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Multi-source and multi-date mapping of deforestation in Central India (1935-2010) and its implication on standing phytomass carbon pool

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ABSTRACT

Information on the historical distribution of Indian forest cover change and carbon stocks is scarce and far from comprehensive. Geospatial methods were used to study changes in forest cover and above ground carbon stocks over seven decades in Central India, which covers over a tenth of India (13.5%) and accounts for almost a fifth of its forest cover (19.27%). Changes in the above ground phytomass carbon pool were computed. There is a significant contribution of deforestation to the reduction in the C pool. The overall loss of forest cover was 2.5 Mha (16%), while the reduction in carbon stock was 343.5 Tg C (42%) since 1935. The overall rate of deforestation in Central India (0.23 from 1935 to 2010), has been on decline in recent years. In order to increase the amount of carbon accumulation, open forests which are occupying about 45.8% of forest area must be considered for improvement of carbon stocks. The above results indicate that the forests of central India could act as important carbon sinks in India.
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1. Introduction

Tropical deforestation is the second largest source of greenhouse gas emissions and is an issue that affects carbon fluxes, biodiversity and climate (Kindermann et al., 2008). Change in forest cover affects the carbon exchange with the atmosphere and determines its role as source or sink of carbon (Dixon et al., 1994). Long term monitoring of land cover and forests that can detect deforestation, afforestation and reforestation events is essential for the accounting of carbon change in forests (Furby, 2002). The long-term changes in forest carbon are dependent on changes in the forest area as well as changes in phytomass per unit area (Houghton, 2005). The quantity of phytomass carbon in a given ecosystem is one of the most uncertain factors involved in estimating changes in carbon flux from terrestrial ecosystems (Brown et al., 1989).

Long-term forest change information is needed in a spatial format to model net carbon emissions covering phytomass and associated studies. A global dataset is reported by (Hansen et al., 2010) but is coarse scale and covers only the 2000–2005 time period. Richards et al. (1994) estimated the state wise forest carbon stock over India for 1880 with an ecological model and used a population based phytomass degradation model to estimate change in carbon till 1980. Reddy et al. (2013) estimated long term forest cover change over Odisha, India and observed that studies on deforestation of Indian forests over the past decade have largely concentrated only the areas which are undergoing large scale deforestation and that information on historical amounts and distribution of Indian forest cover is scarce.

Forest carbon stock and land use change led C emissions in India has received attention from a number of workers using methods based on growing stock volume data from forest inventories or those recommended by the IPCC, with assumptions of a steady state phytomass density. Ravindranath et al. (1997) estimated a mean standing above ground phytomass of 130.8 t ha^{-1} using area under different crown cover classes and published estimates of phytomass density for a few forest types that were extrapolated to other forest types. Dadhwal and Shah (1997) used satellite remote sensing and field inventory based growing stock in two forest density classes and estimated total forest phytomass as 7956 and 8142 Mt for 1982 and 1991. Using a similar approach, Chhabra et al. (2002) estimated state wise growing stock volume density and phytomass density in three density classes and reported total standing phytomass to be 8683.7 Mt for 1992–1993 with a mean phytomass density of 135.6 t ha^{-1}. Haripriya (2000) estimated the total C stock in Indian forest as 2156 Tg with a carbon density of 44 Mg C ha^{-1} including the contribution from smaller trees. Haripriya (2003) used forest inventory data with a simulation model accounting for growing stock, total phytomass, litter, soil carbon as well as losses from harvesting, fires and pests and estimated total carbon stock in phytomass for 1994 as 2934 Tg C with an average carbon density

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of 46 Mg C ha^{-1}, 76% of which was from above ground phytomass. Lal and Singh (2000) report total carbon storage of 2026.72 Mt C based on published growing stock for 1995 with an afforestation rate of 2 Mha and an increase in the productivity of 0.7 cu m ha^{-1} for the 1985–1995 time period. Manhas et al. (2006) used growing stock data to estimate and report a reduction in the forest carbon stock from 1085.06 Mt in 1984 to 1083.69 Mt in 1994. Kaul et al. (2009) estimated the net carbon flux from land use change for two decades between 1982 and 2002. They report a reduction in the annual deforestation rate from 0.22 to 0.07 Mha^{-1} based on remote sensing based forest cover data for 1982, 1992 and 2002 and state level phytomass increment values. Pandey et al. (2011) estimate that India's forest carbon stocks increased from 6244.78 Mt C in 1995 to 6621.55 Mt C in 2005 and attribute this increase to forest policies that favour the conservation and sustainable use of forests.

