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Spatial mapping of rice extent using multi temporal sentinel-1 SAR imagery in southern Telangana zone

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Abstract

Rice is a staple crop in India, accurate estimation of rice acreage is important for effective planning and resource management. Sentinel-1 C band Synthetic Aperture Radar (SAR) with VV (Vertical-Vertical) and VH (Vertical-Horizontal) polarizations is effective resource for rice crop mapping especially during the *kharif* season when persistent cloud cover limits the applicability of optical remote sensing data. The present study is aimed to map the spatial distribution of rice crop in Mahbubnagar and Wanaparthy districts of Southern Telangana Zone during *kharif* 2025. The backscatter response of rice exhibited minimum dB values during the flooding stage ranging from -18.0 dB to -12.0 dB in VV and -25.0 dB to -18.0 dB in VH polarizations corresponding to the transplanting stage of rice crop. Rice crop maps were generated over study area using Random Forest algorithm, achieving an overall accuracy of 92.02% and a kappa coefficient of 0.894 confirming the potential of SAR microwave data. The total rice area estimated was 92,648 ha and 96,548 ha for Mahbubnagar and Wanaparthy districts, respectively during *kharif* season accounting 94% and 86% of total cropped area.

Keywords: SAR, random forest, sentinel-1, rice, multi-temporal, crop classification, remote sensing, supervised classification

Introduction

Rice is the staple food for more than half of the world's population and plays a crucial role in global food security India, the world's second-largest rice producer and consumer of rice, cultivates nearly 45 million hectares of rice annually and provides livelihoods to over 100 million livelihoods (IRRI 2025) [3]. The country contributes approximately 20% of global rice production, highlighting the need for timely and accurate estimation of rice cultivation area. According to the FAO [2], India's average per capita annual rice consumption is 68.2 kg, exceeding the global average of 50 kg. Rapid population growth and changing dietary preferences are expected to increase global rice demand, with production projected to reach 555 million tonnes by 2035. (Son *et al.*, 2014) [8]. Accurate and reliable information on rice cultivation extent is essential for national and state-level agricultural planning, food security, crop production forecasting, policy formulation and climate resilience strategies at both national and regional scales. Traditionally, the spatial extent of crop acreage has been assessed through field surveys and direct observations. These conventional approaches are limited by the issues of accuracy, efficacy and restricted geospatial coverage. However, these methods are often labor-intensive, time-consuming, costly, and constrained by limited spatial coverage and variable accuracy.

Recent advances in satellite remote sensing have provided efficient alternatives for large scale crop monitoring (Xue *et al.* 2008) [13]. Tools such as Remote Sensing (RS), Geographic Information Systems (GIS) and the Global Positioning System (GPS) have been widely adopted for land-resource mapping and agricultural land-use planning. Among these, GIS facilitates the integration, storage, analysis and visualization of multi-source spatial data, thereby supporting informed decision-making in agricultural planning and land-resource management (Reddy *et al.*, 2018) [6].

Optical Remote Sensing is often constrained by persistent cloud cover, during the rainy season, when rice is predominantly cultivated, clouds limiting its effectiveness for timely and accurate

crop mapping. In contrast, Multi-temporal Synthetic Aperture Radar (SAR) data provide all-weather, day-and-night imaging capabilities, enabling reliable monitoring of rice growth throughout the cropping season thereby improving accuracy (Setiyono *et al.*, 2017) [7]. High-resolution SAR data further facilitates accurate estimation of rice cultivation at farm and village scales (Qader *et al.*, 2023) [5]. Previous studies have demonstrated that rice area maps generated from SAR data can achieve high classification accuracies, ranging from 88% (Tiwari *et al.*, 2021) [12] to 94.5 (Pazhivelan *et al.*, 2022) [4].

