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Integrating SAR and Optical Data for Crop Area Estimation in Gauribidanur Taluk, Chikkaballapura District, Karnataka

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S. P. Raghavendra : Collection of ground truth, datasets preparation, spatial data analysis and draft preparation;
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Abstract

The study reported here is based on the research conducted in Gauribidanur taluk of Chikkaballapura district of Karnataka State using a combination of remotely sensed data in the optical region of the electromagnetic spectrum (EMS) using the data from European space agency (ESA)'s Sentinel-2B Multispectral instrument (MSI) and synthetic aperture radar (SAR) data from ESA's Sentinel-1A satellite. Datasets comprising of multi-band, multi-polarization and multi-temporal covering *kharif* and *rabi* seasons of the year 2022-23 were used in the study. Data reduction using principal component analysis (PCA) and digital spatial data analysis using Random forest (RF) algorithm were carried out. Different combination of polarizations *viz.,* Parallel polarization (VV), Cross polarization (VH) and VH/VV were used for information extraction from SAR data. Spectral reflectance (signatures), Spectral-temporal profiles of VV and VH polarizations and normalized difference vegetation index (NDVI) were used to identify the crops and associated cover types. Reference data (ground truth), collected twice during April 14-17, 2023 and May 2-5, 2023 was used to train the RF algorithm and for evaluation of classification accuracy. Digital image classification of single date (April 22, 2023) MSI (optical) and multi-polarization SAR data of the same day did not give satisfactory results. However, the multi-date, multi-polarized SAR data fused with optical datasets permitted better identification of crop types and their area estimation in the month of September 2022 during *kharif* season.

Keywords : Sentinel-1A, Sentinel-2B, Synthetic aperture radar (SAR), Multispectral instrument, Random forest (RF) algorithm, Polarization, Data fusion, Crop area estimation

In India the major crop growing season is during June to September (*kharif*) when the monsoon is also active and cloud cover prevents acquiring remotely sensed data from satellite platforms in the visible and infrared portion of the EMS. It is to overcome this constraint, many researchers made use of the SAR data for crop acreage estimation and crop monitoring. The physical basis of using active microwave sensors for studying vegetation canopies is the 'water cloud model' (WCM) wherein the canopy is modelled as a cloud of identical, randomly oriented scatterers, namely the leaves and branches (Attema and Ulaby, 1978). These authors attributed the backscattering coefficient from plant canopies as a function of i) volumetric moisture content of soil, ii) volumetric moisture content of vegetation and iii) plant height. Many researchers reported additional information from microwave remote sensing of croplands in terms of crop growth stages, vigour, yield potential, etc in addition to its all-weather capability. The unique sensitivity of radar waves to crop canopy structure, size, orientation, dielectric constant and roughness gives complementary information to that of optical sensors (Pemalatha & Nageswara Rao, 1994; Patel *et al.,* 1995; Chakraborty *et al.,* 2002 and Kumar *et al.,* 2013). As the crop goes through its growth stages the structure of vegetation undergoes changes resulting in changes in the dielectric constant and surface roughness. The most important aspect for identifying different crops is through capturing these temporal changes. (Dave *et al.,* 2019; Tian *et al.,* 2021 and Poonam *et al.,* 2022).

Research shows that the availability of multi-frequency, multi-temporal, multi-polarization datasets gives better discrimination of crops and improved classification accuracies (Das *et al.,* 2021). Combined with optical data sets, having the complementary information, it is possible to give accurate crop yield predictions (Mcnairn *et al.,* 2009 and Verma *et al.,* 2019). The availability of SAR data from satellites like ESA's Sentinel-1, Canadian RADARSAT, India's RISAT- 1 & 2 has expanded the scope of using SAR technology for agricultural applications. Similar studies assume importance in the context of opportunities opening up for researchers to access and analyse the data from the near-future NASA–ISRO Synthetic Aperture Radar (NISAR) satellite mission with better sensor characteristics in dual frequency (L- and S- bands) mode.

In the current study an attempt was made to i) develop backscatter signatures of various crop cover types in the study area, ii) demonstrate the use of multi-polarization and multi-date SAR data for crop identification and area estimation and iii) integrate multi-date optical reflectance data with SAR backscatter to achieve better information extraction from a multi-cropping agroecosystem.

