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CLASSIFICATION OF RICE, COTTON, AND MAIZE CROPS IN NAGARKURNOOL DISTRICT OF TELANGANA STATE USING MULTI-TEMPORAL SENTINEL-1A SYNTHETIC APERTURE RADAR DATA AND MACHINE LEARNING TECHNIQUES

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ABSTRACT

India's diverse agricultural landscape supports the production of a wide array of crops that are essential to its economy. Staple crops such as cereals, millets, and pulses are cultivated alongside key cash crops and oilseeds. Rice stands as a primary staple, cotton serves as a major cash crop, and maize is gaining importance for both food and fodder, especially in the poultry and industrial sectors. However, mapping these crops accurately during the kharif season using optical remote sensing data is often restricted by persistent cloud cover, highlighting the advantage of all-weather-capable SAR (Synthetic Aperture Radar) data for crop mapping. This study focuses on mapping *kharif* crops specifically cotton, rice, and maize in the Bijinapally and Peddakothapally mandals of Nagarkurnool district, Telangana, using multi-temporal Sentinel-1A C-band SAR data. The SAR data, covering the crop growth period from June to December in the *kharif*-2023 season, was analyzed to generate mean backscatter profiles in VV (Vertical-Vertical) and VH (Vertical-Horizontal) polarizations for each crop type. Ground truth points were systematically collected from fields of cotton, rice, and maize, enabling precise backscatter profile extraction and facilitating crop differentiation based on temporal backscatter response. In Bijinapally mandal, cotton and rice were distinguishable during August and September. Cotton exhibited backscatter values ranging from -13.01 to -7.44 dB in VV and -16.30 to -13.62 dB in VH polarization, while rice showed values of -12.62 to -9.34 dB in VV and -20.65 to -17.70 dB in VH polarization. Similarly, in Peddakothapally mandal, maize and rice were differentiable from August to mid-September. Maize showed backscatter values between -7.52 and -9.08 dB in VV and -15.04 to -15.21 dB in VH, while rice showed -12.61 to -9.77 dB in VV and -20.49 to -17.84 dB in VH polarization. To classify these crops, two machine learning algorithms—Random Forest (RF) and Support Vector Machine (SVM)—were employed. Among these, RF with VH polarization achieved the highest accuracy. In Bijinapally, RF classification showed deviations of -17.67% and -9.7% for cotton and rice areas, respectively, when compared to official agricultural statistics (7596 and 7311 ha). In Peddakothapally, maize and rice areas showed minimal deviations of 1.1% and 3.7% (6131 and 4373 ha), respectively. The RF classifier using VH polarization achieved an overall accuracy of 94.44% with a kappa coefficient of 0.91, underscoring its effectiveness for crop classification in this region.
***Keywords*:** Sentinel-1A, SAR, Random Forest, Support Vector Machine, crop classification.

Introduction

India is well known for its diverse agricultural landscape, producing a wide range of crops essential to its economy. The country grows staple crops such as cereals, millets, and pulses, along with key cash crops and oilseeds. Rice is a dominant staple, cotton serves as a major cash crop, and maize, used for both food and fodder, is gaining significance, especially in the poultry and industrial sectors. These crops account for 46.38%, 11.1%, and 10.4% of the total cultivated area in the kharif season, respectively (Directorate of Economics and Statistics, 2021-22). In Telangana, these crops occupy nearly 85% of the total cultivated area during the *kharif* season.

The need for timely and reliable crop area and production information for strategic and tactical decision-making in agriculture is well recognized by stakeholders and the government (Ashmitha Nihar *et al.*, 2019). Traditional methods of acquiring crop area data are costly, labor-intensive, and subjective, requiring substantial manpower. Thus, remote sensing data has become a valuable tool for agricultural assessment, offering timely, accurate, and objective estimates at various temporal and spatial scales, enabling crop identification, monitoring, acreage, and yield estimation (Subbarao *et al.*, 2021).

During the monsoon season, cloud cover and atmospheric disturbances hinder the use of optical remote sensing (RS) data for crop discrimination. Microwave RS addresses these limitations effectively, as it can acquire data under all-weather, day-or-night conditions, making it suitable for multi-seasonal crop monitoring (Ranjan *et al.*, 2021). Microwave RS provides robust support for crop identification and agricultural monitoring in data and technology aspects (Raman *et al.*, 2019). Synthetic Aperture Radar (SAR) is an active system that uses longer wavelengths in the microwave range, typically ranging from 1 mm to 1 m. It provides cloud-free, all-weather data, making it ideal for monitoring crops during the *kharif* season Sharma *et al.* (2022).