Sentinel-1 operating in the C-band, is particularly well suited for rice monitoring due to its sensitivity to changes in crop structure and surface moisture. Variations in VV and VH polarization backscatter effectively capture key rice phenological stages, including flooding, transplanting and tillering-through backscatter changes in VV and VH polarisations. In this context, the present study employs multi-temporal Sentinel-1 SAR imagery to map rice cultivation extent in the Mahbubnagar and

Wanaparthy districts of Telangana, demonstrating the potential of SAR data for operational rice area estimation.

Study area

Mahbubnagar district in Telangana, is located at approximately 16.74° North latitude and 78.01° East longitude, with an average elevation of about 498 meters above sea level and Wanaparthy district is situated at around 16.36° North latitude and 78.06° East longitude and lies at an average elevation of approximately 400 meters above sea level. Mahbubnagar's economy is primarily agrarian, supported by red sandy and black cotton soils. The major crops grown include paddy, jowar, maize, cotton, groundnut and castor. Wanaparthy's economy is primarily agrarian, supported by Red Sandy Soils, Sandy loam Soil, loamy sand and Black Cotton Soils. The major crops grown in the district are rice, groundnut, jowar, maize, redgram, castor, cotton and chillies.

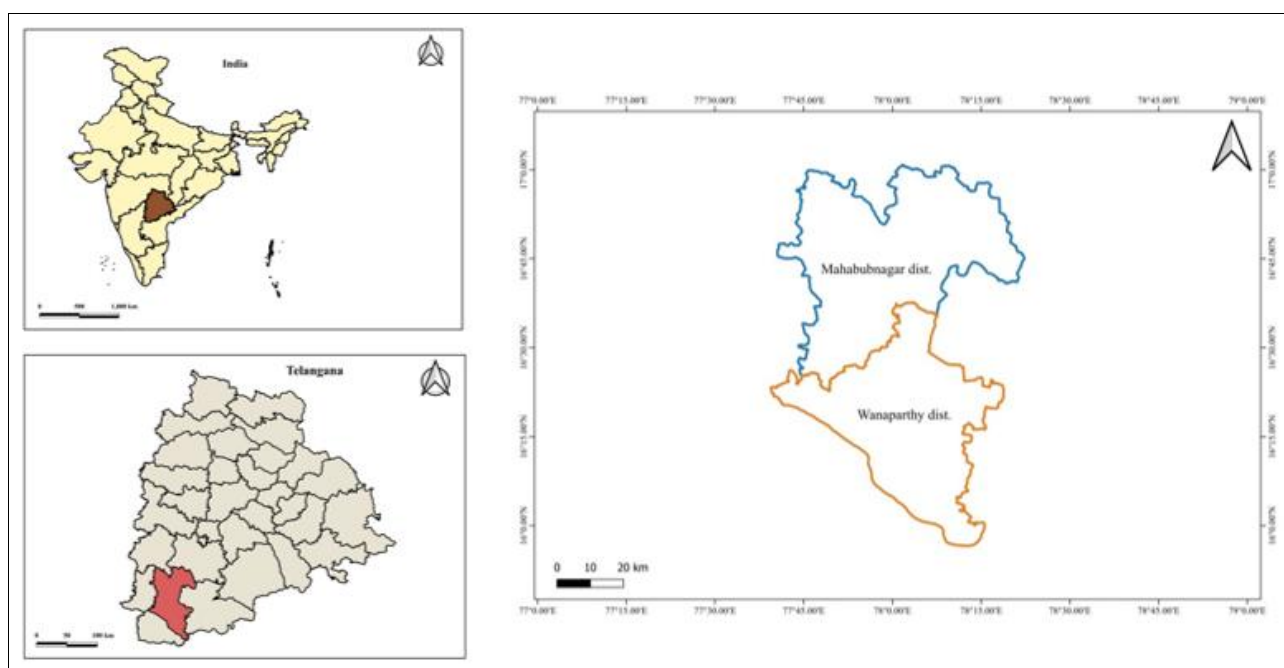


Fig 1: Study area is Mahbubnagar and Wanaparthy districts, Telangana state, India.