Material and Methods

Study Area

The study was conducted in Gauribidanur taluk of Chikkaballapura district, Karnataka state (Fig. 1). The taluk headquarter Gauribidanur located at 13.61°N, 77.52°E. It has an average elevation of 694 metres above MSL. The economy of Gauribidanur is primarily agrarian with agriculture as the main occupation of majority of the population. The climate and availability of appropriate land and water resources support the cultivation of various crops in two major crop seasons namely *kharif* (June to mid-October) and *rabi* season (November to mid-February). Major crops grown in *kharif* season are maize, ragi, paddy and vegetables while the *rabi* season crops are ragi and maize. The study area also

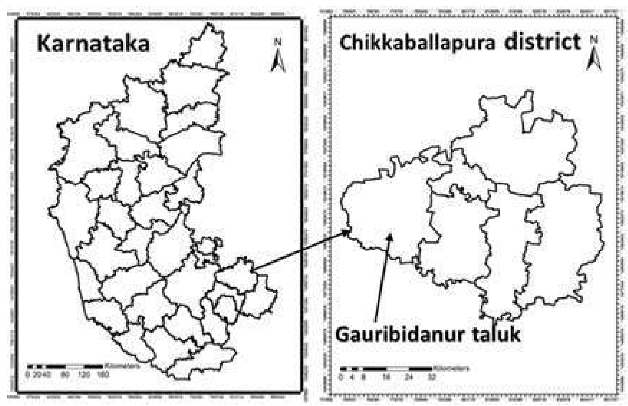

Fig.1: Gauribidanur taluk located in Chikkaballapura district of Karnataka

Table 1
Data sources and data products used in the study

Data Sources	Data Products Used
European Union's ESA- Copernicus programme.	Sentinel 1A C-band SAR, pre-processed (Thermal noise removed, Radiometric calibration, Terrain correction), Polarization: VV and VH, Spatial Resolution: 10m Central Frequency: 5.4 Ghz (C-band) Temporal Resolution: 12 days
European Union/ESA/Copernicus programme	Harmonized Sentinel-2B Multispectral Instrument (MSI), Level-2A, Spatial Resolution 10m in Blue, Green, Red, NIR bands, 20m in Red-Edge 1,2,3; Near IR; SWIR, Temporal Resolution: 5 days
World Resources Institute Google	Land Use/Land Cover (LULC) with a spatial resolution of 10 metre.
KGIS website -KSRSAC	Administrative Boundaries from Vector (.shp Files)

has mulberry, horticulture crops, perennial tree cover types and forest areas.

Spatial Data Used

Spatial data used for the study was from different sources (Table 1). The Google Earth Engine (GEE), a cloud-based geospatial analysis platform developed by Google, having various built-in tools and functions, was used in dataset preparation, processing, analysis and visualization of spatial data.

Ground Truth Data

QField, an open-source mobile app, designed for field mapping and ground truth collection was used to collect ground truth (reference) data. The configuration of the application was done using Quantum Geographic Information System (QGIS) desktop application. Ground truth was collected from 50 locations during April 14 - 17, 2023 and May 2 - 5, 2023. Additional 50 locations were inferred through visual image interpretation of false colour composites (FCCs). The sites chosen had fairly large fields of different crops at least one-hectare (ha) size, so that they are easy to locate on the ground. This data was used for training the RF algorithm and estimating the accuracy of crop classification.