The crop growth cycle can be monitored based on SAR backscatter changes in response to phenological stages (Venkatesan *et al.*, 2019). Crop growth, a dynamic process from planting to maturity, is captured by SAR's high spatial resolution and complete temporal information on crop development, which can enhance crop mapping accuracy (Lin *et al.*, 2022). The C-band backscatter's sensitivity to crop phenology has led to its application in monitoring crop

This study focuses on classifying key *kharif* crops—cotton, rice, and maize—in the Bijinapally and Peddakothapally mandals of Nagarkurnool district, Telangana, using advanced multi-temporal Sentinel-1A C-band Synthetic Aperture Radar (SAR) data and machine learning techniques.

The Sentinel-1A satellite, launched by the European Space Agency (ESA) in April 2014, is equipped with a C-band radar sensor that acquires images every 12 days. This SAR data, collected across the entire *kharif*-2023 season from June to December, enables consistent monitoring by penetrating cloud cover and capturing all-weather, day-and-night observations.

Materials and Methods

Study area

Nagarkurnool district is located in the southern region of the Telangana state in that Bijinapally and Peddakothapally mandals lies between 16°29'21" N latitude, 78°18'30" E longitude and 16°17'47" N latitude, 78°21'50" E longitude selected for study site. The monsoon arrives in June and lasts until September with about 550 mm of rainfall and average temperatures in the 22–23 °C range. The dominant crops cultivated in the study area are cotton and rice crops in Bijinapally mandal and maize and rice crops in Peddakothapally mandal selected for study.

