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Mapping of agroforestry systems and *Salix* species in Western Himalaya agroclimatic zone of India

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In the present study, agroforestry was mapped in nine districts from Western Himalayan Region. The agroforestry area in these nine selected districts was estimated to be 332127.55 ha (12.4%). *Salix alba*, an important agroforestry species, accounted for about 12% of total agroforestry area in three districts of Kashmir valley.

Keywords: Agroclimatic zone, agroforestry mapping, object-oriented classification, remote sensing, tree species.

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IN India, agroforestry has been a tradition and become a way of life and livelihood for centuries. Now it is a modern science inviting deliberate management of trees on farms and surrounding landscape[1,2]. The growing awareness on the importance and potential of agroforestry has resulted in invaluable proliferation of site-specific case studies[3]. The diagnostic survey and appraisal of agroforestry practices in India revealed that there are innumerable practices in different agro-ecological zones[4]. Agroforestry is land management and farming system that is not only capable of producing food from marginal agricultural land, but also capable of maintaining and improving the quality of environment[5].

The Task Force on Greening India of the Planning Commission, Government of India has recommended that for sustainable agriculture, agroforestry may be introduced in 14 out of 46 million hectare (mha) irrigated area that is degrading due to soil erosion, waterlogging and salinization[6]. Agroforestry, as defined by tree cover greater than 10%, is found on more than 46% agricultural lands globally. This land-use type represents over 1 billion hectare of land and more than 900 million people[7]. Remote sensing and GIS have emerged as a powerful tool for planning and decision support in agricultural research and management. GIS enables the storage, management and analysis of large quantities of spatially distributed data[8]. Mapping of land use land cover (LULC) by manual methods takes a relatively long time and is expensive. Rizvi *et al.*[9] highlighted several issues with mapping of agroforestry area using remote sensing. Under the National Innovations for Climate Resilient Agriculture (NICRA) project, area under agroforestry in 13 agroclimatic zones of India has been mapped and estimated[10]. Various agroforestry systems are prevalent in the Western Himalayan agroclimatic zone. Therefore, the present study focuses on an assessment of area under agroforestry in selected districts of this zone and also area under *Salix*, which is the most common multipurpose species, using GIS and remote sensing techniques.

Nine districts from the Western Himalaya zone, namely Kangra, Kullu and Sirmaur from Himachal Pradesh; Champawat and Pauri Garhwal from Uttarakhand, and Badgam, Kulgam, Pulwama and Udhampur from Jammu and Kashmir (J&K) were selected (Figure 1). This zone has latitudinal extent of 28°40′0″–37°0′0″N and longitudinal extent of 72°30′0″–81°0′0″E. The total geographical area of the selected districts is about 2.677 mha, which is 8.11% of the total geographical area of this agroclimatic zone.

Multispectral remote-sensing images of Resourcesat2/LISS IV (spatial resolution 5.8 m) were procured from the National Remote Sensing Centre (NRSC), Hyderabad. Cloud-free images for April–July 2020 were analysed for LULC of the selected districts. Dates of acquisition of these images were between 2 April 2020 and 18 July 2020. A shape file of the district boundary was obtained from Survey of India, Dehradun, Uttarakhand. Pre-processing of these images, including layer-stacking, sub-setting with district boundary and mosaicking was done. False colour composite (FCC) image was created for the generation of signatures for different LULC classes.

A field survey was conducted in the selected districts, and tree growth and GPS data were collected from existing agroforestry systems on farms. Tree species, spacing, diameter at breast height (DBH), and agroforestry system (boundary, block, agri-silviculture) were also recorded.

Forest area was masked from the districts area with the help of forest-cover maps obtained from Forest Survey of India, Dehradun. Agroforestry area was mapped and estimated using object-oriented classification method, which gave more precise estimates of area. The methodology developed by Rizvi *et al.*[11] was adopted for mapping agroforestry in the selected districts.

The different steps involved in this methodology are described below.

1. Multispectral, high-resolution LISS-IV data (spatial resolution 5.8 m) were procured from NRSC, Hyderabad.
2. Pre-processing of scenes included layer-stacking, mosaicking and sub-setting of LISS-IV bands (green, red and NIR) with district boundary shape file.
3. Unsupervised classification method (*k*-means/ISODATA) was used for getting different LULC classes, including forest cover.

