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Estimation of biomass density and carbon storage in the forests of Andhra Pradesh, India, with emphasis on their deforestation and degradation conditions

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ABSTRACT

The current study evaluates the growing stock, biomass and carbon content of Andhra Pradesh state's forest (India) along with its current status of forest degradation and loss. For this purpose, the study used the growing stock data collected by state forest department in 2010 for the calculation of biomass and carbon storage using the standard conversion and expansion factors given by IPCC. The analysis shows low biomass and carbon values for the state's forest in comparison to the mean values recorded in different studies made for Andhra Pradesh. It is also observed to be lower when compared with the average carbon and biomass for Indian forests. Overall, the analysis showed degradation and loss of forest in the state, coupled with reduction in biomass and carbon sink.

KEYWORDS

forest degradation – plantations – canopy density – afforestation – encroachment

INTRODUCTION

Forests play an important role in global carbon cycle, and especially, tropical forests have major share in sequestering total earth's carbon as they account for 50% of global biomass (Chapin et al. 2002). However, forests, which act as sinks as well as source of carbon (Haripriya 2002), are degraded rapidly because of both natural calamities and manmade activities (Hooijer et al. 2010). This has resulted in the increased carbon emissions in the atmosphere (van der Werf et al. 2009), thereby affecting the climatic patterns (Bala et al. 2007). Based on the ever increasing carbon dioxide (CO_2) contents in the atmosphere, it is estimated that the global carbon stock will rise by a net value of 290 Gt, which has direct impact on climate, leading to redistribution of tree lines of forest ecosystems (IGBP 1998). Therefore, forests, which act as major key players of carbon sequestration, are at high priority for protection, management and conservation measurements (Johnson & Kern 2002; Canadell & Raupach 2008). Alternatively, plantation activities gained significant importance, as they are immediate apparatus that can sequester and store a good amount of carbon in the form of biomass (Prasad et al. 2012).

Carbon in forest (agro) ecosystems is sequestered both in vegetation as well as in the soil (Sedjo et al. 1998; Takashi et al. 2007; Sharma et al. 2011). The carbon content and the biomass of the forests are interrelated, and quantifying biomass helps in understanding the changing carbon pool and productivity within defined ecosystem (Marland 1997). A change in the biomass reflects the amount of carbon sequestered by a tree, as 50% of the forest dry mass is inferred to the net intake of carbon (Pan et al. 2011; Irvin et al. 2012). The total forest carbon pool can be assessed by measuring the biomass at both above and below the ground that is, at root part (Hairiah et al. 2001). Research studies (Malhi et al. 2002; Negi et al. 2003) showed that 43-50% of tree biomass consists of carbon, and this varies according to the geographical locations, climatic conditions, species, their age, land use and land cover (LULC) changes and management practices (Van Noordwijk et al. 1997). Thus, managing and monitoring the forests at regular intervals help the forest managers to assess the growing stock of the region, which subsequently provide details on the biomass density and carbon amount hold by the forests.

Forest biomass either at global level or at regional level can be estimated using mean biomass densities from ecological studies, from field inventories by assessing growing stock or by GIS (Geographical Information System) modelling of spatial data (Chhabra et al. 2002). Within Indian scenario, studies have been carried out to estimate the biomass and carbon sequestration by assessing the growing stock in different forest types and for the entire country (Singh et al. 1985; Dadhwal & Shah 1997; Ravindranath et al. 1997; Lal & Singh 2000; Chabra et al. 2002; Manhas et al. 2006; Sharma et al. 2010; Sheikh et al. 2011). With reference to Andhra Pradesh (AP) state, India, few studies have recorded values for growing stock, carbon and biomass for different time periods. However, studies at national level provide only mere values, and detailed state level information can be depicted if narrowed down to lower scales, say at district or forest division levels. This kind of study brings out the contribution of the state forest in terms of their carbon storage, active performance in climate change mitigation along with their degradation status.

1. OBJECTIVES

In view of the above context, in the current study, an attempt has been made to estimate the status of biomass areal density (BD) and carbon storage (CS, areal density) of AP state forests, India, at micro level, that is, at the level of forest circle. The study used the growing stock density (GS, above ground) assessment field inventory data of AP state Forest Department (APFD) collected in 2010. Study also focused on the factors that have contributed to the deforestation and degradation of forests linking with changes in GS, BD and CS in temporal domain.

1.1. Study area

The study represents the analysis done before the bifurcation of AP state into Andhra Pradesh and Telangana states. We refer both the states as AP to compare with the previous studies done for AP forest (both the states put together) at national level. AP is the fourth largest state of India and lies between 12° 40′ and 19° 50′ E North Latitude and 76° 45′ and 84^0 40′ East Longitude. The state has 23 districts, covering an area of 27.51 million hectares (M ha) and is divided into three regions as *Telangana* comprising 10 districts, *Coastal Andhra* with 9 districts and *Rayalaseema* having 4 districts (Fig. 1).