Sentinel 1A - Synthetic Aperture Radar (SAR) data

Sentinel-1A, launched by the European Space Agency (ESA) under the Copernicus Programme, is equipped by a C-band Synthetic Aperture Radar (SAR) sensor that provides high-resolution, all-weather, day-and-night imagery of Earth's surface. The satellite primarily operates in Interferometric Wide Swath (IW) mode, offering a 250 km swath with a spatial resolution of 5×20 m and supporting both single and dual polarizations for enhanced surface characterization. Owing to its ability to penetrate cloud cover and operate independently of

solar illumination, Sentinel-1A SAR data are extensively used for agricultural applications, including crop monitoring, crop-type classification and phenological assessment. The data is available in Ground Range Detected (GRD) and Single Look Complex (SLC) formats and are freely accessible through the Copernicus Open Access Hub. In the present study, Sentinel 1A Level-1GRD products were acquired at 12 days intervals during the crop growing season from June to November were downloaded and used for multi-temporal rice mapping.

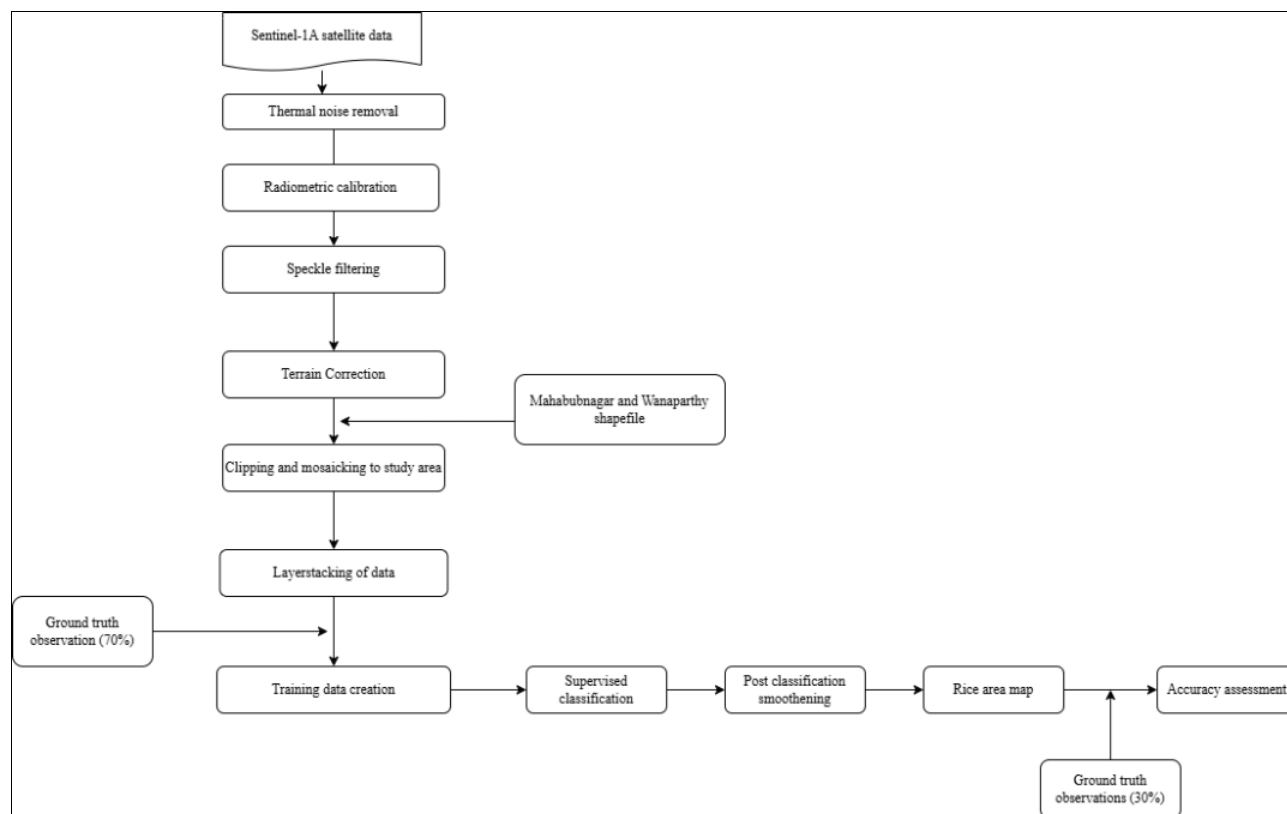


Fig 2: Flow chart for SAR data processing and crop area estimation

Ground truth collection:

Ground truth data was collected from different mandals of the Mahbubnagar and Wanaparthi districts during the field surveys conducted during September. The representative samples of rice, other crops, fallow land and waterbodies were recorded using Google Earth mobile based application. To ensure accurate geo-referencing and minimize edge effects, ground truth points were collected at the center of each field.

Pre-processing of SAR data

Sentinel-1A SAR data was pre-processed using SNAP (Sentinel Application Platform) version 12. The large volume of SAR data requires thorough pre processing to reduce noise and error corrections to produce data of adequate quality for subsequent analysis. The pre-processing workflow includes thermal noise removal, radiometric calibration, speckle filtering (using the RefindLee filter) and terrain corrections. Batch processing was adopted to pre-process the SAR data using the batch processing module in the SNAP's Graphical Builder. Thermal noise removal was applied to eliminate random electronic noise generated by the sensor's hardware, improving radiometric accuracy and consistency of the data. Radiometric calibration was performed to derive sigma naught (σ^0) backscatter coefficient values, Lee Sigma