Early Season Crop Acreage Estimation for Pigeon Pea (*Cajanus Cajan*) using SAR Data: A Case Study of Kalaburagi District, Karnataka

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Abstract: Crop acreage estimates using space-based observations during mid-season and pre-harvest periods are operationally provided for major Kharif and Rabi crops in India. These are critical inputs for planning and decision-making concerning food security, storage, pricing, and procurement. This work explores the potential of Satellite C-band Synthetic Aperture Radar (SAR) data in VV and VH polarization, acquired during monsoon season, for early crop acreage assessment of Pigeon Pea. The present study evaluates two classification approaches based on multi-temporal SAR data to generate a spatial distribution map of the pigeon pea crop in the Kalaburagi region of Karnataka. The temporal profiles of sigma nought (backscatter coefficient) and Entropy vs. Alpha Angle were studied with reference to crop phenology. Random forest algorithm has been used to classify multi-temporal SAR Ground Range Detected (GRD) data from June to November 2019. Temporal SAR data from June to early November with VV+VH polarization was optimal for tur area assessment with 85% accuracy. This study also examines phase and intensity information from 3-date SAR Single Look Complex (SLC) data with an unsupervised Wishart Classification approach for improved crop acreage estimation. The results emphasize the effectiveness of dual-polarimetric SAR data for timely crop inventory of Pigeon Pea during the Kharif season.

Keywords: Pigeon Pea, SAR data, Early season crop Acerage, Random Forest Classifier, Polarimetric Analysis

1. Introduction

Pigeon Pea (*Cajanus cajan*), commonly known as Redgram, Arhar or Tur, is an essential tropical grain legume crop (Tiwari & Shivhare, 2019; Marawar & Ujjainkar, 2019; Ramamurthy et al., 2019), and being drought-resistant, is suitable for rainfed and dryland farming (Silim et al., 2001; Kaoneka et al., 2016). In the global scenario, India is the largest producer and consumer of pulses. Karnataka is the major Pigeon Pea producing state in the country, followed by Maharashtra, Madhya Pradesh, Uttar Pradesh and Telangana. The Department of Agriculture & Farmers Welfare has implemented National Food Security Mission (NFSM)-Pulses with the objective of increasing pulses production through area expansion and productivity enhancement in the Country. The production of pulses during 2022-23 as per third advance estimates is given as 275.04 Lakh Tonnes (https://pib.gov.in/PressRelease).

A systematic inventory of early-season crop acreage and reliable in-season production estimates are critical for policymakers to make appropriate decisions (Parihar & Manjunath, 2013). With advances in geospatial technology as well as user requirements, there is a need to enhance the scope of the technology for monitoring important crops like pulses, which play an essential role in Indian Agriculture. Multi-temporal remote sensing techniques have been utilized in India for crop monitoring and acreage estimation through operational Earth Observation Systems, using both optical and microwave SAR (Synthetic Aperture Radar) techniques, during *Kharif* and *Rabi* seasons, as part of the National Inventory of Crop Acreage and Yield estimation (Bhagia et al., 2017; Dadhwal et al., 2002; Parihar & Dadhwal, 2002; Ray et al., 2014; Parihar and Oza, 2004 & 2006; Chakraborty et al., 2006; Singh et al., 2019; Paul & Kumar, 2019). Under the FASAL (Forecasting Agricultural output using Space, Agro-meteorology and Land based observations) programme, MNCFC (Mahalanobis National Crop Forecast Centre) generates crop production forecasts at District/State/National level for major crops of the country such as Jute, Kharif Rice, Sugarcane, Cotton, Rapeseed, Mustard, Rabi Sorghum, Wheat, Rabi Pulses and Rabi Rice, using multi-date AWiFS NDVI, LISS-III, Sentinel-2, Landsat-8 and Sentinel-1 SAR data products.

Pigeon Pea is a *Kharif* crop sown in June-July with the onset of the Monsoon and harvested during November-January in Karnataka. Crop discrimination in *Kharif* season is challenging using optical remote sensing data due to persistent cloud cover. Studies have been carried out using characterization of backscatter response from multi-temporal dual-pol and quad-pol SAR (Synthetic Aperture Radar) data for the classification of *Kharif* crops such as paddy, cotton, jute, maize and finger millet (Uppala et al, 2015; Verma et al., 2019; Haldar et al., 2014; Tiwari et al., 2021; Parihar et al., 1998; Inglada et al., 2016). Similarly, target decomposition of fully polarimetric and dual-polarimetric SAR SLC (Single Look Complex) data have been effectively used for crop classification and for studying scattering mechanisms of wheat, oat, soybean, canola, forage, barley, ginger, tobacco, rice, cabbage, and pumpkin (Xianfeng Jiao et al., 2014; Harfenmeister et al., 2021; Shaik Salma et al., 2022). MODIS NDVI 16-day time-series data was used to analyze the significant expansion of pigeon pea crop between 2010 and 2017 in Malawi (Gumma et al., 2019).

