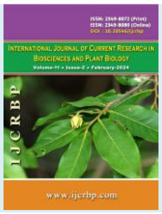
EXCELLENT PUBLISHERS

International Journal of Current Research in
Biosciences and Plant Biology

Volume **11** • Number **2** (February-2024) • ISSN: 2349-8080 (Online)

Journal homepage: www.ijcrbp.com



Original Research Article **doi:** https://doi.org/10.20546/ijcrbp.2024.1102.003

Sentinel-1A for Smart Agriculture: Accurate Paddy Area Estimation in Thiruvarur During *kharif* Season

Sugavaneshwaran Kannan*, Ragunath Kaliaperumal, S. Pazhanivelan, R. Kumaraperumal and K. Sivakumar

Department of Remote Sensing & GIS, Tamil Nadu Agricultural University, Coimbatore, India

*Corresponding author

Article Info

Keywords:
SAR, Sentinel-1, Paddy

Abstract

Timely and accurate crop area estimation is a critical component of precision agriculture and agricultural resource management. This study evaluates the utility of multi-temporal Sentinel-1A C-band Synthetic Aperture Radar (SAR) data for *kharif* paddy area estimation in Thiruvarur district, Tamil Nadu—an agriculturally vital region of the Cauvery Delta. SAR data acquired at 12-day intervals from May to October 2019 were pre-processed using a fully automated chain in MAPscape-RICE software, including steps such as strip mosaicking, temporal co-registration, speckle filtering, terrain geocoding, radiometric calibration, and anisotropic non-linear diffusion filtering. A rule-based classification algorithm was employed to exploit temporal σ° backscatter signatures specific to paddy phenology, guided by agronomic knowledge and ground truth observations from 124 geo-referenced locations. Temporal features—such as minimum and maximum σ°, variation metrics, and flooding duration—were used to parameterize a classification model optimized for the agro-ecological conditions of the region. The classification output revealed that Thiruvarur district had a total *kharif* paddy area of 17,141.5 hectares, with block-wise distributions mapped and analyzed. Accuracy assessment using 94 independent validation points produced an overall classification accuracy of 91.9% and a Kappa coefficient of 0.77, indicating a strong correlation with ground truth data. The results confirm that SAR remote sensing, with its all-weather, day-and-night imaging capabilities, is a robust alternative to optical sensors for paddy mapping, particularly under persistent cloud cover.

• *Received: 10 December 2023* • *Revised: 5 January 2024* • *Accepted: 2 February 2024* • *Published Online: 6 February 2024*

Introduction

The United Nations General Assembly proclaimed 2004 as the "International Year of Rice" to recognize this crop's value (IYR). The IYR theme "Rice is life" represents the value of rice as a primary source of food and also is focused on the understanding that rice-based systems are essential for food security, poverty alleviation, and livelihood security. Remote sensing data are reliable, rapid, and accurate having an advantage in the multi-temporal data acquisition aspects. Crop type, Density, Crop geometry and yield can be acquired using spectral signatures provided by remote sensing data, which can help in agricultural analyses and surveys (Alganci *et al.*, 2010). Optical remote sensing's operational utility is often constrained by atmospheric conditions, particularly cloud cover during key periods of the cropping cycle, which hinders timely and consistent data acquisition.

To address these limitations, spaceborne Synthetic Aperture Radar (SAR) has emerged as a robust alternative. SAR sensors can acquire data independent of daylight and weather conditions, enabling frequent and reliable monitoring of agricultural landscapes. Temporal variations in SAR backscatter, which are influenced by crop structure, moisture content, and phenological stage, can be used effectively to characterize and discriminate between crop types. Several studies have demonstrated the efficacy of SAR-based monitoring in differentiating crops such as rice, groundnut, maize, mango, and banana, based on their unique backscatter temporal signatures. Significant contributions in this area include the works of Bouvet *et al.*, (2009); Kannan *et al.*, (2021); Mugilan *et al.*, (2017) and Venkatesan *et al.*, (2019), all of which underscore SAR's operational potential in crop classification and mapping. In the specific context of the Cauvery Delta region and Nagapattinam district, Kannan *et al.*, (2021) employed Sentinel-1 SAR data to successfully estimate rice cultivation areas.

