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Spatial analysis of area and carbon stocks under *Populus deltoides* based agroforestry systems in Punjab and Haryana states of Indo-Gangetic Plains

R. H. Rizvi · A. K. Handa · K. B. Sridhar · R. K. Singh · S. K. Dhyani · Javed Rizvi · Gaurav Dongre

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Abstract Various agroforestry systems are prevalent in different agro-climatic regions of India and occupy sizeable area. *Populus deltoides* (poplar) based agroforestry systems are very predominant in Indo-Gangetic Plains of northern India. These systems are not only meeting wood demand of wood-based industries but also contributing significantly in generating employment, reducing atmospheric CO_2 vis-à-vis mitigating climate change. The present study aimed at estimating area under poplar plantations and assessment of biomass production and carbon stock at district level for selected districts of Punjab and Haryana states. High resolution multispectral remote sensing data (LISS-IV, spatial resolution- 5.8 m) have been used for mapping poplar area in these districts. Growth data (tree density, diameter at breast height) from farmers' fields were collected for assessment of aboveground and total biomass. Poplar area in Hoshiarpur, Rupnagar, Ludhiana, Shahid Bhagat Singh Nagar, Yamunanagar, Kurukshetra and Karnal districts accounted for 3.19, 4.09, 1.02, 0.43, 7.25, 1.58 and 0.97%, respectively, of their geographical area. As percentage of agroforestry area, poplar area occupied 43.8% in four districts of Punjab and 53.4% in three districts of Haryana. Estimated carbon stock in total biomass of poplar plantations was 0.931, 0.481, 0.287, 0.040, 0.949, 0.256 and 0.229 million tonnes, respectively. CO_2 equivalent C in aboveground and total biomass was estimated to be 7.854 and 9.946 million t, respectively, in all these seven districts. The proposed methodology based on object-oriented image classification showed promis-

R. H. Rizvi (✉) · A. K. Handa
ICAR-Central Agroforestry Research Institute, Jhansi, India
e-mail: Raza.Rizvi@icar.gov.in

A. K. Handa
e-mail: Arun.Handa@icar.gov.in

K. B. Sridhar
ICAR-Central Research Institute on Dryland Agriculture, Hyderabad, India
e-mail: sriaranya@gmail.com

R. K. Singh · S. K. Dhyani · J. Rizvi
ICRAF South Asia Regional Program, World Agroforestry Centre, New Delhi, India
e-mail: Raj.Singh@cgiar.org

S. K. Dhyani
e-mail: S.Dhyani@cgiar.org

J. Rizvi
e-mail: J.Rizvi@cgiar.org

G. Dongre
ICAR-Indian Institute of Farming Systems Research, Modipuram, India
e-mail: gauravdongre9@gmail.com

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ing results as far as mapping of agroforestry systems/species is concerned.

Keywords Carbon stock (CS) · Indo-Gangetic Plains (IGP) · Object-based image analysis (OBIA) · *Populus deltoides* · Remote sensing (RS)

Introduction

Agroforestry in India received well deserved attention from different stake holders particularly policy planners and implementing agencies with the adoption of National Agroforestry Policy in 2014 (NAF, 2014) followed by National Mission on Agroforestry. It has been recognized as an alternate land use, which restores ecosystems by reclamation of degraded soils/lands, conservation of soil/water, amelioration of environment, livelihood security and mitigation of changing climate. Various agroforestry systems prevalent in the country are meeting demand of local communities as well as producing raw material for the industries. Pathak et al. (2000) gave an account of prominent agroforestry systems in different agro-climatic regions of India. Agri-silviculture and agri-horticulture systems in western and eastern Himalayan regions; agri-horti-silviculture system in upper and trans-Gangetic plains; agri-silviculture and silvipastoral systems in southern plateau & hilly regions are prominent systems in different agro-ecological regions. In India, the diagnostic survey and appraisal of agroforestry practices in the country revealed that there are enumerable practices in different agro-ecological zones, which occupies sizeable area but their accurate assessment is not yet known.

Currently India is net importer of wood and wood-based products and there is renewed efforts through National Agroforestry Policy (2014) to reduce import bill by increasing area under on-farm tree cover particularly of industrial agroforestry tree species. Before large-scale plantation of any particular tree species, there is need to understand the present status of that species in different agroforestry systems. These estimates will be very helpful in developing suitable decision support system for that particular agroforestry system. Different estimates of area under agroforestry at country scale are available, but they do not seem realistic due to lack of physical ground verification. Dhyani et al. (2013) estimated the agroforestry area as 25.32 million ha or 8.2% of the total geographical area of the country. In other words, on an average, 14.2% of total cultivated land has on-farm trees in one or the other. As per FSI (2013), 11.15 million ha area was found under green tree cover/agroforestry. For the purpose of agroforestry, only rural trees outside forest have been accounted. High resolution satellite data (LISS-IV) was used for stratification of culturable non-forest area into three strata viz. block, linear and scattered. Out of three strata, only block and scattered trees were accounted and linear stratum is excluded as they do not qualify the definition of agroforestry. Another estimate of area under agroforestry was given by Rizvi et al. (2019), which is 23.25 million ha in 12 agro-climatic zones out of 15 zones in India. Globally agroforestry, if defined by tree cover on agricultural land of greater than 10%, is found on more than 43% of all agricultural lands. This land-use type represents over 1 billion ha of land and more than 900 million people (Zomer et al. 2014).

Among the various agroforestry systems, *Populus deltoides* (Poplar) are dominant in Punjab, Haryana, south Uttarakhand, north-western Uttar Pradesh and central Bihar states of India. This species gained popularity among farmers due to its fast growth and short rotation (5–6 years). Its wood is used for making different products like ply, plyboard, matchstick, paper, packaging cases, etc. Due to its deciduous nature, it favors the farmers to grow *rabi* (winter) crops like wheat with little effect on crop yield (Chauhan et al. 2012).