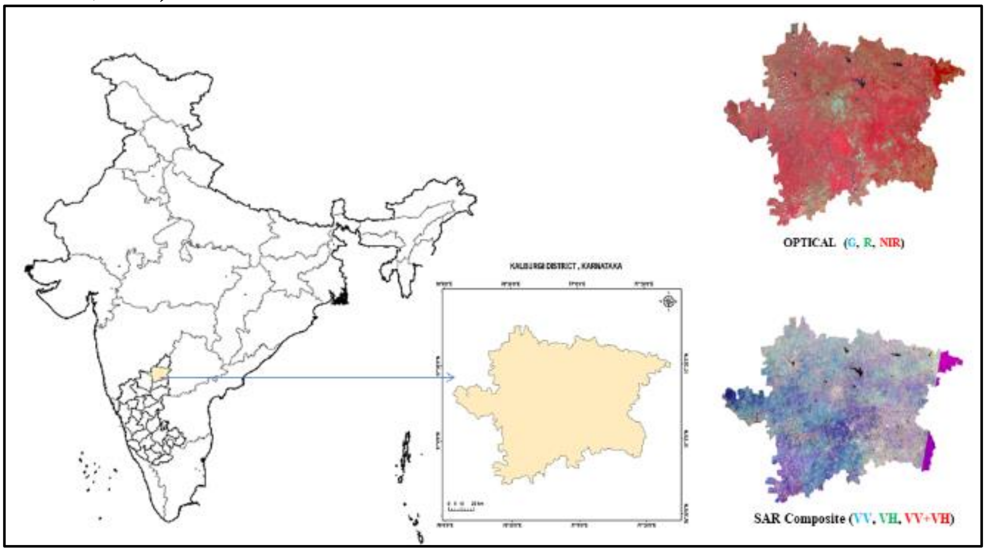

Figure 1. Location Map and Satellite Images of Study Area (Kalaburagi District, Karnataka)

However, studies on using SAR data for pigeon pea crop identification during the *Kharif* season are limited. Hence, the present work is a feasibility study taken up under the SUFALAM (Space Utilization for Food-security and Agricultural Assessment and Monitoring) project to explore the use of dual-pol (VV, VH) C-band SAR data for pre-harvest crop acreage estimation of *Kharif* season pigeon pea crops in Karnataka.

2. Study Area

Kalaburagi, formerly called 'Gulbarga' district, is popularly known as the 'Tur bowl' of the State of Karnataka, India. Kalaburagi district is situated in north Karnataka comprising of eleven talukas (Kalaburagi, Aland, Afzalpur, Jevargi, Sedam, Shahabad, Kalgi, Kamalapur, Chitapur, Chincholi and Yedrami). Pigeon Pea is primarily grown in the Northern districts of Karnataka, namely Kalaburagi, Vijayapura, Raichur, Bidar, and Yadgir, which accounts for nearly 90 percent of the total Pigeon Pea area in the State (Siddayya et al., 2016). Kalaburagi and Vijayapura contribute more than 65 percent to state-level areas and production among the five major districts. Kalaburagi Pigeon Pea has received the Geographical Indication (GI) tag from the Geographical Indications Registry of India (2019). According to the Directorate of Pulses Development, a total area of 13 lakh ha is covered under Pigeon Pea production in Karnataka during 2019-20, producing 9.10 lakh tonnes (DPD Report, 2020).

Depending on the crop cycle, the pigeon pea crop is grown in different agro-climatic zones: short duration (130-150 days), Medium duration (160-180 days), and Long duration (250-280 days). However, medium–long duration varieties are most popular in the study area, with more than 150 days of crop duration.

3. Satellite data

SAR's cloud-penetrating and all-weather sensing capabilities are helpful for *Kharif* crop characterization (Ranjan & Parida, 2019; Natteshan & Suresh Kumar, 2020). Crop classification accuracy is greatly improved with the use of temporal satellite data due to the difference in crop structure, water content, and soil condition during various crop phenological stages. Multi-temporal C-band Sentinel-1 SAR data acquired in Ground Range Detected (GRD) and Single Look Complex (SLC) formats have been used in this study (Table 1). For SAR intensity data analysis, Sentinel-1B GRD (Ground Range Detected) data, acquired in Interferometric Wide Swath (IW) mode from June to November 2019, with a swath width of approximately 250 km, incidence angle of 37-45°and resampled spatial resolution of 10 m was used (Sentinel-1 Product Specification, 2020).

Table 1. Satellite data used for the study

Satellite/Sensor	Date of Satellite pass
Sentinel-1B SAR (GRD format), VH, VV pol	**2019**: 16-Jun, 22-Jul, 03-Aug, 27-Aug, 20-Sept, 14-Oct, 07-Nov
Sentinel-1B SAR (SLC format), VH, VV pol	**2019**: 10-Jul, 08-Sept, 14-Oct

Level-1 SAR SLC (Single Look Complex) data from Sentinel-1B acquired in the Interferometric Wide Swath (IW) mode during stages of pre-sowing (July), crop-growing (September) and pre-harvest (October) months were used for the polarimetric analysis to utilize the phase and intensity information for crop acreage estimation. SLC data acquired in IW mode consists of three sub-swaths (IW1, IW2, and IW3) imaged with Incidence angle range of 36.5° to 41.9°, Slant range resolution of 2.33 m and Azimuth resolution of 13.99 m. Each sub-swath image consists of nine bursts or slices in the azimuth direction. Every SLC product has phase and intensity channel images per sub-swath for VH and VV polarizations, resulting in six data layers.