Materials and Methods

Study area

The Thiruvarur district lies between 10° 20′ N to 11° 07’ N latitude and 79° 15′ E to 79° 45′ E longitude. The district occupies 2374sq.km of an area with an average elevation of 10m above MSL. Thiruvarur District has been one of the districts in the state with a creditable agricultural production performance with the farmers relatively more responsive and receptive to changing technologies and market forces. Ninety *per cent*of the district population is engaged in Agriculture and allied activities. The district has a net cultivated area of around 3,22,859 ha.

Satellite data

Sentinel 1A data was taken for months of May to October 2019 acquired at 12 days intervals having 20 m resolution.

Ground truth collection:

Ground truth data were collected across the study area at various stages of the crop growth cycle to ensure comprehensive representation of land cover conditions. A total of 124 sampling points, including both paddy and non-crop locations, were recorded using GPS-based field surveys. Of these, 40% of the points were utilized for training the classification algorithm, while the remaining 60% were reserved for independent validation. This stratified sampling approach facilitated robust calibration and accuracy assessment of the remote sensing-based classification model.

Pre-processing of SAR data

A fully automated processing chain developed by Holecz *et al.*, (2013) is adopted to convert the multi-temporal space-borne SAR GRD data into terrain-geocoded σ° values. The processing chain is a module within the MAPscape-RICE software. The basic processing chain included the following steps:

Strip mosaicking

To facilitate the overall data processing and data handling, single frames of the same orbit and acquisition date were mosaicked along their azimuth, generating long strips in slant range geometry.

Co-registration

Temporal Images acquired with the same observation geometry and mode will be co-registered in slant range geometry. The co-registration performed in three steps:

(i) a gross shift estimation based on the orbital data;
(ii) a set of sub-windows was automatically identified based on a reference image and the images to be co-registered, and subsequently, the shifts between pixels of corresponding sub-windows were calculated, including elevation employing cross-correlation;
(iii) the shifts to be applied in the azimuth direction and range direction were calculated by a polynomial function depending on the pixel position, respectively, in the azimuth and range.

Time-series speckle filtering

Within the multi-temporal filtering, an optimum weighting filter was applied to balance differences in reflectivity between images at different times (De Grandi *et al.*, 1997). Multi-temporal filtering was based on the assumption that the same resolution element on the ground was illuminated by the radar beam in the same way and corresponds to the same slant range coordinates in all images of the time series. The backscattering could change from one time to the next because of a change in the dielectric and geometrical properties of the elementary scatter, but should not change because of a different position of the resolution element concerning the radar.

Terrain geocoding, radiometric calibration and normalization

A backward solution by considering a digital elevation model (DEM) was used to convert the positions of the σ° elements into slant range image coordinates. A range-Doppler approach is applied to convert the two-dimensional row and column coordinates of the slant range image into three-dimensional object coordinates in a given cartographic reference system. During this step, the radiometric calibration was performed using the radar equation, in which scattering area, antenna gain patterns, and range spread loss were considered. Finally, to compensate for the range dependency, σ° was normalized according to the cosine law of the incidence angle.

Anisotropic non-linear diffusion (ANLD) filtering

This filter significantly smoothened homogeneous targets, while enhancing the difference between neighbouring areas. The filter used in the diffusion equation, in which the diffusion coefficient, instead of being a constant scalar, was a function of image position and assumed a tensor value (Aspert *et al.*, 2007). In this way, it was locally adapted to be anisotropic close to linear structures, such as edges or lines.

Removal of atmospheric attenuation

Although microwave signals can penetrate clouds, σ° from shorter wavelengths (X- and C-band) can be locally attenuated by water vapor in the range of several dB, because of severe (tropical) storms. The temporal signature of σ° can be affected by these events in two ways: (i) the thick layer of water vapor generates a strong decrease in σ° during the event, followed by a strong increase after the event; (ii) the intense rainfall generates a strong increase in σ° during the event, followed by a strong decrease after the event. These effects were removed by analyzing the temporal σ° signature: anomalous peaks or troughs were identified, and the σ° values were corrected utilizing an interpolator. The correct application of this process relied strongly on *a priori* knowledge of the rice crop calendar and the weather conditions when the image was acquired.