filter with a 5x5 moving kernel was employed to reduce speckle noise. Geometric distortions caused by terrain were corrected using the Range-Doppler Terrain Correction algorithm with the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). Finally, the calibrated backscattered values were converted to decibel (dB) scale. The pre-processed VV and VH polarization images were exported in TIFF/GeoTIFF format and subsequently clipped to the study area, mosaicked, layer stacked to generate a multi-temporal dataset covering Mahbubnagar and Wanaparthi districts during the *kharif* season (June to November).

Image classification

Crop area was estimated using a supervised classification approach, based on the Random Forest (RF) machine learning algorithm. The RF classifier was developed using the threshold values derived from temporal backscatter signatures and texture metrics, enabling the algorithm to differentiate the various land cover classes including agricultural crops, water bodies, scrub and natural vegetation. The derived decision rules effectively captured the spatial and temporal characteristics that are specific to crop for accurate identification of agricultural areas. The RF model was trained and validated using the ground truth data collected from the study area on the layer stacked temporal Sentinel-1 SAR dataset.

Accuracy assessment

The crop area map generated using the Random Forest (RF) algorithm was applied to the temporal SAR, Sentinel-1A (VV-VH polarization) data, showed better results with ground referenced data, demonstrating the effectiveness of the classification approach. In the Mahbubnagar and Wanaparthi districts, rice emerged as the predominant crop during the *kharif* season. The classified crop maps were then validated against ground truth data, with 75% of the samples used for model training and the remaining 25% reserved for validation in the study area. Classification performance was evaluated using a confusion (error) matrix, from which Producer's Accuracy, User's Accuracy, Overall Accuracy and the Kappa coefficient were computed.

Results and Discussion

Rice area estimation

The temporal SAR backscatter signature of the rice canopy exhibited distinct seasonal variations corresponding to different crop growth stages. In the vertical-vertical (VV) polarization, the backscatter values ranged from -14.6 dB to -9.1 dB, while in

the vertical-horizontal (VH) polarization they varied from -19.71 dB to -16.3 dB throughout the growing season.