The state ranked as the second largest state of India in terms of forest area occupying 63,81,400 ha (notified area). Khammam district has high area under forest (8, 43, 694 ha) and Krishna district under least (66, 428 ha). The average forest area per capita is 0.07 ha (AP State of Forest Report 2013). The state forest area is categorized as Reserved (79%), Protected (19.4%) and unclassified forests (1.5%). There are 6 National Parks and 21 Wildlife Sanctuaries under the umbrella of Protected Area Network (AP State of Forest Report 2010)). As per

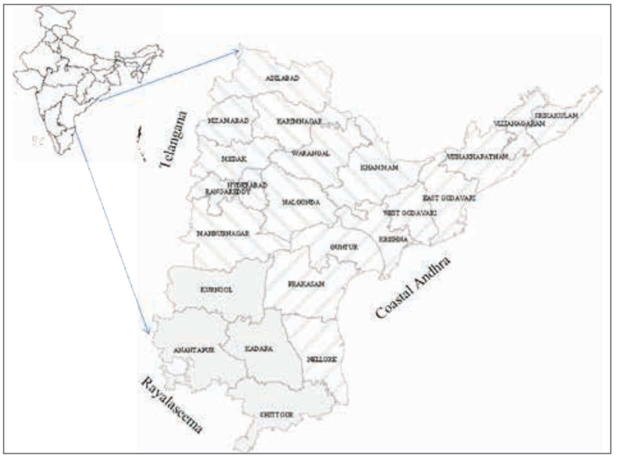

Figure 1. Map showing study area with three regions of Andhra Pradesh state, India.

Champion and Seth (1968), the state shows five important forest types *viz*: tropical dry deciduous forests, 28,43,100 ha (5A/C1); southern tropical moist deciduous forests, 16,10,000 ha (3B/C2); southern tropical thorn forests, 16,11,000 ha (6A/C1); littoral,2,85,600 ha (4A/L1) and tidal swamp mangrove forests, 31,700 ha (4B/TS2).

State depicts hot and humid climate with summer and winter temperatures ranging between 20–45°C and 13–30°C , respectively. Though climate of the state is mainly influenced by south-west monsoon, it receives major rainfall from north east monsoons recording annual rainfall between 1100 and 1250 mm (AP State of Forest Report 2010). However, there is variation in climatic conditions encompassed by three regions of the state with fluctuations in the amount of humidity, precipitation and temperatures. The LULC map (2013) generated by National Remote Sensing Centre using satellite data (AP State of Forest Report 2013) showed different thematic classes of the state as forest including scrub (55,66,400 ha), agriculture (16,82,100 ha), land with scrub (17,13,800 ha), fallow lands (10,33,400 ha), grasslands (65,200 ha), settlements (2,63,300 ha), vegetation outside the forest (9,13,300 ha) and water bodies (10,34,300 ha).

2. METHODS AND MATERIALS

The study is a meta-analysis of the data derived from the field inventory report (refer AP State of Forest Report 2010) and annual reports (2009, 2010, 2011, 2012 and 2013) of APFD including other literature data available for the state's forest. The APFD used satellite data to prepare detailed vegetation type and canopy density map. These maps were used to analyse the spatio-temporal changes in the forest area as well as in density classes and are presented in their annual reports, which were further used in the current study to quantify the forest properties changes.

The main objective of the field inventory carried out by APFD is to collect qualitative and quantitative information about state forest resources and to assess species-wise distribution and GS in different canopy density classes of forests (AP State of Forest Report 2010). The GS is calculated as the volume occupied by all the living trees with a diameter of 10 cm and beyond at breast height. The field inventory plots were randomly distributed using the vegetation-type-wise density map generated from satellite data. Overall, 2,095 plots in dense forest (DF), 2,587 in open forest (OF) and 2,234 in scrub class were sampled in the entire inventory, accounting to a total of 6,916 plots. DF refers to an area with more than 40% canopy closure, OF 10–40% and scrub less than 10%. The size of each plot is 0.1 ha (dimensions of 22.36 m × 31.62 m) and within each plot, enumeration of trees along with their girth and height measurements were collected (AP State of Forest Report 2010).

For calculation of GS, equations were used from different sources such as local volume table of the concerned working plan, volume table of species in similar ecosystem or in other parts of country and from the general volume table of phyto-morphologically similar species (AP State of Forest Report 2010). With reference to the BD, a sum weight of above and below ground parts is counted as total biomass, and in the current study, only above ground dry matter of trees was assumed and accounted as BD. APFD study was restricted only in assessing the GS of the forest, and this data is further used in the current study to evaluate BD and CS of AP forests. For estimation of BD and CS from the GS, the default value of 0.95 was used as the conversion and expansion factors, to convert volume (m^3) to BD (expressed as tonnes of dry matter) and a factor of 0.45 for converting the BD into CS, as prescribed by IPCC guideline (1995), similar to the study of Lal and Singh (2000).