Many studies have reported good potential of poplar trees in agroforestry systems in the carbon storage and sequestration (Rizvi et al. 2011; Singh and Gill 2014; Chauhan et al. 2015; Panwar et al. 2017) and recently Giri et al. (2019) concluded that poplar based agroforestry systems are sustainable land use system for increasing biomass, soil carbon and fertility as well as other ecosystem services in northern India.

Out of the five prominently poplar growing states—Punjab and Haryana states in northern India have considerable area under the species. However, the exact area and carbon storage under poplar based systems in the two states are not yet estimated, which is essential for planners to know wood production from this species to meet domestic requirement. Tauqeer et al. (2016) estimated area under *Populus*-

and *Eucalypts*-based agroforestry systems in only one district of Punjab (Ludhiana) using LISS-IV multispectral data. Keeping this in view, the present study was undertaken with the objectives: to estimate area under poplar-based agroforestry systems in selected districts of Punjab and Haryana states using geospatial technologies, and to quantify biomass production and carbon stocks in poplar plantations and their spatial pattern.

Materials and methods

Field survey and data collection

Four districts of Punjab state viz. Hoshiarpur, Ludhiana, Rupnagar and Shahid Bhagat Singh (SBS) Nagar and three districts of Haryana viz. Karnal, Kurukshetra and Yamunanagar were surveyed during August 2018. Growth data on poplar (*Populus deltoides*) plantations of different ages from these districts have been recorded. Field data on spacing, age of plantation, diameter at breast height for selected sample plots were recorded. Ground check points (GCPs) on poplar and other species were collected with the help of GPS and field plots of poplar plantations were also tracked. A total 89 GPS points were recorded out of which 69 were for poplar species. These GCPs were used for identification and generation of spectral signature for poplar species (Figs. 1 and 2).

Multispectral remote sensing LISS-IV (spatial resolution- 5.8 m) images for selected districts of Punjab and Haryana were procured from National Remote Sensing Centre, Hyderabad. Besides this, forest cover maps of selected districts were purchased from Forest Survey of India, Dehradun, India. This forest cover data were used to mask forest area from district area. Apart from data procurement, Sentinal-2A data (spatial resolution- 10 m) was also downloaded from USGS website. High resolution LISS-IV data were pre-processed and analyzed for mapping and estimation of area under poplar based agroforestry systems. Object-oriented image classification technique was applied for identification and mapping of trees on farmlands. For this purpose, object based image analysis (OBIA) module of ERDAS Imagine software was used (ERDAS 2009).

Methodology for mapping agroforestry/poplar species

Different steps involved in this methodology are described here:

1. Multispectral high resolution LISS-IV data (spatial resolution- 5.8 m) were procured from NRSC, Hyderabad.
2. Pre-processing of scenes includes layer stacking, mosaicking and sub-setting of LISS-IV bands (Green, Red & NIR) with district boundary shape file.
3. Unsupervised classification method (k-means/ ISODATA) was applied for getting different land uses and land covers (LULC) including forest cover.
4. Extracting the forest cover area from the FCC image with the help of LULC image of district.
5. OBIA Module: Applying single feature probability (SFP) with the help of training samples, background pixels (crop, bare soil, etc.) on FCC image. Thereafter, threshold and pixel probability are fixed for target feature (trees); output will consist of trees outside forest (TOF) in the form of polygons.
6. Post-classification correction was applied on TOF to remove trees along roads, canals, within urban areas, etc., to get agroforestry area.
7. Accuracy of agroforestry area so obtained is determined with the help of ground check points (GCPs) and final map is prepared.

For mapping poplar species, OBIA module was repeated with the help of GCPs using spectral signatures and specific range of NDVI for poplar. Then SFP method was applied for segmenting the image and extracting poplar trees. Methodology developed for mapping of agroforestry and poplar species on farmlands is depicted in Fig. 3.

Object-oriented classification method

Object-oriented classification method is a useful and promising method of classifying objects from high resolution satellite images. This approach considers not only identification of land cover on a pixel but also organizes such pixels into groups (segments) that correspond to real-world objects. Pixels of the image are segmented into objects according to the color,