Both VV and VH polarizations exhibited a characteristic temporal pattern, with a minimum at the transplanting stage due to the specular reflection from the standing water. As the crop developed, the backscatter gradually increased, reaching its maximum during the tillering and flowering stages as a result of increased canopy biomass and volume scattering. Specifically,

the VV backscatter during the transplanting stage ranged from -18.0 dB to -12.0 dB, increasing to -13.0 dB to -9.6 dB during the tillering stage. Similarly, the VH backscatter varied from -25.0 dB to -18.0 dB during transplanting and increased to -17.0 dB to -14.0 dB during the tillering stage. This temporal behaviour is consistent with the findings reported by Raman *et al.* (2019) ^[10], confirming the sensitivity of Sentinel-1 SAR backscatter to rice phenological development.

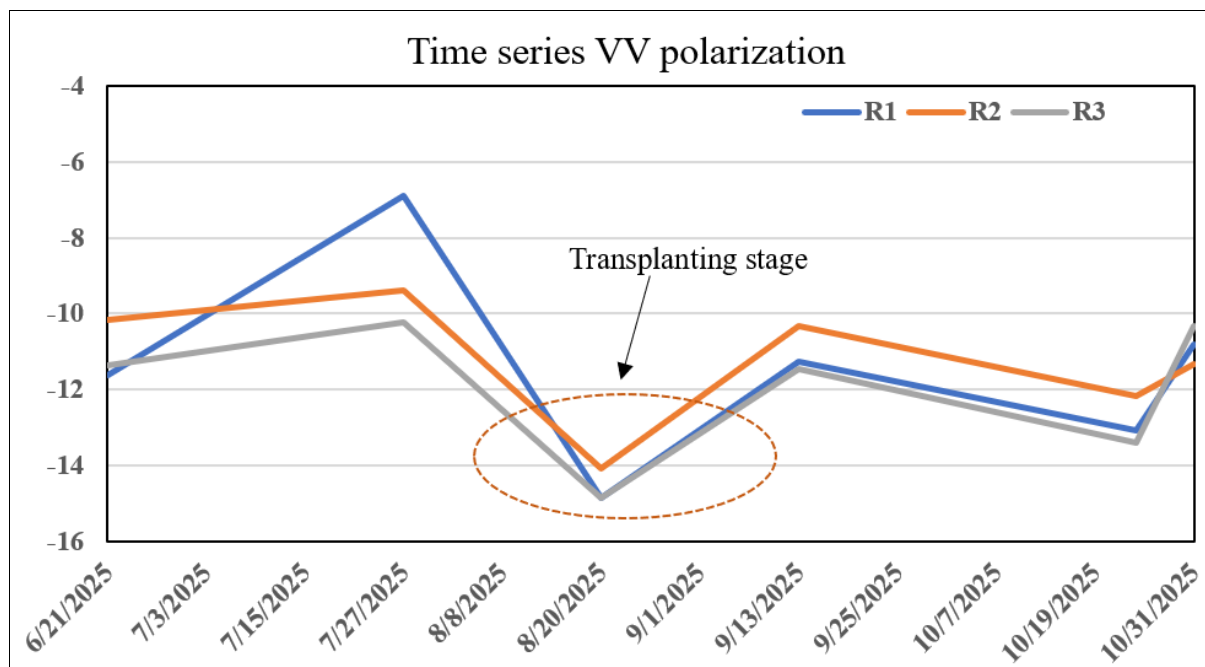


Fig 1: Time-series VV signatures for rice in Mahbubnagar and Wanaparthi during *kharif*, 2025