The entire forest area was divided into 12 territorial circles covering 23 districts of the state and the analysis was performed in three forest canopy density classes of each circle. Each circle has its own subclasses referred as "Divisions" (Table 1). Further, the GS data of the state available for various time periods from different sources is also converted to derive the BD and CS values for comparison.

3. RESULTS AND DISCUSSION

3.1. At region level

Telangana region showed large forest area of 2,59,875 ha, followed by Coastal Andhra (24,06,285 ha) and Rayalaseema (13,76,360 ha), with respect to the geographical extent covered by them. Similar patterns for GS, BD and CS were observed, except for number of stem density per hectare where Rayalaseema showed values greater than or equal to that of Coastal Andhra region (Table 2).

3.2. At forest level

The total GS, BD and CS of the state accounted to 232.08 M m^3, 220.49 Mt and 99.22 Mt from all the three forest density classes. The estimations from 1975 data (AP State of Forest Report 2010), for the state showed GS of 291.3 M m^3 that accounts to a BD of 276.7 Mt and CS of 124.5 Mt. This indicates a huge loss of forest area linked with net change of GS of 59.22 M m^3, BD of 56.3 Mt and CS of 25.3 Mt from 1975 to 2010 (approximately 45 years period). The assessment of Manhas et al. (2006) for the periods 1984–1994 and 1991–1994 for the state recorded a loss of 27.65, 27.28 M m^3 of GS, 20.81, 20.53 Mt of BD and 9.35, 9.23 Mt of CS, respectively, accounting to a loss of 26.5% of forest area. They reported Podu cultivation (a kind of shifting cultivation adopted by tribal people) as major reason for deforestation. It is observed from this study that much loss of forest occurred mostly during 1991–1994 period (within a span of four years).

The Forest Survey of India (FSI) assessment for the year 2009 estimated about 242.39 M m^3 volumes of GS for the state (Indian State of Forest Report 2009). Thus the net change

Table 1. Forest circle and divisions in Andhra Pradesh state Forest Department.

S.No	Circle	Divisions
1	Adilabad	Adilabad, Bellampally, Jannaram, Kagaz Nagar, Mancherial, Nirmal
2	Anantapur	Anantapur, Chittoor west
3	Guntur	Giddalur, Guntur, Nellore
4	Hyderabad	Hyderabad, Mahabubnagar, Nalgonda
5	Khammam	Bhadrachalam North and South, Khammam, Kothagudem, Paloncha, Paloncha WLM
6	Kurnool	Kadapa, Kurnool, Nandyal, Proddutur
7	Nizamabad	Kamareddy, Medak, Nizamabad
8	Rajahmundry	Eluru, Kakinada, Krishna
9	Srisailam	Achampet, Atmakur, Markapur, Nagarjuna Sagar
10	Tirupati	Tirupati, Chittoor, Rajampet
11	Visakhapatnam	Narsipatnam, Paderu, Srikakulam, Visakhapatnam, Vizianagaram
12	Warangal	Karimnagar East and West, Warangal WLM, Warangal North and South

Table 2. Forest growing stock (GS), biomass density (BD), and carbon storage (CS) in three regions of Andhra Pradesh state, India.

Region	Forest area (ha)	Non-forest area (ha)	Total area (ha)	Total GS (M m^{3})	Total stem density (M)	BD (Mt)	CS (Mt)	GS m^3 ha-1	Stem density ha^{-1}	BD Tonnes ha^{-1}	CS Tonnes ha^{-1}
Telangana	2247206	351580	2598785	113	521	107	48	43	201	41.2	18.6
Coastal Andhra	1952719	453567	2406285	92	394	88	40	38	164	36.5	16.4
Rayalaseema	1070726	305634	1376360	27	228	26	11	20	165	18.5	8.3
Total	5270650	1110780	6381431	232	1143	220	99	36	179	34.5	15.5

in GS, BD and CS during 2009–2010 (current inventory) accounts to 10 M m^3, 2 Mt and 4 Mt, respectively (approx). This is perhaps a big change indicating rapid loss of forested area. Further as per FSI report of 2011, between 2009 and 2011 the state has lost an area of 28, 100 ha of forest cover and topped the list of forest loss states (Kumar, 2012). The decrease in forest is primarily attributed to illegal felling of trees by the Maoists (local terrorist) mostly in Khammam district and management practices adopted by APFD, besides illegal logging and forest land encroachments by local people (India's forest cover decreasing," 2012; Kumar 2012).