Preparation of Datasets

The following combination of data sets were prepared: *viz.,* a) Single-date multi-band FCC of optical dataset using Sentinel-2B MSI acquired on April 22, 2023, b) Single-date multi-polarization composite using Sentinel-1A SAR data of the same day (April 22, 2023), c) Temporal SAR composites of *rabi* season (November-April, 2022-23) and *kharif* season (June-October, 2022) and d) Fused (Optical + SAR) data of September, 2022. The single-date multi-band FCC of optical dataset was prepared using Sentinel-2A MSI spectral bands Blue (490nm), Green (560nm), Red (665nm), NIR (842nm) of 10 metre spatial resolution, Short Wave Infrared-1 (1610nm), Short Wave Infrared-2 (2190nm), Vegetation Red Edge-1 (705nm), Vegetation Red Edge-2 (740nm), Vegetation Red Edge-3 (783nm), Vegetation Red Edge-4 (865nm) of spatial resolution 20m. The following indices were calculated using the above optical data sets: i) Normalized Difference Vegetation Index (NDVI) that responds to pigment composition, growth stages, green biomass and type of plant species, NDVI = (NIR-Red) / (NIR+Red), ii) Bare Soil Index (BSI) which is related to the extent of bare soil and areas without any vegetation cover., BSI = [(Red+SWIR) - (NIR+Blue)] / [(Red+SWIR) + (NIR+Blue)].

The procedure for selection of 'green pixels' and minimization of 'cloud pixels' in the MSI data was as per the details given in the Sentinel-2 User Handbook (ESA, 2015). It broadly involves atmospheric correction, threshold on blue reflectance for opaque clouds detection, detection of sub-pixel level cirrus clouds, snow index calculation, etc.

Though multi polarization composites of SAR data from Sentinel-1A satellite acquired on April 22, 2023 were available for VV, VH and VH/VV band ratio, we have used only VH polarized data as suggested by several authors (Karjalainen *et al.,* 2008; Jiao *et al.,* 2011; Liu *et al.,* 2013; Wiseman *et al.,* 2014; Selvaraj *et al.,* 2022 and Li & Wang, 2018). Cross-polarized backscatter is sensitive to crop structure within the total canopy volume, crop growth stages and preferred for identifying vegetation / crop types and for capturing variations between different crop types. In the early stages of the plant growth, surface scattering occurs from the interaction of the radar signal with the sparse canopy, stem and the soil surface. Hence, parallel polarized images tend to be brighter and show high mean backscatter values when compared with the cross-polarized images (Haldar *et al.,* 2012 and Cable *et al.,* 2014). So, we used VH polarization to prepare multi-temporal composites. For *rabi* season VH polarization data was acquired on November 2022, January 2023 and April 2023. For *kharif* season, data acquired during June 2022, August 2022 and October 2022 were used in preparing the time composited FCCs.

Preparation of Training Dataset and Identification of Crops Grown in *kharif* Season 2022

FCC images of *kharif* season Sentinel-2B MSI data (optical) were imported into the map window in GEE and the samples were selected for which crop types had to be identified. As the field visit and ground truth could not be conducted during *kharif* season (June–September, 2022), we resorted to a learning exercise using the MSI (optical) data acquired in the *rabi* season (April-May, 2023). This involved basic image interpretation involving tone, texture, field patterns, size, shape etc. of the crops, generating the spectral signatures of major crops grown in *rabi* season (Fig. 2), their temporal-spectral profiles of NDVI (Fig. 3) and the ground truth collected in *rabi* season. The experience thus gained was used to infer the crop classes of unknown points (crop types) of the *kharif* 2022.

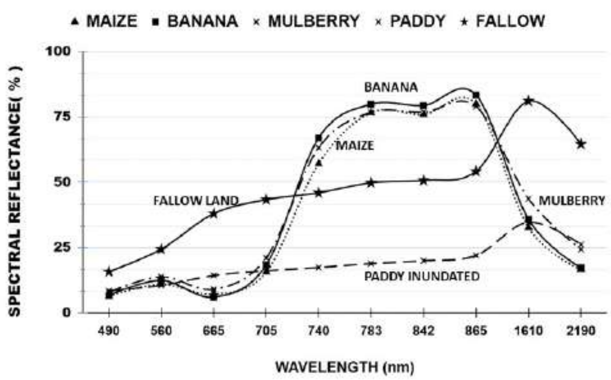

Fig. 2: Spectral reflectance (signatures) of major crops in the study area during March to April 2023