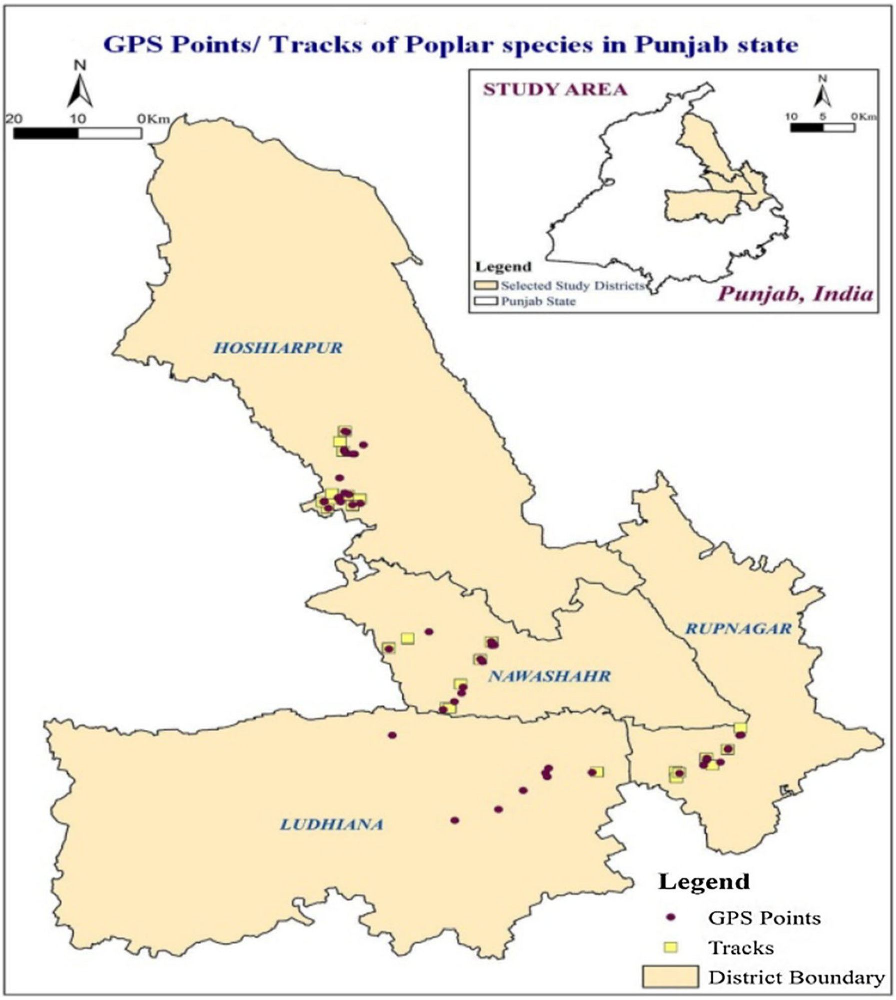


Fig. 1 GPS points and tracks in surveyed districts of Punjab

tone, texture, etc., and then classify objects by treating them as a whole. Object-oriented image analysis approach combines spectral information and spatial information contrary to traditional methods relying on spectral information only. Utilizing characteristic information like size, shape, orientation, shadow, etc. of an object in addition to spectral information, object-oriented image analysis becomes a powerful image classification approach.

IMAGINE Objective in ERDAS 2010 and higher versions is one of the software solution to object-oriented classification and feature extraction available in the market. IMAGINE objective tool employs feature models, which work on objects produced by image segmentation and various other pixel-based algorithms (Blaschke et al. 2008; Lack and Bleisch 2010). With object-oriented analysis, it is possible to get better results from remote sensing information. That information may be immediately integrated into GIS allowing direct realization of vector maps (Barrile and Bilotta 2008).

Poplar plantation mapping at state-level

For mapping of poplar tree area at state level, Sentinal-2A data (spatial resolution- 10 m) available in 12 different spectral bands has been used. Top-of-atmospheric (ToA) correction was applied on this data to get the reflectance values for each pixel. Then the images were mosaicked, clipped from state boundary and false color composite (FCC) was generated. Forest cover area had been masked with the help of FCC and

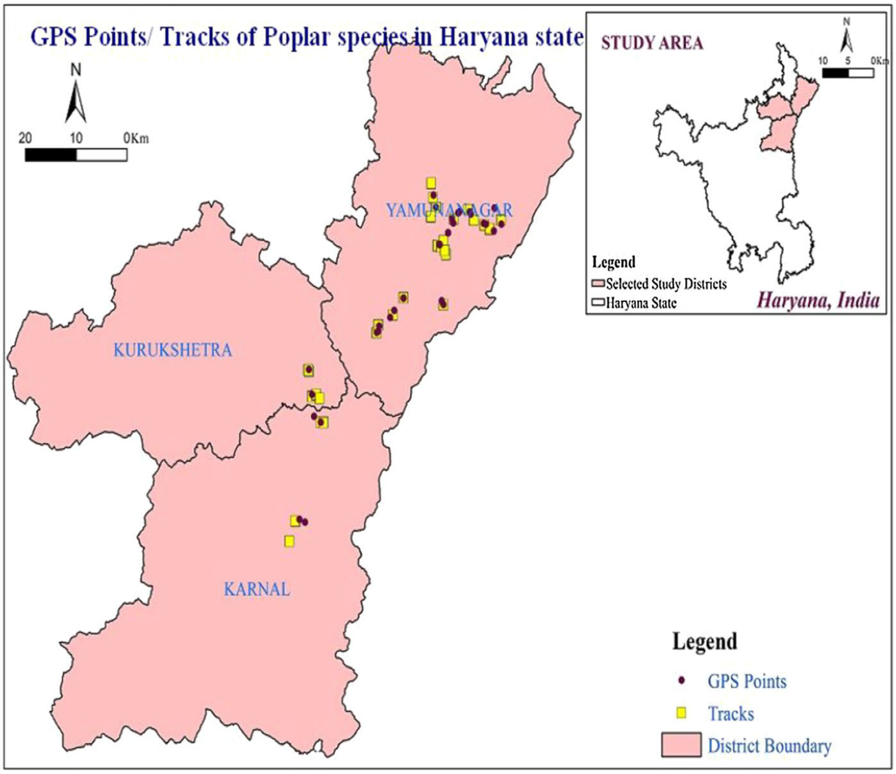
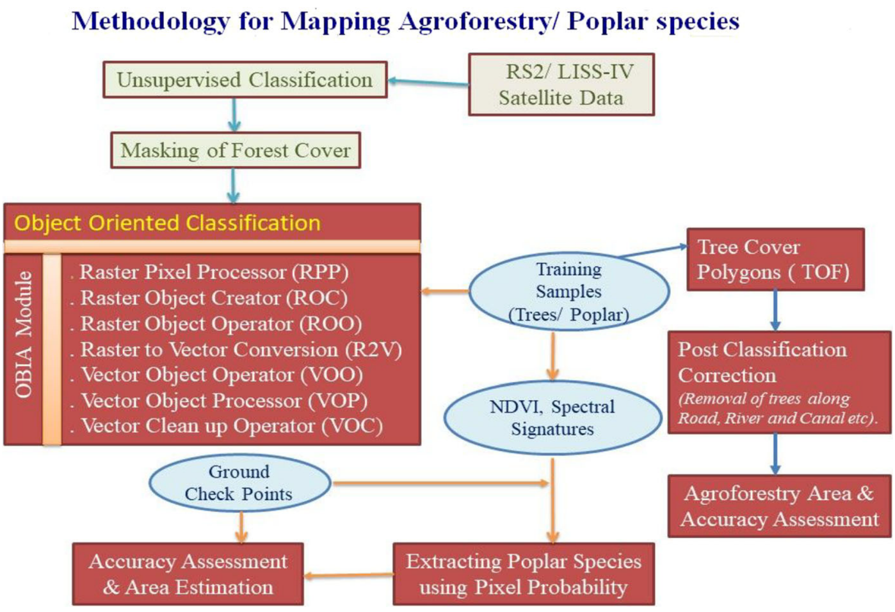