Multi-Temporal σ° Rule-Based feature extraction from SAR data

The multi-temporal stack of terrain-geocoded σ° SAR images was used as input to a rule-based rice detection algorithm in MAPscape-RICE software. The temporal evolution of σ° was analyzed from an agronomic perspective, which also required *prior* knowledge of rice maturity, calendar and duration, and crop practices from field information and knowledge of the study location. The temporal signature was frequency and polarization-dependent and also relied on the crop establishment method and to some extent on crop maturity. This implied that general rules could be applied to detect rice, but that the parameters for these rules needed to be adapted according to the agro-ecological zone, crop practices, and rice calendar. The Rule-based rice detection algorithm for multi-temporal C-band σ° is presented in Fig.1. with the parameters used in the MAPscape-RICE software.

Crop classification

Parameterized classification

The choice of parameters a, b, c, d, e, and f was guided by a simple statistical analysis of the temporal signature of σ° values in the monitored fields. The criteria used to guide the selection of parameters. The mean, minimum, maximum, and range of σ° were computed for the temporal signature of each monitored field. Then, we calculated the minima and maxima of those mean σ° values across fields, the maxima of the minimum σ° values across fields, the minima of the maximum σ° value across fields and the minimum and maximum of the range of σ° values across fields (Holecz *et al.*, 2013). These six statistics, which we call temporal features, concisely characterize the critical information in the observed fields' rice signatures, and each one relates directly to one parameter. Hence, the value of the six temporal features from the monitoring locations at each site can be used to guide the choice of the six parameter values, as shown in Table 1.

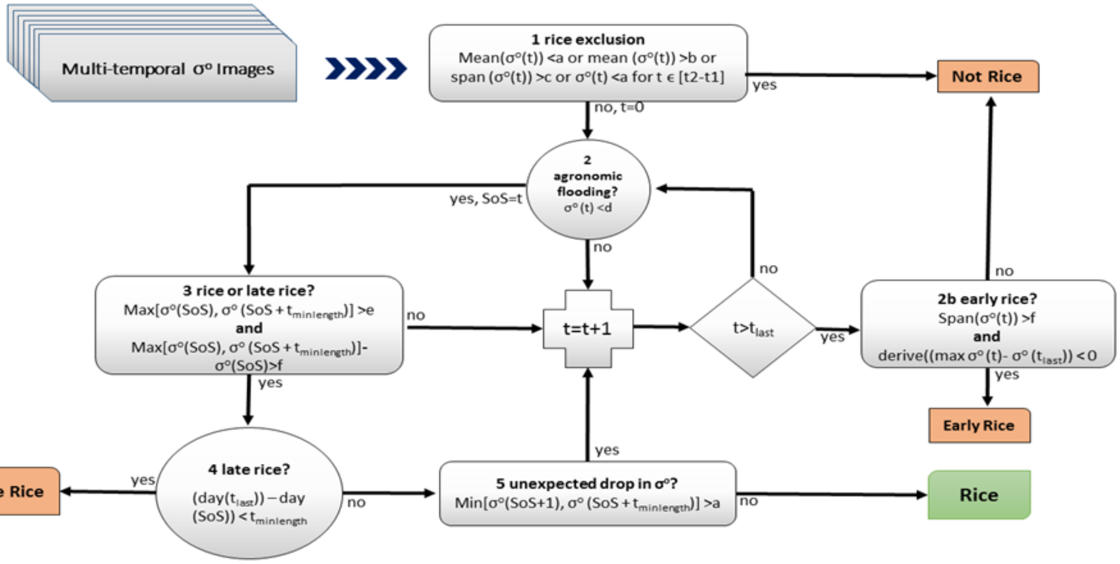


Figure.1 Rule-based rice detection algorithm for multi-temporal C-band σ° in MAPscape-RICE software

a = lowest mean
b = highest mean
c = maximum variation
d = maximum value at SoS
t_2-t_1 = maximum time underwater

e = minimum value at maximum peak
f = minimum variation
t = time
SoS = Start of Season

t_{min}length = minimum number of days of season length
t_{max}length = maximum number of days of season length
t_{last}= date of the last acquisition

Table.1 Site-specific parameters for the rule-based classification and the criteria used to select them based on temporal features.