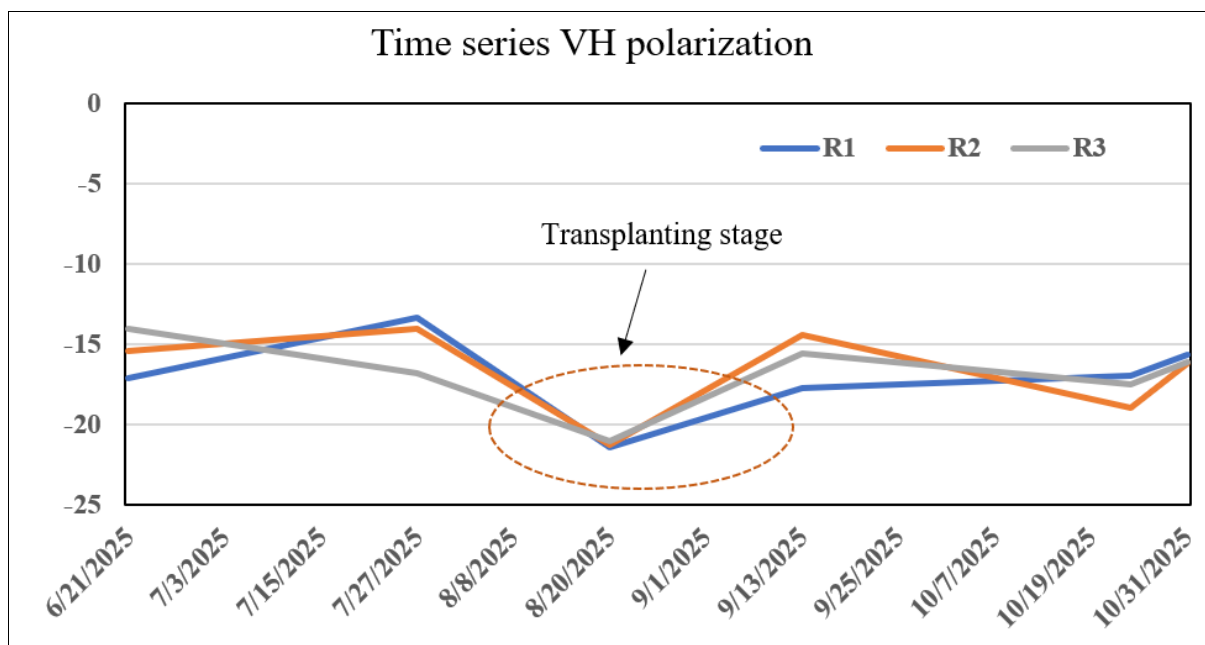


Fig 2: Time-series VH signatures for rice in Mahbubnagar and Wanaparthi during *kharif*, 2025

The total rice area was estimated as 96,623 ha and 96,272 ha, in Mahbubnagar and Wanaparthi districts, respectively, with a deviation of 4.02% and 2.02% against the statistics reported by the Department of Agriculture (DoA) ^[1], Telangana, during the *kharif*, 2025. Among the mandals, Pangal of Wanaparthi district has recorded the highest area about 12,069 ha followed by Koilkonda (10,183 ha) of Mahbubnagar district. The rice

cultivation was low in Mahbubnagar Urban (1,795 ha), followed by Rajapur (3,051 ha), Koukuntla (2,997 ha) of Mahbubnagar district due to the semi-urban character of Mahbubnagar district coupled with increasing of land-use conversion towards non-agricultural uses. Revally mandal (3,279 ha) of Wanaparthi district has less extent of rice area due to rainfed conditions.