Fig. 2 GPS points and tracks in surveyed districts of Haryana

Fig. 3 Methodology developed for mapping agroforestry/poplar species using LISS-IV



remaining area was analyzed. Reflectance values for poplar species were determined with the help of GPS points collected from farmers' fields. By applying the range of reflectance values in knowledge classifier, poplar area was identified. The resultant images were subjected to correction for removing undesired area along roads, canals and within urban areas. Finally the accuracy was assessed and poplar area statistics calculated for the state.

Estimation of biomass, carbon stock and CO_2 equiv. C

Dry stem (tree bole upto 10 cm girth) and aboveground biomass for poplar trees of different ages were computed using developed biomass equation (Puri et al. 2002). The total biomass was derived by considering 79% of total biomass as aboveground biomass (Singh and Lodhiyal 2009). Studies suggested that carbon concentration in stem wood of poplar was 45–46% (Zebek and Prescott 2006; Chauhan et al. 2009).

Carbon stock (CS) in stem biomass was then calculated by formula CS = C × B; where, C—carbon content (45.5%) and B—stem dry biomass (kg/tree). Accordingly per tree biomass and carbon was converted into per hectare biomass and carbon after multiplying with number of trees on hectare scale. CO_2 equivalent C was computed by multiplying estimated carbon stock in stem, aboveground and total biomass with a factor of 3.67.

Results and discussions

Mapping poplar area in Punjab and Haryana

Resoucesat-2/LISS-IV data of Ludhiana, SBS Nagar, Rupnagar, Hoshiarpur districts of Punjab and Yamunanagar, Kurukshetra, Karnal districts of Haryana have been layer stacked, mosaicked and analyzed using ERDAS Imagine 2015. Agroforestry area has been mapped and estimated in these districts by applying object-oriented classification techniques. From the agroforestry area, poplar species was identified with the help of ground check points and then its spectral values (NDVI) were determined. Using the range of NDVI, the poplar area has been mapped by applying OBIA method. In case of Punjab and Haryana states, agroforestry area was highest in Hoshiarpur district (19600.38 ha) and Yamunanagar district (16292.88 ha), respectively (Figs. 4, 5, 6 and 7).

Area under poplar species in Ludhiana, SBS Nagar, Rupnagar and Hoshiarpur districts was estimated to be 3698.7, 534.0, 5465.2, and 10573.1 ha, respectively, which was 1.02, 0.43, 3.19 and 4.09% of geographical area of these districts, respectively (Table 1). Poplar based agroforestry systems accounted for more than 50% of total agroforestry area in Rupnagar (57.4%) and Hoshiarpur (53.9%) districts. More than 86 per cent accuracy was found in poplar species mapping in these districts. In Yamunanagar district of Haryana, poplar area was estimated to be 12169.66 ha (9.71%), which was about 74.7% of total agroforestry area in the district. In case of Kurukshetra and Karnal districts, estimated poplar area was recorded 2581.73 and 2317.34 ha, respectively (Table 2), representing about 32.3 and 30.3% of the total agroforestry area in respective districts (Figs. 8, 9 and 10). Accuracy of poplar area, assessed with the help of ground check points (GCPs), was found more than 88% in three districts of Haryana state.

Poplar mapping at state level was also done with Sentinel-2A data using the methodology described above. Estimated area under poplar species in Punjab state was found 0.276 million ha (5.63%) with a reasonably good accuracy of 81%. Similarly, area under poplar species in Haryana state was estimated to be 0.205 million ha (4.66%) with an accuracy of 85.2%. Besides this, spectral reflectance patterns of