For the year 1995, FSI estimated GS of 291 M m^3 with an average value of 61.66 m^3 ha^{-1}, whilst for the current inventory (2010), it is 36.68 m^3 ha^{-1}. A decrease trend is observed from 1995 to 2010. Kaul et al. (2010) calculated mean annual average biomass increment for the state as 0.763 t ha^{-1} and estimated an increase in BD for DF (18.8 t ha^{-1}) and OF (6.0 t ha^{-1}) for the decade 1992–2002. But, overall, it is observed that there is ongoing degradation and decrease in forest cover for the state from 1992 to 2002.

Based on GIS spatial modelling, Brown et al. (1999) quantified the potential and actual BD of Indian forests to be in the order of 402 and 154 t ha–^{1}, respectively. Chhabra et al. (2002) in their 1992–1993 study estimated an average GS volume and BD Indian forests to be 74.42 m^3 ha^{-1} and 135.6 t ha^{-1}, respectively. It was estimated that the mean CS within Indian forests ranges between 30 and 68 t ha^{-1} (Kaul et al. 2010). However, in the current study, for the state, it is observed to be 36.68 m^3 ha^{-1} (GS), 34.55 t ha^{-1} (BD) and 15.5 t ha^{-1} (CS). These were the estimates when we considered non-forest regions of forested area (which is referred as notified forest area) for calculation. Even if we take into account only the forested area with tree cover for computation, the values for GS accounts to 44.03 m^3 ha^{-1}, BD to 41.83 Mt and CS to 18.82 Mt, which are lower compared with the average values of Indian forests.

A comparison of Food and Agriculture Organization (FAO) assessment (The state of forestry in the country and major trends, 1995) with the current state forest report (AP State of Forest Report 2013) showed an area of 50,47,900 ha, 50,47,863 ha as Reserve forest, 12,36,500 ha, 12,36,534 ha as Protected forest, 97,000 ha, 96,976 ha as unclassified areas, 24,82,700 ha, 19,33,234 ha under DF and 21,90,200 ha, 22,59,492 ha as OF respectively. This shows the changes both in the forest categories as well as in the density classes. Though at the forest level changes are minimal, significant major alteration has been observed in forest canopy density classes. An area of 5,49,466 ha of DF was converted to OF, scrub and other non-forest areas. Interestingly, FAO (1995) reported shifting cultivation as one of the reasons for forest degradation, and in the current scenario, different socio-economic and policy driven factors are added for loss of forests, in addition.

3.3. At Circles level

Amongst the 12 forest circles, Khammam circle showed maximum forest area of 7,94,534 ha, forming 12% of the total state's forest area (Table 3). It also recorded high GS (contributing 19% of the state's GS – 42.9 M m^3), stem density (193.59 million), BD (40.46 Mt) and CS (18.2 Mt) values. In contrast, Hyderabad circle showed minimum values for all the parameters. Comparing the values at per hectare level, Visakhapatnam circle showed high GS (57.83 m^3 ha^{-1}) BD (5.49 t $ha^{-1)}$ and CS (2.47 t ha^{-1}), whilst Tirupati showed high number of stem density per hectare (263) and Anantapur showed the least (82 stem density ha^{-1}). Forest growth was observed in Prakasam, Adilabad and Karimnagar divisions and a drastic decrease in Khammam and Warangal (Chetan, 2011).

3.4. At canopy level

Maximum numbers of plots (926) were sampled in Srisailam circle. If analysed areawise, high proportion of DF and OF is found in Khammam circle (3,99,558 and 2,85,104 ha, respectively) and scrub in Visakhapatnam Circle (84,562 ha). With reference to stem density per hectare, low and high numbers were recorded in Anantapur (179,108) and Tirupati (370,251) in DF and OF classes, respectively. In the case of scrub, analysis showed lower in Anantapur (50) and higher in Guntur (197). In terms of GS, BD and CS, Visakhapatnam circle showed maximum values in DF, and Khammam circle showed maximum values both in OF and scrub classes, whilst

Table 3. Total growing stock (GS), biomass density (BD) and carbon storage (CS) in different circles of Andhra Pradesh forest.