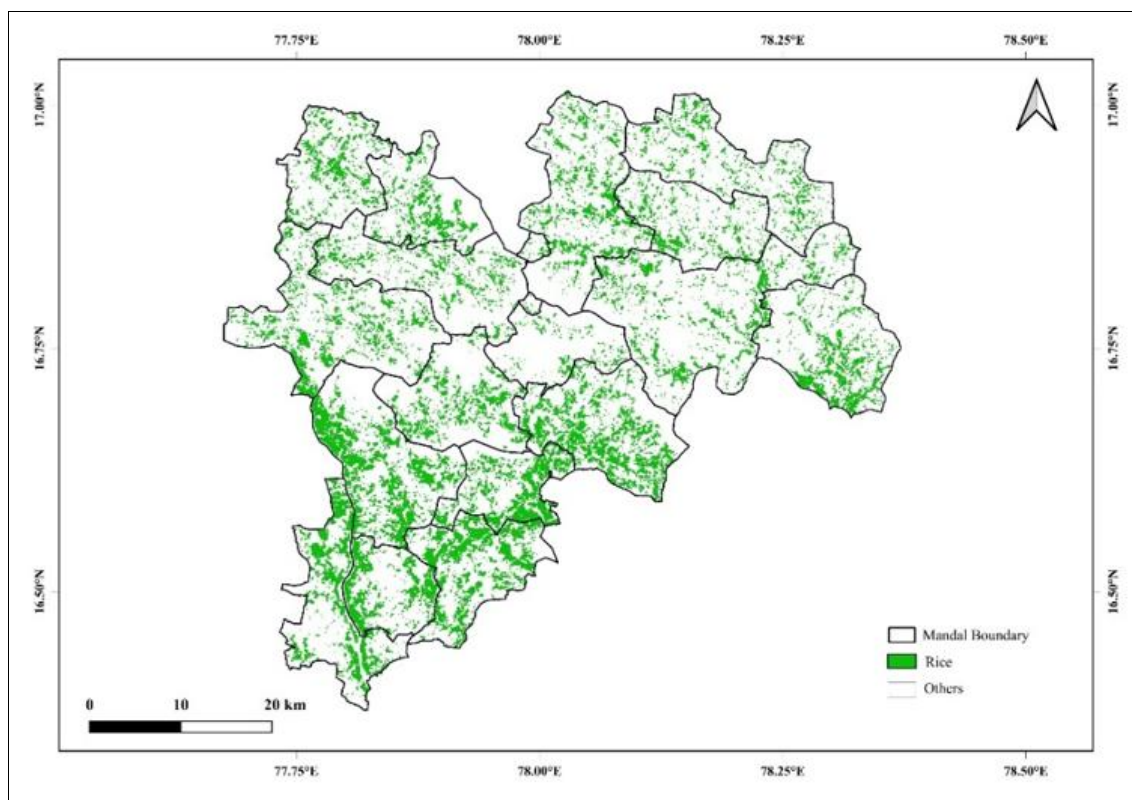


Fig 3: Spatial distribution of rice crop in Mahbubnagar district during *kharif*, 2025