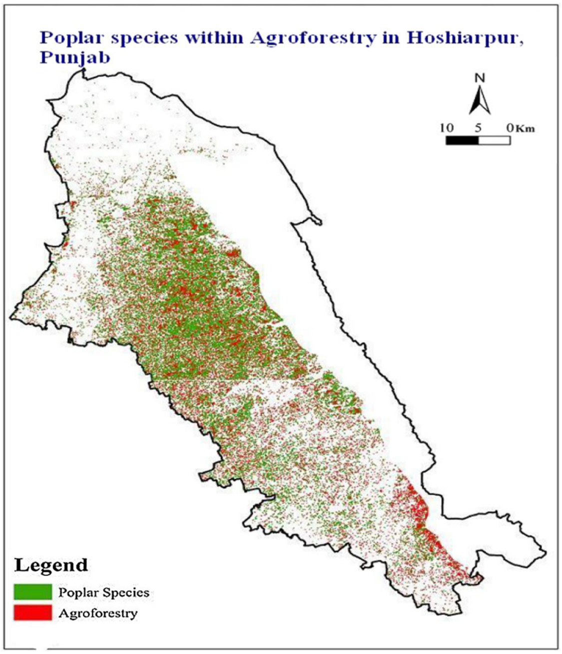


Fig. 4 Poplar area in Hoshiarpur district of Punjab

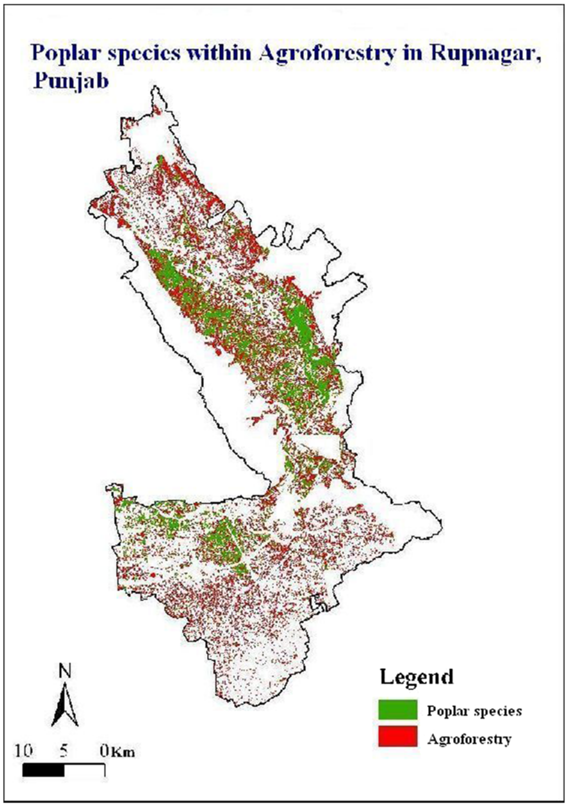


Fig. 5 Poplar area in Rupnagar district of Punjab

poplar species at different ages were also investigated with the help of GPS points collected from field. It was found that spectral reflectance was different for different ages in the visible range (0.450–0.705 μm). But spectral reflectance pattern becomes almost similar in near-infra red spectral range (0.705–0.865 μm) for all ages except for 3 years and then converges at 0.945 nm, which is water absorption band (Fig. 11). It indicates that for poplar tree mapping we can use a composite signature instead of spectral signatures for different ages.

Biomass, carbon stocks and CO_2 equiv. C under poplar plantations

Data on diameter at breast height (DBH), tree spacing and system type were recorded during field survey. Stem and aboveground biomass was computed from available biomass equations. Poplar plantations of different densities were found with minimum 200 trees ha^{-1} in Ludhiana to maximum 1905 trees ha^{-1} in Hoshiarpur and SBS Nagar districts. DBH of poplar plantations varied from minimum 9.54 cm in SBS Nagar to maximum 24.76 cm in Hoshiarpur district. Per tree biomass was converted to per ha biomass by multiplying it with number of trees per ha (Table 3).

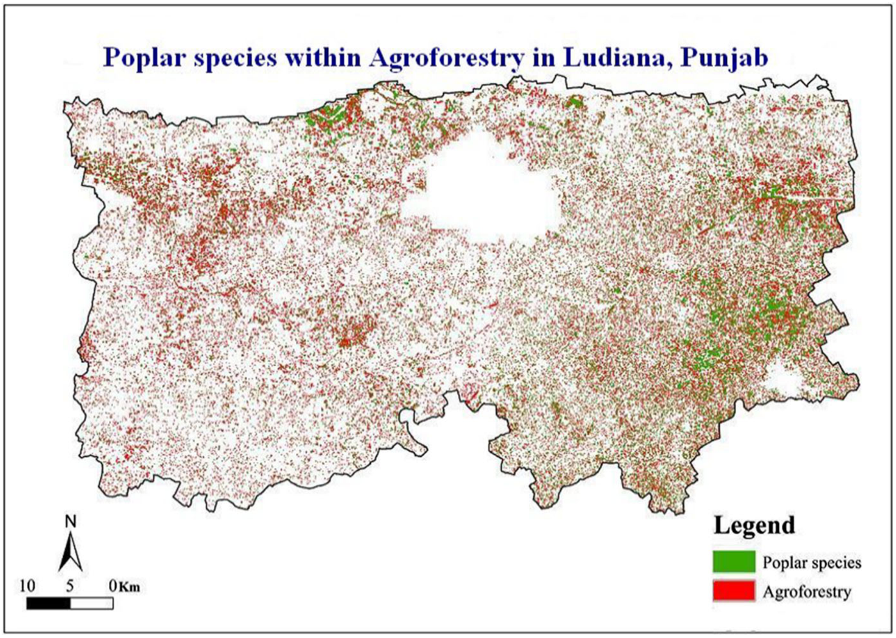


Fig. 6 Poplar area in Ludhiana district of Punjab

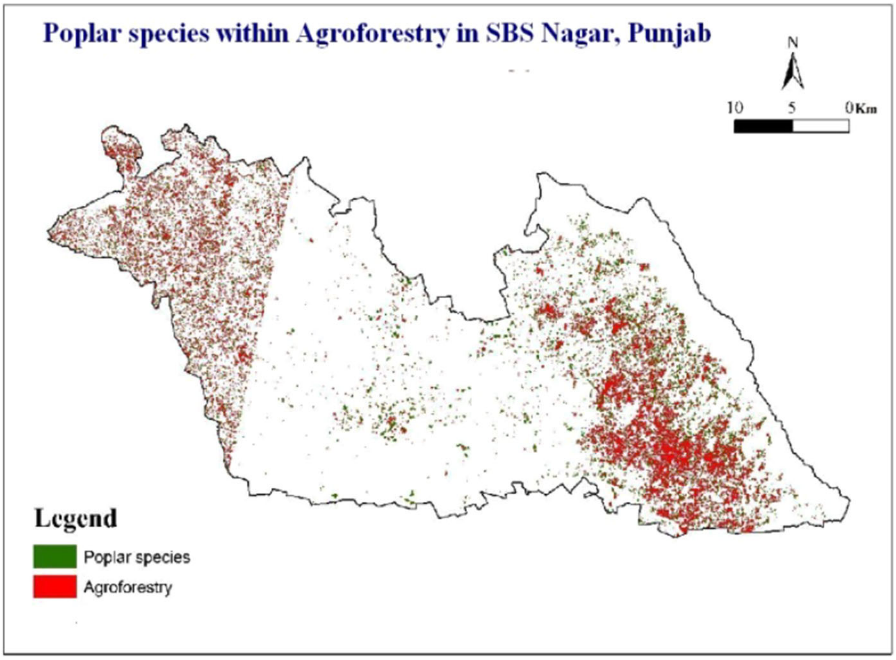


Fig. 7 Poplar area in SBS Nagar district of Punjab

Table 1 Estimated area under agroforestry and poplar trees in four districts of Punjab