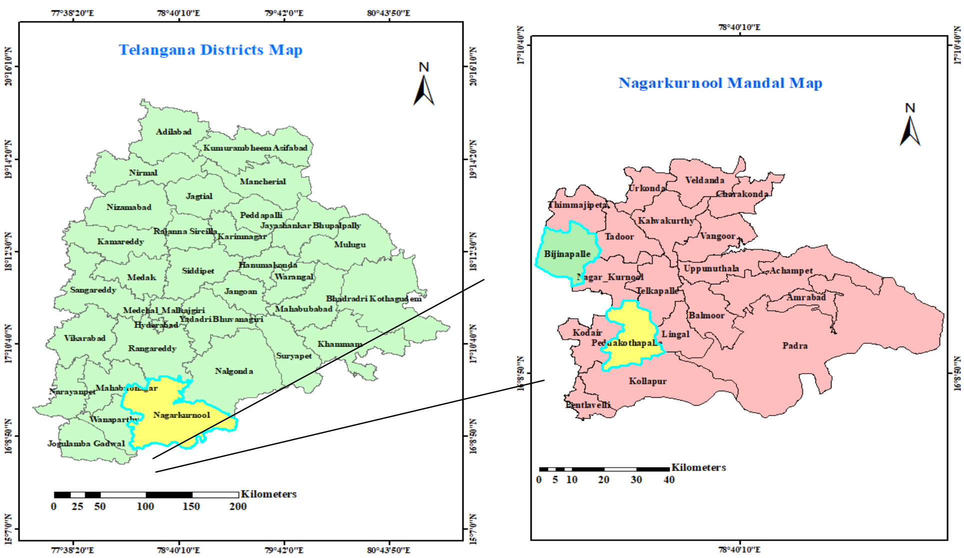


Fig. 1 : Study area location of Nagarkurnool district

Satellite data

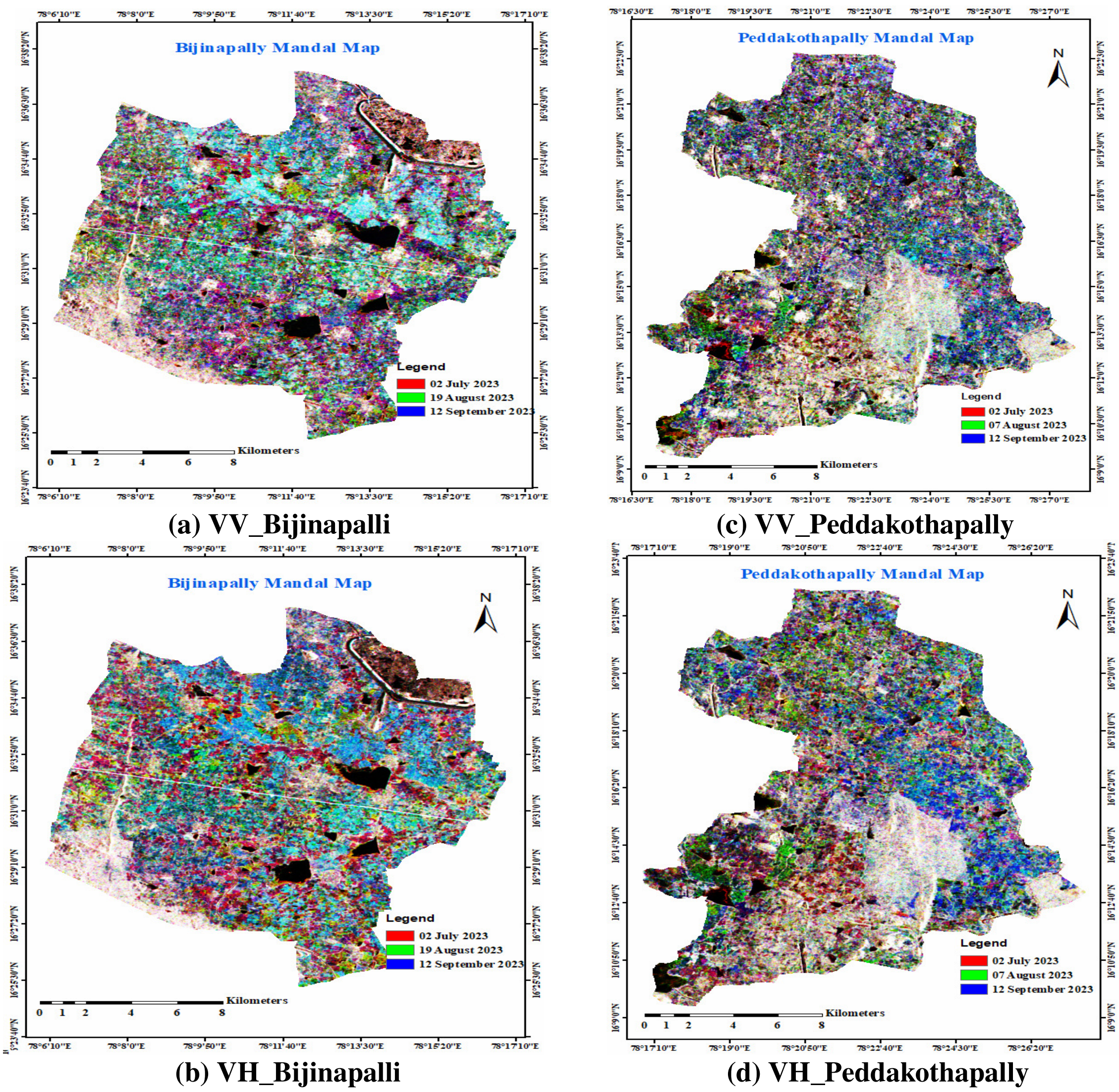
Sentinel-1A is equipped with C-band Synthetic Aperture Radar (SAR) data that supports various polarizations, including VV (Vertical-Vertical), HH (Horizontal-Horizontal), VV+VH, and HH+HV. This study utilized Interferometric Wide Swath (IW) data provides level-2 Ground Range Detected (GRD) data and focusing specifically on the VV and VH polarizations available free of cost from Copernicus data space ecosystem web portal. The satellite data collected from June to December, 2023 covering the entire growth period for cotton, rice and maize was downloaded for the study area.

Methodology

Pre-processing of the satellite data:

The SNAP 6.4 software was utilized for the pre-processing of Sentinel-1A SAR data, which involved several key steps to ensure data quality. First, radiometric calibration was performed to convert raw pixel values into surface backscatter measurements. Refined Lee speckle filtering was applied to reduce speckle noise while preserving image resolution. The data was then converted to dB, transforming the unitless backscatter coefficient into decibels for standardization. Terrain correction was applied to mitigate distortions caused by topography, ensuring accurate geometric representation of the surface.

The processed data, including VV and VH polarization bands, was exported in TIFF/Geo TIFF format. These images were mosaicked to cover the study area, then subset and layer-stacked for the Bijinapally and Peddakothapally mandals over the *kharif* season (June to December). The temporal FCC of these data are shown in figure-1.



(a) VV_Bijinapalli

(c) VV_Peddakothapally

(b) VH_Bijinapalli

(d) VH_Peddakothapally

Fig. 1 : Multi- temporal Sentinel- 1A SAR data VV and VH polarizations for Bijinapally and Peddakothapally mandals (Red:02.07.2023; Green:19.08.2023; Blue:12.09.2023)

Ground truth point collections and Spectral-signatures extraction

The ground truth point location information was recorded by the mobile based app i.e., GNSS viewer application. These points were collected from center of the crop field with a total of 20 samples of each crop cotton, rice and maize. These points were monitored to collection data on plant height, moisture content, leaf area index (LAI) and biomass from the study area. The mean backscattered (dB) values were extracted fromlayer stacked multi-temporal SAR data for generating signatures of cotton and rice for the period from June to December and maize crops from June to October in the study area.