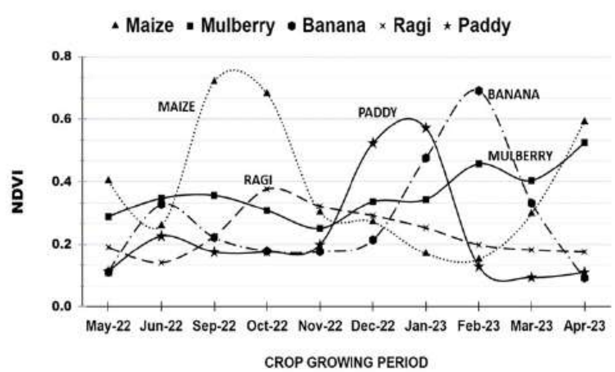

Fig. 3: NDVI time series for crops in the study area during May 2022 to April 2023.

It was found that the spectral reflectance of the crop lands meant for paddy cultivation was much less than dry fallow lands. The reflectance curves from the three major crops *viz.,* banana, maize and mulberry were typical of a plant leaf but having subtle variations in the red, NIR and SWIR bands. As revealed by the Euclidian Distance (ED) values between these three crops, their separability was not as expected. However, the NDVI profiles of these crops were different, enabling their identification (Fig. 3).

Optical and SAR Data Fusion

Data fusion was carried out after data reduction using Principal Component Analysis (PCA), a technique used for dimensionality reduction, available in GEE. The dataset consisting of eleven data layers, out of which eight from MSI (blue, green, red, red-edge, NIR, SWIR, NDVI, BSI) and three of SAR (*viz.,* VV, VH and VV/VH polarizations) was flattened into a 2D array, where each row represents a pixel and each column represents a different layer. The resultant image had new bands representing the components that are orthogonal and ordered based on the amount of variance they explain in the original data. The first three principal components that typically represent the most important patterns and variations in the fused data were used to prepare FCC for subsequent classification. Noise reduction, particularly speckle inherent in the SAR imagery was accomplished using Refined Lee Speckle filter through Java Scripting in the GEE. Further data reduction was carried out by masking non-cropped areas using the ESA's World Land Cover Product 2020. This has reduced the amount of data to be processed, thus improving computational efficiency and classification performance (Phan *et al.,* 2020).

Data Normalization, Crop Classification and Area Estimation

As mentioned earlier entire data processing, normalization and classification were performed in GEE environment. As the data came from different sources and the parameters of spectral bands and indices derived from them have different scale and ranges, the values of all parameters were rescaled between 0 and 1. This technique is termed as min-max scaling normalization (Singh and Singh, 2020). Digital image classification was performed using the RF algorithm because it was reported to give acceptable accuracy of crop classification using SAR data. The RF applies a set of decision trees to improve prediction accuracy (Breiman, 2001 and Nhemaphuki *et al.,* 2017). Feature importance and number of trees required for the RF model were calculated. Hyper-parameter-tuning, an experimental trial-and-error model was used to optimize the RF algorithm in terms of the number of decision trees required for the GEE's inbuilt-function to give better accuracy and classification. The number of trees thus selected for RF algorithm was 20. The sequence of steps followed is illustrated in Fig. 4.

