International Journal of Current Research in
Biosciences and Plant Biology

Volume **11**• Number **5** (May-2023) • ISSN: 2349-8080 (Online)

Journal homepage: www.ijcrbp.com

Original Research Article **doi:** https://doi.org/10.20546/ijcrbp.2023.1005.003

Estimation of *kharif* Paddy area in Cauvery delta region by integrating SAR and Optical data

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:
Paddy area,
Sentinel-2,
Sentinel-1,
Integration and
Satellite remote
sensing

Abstract

Accurate crop area estimation is essential for agricultural planning and food security. This study explores the integration of Sentinel-1A SAR and Sentinel-2A optical data to map *kharif* paddy areas in Tamil Nadu's Cauvery Delta region. Data acquired from May to October 2019 were analyzed using parameterized classification of SAR backscatter time-series and maximum likelihood classification of optical imagery. Ground truth data from 300 field samples supported model training and validation. While SAR provided reliable temporal data unaffected by cloud cover, optical data offered rich spectral information. Pixel-level agreement between the two classification outputs was assessed using TerrSet's ERRMAT module, yielding a Kappa value of 0.83. Feature-level fusion was then applied, resulting in an integrated paddy map estimating 86,152.20 hectares across Thanjavur, Thiruvarur, and Nagapattinam districts. Accuracy assessment using independent validation points revealed an overall accuracy of 94%, with rice classified at 96% accuracy and a Kappa index of 0.86. The integration approach improved accuracy over individual datasets. This study confirms that combining SAR and optical data enhances classification robustness and supports operational-scale crop monitoring under frequent cloud cover, providing valuable input for precision agriculture and policy planning.

• *Received: 22 March 2023* • *Revised: 20 April 2023* • *Accepted: 30 April 2023* • *Published Online: 6 May 2023*

Introduction

Accurate and consistent information on the area under production is essential for national and state-level planning. This information is vital to the policy decisions related to imports, exports, and prices, directly influencing food security. Remote sensing allows growers to collect, visualize, and evaluate crop and soil health conditions at various production stages, conveniently and cost-effectively. 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). To extend the accuracy of crop identification and space estimation, we need to possess a much better understanding of the crop and the underlying soil characteristics that influence the measuring instrument to break up throughout the season and establish acceptable methodologies to extract crop data. Owing to the distinction in imaging and knowledge content, information from optical and SAR-based measuring device systems are unit complementary. Many studies have shown that desegregation information from the two sources improves classification accuracies over the employment of either one. The combination of two SAR images and one optical image can be integrated for crop mapping while the absence of periodical optical images. (Olthof *et al*., 2018). SAR data classification and Optical information adopted unattended classification methods, and the classified pictures are validated. The individual report showed less accuracy, whereas the accuracy achieved by the fusion of SAR and Optical information is higher (Hirschmug *et al*., 2018). This study attempted to identify and estimate *kharif* paddy using the cloud-free optical data or data with less cloud cover during the season integrating with the SAR data.

Materials and Methods

Study area

Cauvery Delta Region lies in the eastern part of Tamil Nadu with a total geographic land area of 8.29 lakh ha (Fig. 1). The study area districts are Thanjavur, Thiruvarur and Nagapattinam, which occupies more than 57 per cent of the Cauvery Delta region, followed by Trichy, Ariyalur, Cuddalore, and Pudukkottai districts. This zone is the 'rice bowl' of Tamil Nadu with Rice as the principal crop is grown either as a single or double-crop. Pulses viz., black gram and green gram are cultivated as rice follow crops. Gingelly, Brinjal, chilies, and greens are grown during the summer, while crops Such as groundnut, maize, and irrigated pulses are grown as alternate crops. In addition to that, banana, sugarcane, pomegranate, mango, guava, custard apple, coconut and bamboo are grown in different locations throughout the delta. The details of the study districts are as follows.

Satellite data

Sentinel-1A and Sentinel-2 data was taken for months of May to October 2019. The Sentinel-1A C-band SAR satellite mission imaging system operates at four imaging modes with different resolutions and area coverage. Table 1 details the characteristics of Sentinel-1A data. The Multispectral Imager (MSI) covering 13 spectral bands (443–2190 nm), with a swath width of 290 km and a spatial resolution of 10 m (four visible and near-infrared bands), 20 m (six red edges and shortwave infrared bands), and 60 m (three atmospheric correction bands) are the strength of Sentinel-2 data. Table 2 presents the details on the different bands available with Sentinel-2.