Image classification

The classification of SAR data using the random forest (RF) and support vector machine (SVM) algorithm was performed in ArcMap 10.8 software. These two algorithms relies upon polygon-based training data to train the model. For this training samples were generated for VV and VH polarizations separately for different land use and land cover classes to generate the classifier definition file specific to algorithms. The classification was performed using the prepared training sample file and layer-stacked time-series SAR data for VV and VH polarizations separately for RF and SVM classification algorithms. Post-classification smoothing was applied to the classified image to retain the specific crop classes (cotton, rice, and maize) and removed other classes, including the elimination of small patches and clumping of adjacent pixels.

Accuracy assessment

Accuracy assessment was conducted to validate the classification results, ensuring reliable information for decision-makers and supporting effective decision-making. A comparative analysis was also performed between different classification methodologies and datasets, such as VV and VH polarizations. Ground-truth points were collected from the study area separately for validation purposes. The results include producers accuracy, user accuracy and overall accuracy as well as kappa coefficient.

Classification accuracy was assessed using layer-stacked data from VV and VH polarizations with both RF and SVM algorithms. In Bijinapally mandal, RF classification for cotton and rice achieved an overall accuracy of 88.9% with a kappa coefficient of 0.83 for VV polarization, and 94.4% with a kappa coefficient of 0.91 for VH polarization. Using SVM, the overall accuracy for VV polarization was 93.3% with a kappa coefficient of 0.90, and for VH polarization, it was 91.1% with a kappa coefficient of 0.86. In Peddakothapally mandal, RF classification for maize and rice yielded an overall accuracy of 91.1% with a kappa coefficient of 0.86 for VV polarization, and 94.4% with a kappa coefficient of 0.91 for VH polarization. SVM classification showed an overall accuracy of 84.4% with a kappa coefficient of 0.76 for VV polarization, and 92.2% with a kappa coefficient of 0.88 for VH polarization. Overall, the best accuracy was achieved using RF classification with VH polarization, showing 94.4% accuracy and a kappa coefficient of 0.91 (Table -2). The same results were reported Son *et al.* (2018), Onojeghuo *et al.* (2018), Kaur *et al.* (2024), Billah *et al.* (2023) and Nguyen *et al.* (2016).

Results and Discussion

In Bijinapally mandal, the dB values for cotton crops showed an increase in VV and VH polarizations, rising from -13.01 to -7.44 and -21.88 to -15.68, respectively, from sowing to the maximum vegetative stage between June and August. However, as the crop matured, the dB values declined in October. These findings align with the results reported by Ramalingam *et al.* (2019). For the rice crop, the dB values for both polarizations increased from -12.62 to -9.34 and -20.65 to -15.96, respectively, from transplanting to the maximum tillering stage between July and September. However, a decline in values were observed in November. Similarly, Selvaraj *et al.* (2019) reported the potential of dual polarized C-band Sentinel-1A data to discriminate different *kharif* crops ie., rice and cotton in Agra district of Uttar Pradesh.

In Peddakothapally mandal, the dB values for the maize crop increased from -13.50 to -7.52 and -19.99 to -15.04 for VV and VH polarization, respectively, as the crop reached maximum vegetative growth in July, followed by a decline as the crop matured in October. Similar results were reported by Ramalingam *et al.* (2019), Venkatesan *et al.* (2019) and Kumar *et al.* (2021). For the rice crop, the dB values for both polarizations increased from -12.61 to -9.77 and -20.49 to -17.84, respectively, as the crop reached the maximum tillering stage in September, with values declining as the crop matured in November. Similarly, Bhargav *et al.* (2022) could discriminate D-DSR and TP-R ecosystems in Jogulamba Gadwal dist.; Harika *et al.* (2022) and Neelima *et al.* (2023) could differentiate the early season and late season rice crop phenology in Nizamabad dist., using multi-temporal Sentinel 1 synthetic aperture radar (SAR) data. The temporal backscatter response of different crops in VV and VH polarizations are given in figure 2 to 5. It was observed that both VV and VH polarization exhibited an increasing trend with crop growth, driven by the peak vegetation, which increased volume scattering of the crop canopy and a continuous decline in backscatter intensity values of VH band at maturity stage, was due to decrease in greenness and moisture content in leaves. These results are in line with Verma *et al.* (2019) who reported the capability of multi-temporal SAR data for discrimination of cotton and maize crops in Ranchi district, East India.