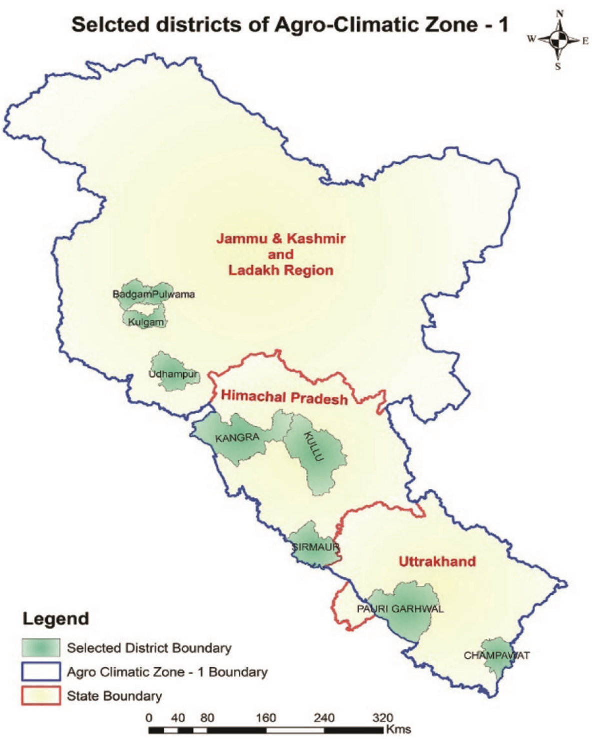

Figure 1. Selected districts of the Western Himalaya zone of India.