Parameter	Relationship between Parameter and Temporal Feature
a = lowest mean	a < (i) minima of the mean σ° across all rice signatures
b = highest mean	b > (ii) maxima of the mean σ° across all rice signatures
c = maximum variation	c > (vi) maxima of the range in σ° across all rice signatures
d = max value at SoS	d > (iii) highest minima in σ° across all rice signatures
e = min value at peak	e < (iv) lowest maxima in σ° across all rice signatures
f = minimum variation	f < (v) minima of the range in σ° across all rice signatures

The parameters $t_{minlength}$, $t_{maxlength}$, and $t_2 - t_1$ are easier to estimate. $t_{minlength}$restricts the number of days between a start-of-season detection and the subsequent highest σ° value in the temporal signature. Since C-band σ° saturates before rice flowering, this value can be set to 40–70 days. $T_{maxlength}$restricts the duration between two σ° minima in the series and 120 days is a suitable cut-off that would be representative of an intensive triple-rice system (three crops in one year). t2 − t1 is the maximum duration of agronomic flooding at the start of the season, which can be set to a relatively high value of 40 to 50 to capture even the longest land preparation phases.

Accuracy assessment

The error matrix and Kappa statistics are used for evaluating the accuracy of the estimated rice area.

$$\text{Overall Accuracy} = \frac{\Sigma(\text{Correctly classified classes along diagonal})}{\Sigma(\text{Row Total or Column Total})}$$

$$\text{Producer's Accuracy} = \frac{\text{Number of correctly classified class in a column}}{\text{Total number of items verified in that column}}$$

$$\text{User's Accuracy} = \frac{\text{Number of correctly classified item in a row}}{\text{Total number of items verified in that row}}$$

$$\widehat{K} = \frac{\mathrm{NA} - \mathrm{B}}{N^2 - B}$$

Results and Discussion

With the availability of high spatial and temporal resolution Synthetic Aperture Radar (SAR) satellite sensors, Crop area mapping with higher accuracies has become possible. Sentinel-1*A* SAR satellite data from European Space Agency (ESA) was acquired at 12 days intervals during the *kharif*cropping season between May and October 2019. SAR data was used for theinvestigation for the identification of rice crops and the area estimation in the Thiruvarur district of Tamil Nadu.For the ground truth points chosen randomly over the study area, temporal backscattering values were extracted. In the Thiruvarur district, the minimum dB values ranged from -19.93 to -17.09 and the maximum values ranged from -20.54 to -17.29. In major blocks viz., Koradacheri, Kottur, Mannargudi, Muthupettai, Needamangalam, Thiruthuraipoondi and Thiruvarur, the minimum dB values were recorded during D5 while in the other blocks, it ranged between D2 and D7, indicating the start of the season in the blocks ranging from the third week of May to the first week of August. Thiruvarur district registered a total *kharif* paddy area of 17141.50 ha. Blockwise area statistics in the 10 blocks viz., Koradacheri, Kottur, Kudavasal, Mannargudi, Muthupettai, Nannilam, Needamangalam, Thiruthuraipoondi, Thiruvarur and Valangaimanwas performed to understand the distribution of paddy area in the district. The area statistics and *per cent* area coverage is presented in Table 2.The spatial distribution of the *kharif* paddy area is presented in Fig. 2.