Among the polarizations, VH polarization was found to better differentiate the crops compared to VV polarization. In Bijinapally mandal, the backscattered dB values for cotton and rice showed increasing patterns during their respective growth stages. For cotton, the dB values initially were found to be low due the dominated backscatter response from the background soil due to low vegetation cover, then increased during later growth stages, such as square formation and boll development, before declining at harvest (when cotton lint is picked from mature bolls). In rice, the dB values decreased during the initial transplanting stage due to waterlogged conditions, increased during the maximum tillering stage, and then declined at the maturity stage (grain hardening). In Peddakothapally mandal, both maize and rice showed increased backscattered dB values during their growing stages. For maize, the dB values increased during initial phase with higher rate due to fast growth rate of the crop compared to rice crop and remain stable during further stages before declined at the physiological maturity stage.

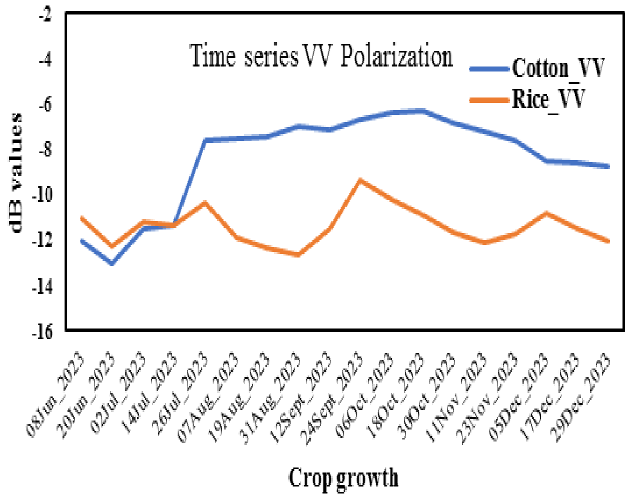


Fig. 2: Time-series VV signatures for cotton and rice in Bijinapally mandal during *kharif*, 2023

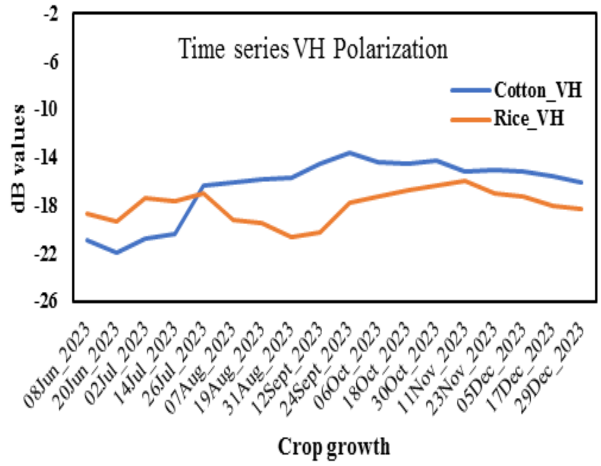


Fig. 3: Time-series VH signatures for cotton and rice in Bijinapally mandal during *kharif*, 2023

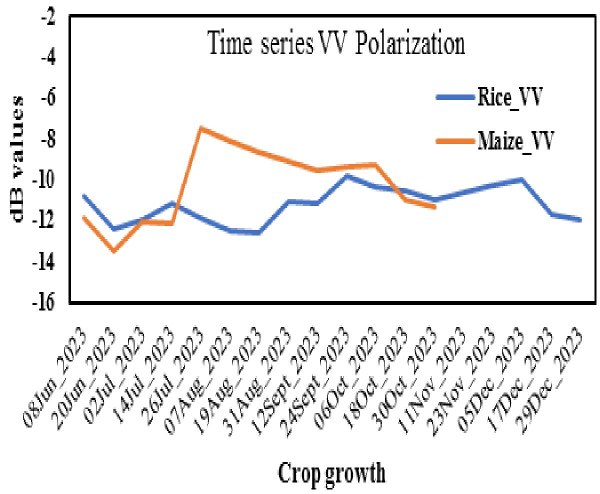


Fig. 4: Time-series VV signatures for maize and rice in Peddakothapally mandal during *kharif*, 20