Parameter	Ludhiana	SBS Nagar	Hoshiarpur	Rupnagar
Agroforestry area (ha)	11691.85	5501.00	19600.38	9567.30
Poplar area (ha)	3698.67	534.00	10573.13	5495.20
Poplar area (%)[a]	1.02	0.43	3.19	4.09
Poplar area as % of agroforestry	31.6	9.71	53.90	57.43

[a]Geographical area of the district

Table 2 Estimated area under agroforestry and poplar trees in three districts of Haryana

Parameter	Yamunanagar	Kurukshetra	Karnal
Agroforestry area (ha)	16292.88	7997.87	7641.09
Poplar area (ha)	12169.66	2581.73	2317.34
Poplar area (%)[a]	9.71	1.58	0.97
Poplar area as % of agroforestry	74.69	32.28	30.33

[a]Geographical area of the district

Stem and aboveground biomass ranged from 23.61 to 209.16 t ha^{-1} and 31.62 to 286.07 t ha^{-1}, respectively, in all seven districts. This large range is mainly due to variable age and tree density. Stem and aboveground biomass was in the range of 74.26–170.07 t ha^{-1} and 117.69–209.68 t ha^{-1}, respectively, in Rupnagar district of Punjab. Total stem and aboveground biomass was found to be highest 1.339 and 1.617 million t (Mt), respectively, in Hoshiarpur district followed by 0.718 and

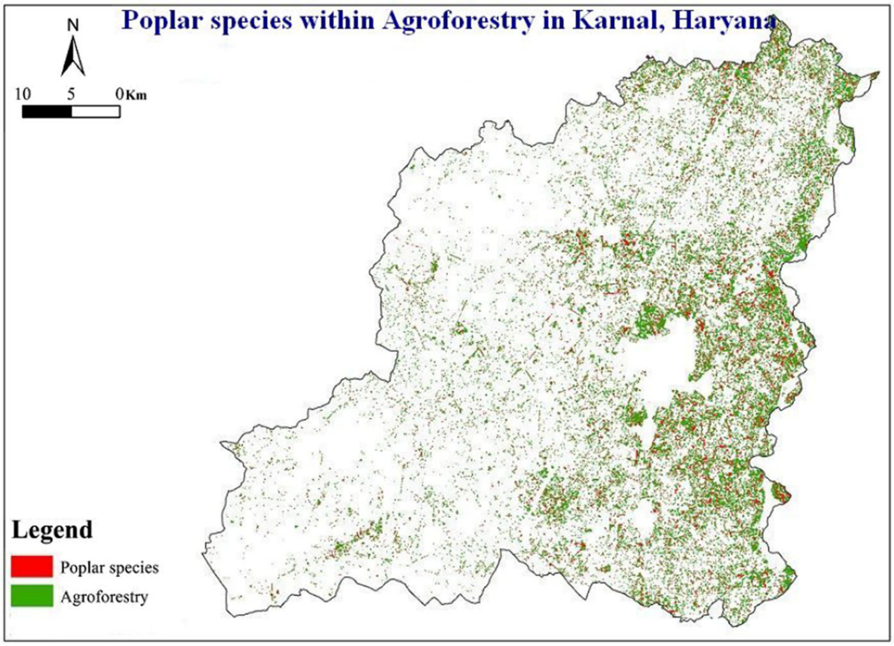


Fig. 8 Poplar area in Karnal district of Haryana

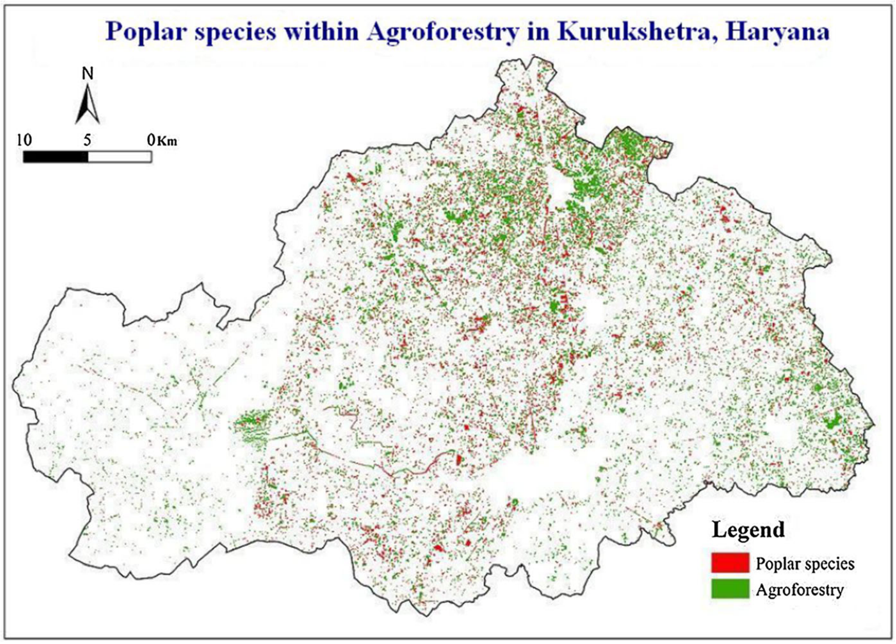


Fig. 9 Poplar area in Kurukshetra district of Haryana

0.836 Mt, respectively, in Rupnagar district. Carbon stock in stem and aboveground biomass under poplar based systems was also highest in Hoshiarpur district and estimated to be 0.609 and 0.736 Mt, respectively (Table 3). In case of Yamunanagar district of Haryana, where poplar based agroforestry is very predominant, density varies from 540 to 1560 trees ha^{-1}. DBH was found in the range of 13.96–22.71 cm.