3.1 Field Data Collection

Field data is essential for the accuracy assessment and validation of crop classification using Satellite data. The Karnataka State Remote Sensing Applications Centre (KSRSAC) team conducted a random sampling-based field survey using mobile app in the Kalaburagi region to collect Ground Truth (GT) information about crop parameters such as Crop variety, sowing period, Crop growth stage, Crop condition, crop vigor, crop percentage cover on the ground, soil moisture, and field photographs. About 350 GT points (Table 2) with geotagged photos were uploaded directly to the ISRO BHUVAN portal from the field. The GT database was systematically prepared using ArcGIS software.

Figure 2 shows the Ground Truth (GT) points of Pigeon Pea and other crop categories (Cotton, Paddy, and Sugarcane) overlaid on Optical and SAR composite images. It was observed during the field visit that Pigeon Pea and cotton crops were at the maximum vegetative stage or flowering stage while paddy and sugarcane crops were at harvesting stage, and Jowar was at early crop growth stage.

4. Methodology

The detailed procedure for crop acreage estimation includes pre-processing of SAR data, unsupervised/supervised classification, accuracy assessment and generation of crop map as shown in Figure 3. SAR data processing was carried out using SNAP (Sentinel Application Platform) software. The major pre-processing steps of SAR GRD (Ground Range Detected) data are (a) Radiometric calibration for generating sigma nought (σ^0) values, (b) Speckle noise filtering using adaptive 5 x 5 Lee filter, (c) Geometric correction with Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM 30m), using Range Doppler Terrain correction algorithm and (d) Conversion of linear σ^0 values to dB. Random Forest (RF) supervised classifier, a machine learning algorithm and based on the concept of ensemble of decision trees, was used to classify multi-temporal SAR data.

Table 2. Ground Truth points collected

Crop Type	Number of GT points
Pigeon Pea	120
Cotton	64
Paddy	87
Sugarcane	70
Jowar	9