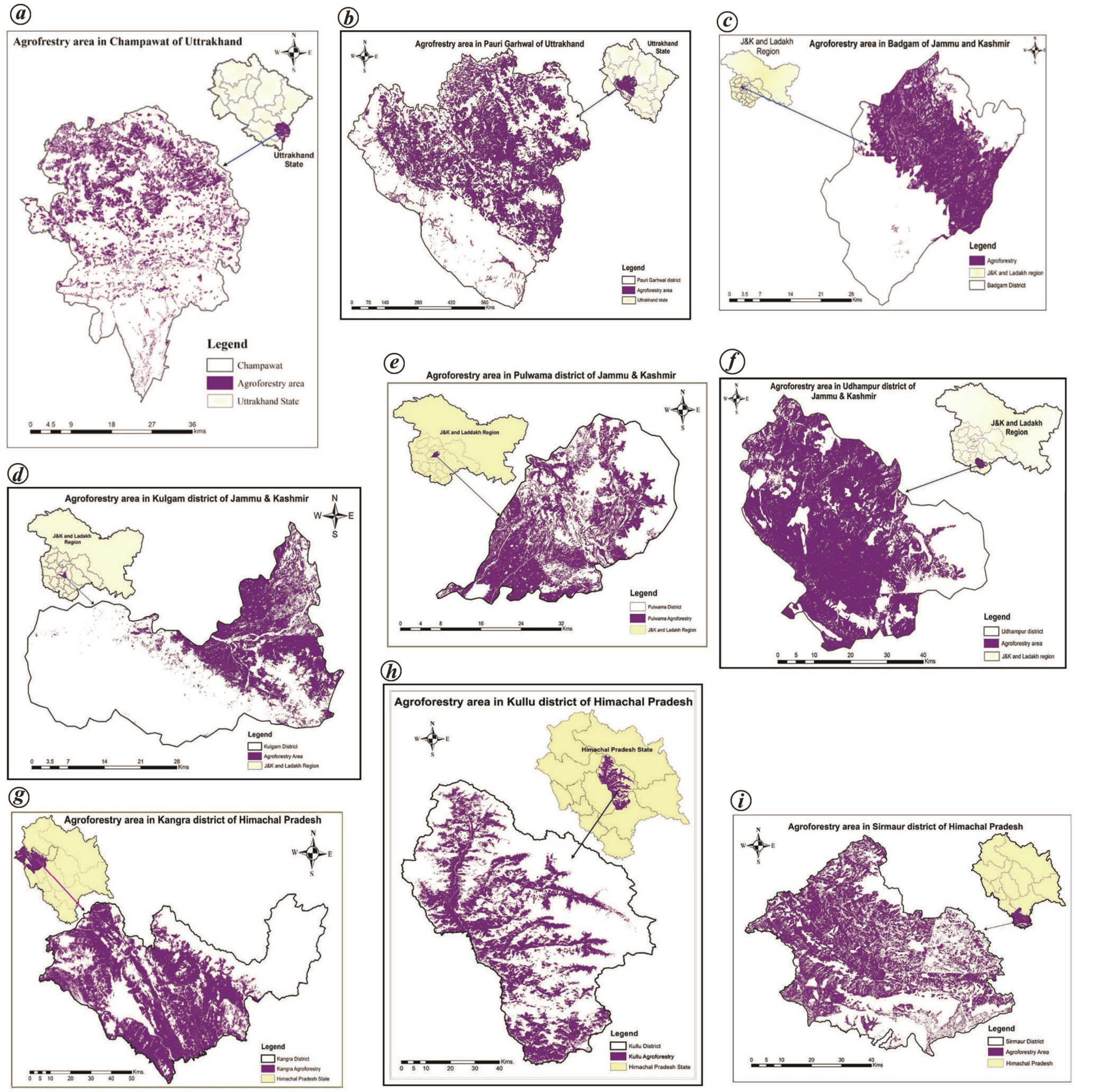

Figure 2. Agroforestry area: ***a***, Champawat district, Uttarakhand; ***b***, Pauri Garhwal district, Uttarakhand; ***c***, Badhgam district, Jammu and Kashmir (J&K); ***d***, Kulgam district, J&K; ***e***, Pulwama district, J&K; ***f***, Udhampur district, J&K; ***g***, Kangra district, Himachal Pradesh; ***h***, Kullu district, Himachal Pradesh; ***i***, Sirmaur district, Himachal Pradesh.

4. Extracting the forest-cover area from FCC image using LULC image of the districts.
5. Object Based Image Analysis (OBIA) module: Applying single feature probability (SFP) using training samples, background pixels (crop, bare soil, etc.) on the FCC image. The threshold and pixel probability are fixed for target feature (trees). The output consists 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 estimate agroforestry area.
7. The accuracy of agroforestry area so obtained was determined using ground check points (GCPs) and the final map was prepared.

Mapping of agroforestry area in selected districts of the Western Himalaya zone was done using OBIA method. Rizvi *et al.*[12] found that the OBIA method was better than pixel-based method for mapping trees on farmlands. Object-oriented analysis provides better results from remote sensing information, which may be immediately integrated into GIS allowing direct realization of vector maps[13].

Table 1. Estimated area under agroforestry (AF) in the selected districts of agroclimatic zone-1

State/Union Territory	District	Geographical area (ha)	AF area (ha)	AF area (%)
Himachal Pradesh	Kangra	576,422.00	77,159.90	13.39
	Kullu	549,989.00	54,412.92	9.89
	Sirmaur	283,713.58	26,981.00	9.50
Jammu & Kashmir	Badgam	120,559.00	15,722.70	13.04
	Kulgam	127,653.00	20,596.63	16.30
	Pulwama	88,445.00	18,315.02	20.71
	Udhampur	225,054.00	44,294.13	19.80
Uttrakhand	Champawat	176,897.00	15,969.74	9.03
	Pauri Garhwal	528,347.94	58,675.51	11.1

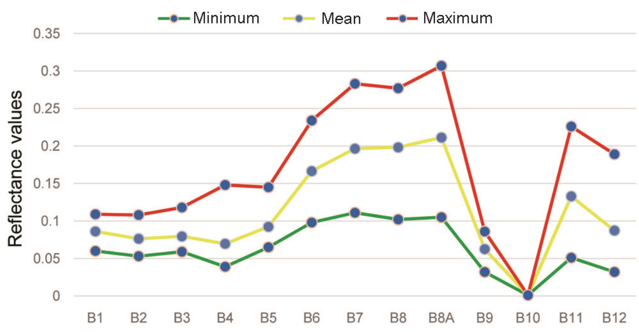

Figure 3. Spectral signature of *Salix* species generated from Sentinel 2A/2B data.