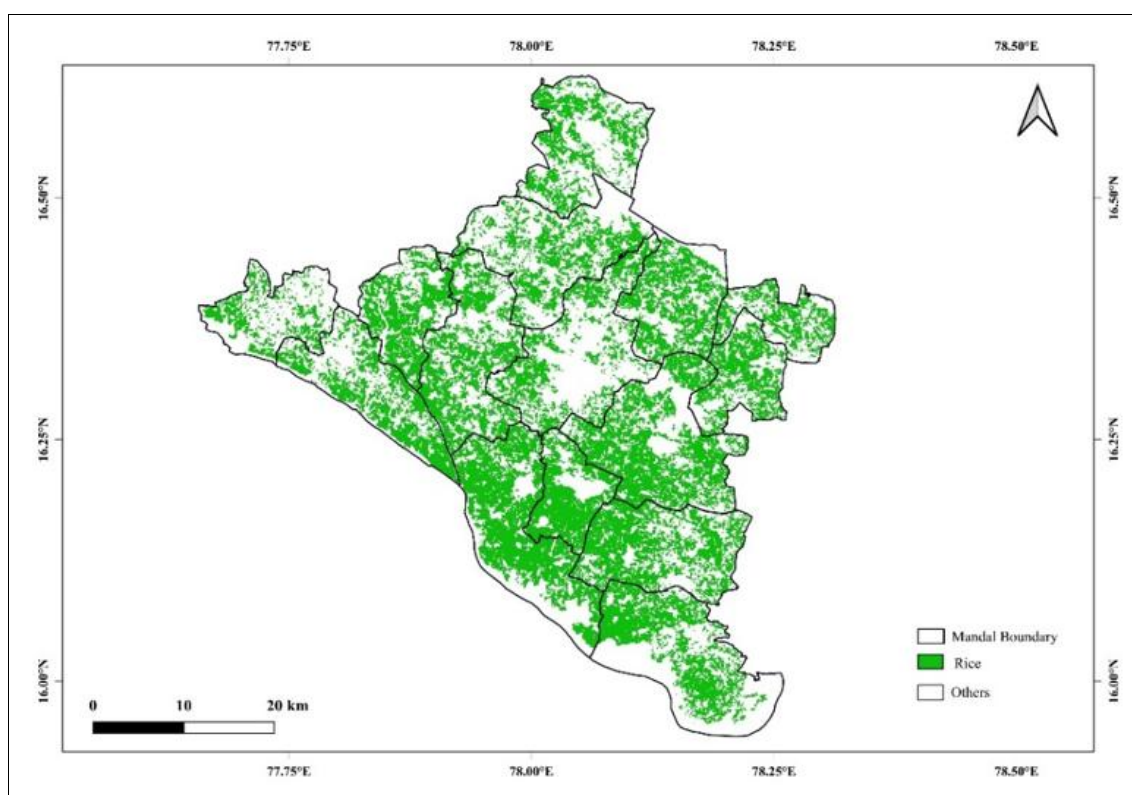


Fig 4: Spatial distribution of rice crop in Wanaparthy district during *kharif*, 2025

Accuracy assessment

A confusion matrix was generated to evaluate the accuracy of rice area map by using ground reference data collected during field surveys conducted in the *kharif* 2025 season across the study area. A total 163 validation points, representing rice and non-rice land cover classes, were used for assessment. The Random Forest (RF)-based rice acreage mapping approach using

multi-temporal Sentinel-1 SAR data achieved the overall accuracy of 92.02% and with a kappa coefficient of 0.893 indicating strong agreement between classified map and reference data. The user's accuracy for the rice class was 96.92% indicating a high reliability in mapping rice crop while the non-rice class achieved a user's accuracy of 87.49%. These results indicated that rice and non-rice classes were classified

with a high degree of reliability and with minimal commission errors.

The producer's accuracy, measures the proportion of actual ground reference samples that were correctly identified in the classification was 94.03% for the rice class and 86.12% for the non-rice classes. These values indicate that the RF classifier's efficiency in detected rice cultivated areas with few omission errors. These results are consistent with prior research field. Subbarao *et al.* (2021) ^[9] estimated *kharif* rice acreage in Bhandara district, Maharashtra achieved 91% overall accuracy with a kappa coefficient of 0.80, Tamilmounika *et al.* (2024) ^[11] estimated rice area in the Cauvery Delta region of Tamil Nadu achieved overall accuracies of 92.5% for *kharif* with kappa coefficient of 0.85 respectively, indicating almost perfect agreement. The slightly higher Kappa coefficient obtained in the present study (0.893) further demonstrates the robustness of the proposed RF-based classification approach for rice area estimation using multi-temporal SAR data.

Conclusion

The present study demonstrated the effectiveness of multi temporal Sentinel-1A SAR data combined with the Random Forest (RF) classification approach for mapping of *kharif* rice areas in Mahbubnagar and Wanaparthy districts of Telangana. The proposed methodology achieved an overall accuracy of 92.06% and a kappa coefficient of 0.893, confirming the reliability of SAR based rice area estimation under monsoon conditions. These results highlight the potential of SAR based mapping as an alternative to conventional ground survey methods, particularly where Optical data availability is limited during the *kharif* season due to cloud cover.

The study demonstrates that multi-temporal SAR data provide a dependable and operational alternative to conventional ground-based surveys and Optical Remote Sensing for crop acreage estimation during the *kharif* season. The proposed approach can support timely crop monitoring, agricultural planning and policy formulation and has the potential to be extended to other rice-growing regions with similar agro-climatic conditions.

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