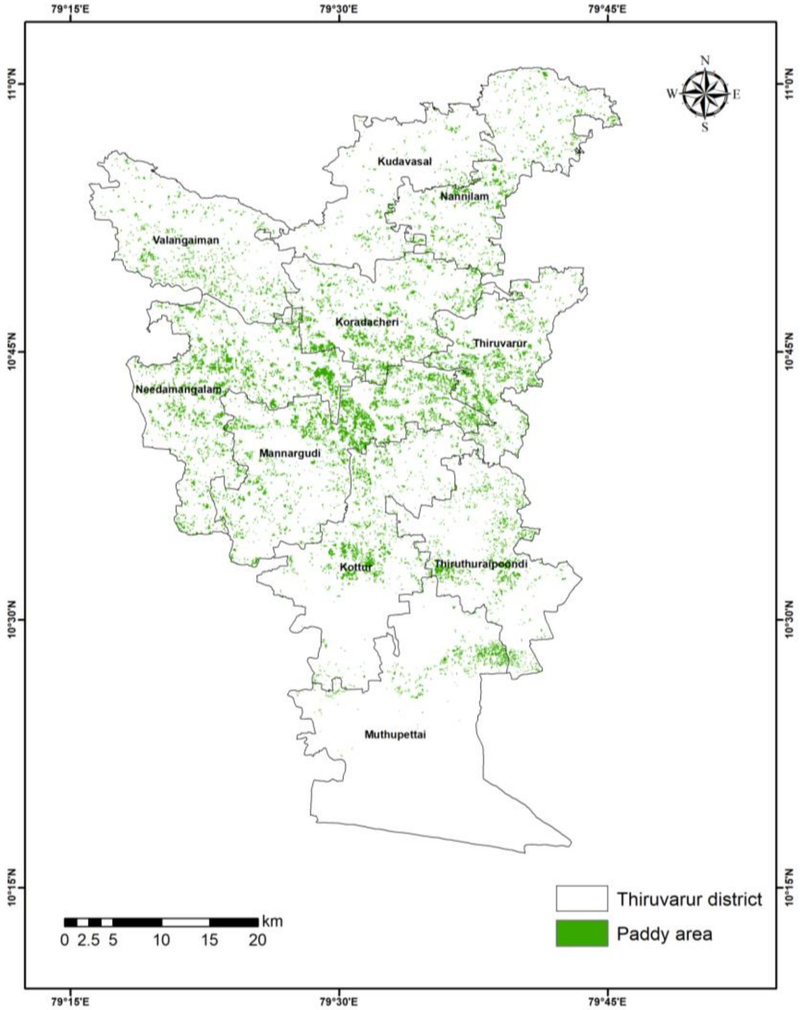


Figure.2 SAR based spatial distribution of *kharif* paddy area in Thiruvarur district

Table.2 Blockwise SAR based paddy area in Thiruvarur district

S.No.	**Block Name**	**Area in ha**	***Per cent* distribution of area**
1	Mannargudi	3594.14	20.96
2	Needamangalam	3295.41	19.22
3	Koradacheri	2000.54	11.67
4	Thiruvarur	1708.22	9.96
5	Kottur	1575.74	9.19
6	Nannilam	1361.09	7.94
7	Thiruthuraipoondi	1255.24	7.32
8	Valangaiman	1108.90	6.47
9	Muthupettai	706.85	4.12
10	Kudavasal	540.36	3.15

Accuracy assessment

The rice area delineated from SAR data using the Multi-Temporal Feature (MTF) Extraction method was evaluated for classification accuracy using an independent set of ground truth points not involved in the training process. For the accuracy assessment, a total of 94 validation points were utilized, comprising 71 rice and 23 non-rice locations. A confusion matrix was constructed to quantify the classification performance. The assessment yielded an overall accuracy of 94%, with a Kappa coefficient of 0.77, as shown in table 1. indicating a strong agreement between the classified rice map and the reference ground truth data. These results confirm the reliability of the MTF-based SAR classification approach for rice area estimation.