Forest Circle	Forest cover (ha)	Non-forest area within forest (ha)	Total area (ha)	GS (M m^{3})	Total stem density (M)	BD (Mt)	CS (Mt)	GS m^3 ha-1	Stem density ha^{-1}	BD Tonnes ha^{-1}	CS Tonnes ha^{-1}
Adilabad	610827	99302	710129	33.14	131.83	31.483	14.167	46.67	186	44.33	19.95
Anantapur	273672	129864	403536	4.25	32.97	4.0375	1.8169	10.53	82	10.01	4.50
Guntur	422214	184222	606436	10.17	86.48	9.6615	4.3477	16.77	143	15.93	7.17
Hyderabad	136576	45915	182491	1.42	16.19	1.349	0.6071	7.78	89	7.39	3.33
Khammam	710225	84309	794534	42.59	193.59	40.4605	18.207	53.60	244	50.92	22.92
Kurnool	427415	128652	556067	10.72	84.86	10.184	4.5828	19.28	153	18.31	8.24
Nizambad	229850	43305	273155	7.76	48.05	7.372	3.3174	28.41	176	26.99	12.14
Rajahmundry	399579	65715	465294	26.42	90.58	25.099	11.295	56.78	195	53.94	24.27
Srisailam	594379	82932	677311	17.84	105.47	16.948	7.6266	26.34	156	25.02	11.26
Tirupati	369640	47118	416758	11.89	109.77	11.2955	5.083	28.53	263	27.10	12.20
Visakhapatnam	536547	120697	657244	38.01	111.17	36.1095	16.249	57.83	169	54.94	24.72
Warangal	559727	78749	638477	27.87	131.71	26.4765	11.914	43.65	206	41.47	18.66
Andhra Pradesh	5270650	1110780	6381431	232.08	1142.67	220.476	99.214	36.368	179	34.55	15.55
Values when considered only forest cover								44.033	217	41.83	18.82

Hyderabad circle showed lower values in all the three forest density classes (Table 4).

3.5. At species level

A compilation of all the top species that has contributed to significant GS in each circle resulted in a total of 40 species from all the 12 circles (Appendix 1). These 40 species contributed a major proportion of 108.27 M m^3 of the total recorded GS of 232.08 M m^3. Out of 40, maximum numbers of species (16) were recorded in Visakhapatnam circle and minimum in Nizamabad (7). Five species, *Anogeissus latifolia, Xylia xylocarpa, Terminalia tomentosa, Tectona grandis* and *Lannea coromandelica* were observed as top five species contributing a good share to GS, BD and CS in the state forest (Appendix 1). If we observe circlewise, Adilabad with six species showed high GS of 19.66 M m^3 and Hyderabad with eight species showed lower GS of 0.42

Table 4. Forest circle wise number of plots sampled, forest area (ha), stem (ha-1) growing stock - GS (million m^3), biomass density-BD (Million tonnes, Mt), Carbon storage - CS (Mt)in different canopy density classes.

	Canopy density classes		Dense forest					Open forest					Scrub				
S.No	Forest Circle	No. of plots	Area	Stem density	GS	BD	CS	Area	Stem density	GS	BD	CS	Area	Stem density	GS	BD	CS
1	Adilabad	670	367925	262	25.08	23.83	10.72	206885	160	7.62	7.24	3.26	36018	60	0.44	0.42	0.19
2	Anantapur	367	94660	179	2.19	2.08	0.94	121577	108	1.59	1.51	0.68	57434	50	0.47	0.45	0.20
3	Guntur	738	223169	274	7.80	7.41	3.33	165121	113	2.12	2.01	0.91	33924	197	0.25	0.24	0.11
4	Hyderabad	265	27495	215	0.51	0.48	0.22	66367	114	0.63	0.60	0.27	42714	63	0.28	0.27	0.12
5	Khammam	807	399558	319	29.22	27.76	12.49	285104	224	12.95	12.30	5.54	25563	78	0.41	0.39	0.18
6	Kurnool	677	229717	261	8.00	7.60	3.42	151386	144	2.25	2.14	0.96	46311	67	0.47	0.45	0.20
7	Nizambad	287	62303	300	3.06	2.91	1.31	138260	197	4.46	4.24	1.91	29287	71	0.24	0.23	0.10
8	Rajahmundry	495	328578	237	23.90	22.71	10.22	60360	195	2.33	2.21	1.00	10641	75	0.20	0.19	0.09
9	Srisailam	926	264370	237	11.11	10.55	4.75	264806	147	5.97	5.67	2.55	65202	60	0.76	0.72	0.32
10	Tirupati	479	178257	370	7.76	7.37	3.32	163483	251	3.92	3.72	1.68	27900	97	0.21	0.20	0.09
11	Visakhapatnam	663	333328	251	29.57	28.09	12.64	118656	181	6.12	5.81	2.62	84562	72	2.33	2.21	1.00
12	Warangal	542	321574	277	20.46	19.44	8.75	207820	194	6.94	6.59	2.97	30333	70	0.47	0.45	0.20
13	Andhra Pradesh	6916	2830935	271	168.66	160.23	72.10	1949825	174	56.90	54.06	24.32	489891	76	6.53	6.20	2.79

M m^3. Two species *A. latifolia and T. grandis* were also recorded amongst the top 10 species in the study carried out by FSI for the entire country's GS estimations for 2009 (Indian State of Forest Report 2009).