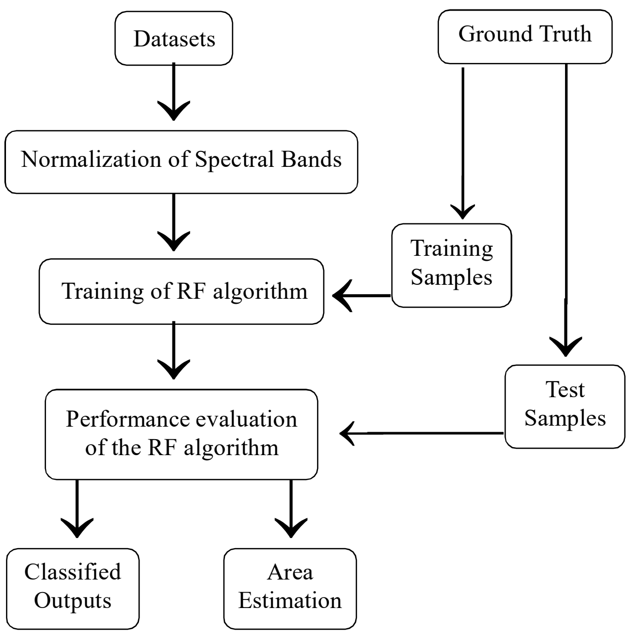

Fig. 4: Sequence of steps involved in crop classification and area estimation

About 50 per cent of ground truth data was used for training the model and 50 per cent of samples kept as test samples for validation. Post classification accuracy assessment was performed and accuracy parameters *viz.,* producer's accuracy, user's accuracy, overall accuracy and Cohen's Kappa coefficient were generated. Area under each crop class was estimated using the relevant built-in function of GEE. Digital outputs from RF algorithm were generated with appropriate colour codes and legend given to crops. The non-cropped area layer showing built-up, forest, barren lands and water bodies was added to the final output.

Results and Discussion

Temporal Backscatter Profiles of Crops

The changes in backscattering coefficient, expressed in decibels (dB), as a function of time observed with cross-polarized (VH) SAR from major crop types are presented in Fig. 5. It is seen clearly that the *kharif* sown paddy had a peak backscatter in the months of August -September (maximum greenness period) followed by gradual drop in the backscatter during October-November indicating its harvest. The low-level peaks and troughs exhibited by paddy crop after November could be due to minor changes in the soil moisture and roughness associated with growth of weeds. The backscatter profile of mulberry represents the pruning and regrowth.

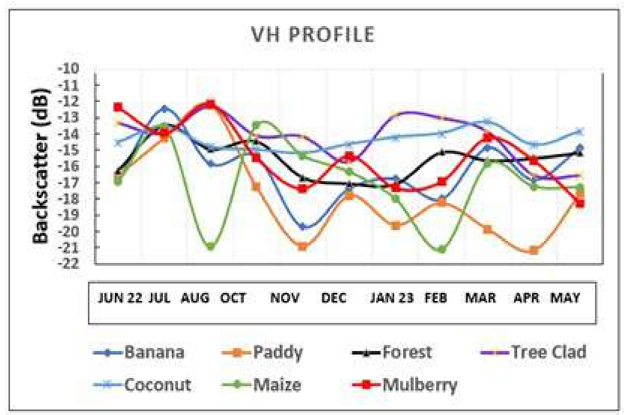

Fig. 5: Backscatter profiles of VH polarization for major crops in the study area during June 2022 to May 2023

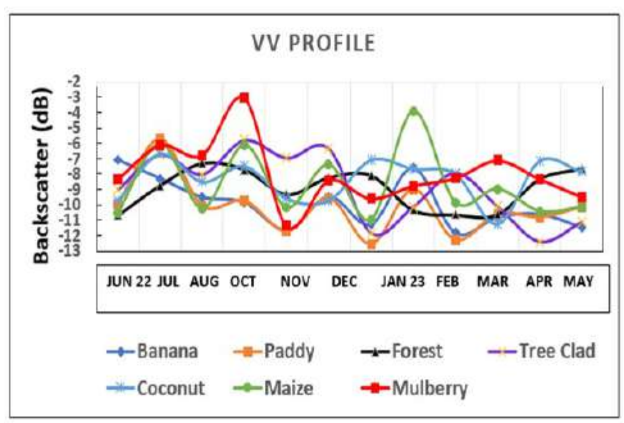

Fig. 6 : Backscatter profiles of VV polarization for Banana, Paddy, Forest, Tree-clad area, Coconut, Maize, Mulberry

Surprisingly the Banana VH profile also showed a rhythm in backscatter similar to mulberry though it is a long duration crop with green biomass much more than mulberry due to volume scattering and wind affecting the broad-leaved canopy. The maize VH profile evidently showed a deep trough in August indicating harvest of *kharif* season crop followed by a gradual rise and fall of the profile during the latter months indicating the presence of the same crop in *rabi* season as well. The changes in backscatter in VV polarization over time during 2022-23 (Fig. 6) have clearly revealed the nature of crops grown in the study area, though the VV backscatter values were found to be higher (-3 to -13 dB) than that of VH profiles of the same crops (-12 to -21dB).