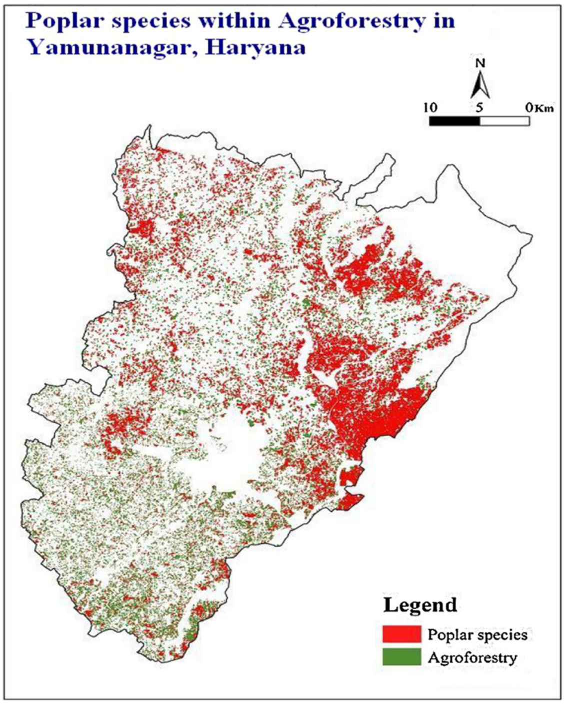


Fig. 10 Poplar area in Yamunanagar district of Haryana

Stem and aboveground biomass under poplar based systems was estimated to be 41.53–160.96 t ha^{-1} and 44.16–185.17 t ha^{-1}, respectively. Total stem and aboveground biomass were estimated to be 1.368 and 1.648 Mt, respectively, in this district. Estimated carbon stock in stem, aboveground and total biomass come out to be 0.622, 0.750 and 0.949 Mt, respectively (Table 4).

CO_2 equivalent C in stem, aboveground and total biomass of poplar plantations in selected districts of Punjab and Haryana was also computed. It was found highest in Yamunanagar district of Haryana i.e. 1.544, 2.391 and 3.026 million t, respectively, followed by Hoshiarpur district of Punjab i.e. 1.522, 2.354 and 2.981 million t respectively (Fig. 12). Lowest values of carbon stock as well as CO_2 equivalent C in stem, aboveground and total biomass were found for SBS Nagar of Punjab. This is due to the fact that SBS Nagar has lowest area under poplar (0.43%) out of seven districts of Punjab and Haryana. CO_2 equivalent C in aboveground and total biomass was estimated to be 7.854 and 9.946 million t, respectively, in all these seven districts. This study corroborated that poplar based systems have significant contribution in offsetting atmospheric CO_2 and can play vital role in climate change mitigation at state/regional level.

Tauqeer et al. (2016) mapped and estimated area under agroforestry in Ludhiana district of Punjab using LISS IV data for the year 2009. Agroforestry area was estimated to be 6043.50 ha out of which *Populus tricocarpa* and *Eucalyptus* species accounted for 4543 and 1426 ha, respectively, in this district. As per present study estimates, area under *Populus* species come out to be 3698.67 ha in Ludhiana district in year 2018. So a decline is observed in poplar area in the district over a period of nine years. This decline is mainly attributed to reduction in timber prices in the market and also farmers are switching over to other species like Eucalyptus, *Melia composite* and *Melia azaderach*.

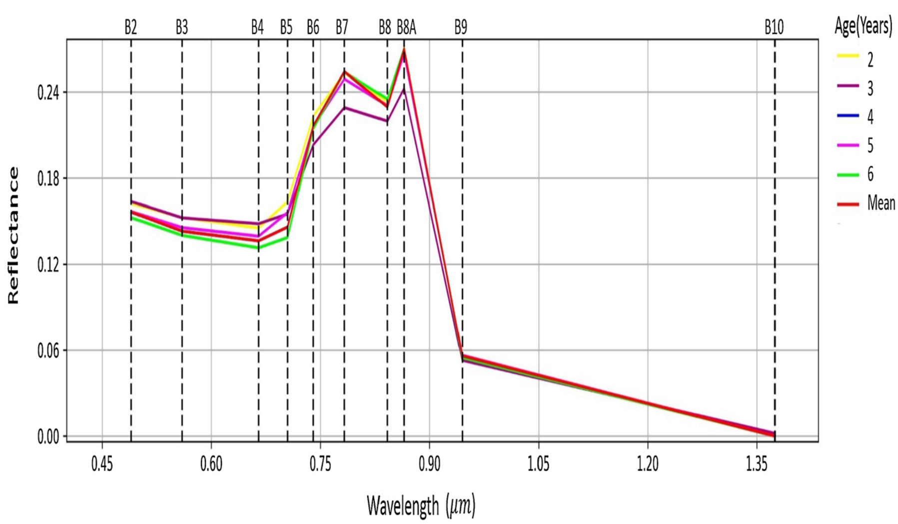


Fig. 11 Spectral reflectance patterns (signatures) of poplar species at different ages

Table 3 Growth and estimated biomass of poplar in four districts of Punjab

Parameter	Ludhiana	SBS Nagar	Hoshiarpur	Rupnagar
DBH (cm)	10.21–22.68	9.54–19.39	12.42–24.76	14.70–20.46
Trees density (trees ha^{-1})	200–1550	494–1905	494–1905	667–1333
Stem biomass (t ha^{-1})	23.61–183.47	29.92–189.53	39.80–209.16	74.26–170.07
Aboveground biomass (t ha^{-1})	34.00–279.91	31.62–261.19	44.28–286.07	117.69–209.68
Total stem biomass (Mt)	0.413	0.065	1.339	0.718
Total aboveground biomass (Mt)	0.499	0.069	1.617	0.836
C-stock in stem biomass (Mt)	0.188	0.030	0.609	0.327
C-stock in AG biomass (Mt)	0.227	0.031	0.736	0.380
C-stock in total tree biomass (Mt)	0.287	0.040	0.931	0.481