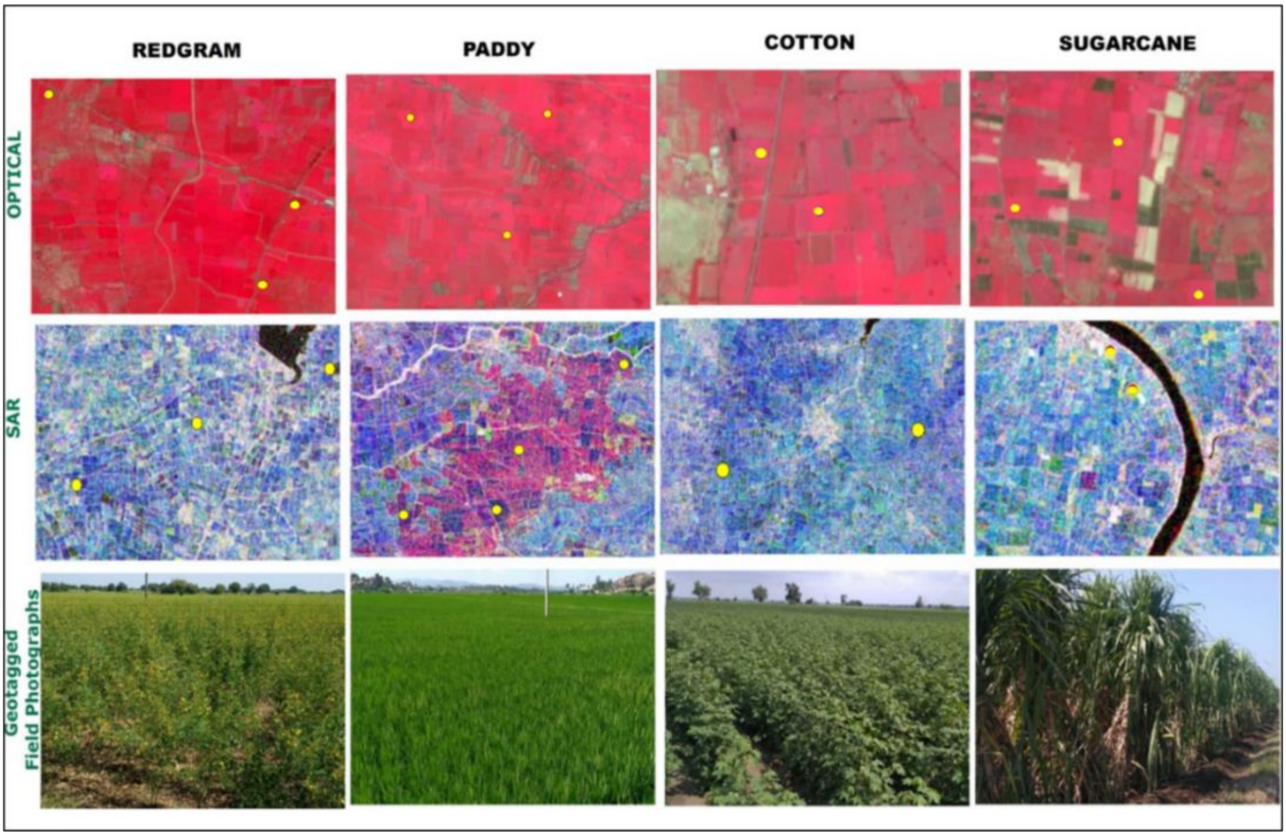

Figure 2. Ground Truth Location Points with Field Photographs

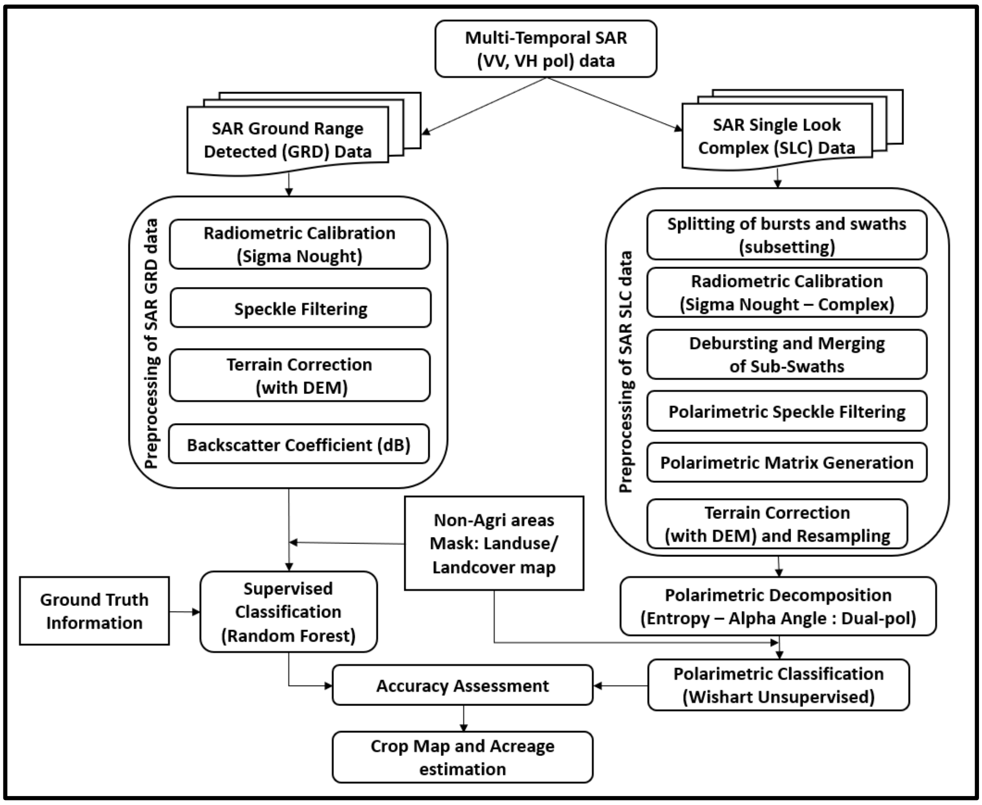

Figure 3. Methodology flowchart for Crop acreage estimation using SAR GRD and SLC Data

Data pre-processing of SAR SLC (Single Look Complex) data (Mandal et al.,2019) includes (a) Splitting of bursts and swaths (Sub-setting of data), (b) Application of satellite precise orbit file, (c) Radiometric calibration to produce sigma nought (σ^0) values in complex form, (d) Debursting and sub-swath merging, (e) Polarimetric speckle filtering using refined Lee filter (5x5), (f) Geometric correction using Range-Doppler terrain correction method with Digital elevation model (SRTM 30m) and (g) Resampling to 10m using UTM projection with WGS 84 datum. The terrain-corrected output of SLC data is further used for the decomposition and classification process. Polarimetric decomposition extracts information about the different scattering mechanisms of landcover features (surface scattering, volume diffusion, and double bounce scattering). H-Alpha Dual-pol decomposition was carried out in this study using a modified form of the conventional full-pol entropy/alpha decomposition H−α method (Cloude & Pottier, 1997).

Entropy(H) is associated with the randomness of the scattering process, where it takes the values between 0 (single scattering) and 1(random mixture of scattering mechanisms with equal probability). Alpha angle (α) indicates the dominant scattering values in the range of 0° to 90°, with surface scattering mechanism (0°), volume scattering (45°), and dihedral scattering (90°) for the full-pol case. H values are similar for dual-pol and quad-pol data, but Alpha angle values vary depending upon the specific dual-pol mode (Ainsworth, 2009). Based on Entropy and Alpha angle values, the widely-used unsupervised iterative Wishart classification method (Jong-Sen Lee et al, 1999) was adopted, which separates data into nine clusters. A typical H- α plane plot represents nine zones: Dihedral Reflector, Dipole, Bragg surface, Double Reflection, Anisotropic particles, Random surface, Complex Structures, Random Anisotropic Scatterers, and Non-feasible (Cloude & Pottier, 1997). Crop map was generated based on the classified output.

A confusion matrix providing class accuracy, overall accuracy, and kappa coefficient was generated to evaluate the accuracy of results. Finally, district-wise crop acreage statistics were extracted and compared with official estimates of the State Agriculture Department by calculating Relative Deviation.

5. Results and Discussion

5.1 Classification using SAR GRD data:

SAR-derived time-series backscatter data in VH and VV polarizations was studied based on the crop phenology from June to November 2019. Temporal backscatter analysis from SAR intensity data showed that the backscatter values in VV polarization were relatively higher than VH polarization for all the crops (Pigeon Pea, Cotton, Paddy (Rice), Sugarcane) in the study area (Figure 4).