3.6. Forest loss (BD and CS) in the state during 2006–2013.

3.6.1 Deforestation, degradation and encroachment

The data from the state forest report (AP State of Forest Report 2008) showed decrease in degradation of forest from 1996 to 2006 as 35,04,400 ha to 23, 88,500 ha. However, as per the state forest report (Indian State of Forest Report 2009), there was a loss of 12,900 ha of forest cover during 2006–2007. The reason for such a loss is attributed to rotational/clear felling of mature *Eucalyptus* plantation by APFD and encroachment because of local disturbances especially in Adilabad, Khammam and Warangal districts. Subsequently, there is a net change of 10,796 ha of forest area during 2007 and 2008 and maximum was found in Khammam circle (5,852 ha) followed by Rajahmundry circle (2,275 ha).

Encroachments during this period, contributed to 65% of the change along with management activities of tree felling for raising plantations by APFD. An observation of the total forest extent between 2008 and 2009, showed an area of 13,095 ha under degradation and 2,364 ha as a positive change. The degradation is noticed from higher canopy density class to lower canopy density class. It was reported that an area of 10,497 ha (out of 13, 095) was converted to non-forest area of which 5,673 ha was lost because of encroachments and rest 4,824 ha for plantation activities. Apart from agricultural encroachments, quarries, hydroelectric projects and shifting cultivation by local dwellers added their contribution in the forest degradation (AP State of Forest Report 2008). A maximum change was found in Khammam, Kothagudem and Warangal south divisions.

Compared to previous year, forest degradation (6,999 ha) decreased in 2009 and 2010 with a net positive change of 585 ha. Out of the recorded degraded area, 5,273 ha was lost as conversion of different forest density classes to non-forest category. Overall, a net loss of 3,644 ha of forest area was recorded because of encroachments after subtracting an area of 1,629 ha as loss owing to management practices by the APFD. The encroachments were mostly observed in Bhadrachalam South, Kothagudem, Khammam, Warangal South and North and Paloncha divisions. An assessment of state forest report (AP State of Forest Report 2013) for 2010 and 2011 periods showed degradation of forests from higher canopy density class to lower canopy density class to an extent of 10,548 ha. There is a positive change of 1,281 ha and a negative change of about 4,377 ha because of encroachments, with maximum in Khammam, Warangal and Visakhapatnam circles. In all the forest assessment reports (2010, 2011, 2012 and 2013), the forest loss under the management interventions of raising and harvesting plantation was not considered as negative change.

Overall, analysis of the reports for the periods 2010, 2011, 2012 and 2013 showed decrease in the forest cover from 42,24,760 ha (2010) to 41,92,726 ha (2013) along with decrease in very DF and an increase in OF and scrub classes. The negative change (32,034 ha) noted was primarily because of forest degradation and conversion into other non-forest classes, with trivial positive change (4,200 ha) because of afforestation programmes and protection of the degraded areas carried out by the APFD. Thus, the net loss of forest accounts to 27,834 ha, and considering the values at per hectare level (Table 3), we can estimate an expected loss of 1.23 M m^3 of GS, 6.03 M of stem density and 1.16 Mt of BD along with 0.52 Mt of carbon sink dearth for the reported periods. Thus the loss of GS is linked with deforestation and degradation, primarily by anthropogenic interventions rather than natural disasters.

On the basis of 2007–2009 assessment of forest cover in India, it was estimated that the AP state has lost an area of 28,100 ha contributing to a decline of 76.5% of net national forest cover (Nikita 2012) and this is mainly due to the harvest of *Eucalyptus* plantation by the APFD and illegal encroachment by the tribal under the Forest Right Act around 2007–2009 (Forest Act blamed for shrinking green cover in Andhra Pradesh, 2012; Nikita 2012). It was reported that the encroachments were done in the guise of Forest Right Act enforced in 2006, causing illegal felling of trees and cultivation in the state's forests areas. The law was brought into action in order to provide justice to the forest dwellers, the tribals, for their sustainable livelihood allowing them to occupy forest land for agriculture and habitations (Chetan, 2011). It was observed that this Forest Right Act proved to be curse for the state forests that has resulted in the loss of 8,400 ha of forest by the way of encroachment during 2009–2011 by the tribals to claim their ownership on that land (Forest Act blamed for shrinking green cover in Andhra Pradesh, 2012). The survey conducted by National Rainfed Authority observed 11,000 ha of forestland as being encroached in the state under the Forest Right Act (Chetan, 2011). High encroachment was observed in Khammam district (1,928 ha) followed by Warangal (666 ha) and Nizamabad (246 ha) (Gowri 2012). In the past too, the state topped in the lists of Indian states for high incidents of encroachments with a record of 3,41,322 ha (Jeevan 2002), and as on 2011, about 2,56,000 ha of area was found to be under encroachment (Encroachment of Forest Land in the Country, 2011).