Table.3 Confusion matrix for accuracy assessment of SAR based Paddy estimate

Actual class from the survey	**Predicted class from the map**			
	Class	**Paddy**	**Non-Paddy**	**Accuracy (%)**
	Paddy	90	8	91.8%
	Non-Paddy	2	24	92.3%
	Reliability	97%	75.0%	**91.9%**
Average accuracy		92%		
Average reliability		86%		
Overall accuracy		**91.9%**	**Good Accuracy**	
Kappa index		0.77		

Conclusion

Remote sensing-based estimates of crop area through the years have improved with the advancement in the technology and advent of new tools. Even though the results of predictions for crop mapping using various tools provide a convincing output with enhanced accuracies, the chance of increasing the accuracies still exists. The identification and estimation of rice cultivation areas within the study region were effectively achieved using Synthetic Aperture Radar (SAR) satellite data, demonstrating a high degree of reliability and classification accuracy. These results underscore the viability of SAR as a robust and complementary alternative to optical remote sensing, particularly under conditions of persistent cloud cover, rainfall, or low solar illumination—factors that often hinder timely acquisition of optical imagery. The all-weather, day-and-night imaging capability of SAR ensures consistent temporal monitoring throughout the crop growth cycle, making it exceptionally suited for operational agricultural applications.The spatially detailed information generated through SAR-based crop mapping offers valuable insights for precision agriculture, enabling the optimization of inputs and resources at a granular level. Furthermore, such data can significantly inform evidence-based policy formulation, particularly in the domains of food security, disaster response, and agricultural resource management. Overall, the study demonstrates that SAR remote sensing holds considerable promise for enhancing the accuracy and resilience of agricultural monitoring systems in data-scarce or weather-constrained environments.

References

Alganci, Ugur, Elif Sertel, and CankutOrmeci. 2010. "Forest fire damage estimation using remote sensing and GIS." Proceedings of the 30th EARSeL Symposium-Remote Sensing for Science, Education, and Natural and Cultural Heritage.

Aspert, François, Meritxell Bach-Cuadra, Alessio Cantone, Francesco Holecz, and Jean-Philippe Thiran. 2007. "Time-varying segmentation for mapping of land cover changes." ENVISAT Symposium.

Bouvet A, Le Toan T, Lam-Dao N. Monitoring of the rice cropping system in the Mekong Delta using ENVISAT/ASAR dual polarization data. IEEE transactions on geoscience and remote sensing 2009;47(2):517-526.

De Grandi, G F, M Leysen, J S Lee, and D Schuler. 1997. "Radar reflectivity estimation using multiple SAR scenes of the same target: technique and applications."IGARSS'97. 1997 IEEE International Geoscience and Remote Sensing Symposium Proceedings. Remote Sensing-A Scientific Vision for Sustainable Development.

Holecz F, Barbieri M, Collivignarelli F, Gatti L, Nelson A, Setiyono T D *et al.*, An operational remote sensing based service for rice production estimation at national scale. In Proceedings of the living planet symposium 2013.

Kannan, S., Kaliaperumal, R., Pazhanivelan, S., Kumaraperumal, R., & Sivakumar, K. (2021). Paddy area estimation in Nagapattinam district using sentinel-1A SAR data. The Pharma Innovation Journal, 10(2), 112-116.

Kannan, S., Kaliaperumal, R., Pazhanivelan, S., Kumaraperumal, R., & Sivakumar, K. (2021). Rice Area Estimation using Sentinel 1A SAR Data in Cauvery Delta Region. Int. J. Curr. Microbiol. App. Sci, 10(2), 848-853.

Raman M G, Kaliaperumal R, Pazhanivelan S. Rice Area Estimation in Tiruvarur District of Tamil Nadu using VV Polarized Sentinel 1A SAR Data. Indian Journal of Natural Sciences 2017;8(44):12782-12793.

Venkatesan M, Pazhanivelan S, Sudarmanian N S. Multi-temporal feature extraction for precise maize area mapping using time-series sentinel 1a SAR data. International archives of the photogrammetry, remote sensing & spatial information sciences 2019.

How to cite this article:

Sugavaneshwaran Kannan, Ragunath Kaliaperumal, S. Pazhanivelan, R. Kumaraperumal and Sivakumar, K., 2024. Sentinel-1A for Smart Agriculture: Accurate Paddy Area Estimation in Thiruvarur During *kharif* Season. Int. J. Curr. Res. Biosci. Plant Biol., 11(2): 18-25. doi: https://doi.org/10.20546/ijcrbp.2024.1102.003