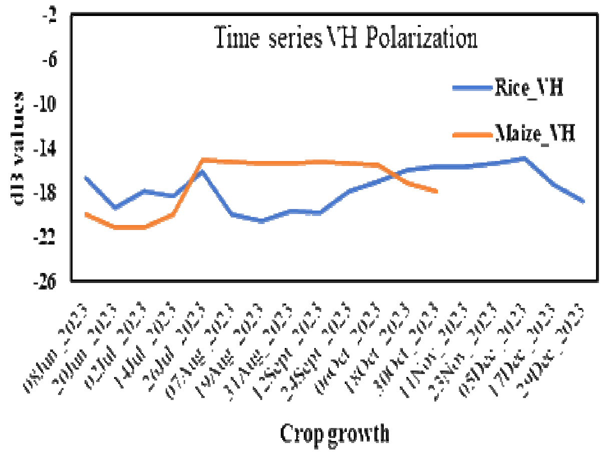


Fig. 5: Time-series VH signatures for maize and rice in

Peddakothapally mandal during *kharif*, 2023

Image classification was conducted using the Random Forest (RF) and Support Vector Machine classifier (SVM) with multi-temporal SAR data and dual polarizations (VV and VH) for cotton, rice, and maize crops, using ArcMap 10.8 software. In Bijinapally mandal, the estimated crop areas for cotton and rice using RF classification were 2,882 ha and 14,441 ha for VV polarization and 6,254 ha and 6,633 ha for VH polarization. With SVM classification, the areas were estimated at 2,209 ha and 13,558 ha for VV polarization and 5,518 ha and 9,138 ha for VH polarization. Similarly, in Peddakothapally mandal, the estimated crop areas for maize and rice using RF classification were 8,739 ha and 6,771 ha for VV polarization, and 6,200 ha and 4,535 ha for VH polarization. The SVM classification estimated 5,658 ha and 5,538 ha for VV polarization, and 5,932 ha and 4,149 ha for VH polarization.

The classified crop maps for Bijinapally and Peddakothapally mandals are given in Figures 6 and 7.