[a]Upper limits are isolated cases otherwise good practices are standardized in poplar planting including tree density

[b]Including 21% below ground biomass

Table 4 Growth and estimated biomass of poplar in three districts of Haryana

Parameter	Yamunanagar	Kurukshetra	Karnal
DBH (cm)	13.96–22.71	13.41–21.99	7.64–25.48
Trees density (trees ha^{-1})[a]	540–1560	476–2500	568–1250
Stem biomass (t ha^{-1})	32.39–152.83	75.16–183.64	76.28–135.47
Aboveground biomass (t ha^{-1})	44.16–185.17	104.03–239.77	127.41–176.18
Total stem biomass (Mt)	1.368	0.374	0.336
Total aboveground biomass (Mt)	1.648	0.444	0.398
C-stock in stem biomass (Mt)	0.622	0.170	0.153
C-stock in AG biomass (Mt)	0.750	0.202	0.181
C-stock in total tree biomass (Mt)[b]	0.949	0.256	0.229

[a]Upper limits are isolated cases otherwise good practices are standardized in poplar planting including tree density

[b]Including 21% below ground biomass

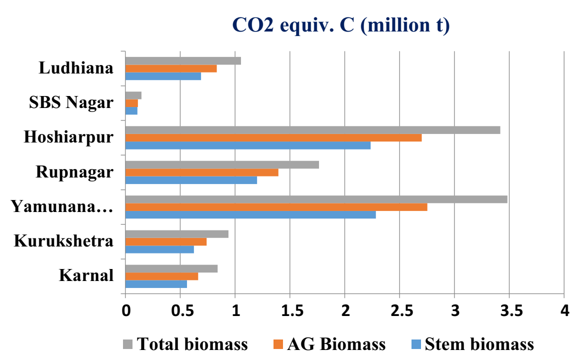


Fig. 12 Estimated CO_2 equivalent C in selected districts of Punjab and Haryana

Rizvi et al. (2016b) mapped sapota (*Manilkara zapota*) species on farmlands in Junagarh district of Gujarat using sub-pixel method of classification and Rizvi et al. (2017) mapped Mango (*Mangifera indica*) by applying Spectral Angle Mapper on hyperspectral remote sensing data. They found reasonably good accuracy of 87% in classification of Mango area. In both these studies, different remote sensing data and methods were used. But as far as identification of tree species is concerned, high resolution remote sensing data (better than 10 m) are more useful. Besides this, digital library of spectral signatures is very important for accurate mapping of tree species on farmlands.

Yadav et al. (2019) mapped trees outside forest (scattered and patch form) in *tarai* Nepal using high resolution Worldview-2 remote sensing data. They mentioned methodology for land use land cover (LULC) change analysis but did not discuss about method applied for mapping trees outside forest. Present study proposed methodology based on high resolution LISS-IV data (spatial resolution- 5.8 m) and object-oriented image classification technique.

Estimated carbon sequestration of poplar culture in India was approx. 2.5 million t C per annum. Carbon locked in poplar based products for different durations and in other tree parts mainly used as firewood was about 1.04 and 1.15 million t C, respectively, and 0.3 million t C is added to the soil through leaf litter every year (Dhiman et al. 2009). Carbon storage potential of poplar based agroforestry systems in Yamunanagar and Saharanpur districts was estimated to be 27–32 t C ha^{-1} in boundary system and 66–83 t C ha^{-1} in agri-silviculture system (Rizvi et al. 2011). Singh and Gill (2014) investigated biomass, carbon and CO_2 storage of five tree species viz. *Populus deltoides* (poplar), *Eucalyptus tereticornis* (eucalyptus), *Melia azedarach* (dek), *Ailanthus excelsa* (maharukh) and *Toonaciliata* (toon) in an agri-silviculture system. After 7 years of growth, the carbon storage by poplar, eucalyptus, dek, maharukh and toon was 54.9, 48.0, 43.3, 20.8 and 19.1 t ha^{-1}, respectively.

Kaul et al. (2010) used dynamic CO2FIX model for estimating carbon sequestration potential of sal, eucalyptus, poplar and teak forests in India. The net annual carbon sequestration rates were achieved for fast growing short rotation poplar (8 Mg C ha^{-1} $year^{-1}$) and eucalyptus (6 Mg C ha^{-1} $year^{-1}$) followed by moderate growing teak forests (2 Mg C ha^{-1} $year^{-1}$). Kanime et al. (2013) assessed biomass, carbon and carbon di-oxide potential of *Populus deltoides, Eucalyptus tereticornis, Dalbergia sissoo, Mangiferaindica, Litchi chinensis* and *Prunus salicina* plantations in *Tarai* region on Central Himalaya. Carbon stocks ranged from 4.51 Mg C ha^{-1} in an 8-year-old *P. deltoides* boundary plantation to 43.39 Mg C ha^{-1} in *D. sissoo* plantation.

All these studies reported carbon stock of poplar plantations under agroforestry/forests. But none of them assessed area under plantations nor total C-stock at district level, whereas present study adopted two way approach in which area of poplar plantations under agroforestry was first estimated using geospatial technologies followed by total carbon stock at district level using estimated area under poplar plantations.

Conclusions

Study concluded that poplar based agroforestry systems occupy sizeable area in Punjab and Haryana states of Indo-Gangetic Plains in India. Poplar-based agroforestry systems have significant contribution towards increasing green tree cover as well as reduction in atmospheric CO_2 through carbon sequestration in these states. Methodology proposed in this study for mapping *Populus deltoides* (poplar) species using high resolution remote sensing data and object-based classification technique yielded promising results. Same can be adopted for mapping other tree species on farmlands, which would help in estimation of carbon sequestration of that particular species in comparison to traditional land use systems. The present study also established that precise assessment of carbon sequestration under agroforestry systems at district/regional level can be done through geospatial and modeling approach.

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