It is observed from the state forest inventory (AP State of Forest Report 2010) that an area of 350,000, 938,000 and 23,56,000 ha were recorded as high, medium and low degraded conditions of forests, respectively, with most of the trees badly mutilated and partially damaged. Deforestation results in the absence of sinks for carbon and degraded forest logs may act as carbon emitters in the later conditions, becoming the source. The inventory (2010) also revealed that the state's GS has decreased by 60 M m^3. As a direct result of the depleting GS, experts say that the state will experience adverse climate changes and increasing temperatures.

3.7. Frequent forest fire incidents

Fire is a major threat to the forests resulting in the damage of both vegetation and soil. Overall, the inventory (AP State of Forest Report 2010) reported an area of 36,69,000 ha as fire prone in the category of high (2,11,000 ha) where trees are burnt and dead, medium (11,64,000 ha) where bark, but not crown, is burnt and tree is alive and low (22,94,000 ha) where undergrowth is burnt. The survey by FSI reported forest fires as major reasons for drop in the state's forest cover in 2012. As per their analysis, the state recorded highest incidents of forest fires (506) in a span of 51 days (as on February 24, 2012) and mostly (169) from Khamman, Adilabad and Mahbubnagar districts (Forest fires main cause of drop in green cover in AP: survey, 2012). This happened by the controlled burning action taken by the APFD coupled with illegal ground clearing by tribal community. The study of Prasad et al. (2008) reported an area of 6,36,900 ha under burnt area in 2000, and Reddy et al. (2012) estimated the area as 8,59,400 ha for 2009. So, there is an increase of 2,22,500 ha, burnt area from 2000 to 2009 and even more if current inventory results are considered as well. Thus the loss of forest accounts to the loss of GS, BD and eventually CS.

The estimations of forest fire scenarios from 2004 to 2013, using MODIS satellite data for the state showed an increase trend of fire accidents accounting to 15,856 recording high number of 2,454 incidents in 2009. Also, the forests being mostly dry deciduous in nature the frequency of occurring of the incidents were observed more in the months of February and April (AP State of Forest Report 2013). Forest fires not only decrease the carbon sink resources but also emit carbon by burning the logs with impact on state's climate.

4. CONCLUSIONS

The current study provides estimations about GS, BD and CS of state forest at forest circle level in contrast to the national studies done previously, which showed the values at state levels. Assessment at the micro-level (circle) helped in identifying the regions where more emphasise should be focused towards protection and management activities. The field inventory of the state forest was carried out by the APFD for the first time, which provided detailed information on GS of the forest. It is reported that considerable proportion of GS (dense canopy areas) is restricted to the northern fringe areas of the state bordering Maharashtra, Chhattisgarh and Orissa states of India. However, these areas are not sampled as they are occupied by naxals (local terrorists) and are probably difficult to survey, based on their topography. It will be more informative if data on GS is collected based on elevation and aspect of the region, as these factors also influence the GS in terms of carbon absorption and can help in identifying the potential sites of carbon sequestration.

The BD and CS values derived using GS are found to be lower compared to average Indian values for different forest ecosystems. However, in the current study, only above ground tree mass was considered for calculation of BD and CS of the forests. The study revealed BD and CS status currently the forest holds, in addition to the driving factors that are threatening the structure of the forests. Khammam, Warangal and Visakhapatnam circles were found to be more vulnerable to forest changes because of various factors.

The overall idea of this study is to arrive at some figures as a baseline data about the current position of the forest in terms of its BD and CS. Further, these values can be used to monitor and assess the spatio-temporal changes at regular interval of time and to implement better protection and conservation measures. Thus managing, checking and controlling the illegal activities more effectively (which indeed a challenging task) can make the state's forest to play active role as sink rather than source of carbon.

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Appendix 1. Dominant species encountered in different circles of AP forest along with their growing stock (GS), biomass density (BD) and carbon storage (CS).