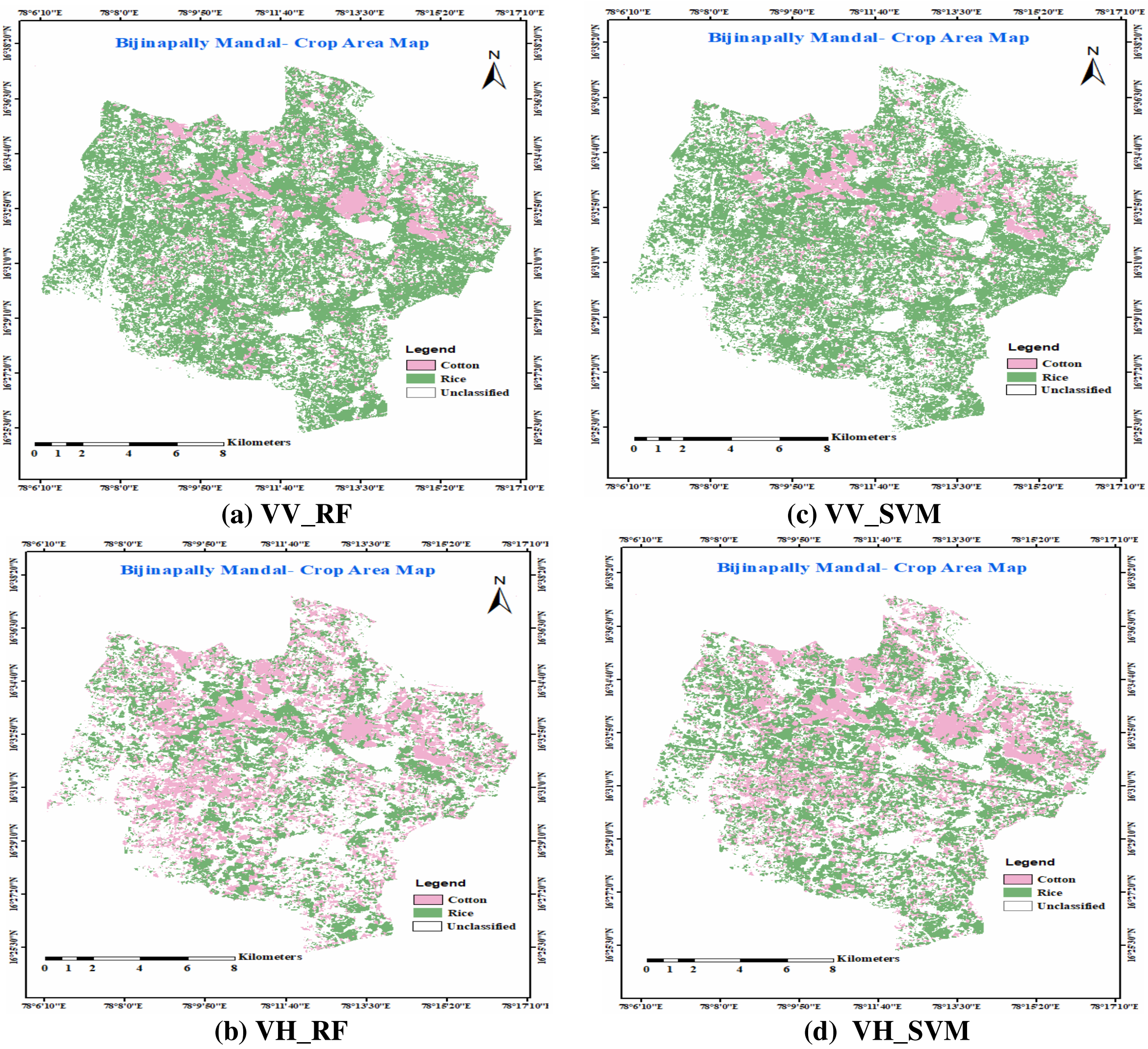
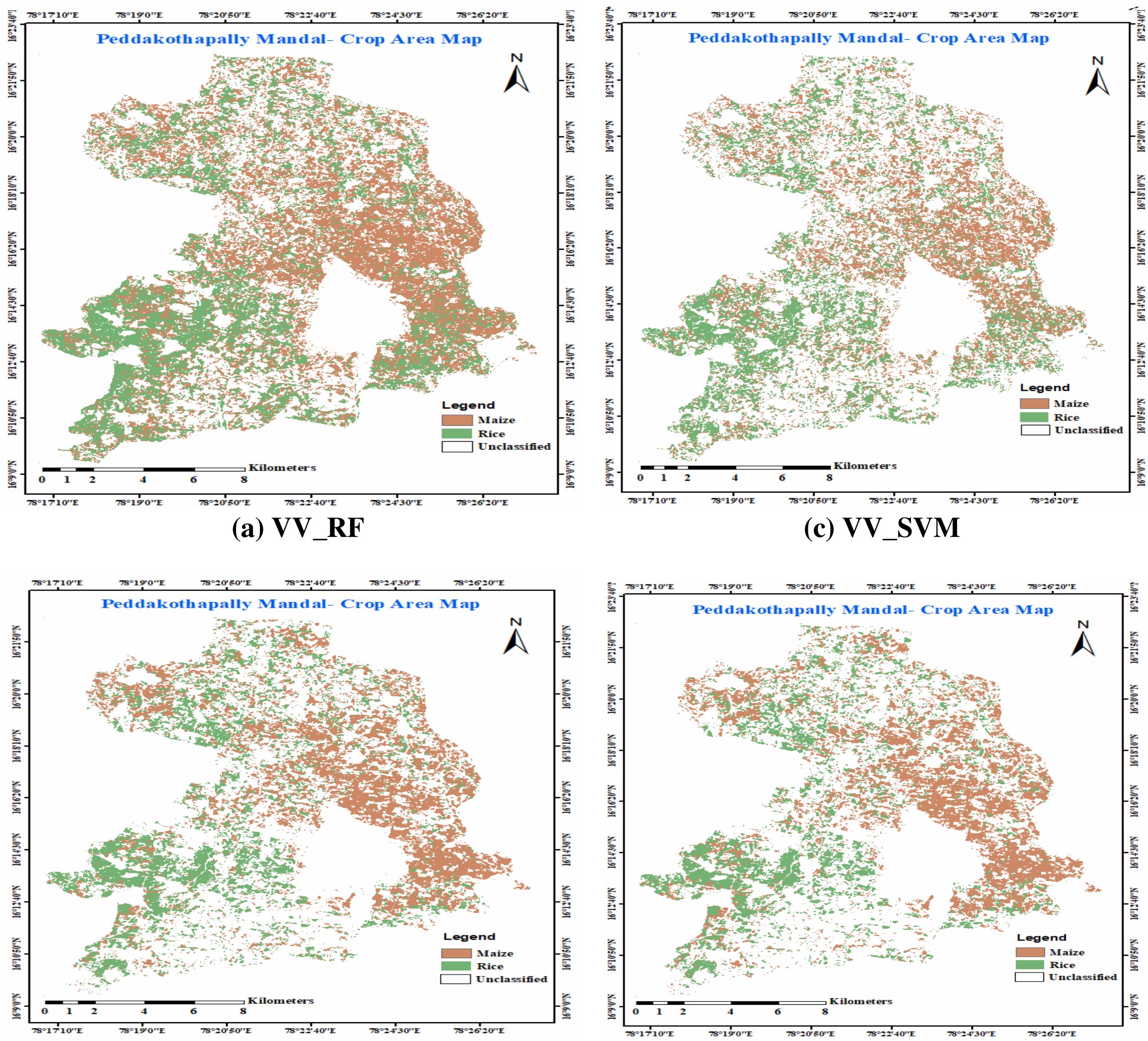