Mean σ^0 (dB) values in VH polarization were higher for all the crops during the initial crop phenological cycle during June-July due to field preparation for sowing and associated surface roughness during ploughing. VH backscatter values were reduced during sowing and subsequently increased, linearly coinciding with crop growth. Paddy crops showed a typical temporal backscatter profile in VH and VV polarization during the transplanting stage in August and subsequent increase in the following months during crop growth stages, thus giving good separability from other crops. Cotton crop showed a unique phenological σ^0 signature in VV and VH during the initial sowing and growing stages. Sugarcane being a longer duration crop, manifested minimal temporal variation in VV polarization during the entire cycle.

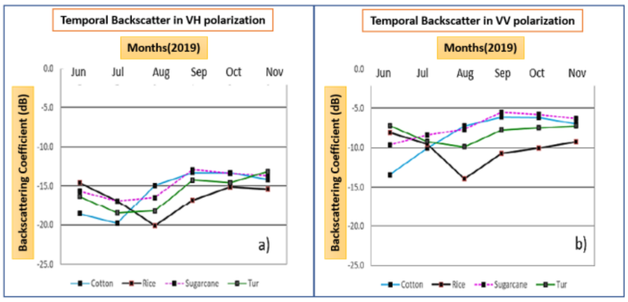

Figure 4. Temporal variation in sigma nought for Pigeon Pea Vs Other Crops (a) VH (b) VV

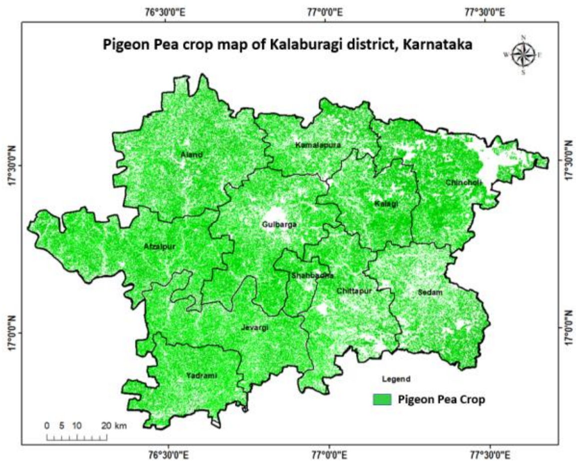

Figure 5. Spatial distribution of Pigeon Pea Crop using SAR GRD data for Kalaburagi district

The backscatter data was then classified using Random Forest Classifier. Cloud-free Resourcesat-2 LISS-III data of 2018 and Land use/land cover (LULC) map generated from SISDP project (Space-based Information Support for Decentralized Planning - Phase I) at 1:50K scale was used for masking non-agricultural land features such as water bodies, built-up, forest, and wastelands during classification. The performance of Random Forest classification was evaluated with varying decision trees (50, 100, 250, and 500), and subsequently, 100 trees were selected as optimal. The training vectors corresponding to various landcover classes, including Pigeon Pea crop, were evaluated with VV, VH and VH+VV polarization covering three ranges of acquisition periods: June to September, June to October, and June to November. The trained classifier was tested for nine such combinations of feature bands, keeping the number of trees at 100. The spatial distribution of the Pigeon Pea crop obtained using the Random Forest classification approach is presented in Figure 5.

Table 3 shows the error matrix and kappa statistics generated for the classification. The SAR intensity-based study using VV+VH backscatter data with an acquisition period from June to early November of 2019 resulted in an accuracy of 85.16% with a relative deviation of 3.79 percent (5.02 lakh ha) from the actual reported area estimates (5.21 lakh ha).

Table 3. Confusion Matrix for Crop Classification

Crop Type	Pigeon Pea	Sugarcane	Cotton	Jowar	Paddy	Total	User's Accuracy (%)
Pigeon Pea	295	5	8	14	16	338	87.28
Sugarcane	3	48	1	0	12	64	75.00
Cotton	7	0	27	4	2	40	67.5
Jowar	5	0	5	17	0	27	62.96
Paddy	10	3	1	0	164	178	92.13
Total	320	56	42	35	194	647	
Producer's Accuracy (%)	92.19	85.71	64.29	48.57	84.54		

Overall accuracy: 85.16%, Kappa Coefficient: 0.77

5.2 Classification using SAR SLC data

An experimental work to evaluate Multi-temporal SAR Single Look Complex (SLC) data having phase and intensity information for pre-harvest crop acreage estimation was carried out for Afzalpur taluk of Kalaburagi district. Sentinel-1B SLC data acquired during July, September, and October 2019 were pre-processed and polarimetric decomposition was performed. The temporal variation of Entropy (H) and Alpha angle (α) values produced from decomposition of multi-temporal SLC data were then analyzed for agricultural crop regions with the help of GT points (Figure 6).

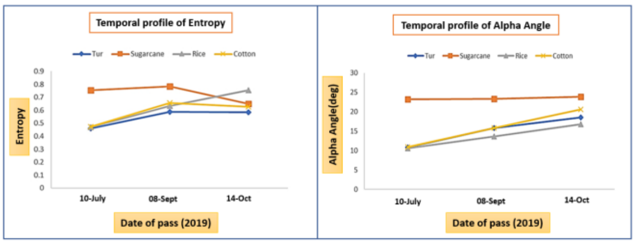

Figure 6. Temporal variation of Entropy & Alpha Angle for Pigeon Pea Vs Other Crops

Temporal variation of entropy values was observed for Pigeon Pea, Paddy (Rice), and Cotton, with lower values during July and higher values during September and October. However, Sugarcane showed a distinct temporal signature with higher H and α values in comparison to other crops. Paddy was separable from other crops due to increasing entropy during the pre-harvest (October) season. Pigeon Pea and Cotton crops had similar temporal signatures of H and α.