TABLE 2

Accuracy assessment at the training stage of the RF algorithm

Dataset used	Accuracy obtained (%)	Kappa Coefficient
MSI-single date (22-04-2023)	94	0.92
SAR-single date (22-04-2023)	97	0.96
SAR multi-temporal composite *kharif* season (June-October)	95	0.93
SAR multi-temporal composite *rabi* (November -April)	97	0.96
Fused data (SAR and Optical)	95	0.93

TABLE 3

Confusion matrix for classification of optical data (Sentinel 2B MSI)-single date (22-04-2023) with 10 spectral bands and two indices

Predicted	Observed				
Crop Types	Maize	Mulberry	Banana	Fallow Land	Producer's Accuracy
Maize	16	2	4	0	0.73
Mulberry	4	4	1	1	0.44
Banana	0	1	10	0	0.91
Fallow	1	0	0	8	0.88
User's Accuracy	0.76	0.57	0.67	0.88	0.72

Overall Accuracy: 72% Kappa Co-Efficient: 0.67

TABLE 4

Confusion matrix for classification of SAR single date (22-04-2023) multiple polarizations (VV, VH, and VH/VV) data

Predicted	Observed				
Crop Types	Maize	Mulberry	Banana	Fallow	Producer's Accuracy
Maize	16	2	3	0	0.76
Mulberry	1	1	2	0	0.25
Banana	3	4	10	0	0.58
Fallow	0	0	0	8	1.00
User's Accuracy	0.80	0.14	0.67	1.00	0.70

Overall Accuracy: 70% Kappa Coefficient: 0.58

TABLE 5

Confusion matrix for classification of Sentinel-1A SAR multi-temporal composite *kharif* season (June-October)

Predicted	Observed					
Crop Types	Maize	Mulberry	Banana	Paddy	Fallow	Producer's Accuracy
Maize	11	2	1	0	0	0.79
Mulberry	1	5	1	0	1	0.63
Banana	1	3	5	1	1	0.45
Paddy	1	1	1	4	0	0.57
Fallow	0	0	0	1	9	0.90
User's Accuracy	0.79	0.45	0.63	0.67	0.82	0.69

Overall Accuracy: 69% Kappa Coefficient: 0.56

Assessment of Performance of the RF Algorithm

Assessment of performance of the RF algorithm at the training stage was carried out for different datasets and the accuracies are presented in Table 2. The overall post-classification accuracy obtained with the RF algorithm was assessed as per Congalton and Green (1999) wherein a confusion matrix was created to evaluate and understand the performance of the classifier.

TABLE 6

Confusion matrix for classification of Sentinel-1A SAR multi-temporal composite of *rabi* (November - April)

Predicted	Observed					
Crop Types	Maize	Mulberry	Banana	Paddy	Fallow	Producer's Accuracy
Maize	10	1	1	0	0	0.83
Mulberry	1	6	1	0	0	0.75
Banana	1	2	8	1	1	0.62
Paddy	1	0	1	5	0	0.71
Fallow	0	0	0	1	9	0.9
User's Accuracy	0.76	0.67	0.73	0.71	0.9	0.76

Overall Accuracy: 76% Kappa Coefficient: 0.73

TABLE 7

Confusion matrix for classification of fused data (SAR and Optical)

Predicted	Observed					
Crop Types	Maize	Mulberry	Banana	Paddy	Fallow	Producer's Accuracy
Maize	13	1	0	0	0	0.93
Mulberry	1	6	0	0	1	0.75
Banana	1	2	6	1	1	0.55
Paddy	1	0	1	5	0	0.71
Fallow	0	0	0	0	10	1.00
User's Accuracy	0.81	0.67	0.86	0.83	0.83	0.80