Fig. 6 : Cotton and rice crop classified using RF and SVM classifier with VV and VH polarizations in Bijinapally mandal, Nagarkarnool district for *kharif,* 2023.



(a) VV_RF **(c) VV_SVM**

(b) VH_RF **(d) VH_SVM**

Fig. 7 : Maize and rice crop classification using RF and SVM classifier with VV and VH polarizations in Peddakothapally mandal, Nagarkarnool distfor *kharif,* 2023.

Among the classifications tested for both VV and VH polarizations using RF and SVM, RF with VH polarization gave the best results compared to VV and SVM with both VV and VH polarizations. In Bijinapally mandal, the cotton and rice areas were classified using the RF classifier with VH polarization showed deviations of -17.67% and -9.7%, respectively, compared to the Department of Agriculture, Government of Telangana statistics (7,596 and 7,311 ha). In Peddakothapally mandal, the maize and rice crop areas deviated by 1.1% and 3.7%, respectively (6,131 and 4,373 ha), outperforming the other classifications tested in the study area. The crop area statistics obtained from RF and SVM classification with VV and VH polarizations is presented in table-1. Similar results were reported by Neelima *et al.* (2022) for rice crop area estimated with an overall accuracy of 92.8% and 95.0 % during *kharif,* 2021 and 2022 with a deviation of -6.62 % and 3.0 % respectively as compared to the Government statistics, using Random Forest algorithm in Nizamabad district, Telangana.

Table 1: Crop area statistics extracted for cotton, rice and maize crops in Bijinapally and Peddakothapally mandals of Nagarkarnool district using random forest (RF) and support vector machine classifier (SVM) algorithms.

Satellite	**Criteria**	**Area (ha)**							
Sentinel-1A SAR data	Mandals	Bijinapally				Peddakothapally			
	Crops	Cotton		Rice		Maize		Rice	
	Classified algorithms	RF	SVM	RF	SVM	RF	SVM	RF	SVM
	VV	2,882	2,209	14,441	13,558	8,739	5,658	6,771	5,538
	VH	6,254	5,518	6,633	9,138	6,200	5,932	4,535	4,149
DOA, GoT		**7596**		**7311**		**6131**		**4373**	

Note: DOA- Department of Agriculture statistics, GoT – Government of Telangana

Table 2: The table showing the accuracy assessment for cotton, rice and maize crops classified using the random forest (RF) and support vector machine classifier (SVM) in Bijinapally and Peddakothapally mandals of Nagarkarnool dist.

Satellite	**Criteria**	**Overall accuracy (%)**				**Kappa coefficient**			
Sentinel-1A SAR data	Mandals	Bijinapally		Peddakothapally		Bijinapally		Peddakothapally	
	Crops	Cotton and rice		Maize and rice		Cotton and rice		Maize and rice	
	Classified algorithms	RF	SVM	RF	SVM	RF	SVM	RF	SVM
	VV	88.9	93.3	91.1	84.4	0.83	0.90	0.86	0.76
	VH	94.4	91.1	94.4	92.2	0.91	0.86	0.91	0.88

Conclusions

This study aimed to assess the ability to discriminate between cotton, rice, and maize crop areas using multi-temporal Sentinel-1A SAR data with dual polarization (VV and VH) in the Bijinapally and Peddakothapally mandals of Nagarkurnool district, Telangana. The analysis of mean backscatter (dB) values revealed a distinct trend, with increased backscatter corresponding to peak growth stages for each crop: cotton during the square formation and boll development stages, rice during maximum tillering, and maize during tasseling, relative to their early growth stages. While both VV and VH polarizations demonstrated good classification performance for these crops, VH polarization exhibited superior and consistent classification accuracy in both RF and SVM classifications. Among the two machine learning algorithms tested, Random Forest (RF) outperformed Support Vector Machine (SVM) in classifying the crops. Overall, the study concluded that multi-temporal Sentinel-1A SAR data, particularly with VH polarization and high temporal resolution, effectively discriminates between cotton, rice, and maize crops, capturing the full phenological development throughout their growth periods.

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