The H-α Wishart Unsupervised classification was carried out on the polarimetric decomposition outputs corresponding to July, September, and October 2019 (Figure 7). The progressive condition of the cropland was assessed from the multi-temporal classified images. The classified image of the pre-sowing period showed mostly Bragg scattering zones, which are associated with tilling of land in preparation for sowing. Random surface scattering was associated with crop growing stage of various crops, whereas random anisotropic scattering zones was associated with fallow land.

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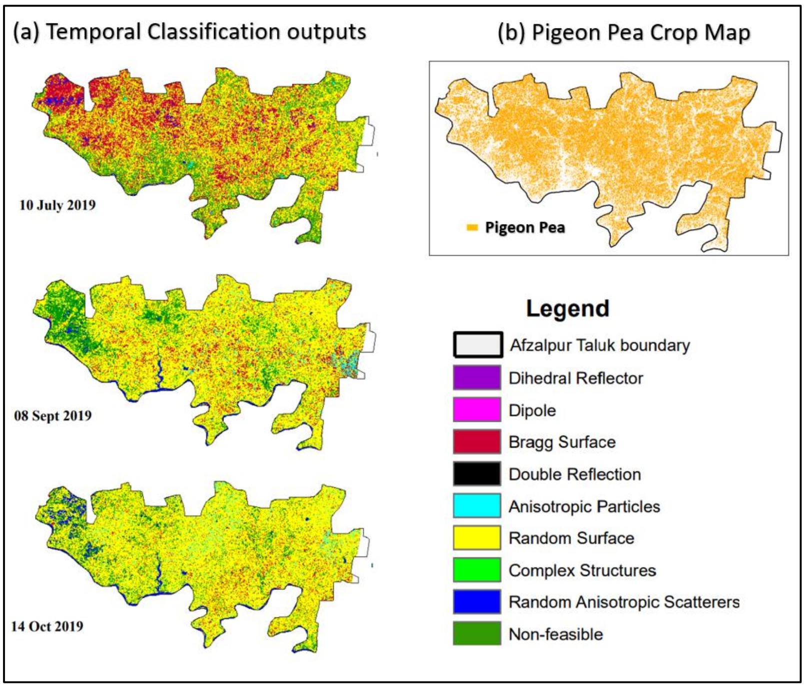

Figure 7. (a)Temporal H-α Wishart Unsupervised Classification outputs (b) Pigeon Pea Crop Map using SAR SLC data of Afzalpur Taluk

Area statistics of the nine zones of classification showed that the extent of Bragg surface scattering is high during July indicating sowing period and decreases during September and October, coinciding with crop growth. Similarly, the random surface scattering zone area corresponding to Cropland increases temporally with crop growth. Sugarcane crop exhibited non-feasible scattering during July and random surface scattering in the later months, hence, the corresponding regions were masked. Comparing with the corresponding temporal entropy and alpha angle values, Paddy and Cotton growing areas were masked. The final crop map for Pigeon Pea was generated by delineating the regions corresponding to random surface scattering zone during the pre-harvest stage. The discrimination of crops having similar phenology and similar scattering characteristics (random surface scattering zone) was found to be difficult. The kappa coefficient for the classification of Pigeon Pea Crop using SLC data was estimated as 0.67, giving an overall classification accuracy of 63.33%. The Remote Sensing-based Pigeon Pea crop area during 2019 for Afzalpur Taluk was 72832 ha compared to the reported area of 64192 ha, showing a relative deviation of 13.45 percent

6. Conclusion

SAR data has been effectively used for Pigeon Pea early season crop area assessment in Kalaburagi district of Karnataka, by overcoming the constraints of cloud-free satellite data during the *Kharif* season. Multi-temporal Sentinel-l C band SAR backscatter data with VV+VH polarization acquired during June-November showed good classification accuracy using the Random Forest algorithm. LULC 50K map integrated into the methodology improves the accuracy by masking non-crop classes thereby reducing misclassification. The analysis showed a relative deviation of less than 10 percent from the reported area estimates for Kalaburagi district. The study revealed that data acquired from June to early November in VV and VH polarization helped in better discrimination of Pigeon Pea crops in the study area. It was also observed that a combination of VV+VH was required for better classification.

Polarimetric analysis of dual-pol SAR (Phase + Intensity) SLC data was experimented with using 3-date Sentinel-1 data with VH and VV polarization. Polarimetric decomposition features, namely entropy H and alpha angle α, were studied using the unsupervised H- α Wishart Classification method to understand Pigeon Pea crop's temporal behavior vis-à-vis other landcover classes. Surface, double-bounce, and volume scattering mechanisms were analyzed using the polarimetric decomposition technique in the H-α space, which provided better class discrimination. However, there is scope for further studies on the discrimination of crops that have similar crop phenology and scattering characteristics. Based on the results, it is observed that the class separability significantly improved with the synergy of phase and intensity information from SAR data. The present study encourages the potential utilization of multi-temporal microwave SAR data for crop acreage studies. However, the procedure must be evaluated in selected districts across the country to develop an operational procedure for state / national level area assessment of Pigeon Pea crops.