Central India has historically been exploited for its forest resources. Forsyth (1889) provides a fascinating account of forest change in the region before the formation of the Central Provinces in 1861 and the establishment of forest department for the control and management of forest resources. The study documented "death blow" to the teak in the northern parts of the Central Highlands following an announcement of the advent of governmental management and conservation. The study documented "all that were worth anything were saved by the forest department in after years. They were not a hundredth part of those that were cut, which should probably reckoned by millions rather than thousands". The expansion of the Indian railway network was another factor that influenced the forests of the region. Rangarajan (2002) estimated the requirement of 2 mega tonnes of wood over two decades of railway expansion (1860–1880). Iron smelting fuelled by charcoal is estimated to have been about 15 mega tonnes of wood in the pre-colonial times. Scientific management of the forests was taken up only following Indian Independence in 1947 and the abolition of the aristocracy (*zamindari*) system in the 1950s. These varied demands and pressures profoundly influenced the phytomass density of the forests in Central India.

Keeping in view the above, this paper presents a geospatial assessment of the long term changes in forest cover changes and carbon pools in Central India over a 75 year period from 1935 to 2010. This is achieved by using an approach that accounts for change in both area and the phytomass density for different time periods to a region that covers over a tenth of India and accounts for almost a fifth of the national forest cover. Chhabra et al. (2002), attempted to report early district-wise phytomass density. Reddy et al. (2013) recently reported on spatio-temporal changes in forest cover and variation in forest type in the state of Odisha, India. Roy et al. (2013) have studied fragmentation status of Indian forests.

The present study is part of a larger effort to establish a long-term geospatial data set on forest area, forest type, phytomass density for studying forest carbon in India.

2. Study area

The present study was carried out in Central India, (area 443,436 km^2; forest cover 133,570 km^2) (FSI, 2011). The forest type is mostly tropical deciduous. The Central Indian region (73°54–75°04 E; 24°42–25°41 N) includes the states of Madhya Pradesh and Chhattisgarh and covers three physiographic zones the Central Highlands, North Deccan and East Deccan (Fig. 1). The topography has vast stretches of plains to gently undulating terrain. These are interspersed with moderately high hills of Satpura Ranges, Vindhyan Ranges, Scarp lands, etc. The highest hills in Central region are in Pachmarhi (c. 1350 m) and Bailadilla (c. 1200 m) in Chhattisgarh. The region has tropical climate. Western parts are hot and semi-arid whereas eastern parts are moist-humid. The region receives rainfall from south-west and the annual rainfall varies from 700 mm to 1650 mm from west to east with an exception around Pachmarhi ranges with >2000 mm. The mean annual temperature varies from 18–20 °C during winter (December–January) and over 42 °C during May. The soils are black, alluvial and mixed red type (http://nidm.gov.in/pdf/dp/Madhya.pdf).

3. Materials and methods

The present study developed spatial layers on forest cover, forest types and forest canopy density.

3.1. Data used

The time periods prior to the availability of satellite data were mapped using Topographical maps surveyed during 1922–1937 time period (Series U502, U.S. Army Map Service, 1:250,000 scale from the Perry Castaneda map collection (http://www.lib.utexas.edu/maps/ams/india/last accessed 15 July 2013)) and those prepared by Survey of India (SOI) (1950–1965). Satellite data analysis and interpretation used Landsat Geocover (Koeln et al., 1999) for 1972–1975 and 1985, while IRS data were used for subsequent years (Table 1). 1935 and 1960 are considered as the base years in the analysis for the 1922–1937 and 1950–1965 periods respectively. Additionally, multi-season IRS P6 AWiFS data of 2009, multi-season IRS P6 LISS III data of 2004, land use/land cover 1:250,000 scale (2009) map generated by NRSC and the 1:50,000 scale forest cover map for 2005 created by the Forest Survey of India (FSI) (FSI, 2006) were also used as reference to aid the preparation of maps and spatial layers. All layers were organized in a geospatial database.

3.2. Data analysis

The spatial data analysis includes visual interpretation from topographical maps and hybrid classification of satellite imagery to assess forest cover. Phytomass density and carbon equivalents per hectare of forests from published literature were used. The details are discussed below, and shown in Fig. 2.

3.3. Total area under forest

The forest area shown in the topographical maps was captured using on screen digitization. Forest area appears green in topographical maps. Satellite data sets used in the study were processed using ERDAS Imagine ver. 10. Image-to-image registration was performed using GCPs selected from orthorectified Landsat ETM+ data (http://glcf.umd.edu/research/portal/geocover/) using a first order polynomial transformation. Data sets were corrected with a root-mean-square error of <1 pixels for all data. To reduce the error due to various atmospheric conditions at different dates of image acquisition conversion of digital number to top-of-atmosphere (TOA) reflectance as suggested by (Chavez, 1996) was performed. The processed satellite imagery was used to map canopy density and forest type using hybrid classification techniques. All the datasets have been resampled to 56 m to have uniformity in spatial analysis.

The present study has used natural forest definition which is being dominated by a composition of native tree species. In hybrid classification method, conjunctive use of visual interpretation, NDVI and supervised classification technique were used in view of phenological variations and field information to be incorporated in terms of context, association and texture to delineate different vegetation type classes. Initially major vegetation types were put to intensive study of its tone, texture, pattern and its associated features from the enhanced false colour composites.

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