forest biomass is the most important step in measuring the carbon stocks

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and fluxes from tropical forests and helps to determine the contribution of forests to the global carbon cycle (Vicharnakorn et al., 2014). REDD (Reducing Emission from Deforestation and Degradation) has been considered as an efficient strategy to reduce greenhouse gas concentration in the atmosphere. It is a mitigation measure which aims at existing forest conservation. $REDD^{+}$ focuses on financial incentives to help developing countries to reduce nationwide deforestation rates and carbon emissions (Sheikh et al., 2011).

In the recent past, remote sensing has been effectively used for estimation of biomass and productivity at local, regional level and global levels. All countries participating in a policy mechanism to reduce emissions from deforestation and forest degradation will need to develop estimates of historic emissions, which will be the starting point for generating reference emission levels (Reddy et al., 2015a). Richards and Flint (1994) had estimated the Indian forest area in 1880 as 102.7 Mha. The study on long term monitoring of forests has provided the distribution, changes in forest cover and the rate of deforestation in India from 1930 to 2013 (Reddy et al., 2016). The study has classified 14 forest types and seven scrub types of India based on multi-season Resourcesat-2 Advanced Wide Field Sensor data and ecological rule bases (Reddy et al., 2015b). The average carbon stock value for each forest strata can be applied to the satellite-based forest map to estimate national-level forest carbon stocks. A major advantage of the forest strata approach is that carbon stock estimates could be applied to estimate emissions in the past, present and future (Gibbs et al., 2007). Of the two approaches, the growing stock volume based approach gives more reliable carbon pool estimates as they are based on large field surveys and overcome the inherent overestimation by ecological point measurement based approach (Brown and Lugo, 1984; Houghton et al., 1987; Chhabra et al., 2002a, 2002b).

The Global Forest Resource Assessment reported a global biomass decrease by about 23Gt, or 3.6% globally between 1990 and 2010 (FAO, 2010). South and South East Asia show a decrease in biomass from 60,649 Mt–51,933 Mt (1990–2010). According to Forest Resources Assessment, the world's forest, become a net source of emissions due to decrease in total forest area. In Asia, there is a decrease in carbon stock from 37,213 Mt to 35,689 Mt from 1990 to 2010. India's carbon stock varies from 2223 Mt–2800 Mt (1990–2010) (FAO, 2010). India's CO_2 emissions in 2012 with the share of 6.8% making it the fourth largest CO_2 emitting country (Oliver et al., 2013). India's biomass stock in forest is 4092 Mt in 2015 (FAO, 2015). India is one of the few developing countries in the world that is making a net addition to its forest and tree cover over the last two decades by afforestation programmes (Kishwan et al., 2009). India has launched a series of policy initiatives on sustainable management of forests which involve significant resources for sustaining and growing India's forest cover (Kishwan et al., 2009). As part of Green India Mission of National Action Plan on Climate Change, major goal is enhancing the carbon sinks in sustainably managed forest and other ecosystems. This mission gives equal importance to afforestation and reforestation along with conservation and restoration of the existing forest (http://greencleanguide.com/green-india-mission-marching-towards-a-greener-future). Richards and Flint (1994) estimated the state wise forest carbon stock over India for 1880 with an ecological model and used a population based biomass degradation model to estimate change in carbon till 1980.

During 1982–1992 a gradual increase in biomass was observed in India (89.21 t ha^{-1}–98.09 t ha^{-1}) and subsequently, the forest biomass decreases to 93.27 t ha^{-1} (Kaul et al., 2009). The total carbon stock in the biomass of the world's forests shows a decrease of about 10 Gt from 1990 to 2010. The annual increase in C stock due to biomass growth in Indian forest was 77.82 (1982–1992) and 79.65 Tg C (1992–2002) which is similar to the estimates of India's National Communication to UNFCCC (Kaul et al., 2009). Lal and Singh (2000) reported

Table 1
Details of spatial data used in the study.

Sl. no	Type	Period	Scale/resolution[a]	No. of maps /satellite scenes
1	Topographical maps	1920–1940	1: 250,000	251
2	Landsat MSS	1975	80 m	356
4	Landsat MSS	1985	80 m	452
5	IRS 1A/1B LISS-I	1995	72.5 m	470
6	IRS P6 AWiFS	2005	56 m	64
7	Resourcesat-2 AWiFS	2013	56 m	64

[a] Scale for topographical maps; spatial resolution for satellite datasets.

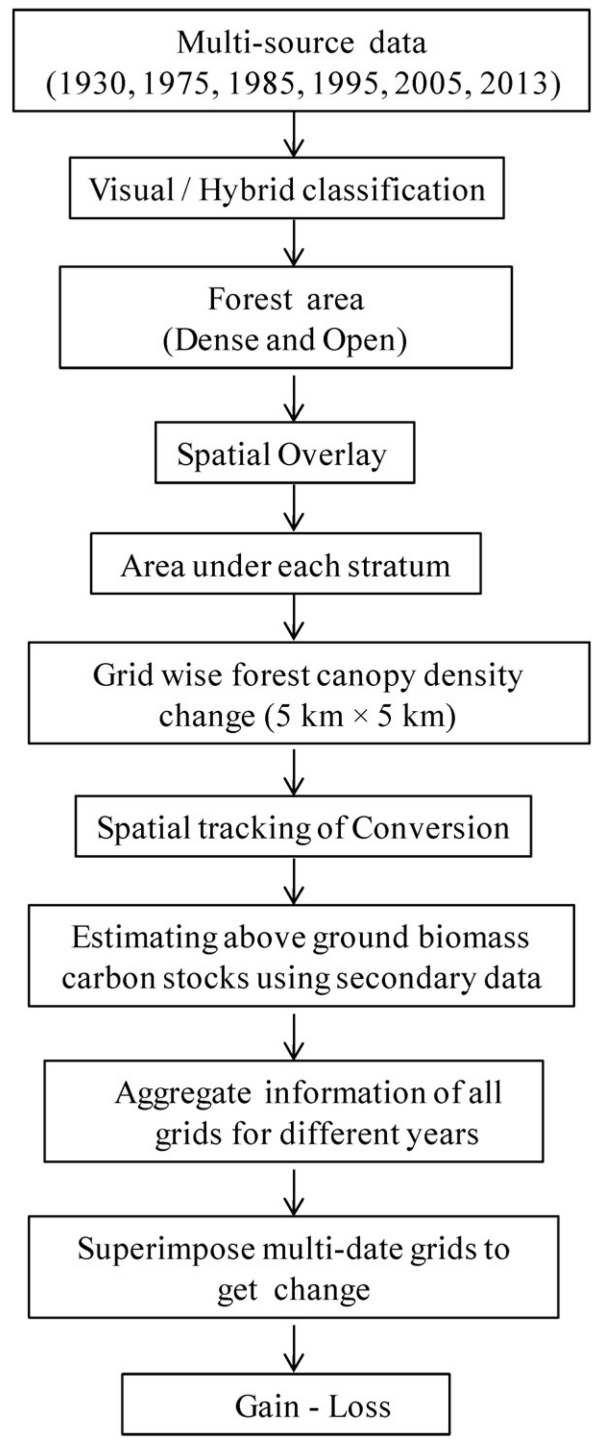

Fig. 1. Flow chart of methodology.