References:

Ainsworth T. L., J. Kelly and J. Lee (2009). Classification comparisons between dual-pol, compact polarimetric and quad-pol SAR imagery. ISPRS Journal of Photogrammetry and Remote Sensing,64,464-471, https://doi.org/10.1016/j.isprsjprs.2008.12.008

Bhagia N., G. D. Bairagi, S. Pandagre, G. Patel, S. P. Vyas, N. Kumar, R. Indal and P. Mesharam (2017). National Inventory of *Rabi* Pulses in India Using Remotely Sensed Data, *J Indian Soc Remote Sens*, 45(2): 285–295. https://doi.org/10.1007/s12524-016-0603-4

Chakraborty M., C. Patnaik, S. Panigrahy and J. S. Parihar (2006). Monitoring of wet season rice crop at state and national level in India using multi-date synthetic aperture radar data. *Agriculture and Hydrology Applications of Remote Sensing*. Proceedings of SPIE Volume 6411. https://doi.org/10.1117/12.693900

Cloude S. R. and E. Pottier (1997), "An entropy-based classification scheme for land applications of polarimetric SAR, *IEEE Trans. Geosci. Remote Sens*., Vol. 35, No. 1, 68–78. https://doi.org/10.1109/36.551935

Dadhwal V. K., R. P. Singh, S. Dutta and J. S. Parihar (2002). Remote sensing-based crop inventory: A review of Indian experience, *Tropical Ecology* 43(1): 107-122.

Directorate of Economics & Statistics (2021). *Agricultural Statistics at a Glance 2021*. Accessed from http:// eands.dacnet.nic.in, Ministry of Agriculture & Farmers Welfare, Directorate of Economics & Statistics, p.272

DPD Report (2020), *Kharif Pulses Prospects 2020-21*, (accessed from http://dpd.gov.in), Directorate of Pulses Development, Ministry of Agriculture & Farmers Welfare

Geographical Indications Registry (2019). *Geographical Indications Journal*, Advertised under Rule 41 (1) of Geographical Indications of Goods (Registration & Protection) Rules, 2002, Geographical Indications Registry, Intellectual Property Rights, Journal No.120, April 12, 2019, 37-43

Gumma M.K., T. W. Tsusaka, I. Mohammed, G. Chavula, N. V. P. R.Ganga Rao, P. Okori, C. o. Ojiewo, R. Varshney, M. Siambi and A. Whitbread (2019), Monitoring Changes in the Cultivation of Pigeon pea and Groundnut in Malawi Using Time Series Satellite Imagery for Sustainable Food Systems. Remote Sens. 2019, 11, 1475. https://doi.org/10.3390/rs11121475

Haldar D., C. Patnaik and M. Chakraborty (2014) Jute Crop Discrimination and Biophysical Para-meter Monitoring Using Multi-Parametric SAR Data in West Bengal, India. Open Access Library Journal, 1: e817

Harfenmeister K, S. Itzerott, C. Weltzien and D. Spengler (2021), Agricultural Monitoring Using Polarimetric Decomposition Parameters of Sentinel-1 Data. Remote Sensing. 2021; 13(4):575. https://doi.org/10.3390/rs13040575

Inglada J., A. Vincent, M. Arias and C. Marais-Sicre (2016), Improved early crop type identification by joint use of high temporal resolution SAR and optical image time series, *Remote Sensing*, vol. 8, no. 5, 362, 2016. https://doi.org/10.3390/rs8050362

Jong-Sen L., M. R. Grunes, T. L. Ainsworth, Li-Jen Du, D. L. Schuler and S. R. Cloude (1999), Unsupervised classification using polarimetric decomposition and the complex Wishart classifier, IEEE Transactions on Geoscience and Remote Sensing, vol. 37, no. 5, pp. 2249-2258, Sept. 1999, doi: 10.1109/36.789621.

Kaoneka S. R., R. K. Saxena, S. N. Silim, D. A. Odeny, N. V. P. R. Ganga Rao, H. A. Shimelis, M. Siambi and R. K. Varshney (2016), Pigeon pea breeding in eastern and southern Africa: challenges and opportunities. *Plant Breed*, 135: 148-154. https://doi.org/10.1111/pbr.12340

Mandal D., D. S. Vaka, N. Bhogapurapu, V.S. K. Vanama, V. Kumar, Y. S. Rao and A. Bhattacharya (2019). Sentinel-1 SLC Preprocessing Workflow for Polarimetric Applications: A Generic Practice for Generating Dual-pol Covariance Matrix Elements in SNAP S-1 Toolbox, https://doi.org/10.20944/preprints201911.0393.v1

Marawar M.W. and V. V. Ujjainkar (2019). Role of Pigeonpea in Indian Food Security. *Remarking an Analisation* 2019;4(2): E-461-466

Natteshan N.V.S. and N. S. Kumar (2020). Effective SAR image segmentation and classification of crop areas using MRG and CDNN techniques, *European Journal of Remote Sensing*, 53:sup1, 126-140, https://doi.org/10.1080/22797254.2020.1727777

Parihar J. S., M. Chakraborty, K.R. Manjunath and S> Panigrahy. (1998). Synthetic aperture radar data as a sustainable system for monitoring the Cropping system - an analysis, Page(s) 245-255, *ISPRS Archives – Volume XXXII Part 1, 1998, ISPRS Symposium on Earth Observation System for Sustainable Development*, Technical Commission I: Sensors, Platforms, and Imagery, 2-27 February 1998

Parihar J. S. and V. K. Dadhwal (2002). Crop production forecasting using remote sensing data: Indian experience. *Proceedings of the ISPRS Comm. VII Symposium "Resource and Environmental Monitoring*", Hyderabad, India during Dec. 3-6 2002, IAPRS & GIS, vol. 34, Part 7, 1-6.