Overall Accuracy: 80% Kappa Coefficient: 0.74

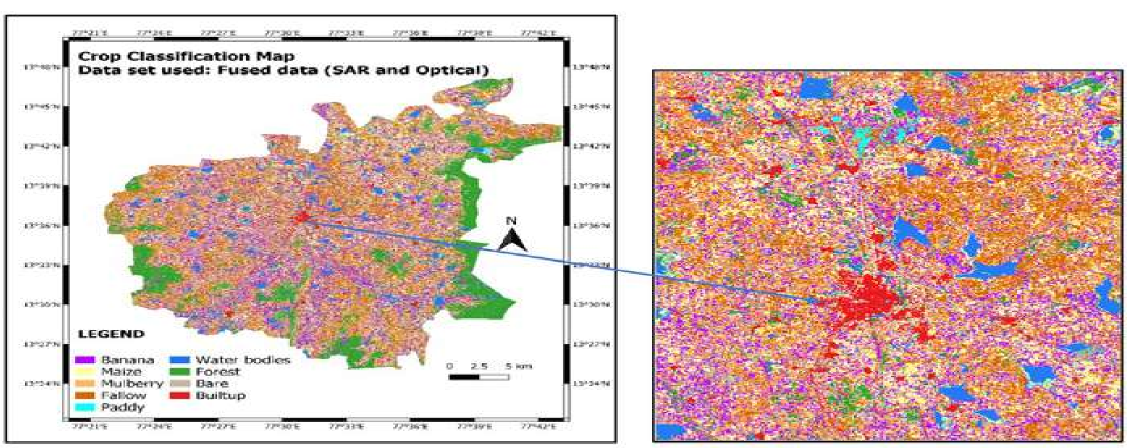

Fig. 7: Crop classification map generated using fused data (SAR+OPTICAL) for September 2022.

Confusion matrix for classification of single date (22-04-2023) optical data (MSI) given in Table 3 showed the overall accuracy was 72 per cent at Kappa coefficient of 0.67 indicating that the single date optical data was not adequate for accurate identification of the crop types. However, the producer's accuracies of maize and fallow-lands were better than the overall accuracy, indicating the probability of better estimation of their areas. Confusion matrix for classification of single date (April 22, 2023) multi-polarization SAR data (Table 4) also showed that the overall accuracy was not satisfactory. Confusion matrix generated with multi-temporal SAR data in the *kharif* (Table 5) and that of *rabi* season (Table 6) were also not encouraging as revealed by the overall accuracies and corresponding Kappa coefficients. The confusion matrix generated with SAR data fused with optical data (Table 7), however gave encouraging results with an overall accuracy of 80 per cent at Kappa 0.74. The digital crop map obtained with fused dataset is shown Fig. 7. The accuracy assessment, Kappa coefficient and crop area estimated with these data sets are summarized in the Table 8. The crop area estimates obtained from the single-date SAR and MSI data sets showed large variations. Although *kharif* SAR dataset yielded low accuracy of 69 per cent in its classification, this was the only source to get information as that optical dataset had major portion of study area under cloud cover.

Table 8

Overall classification accuracy of crop identification and area estimation in Gauribidanur taluk with all five sets of data

DATA SET	A	B	C	D	E
Overall Accuracy(%)	72	70	69	76	80
Kappa Coefficient	0.67	0.58	0.56	0.73	0.74
Crop Class	Estimated Area in hectares (Ha)				
Banana	2335	7005	8812	13517	15464
Mulberry	1787	990	6475	3909	14343
Maize	19904	28880	32784	27489	20662
Paddy	—	—	3864	772	1810
Fallow	44092	31233	16145	22440	15837

A: MSI-single date (22-04-2023), B: SAR-single date (22-04-2023), C: SAR multi-temporal composite *kharif* season (June-October), D: SAR multi-temporal composite *rabi* (November - April), E: Fused data (SAR and Optical)

Though the area estimates of major crop cover types were generated using remotely sensed data, their validation could not be done due to lack of reliable crop area statistics from the District Statistical Office. There were large number of pixels misclassified using SAR data, due to small fragmented fields which are below the resolving power of the sensor. Large size of training and validation datasets would have improved the learning skills of the RF algorithm, thus enhancing the accuracy of classification and area estimation.

The study clearly showed that by integrating the optical data (NDVI and BSI) with SAR (multi-date and multiple polarizations), identifying the major crops and their area estimation can be done. The choice of RF algorithm performed well with multi-temporal composite compared to single date composites. Further studies on data fusion techniques and appropriate choice of data acquisition may enhance the classification accuracy and thus area estimates of multiple crops.

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