Forest Circle	Adila-bad	Ananta-pur	Guntur	Hydera-bad	Kham-mam	Kurnool	Nizam-bad	Rajah-mundry	Srisa-ilam	Tirupati	Visa-khapat-nam	Waran-gal	Total	BD	CS
Species	GS (million m³)													Mt	Mt
Anogeissus latifolia	2.77	---	0.78	---	4.52	1.03	---	1.73	1.32	0.63	2.35	1.96	17.09	16.24	7.31
Xylia xylocarpa	---	---	---	---	4.99	---	---	5.38	---	---	2.04	0.61	13.02	12.37	5.57
Terminalia tomentosa	0.95	---	1.07	---	3.58	---	---	0.99	0.84	---	1.55	2.55	11.53	10.95	4.93
Tectona grandis	7.84	---	---	---	---	---	0.87	---	---	---	---	1.31	10.02	9.52	4.28
Lannea coromandelica	1.14	---	---	---	1.99	0.59	0.76	0.30	0.36	---	1.42	2.12	8.68	8.25	3.71
Madhuca indica	2.54	---	---	---	1.94	---	1.17	---	---	---	---	1.86	7.51	7.13	3.21
Hardwickia binata	---	0.15	1.40	0.15	---	0.67	---	---	3.53	0.36	---	0.33	6.59	6.26	2.82
Mangifera indica	---	---	---	---	---	---	---	1.40	---	---	3.91	---	5.31	5.04	2.27
Dalbergia paniculata	0.60	0.43	0.40	---	0.40	0.42	1.15	0.17	0.33	0.30	0.22	0.78	5.20	4.94	2.22
Boswellia serrata	3.18	---	---	---	---	0.23	0.61	---	---	---	---	0.18	4.20	3.99	1.80
Pterocarpus marsupium	---	---	0.51	---	---	0.41	---	0.98	0.66	---	1.26	0.17	3.99	3.79	1.71
Diospyros melanoxylon	---	---	---	---	1.25	---	---	---	---	---	---	0.79	2.04	1.94	0.87
Pterocarpus santalinus	---	---	0.16	---	---	0.75	---	---	---	1.04	---	---	1.95	1.85	0.83
Tamarindus indica	---	0.10	---	---	---	---	---	---	0.56	---	0.95	---	1.61	1.53	0.69
Terminalia arjuna	0.36	0.09	---	---	---	---	---	---	---	---	---	0.83	1.28	1.22	0.55
Syzygium alternifolium	---	---	---	---	---	---	---	---	---	1.03	---	---	1.03	0.98	0.44
Semicarpus anacardium	---	---	---	---	---	---	---	---	---	---	0.79	---	0.79	0.75	0.34
Chloroxylon swietenia	---	---	0.07	---	---	---	0.07	---	0.62	---	---	---	0.76	0.72	0.32
Albizia amara	---	0.34	0.15	0.03	---	0.04	---	---	0.07	---	---	---	0.63	0.60	0.27
Terminalia chebula	---	---	---	---	---	---	---	---	---	0.34	0.22	---	0.56	0.53	0.24

continued: *Appendix 1. Dominant species encountered in different circles of AP forest along with their growing stock (GS), biomass density (BD) and carbon storage (CS).*

Dillenia pentagyna	---	---	---	---	0.50	---	---	---	---	---	---	---	0.50	0.48	0.21
Shorea robusta	---	---	---	---	---	---	---	---	---	---	0.50	---	0.50	0.48	0.21
Garuga pinnata	---	---	---	---	0.26	---	---	0.07	---	---	0.16	---	0.49	0.47	0.21
Cleistanthus collinus	0.28	---	---	---	---	---	---	---	---	---	---	0.17	0.45	0.43	0.19
Excoecaria agallocha	---	---	---	---	---	---	---	---	---	---	0.41	---	0.41	0.39	0.18
Wrightia tinctoria	---	0.17	---	0.04	---	---	---	---	---	0.13	---	---	0.34	0.32	0.15
Gyrocarpus americanus	---	0.12	---	0.03	---	0.11	---	0.05	---	---	---	---	0.31	0.29	0.13
Anacardium occidentale	---	---	---	---	---	---	---	---	---	0.21	0.07	---	0.28	0.27	0.12
Butea monosperma	---	---	---	---	---	---	0.06	---	---	---	---	0.19	0.25	0.24	0.11
Ficus benghalensis	---	---	---	---	---	---	---	---	---	---	0.22	---	0.22	0.21	0.09
Ficus benjamina	---	0.13	---	---	---	---	---	---	---	---	---	---	0.13	0.12	0.06
Holarrhena antidysenterica	---	---	0.07	---	---	0.04	---	---	---	---	---	---	0.11	0.10	0.05
Drypetes separia	---	---	---	---	---	---	---	---	---	0.10	---	---	0.10	0.10	0.04
Eucalyptus camaldulensis	---	---	0.10	---	---	---	---	---	---	---	---	---	0.10	0.10	0.04
Ficus mollis	---	---	---	0.07	---	---	---	---	---	---	---	---	0.07	0.07	0.03
Manilkara hexandra	---	---	---	0.03	---	---	---	---	0.03	---	---	---	0.06	0.06	0.03
Ficus religiosa	---	---	---	---	---	---	---	---	---	---	0.05	---	0.05	0.05	0.02
Holoptelea integrefolia	---	---	---	0.05	---	---	---	---	---	---	---	---	0.05	0.05	0.02
Borassus flabellifer	---	---	---	---	---	---	---	0.04	---	---	---	---	0.04	0.04	0.02
Grewia rotundifolia	---	---	---	0.02	---	---	---	---	---	---	---	---	0.02	0.02	0.01
Grand Total	19.66	1.53	4.71	0.42	19.43	4.29	4.69	11.11	8.32	4.14	16.12	13.85	108.27	102.86	46.29
No. of species	9	8	10	8	9	10	7	10	10	9	16	14	40		