Parihar J. S. and K. R. Manjunath (2013). Agricultural Applications: Evolution during last 25 Years. *NNRMS Bulletin*. March 2013, 58–75.

Parihar J. S. and M. P. Oza (2004). Remote Sensing for Crop Production Forecasting: Indian Experience. *Twentieth Session of the Asia and Pacific Commission on Agricultural Statistics*, Sept 2004

Parihar J. S. and M. P. Oza (2006). FASAL: an integrated approach for crop assessment and production forecasting, *Agriculture and Hydrology Applications of Remote Sensing*, edited by Robert J. Kuligowski, Proc. of SPIE Vol. 6411, 641101.

Paul S. and D. N. Kumar (2019). Comparison of Landsat-8 and Sentinel-2 Data for Classification of *Rabi* Crops over Karnataka, India, *The International Archives of Photogrammetry*, Remote Sensing and Spatial Information Sciences; Vol. XLII-3/W6, Gottingen: Copernicus GmbH. (2019): 579-584. https://doi.org/10.5194/isprs-archives-XLII-3-W6-579-2019

Ramamurthy V., D. M. Mamatha, K. V. Niranjan, V. Ramakrishnappa, K. Ranjitha, C. Marigowda and S. Singh (2019). Suitability evaluation for pigeon pea in southern transition zone of Karnataka Plateau, India. *Legume Research - An International Journal*. https://doi.org/10.18805/LR-4047

Ranjan A. K. and B. R. Parida (2019). Paddy acreage mapping and yield prediction using sentinel-based optical and SAR data in Sahibganj district, Jharkhand (India). Spatial Information Research, 27, 399–410 (2019). https://doi.org/10.1007/s41324-019-00246-4

Ray S.S., N. M. Sanapala and S. Gupta (2014). Use of Remote Sensing in Crop Forecasting and Assessment of Impact of Natural Disasters: Operational Approaches in India. In Conference Proceedings: *FAO Expert Meeting on Crop Monitoring for Improved Food Security*, Vientiane, Lao PDR, 111-121.

Sentinel-1 Product Specification (2020). Doc No.S1-RS-MDA-52-7441, ESA, 27/02/2020

Shaik Salma, N. Keerthana and B.M. Dodamani (2022), Target decomposition using dual-polarization sentinel-1 SAR data: Study on crop growth analysis,Remote Sensing Applications: Society and Environment,Volume 28,2022,100854,ISSN 2352-9385

Siddayya S., A. Dandekar and S. Kammar (2016). Adoption pattern of improved pigeon pea varieties in Gulbarga district, Karnataka, India. *Agricultural Science Digest - A Research Journal*. 1-36. https://doi.org/10.18805/asd.v36i4.6465

Silim S. N., G. Mergeai and P. M. Kimani (eds) (2001). *PIGEONPEA Status and Potential in Eastern and Southern Africa*, Proceedings of a Regional Workshop Nairobi, Kenya, 12-15 Sep 2000. International Crop Research Institute for Semi Arid Tropics , Patancheru, Andhra Pradesh, India. ISBN 92-9066-432-0, 1-232.

Singh J., A. Mahapatra, S. Basu and B. Banerjee (2019). "Assessment of Sentinel-1 and Sentinel-2 Satellite Imagery for Crop Classification in Indian Region During *Kharif* and *Rabi* Crop Cycles," *IGARSS 2019 - IEEE International Geoscience and Remote Sensing Symposium*, 3720-3723, https://doi.org/10.1109/IGARSS.2019.8900491

Tiwari A.K. and A. K. Shivhare (2019). *Pulses in India: Retrospect and Prospects – 2018*. Directorate of Pulses Development, GoI, Bhopal (MP), India, 1-346.

Tiwari S.K, M. L. Prasad Rao and G. P. Rao (2021). Paddy crop acreage assessment using Sentinel-1 (C-band) SAR data in Andhra Pradesh state, India, Journal of Crop and Weed, 17(2): 10-18 (2021)

Uppala D., K. Ramana, S. Poloju, S. Mullapudi and V. K. Dadhwal (2015). Rice crop discrimination using single date RISAT1 Hybrid (RH, RV) polarimetric data. *Photogrammetric Engineering and Remote Sensing*. 81. 557-563. https://doi.org/10.14358/PERS.81.7.557

Verma A., A. Kumar and K. Lal (2019). *Kharif* crop characterization using combination of SAR and MSI Optical Sentinel Satellite datasets. *J Earth Syst Sci* 128, 230. https://doi.org/10.1007/s12040-019-1260-0

Xianfeng Jiao, M. K. John, J. Shang, H. McNairn, D. Walters, B. Ma and X. Geng (2014), Object-oriented crop mapping and monitoring using multi-temporal polarimetric RADARSAT-2 data,ISPRS Journal of Photogrammetry and Remote Sensing,Volume 96,2014,Pages 38-46,ISSN 0924-2716