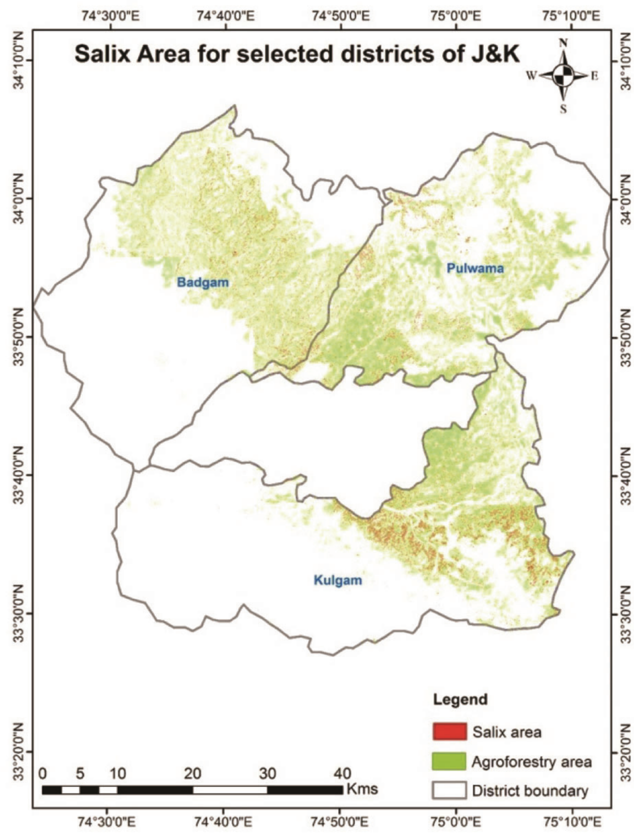

Figure 4. *Salix* area mapped in three districts of J&K.

The agroforestry area in the nine selected districts was mapped and estimated. Total area under agroforestry in these districts was estimated to be 332,127.55 ha (12.4%) (Figure 2 *a–i*). Five out of nine districts had more than 13% area under agroforestry with highest agroforestry area in Pulwama district (20.7%), followed by Udhampur district (19.8%), J&K (Table 1). Mapping accuracy was also assessed with the help of GCPs and per cent correct classification (PCC) was computed for each district. The PCC values ranged from 91.6 to 93.9 for these districts, which is reasonably good.

Indian willow (*Salix*) species is mostly found in the Srinagar part of the Western Himalayan region. Wood of this species is mainly used for making furniture and cricket bats. White willow (*Salix alba* L.) was found to be the dominant species in Kashmir valley with tree density of 81.90 (ref. 14). *Salix alba* stores up to 292.98 tonnes of C ha^{-1} and sequesters around 1075 tonnes CO_2 e ha^{-1}. Mapping of *Salix* species was done in three districts, namely Badgham, Kulgam and Pulwama of Kashmir valley.

Figure 3 shows spectral signatures of *Salix* generated from Sentinel 2A/2B data over different bands (B1–B12). It can be observed that maximum spectral reflectance is in the vegetation red edge band (B8A), which is more than 0.3, but it is less than 0.15 for visible bands (B2–B4). All the three lines (minimum, mean, maximum) converged at B10 (SWIR-Cirrus) with zero reflectance.

Salix area has been mapped and estimated in three districts of Kashmir valley using the generated signatures (Figure 4). As percentage of geographical area, highest *Salix* area was found in Pulwama district (2.23), whereas it was highest in Kulgam district (13.15) as percentage of agroforestry. Total *Salix* area was estimated to be 6551.58 ha, which is about 12% of total agroforestry area in these districts (Table 2).

Rizvi *et al.*[15] identified and mapped *Mangifera indica* (mango) species in Lucknow and Unnao districts of Uttar Pradesh using Hyperion hyperspectral remote sensing data. They use the spectral angle mapper method and found reasonably good mapping accuracy of 87%. Object-oriented classification method considers not only identification of land cover on a pixel, but also organizes such pixels into groups (segments) that correspond to real-world

Table 2. Estimated *Salix* area in three districts of Kashmir valley

District	*Salix* area (ha)	*Salix* as percentage of geographical area	*Salix* as percentage of AF area
Kulgam	2709.4	2.14	13.15
Badgam	1866.73	1.55	11.87
Pulwama	1975.45	2.23	10.79
Total	6551.58	1.95	11.99

objects. This segments the pixel into objects according to colour, tone, texture, etc. of the image and classifies them by treating each object as a whole[16].

Agroforestry has been recognized as a viable strategy for mitigating the effects of climate change by fixing atmospheric CO_2 in the biomass of standing trees in the form of carbon. More than 12% area under agroforestry has been found in selected districts of the Western Himalaya zone. This considerable agroforestry area has a crucial role in not only increasing green tree cover, but also contributing to the local economy of the region. Indian willow (*Salix*), an important agroforestry species, accounts for about 12% of total agroforestry area in three districts of J&K. Thus, existing agroforestry systems in this agroclimatic zone make significant contribution in natural resources conservation and reduction of atmospheric CO_2. Hence promotion of agroforestry in this region needs policy support for farmers to grow trees on their farms and research support for quality planting material.

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