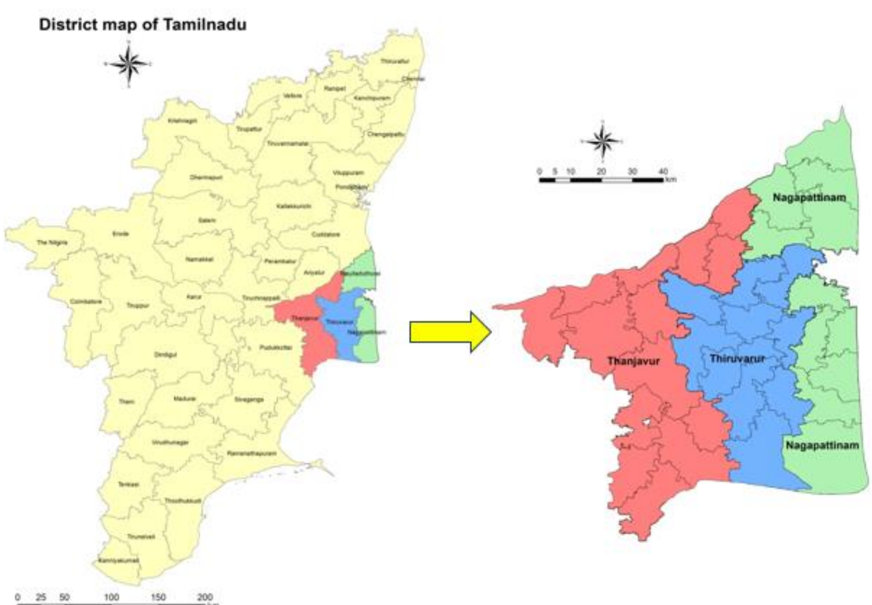

Fig.1 Study area map

Table 1 Characteristics of Sentinel-1A (IW1-GRD-HR) Data used for mapping of *kharif* paddy

Parameters	Characteristics
Pixel value	Magnitude detected
Coordinate system	Ground range
Polarization options	Single(HH or VV) or Dual (HH+HV or VV+VH)
Resolution (range x azimuth in meters)	20.4x21.7
Pixel spacing (range x azimuth in meters)	10x10
Incidence angle (degree)	32.9
Radiometric resolution	1.7 dB
Ground range coverage (km)	251.8
Absolute location accuracy (m) (NRT)	7
Equivalent Number of Looks (ENL)	4.4
Number of looks (range x azimuth)	5 x 1
Range look bandwidth (Hz)	14.1
Azimuth look bandwidth (Hz)	327
Look overlap (range, azimuth)	0.250, 0.000
Bits per pixel	16

Table.2 Details of Bands from Sentinel-2A satellite data

Band	Resolution	Wavelength	Description
B1	60 m	443 nm	Ultra Blue (Coastal and Aerosol)
B2	10 m	490 nm	Blue
B3	10 m	560 nm	Green
B4	10 m	665 nm	Red
B5	20 m	705 nm	Visible and Near Infrared (VNIR)
B6	20 m	740 nm	Visible and Near Infrared (VNIR)
B7	20 m	783 nm	Visible and Near Infrared (VNIR)
B8	10 m	842 nm	Visible and Near Infrared (VNIR)
B8a	20 m	865 nm	Visible and Near Infrared (VNIR)
B9	60 m	940 nm	Short Wave Infrared (SWIR)
B10	60 m	1375 nm	Short Wave Infrared (SWIR)
B11	20 m	1610 nm	Short Wave Infrared (SWIR)
B12	20 m	2190 nm	Short Wave Infrared (SWIR)

Ground Truth collection

Ground truth surveys were systematically conducted across the study area to collect land cover information for validating *kharif* paddy area estimates derived from satellite imagery. Field observations were synchronized with satellite image acquisition dates and included precise geographic coordinates obtained using handheld GPS receivers, along with descriptive metadata such as land use type, crop condition, plant height, and phenological stage. Photographic documentation of each site was also recorded to support interpretation and classification accuracy.

Rice, being the predominant crop across the study districts, is cultivated in extensive contiguous tracts, making it suitable for satellite-based analysis. A total of approximately 300 sampling points covering both rice and non-rice classes were selected using a random stratified sampling approach to ensure representative spatial coverage. Of these, 60% of the points were allocated for training the classification algorithm, while the remaining 40% were retained for independent validation.

Integration of Optical and SAR data

In addition to the difference in imaging and information content, data from optical and SAR are complementary to each other. The paddy area estimation performed individually from SAR and optical data using parameterized and supervised classification methods respectively were further processed for integrating the two data to increase the accuracy of estimates. The Classification accuracies can be increased by integrating both SAR and optical data over the use of SAR or optical data as individuals (Hong *et al*., 2014). In the absence of a good time series of optical data with less cloud cover during cropping seasons, the integration of SAR images with a single optical image is sufficient to deliver operational accuracy above 85 per cent (McNairn *et al*., 2009). The overall accuracy increases up to 5 to 8 per cent while integrating SAR and optical data. Based on the literature proofs, integration was performed with the two outputs. The methodology adopted is as follows.

Agreement between Optical and SAR data

The extracted features from optical Sentinel-2 and SAR Sentinel-1A data were done using different classification methodology and hence a pre-qualifying agreement between the data was assessed. Pixel-wise agreement between the optical and SAR extracted features was done using the ERRMAT module of TerrSet software to assess the confidence level of classification between the two methods. The agreement percentage between the data is an indicator of the possibilities to increase the accuracy levels. Higher the agreement between the data, lesser will be the chance of increasing the accuracy and lesser the agreement, vice versa.

Fusion of Optical and SAR data

The feature-level pixel fusion method as described by Zhang *et al*. (2018) was adopted for the integration of optical and SAR data. The fusion is performed over the extracted features from optical and SAR images. The preprocessed optical and SAR data followed by feature extraction individually using supervised classification and Multitemporal feature extraction methods respectively were used for the fusion. Features will be used in the decision level, feature level, and combined level of fusion. The detailed methodology is presented in Fig. 3.

Accuracy Assessment

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

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

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

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

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

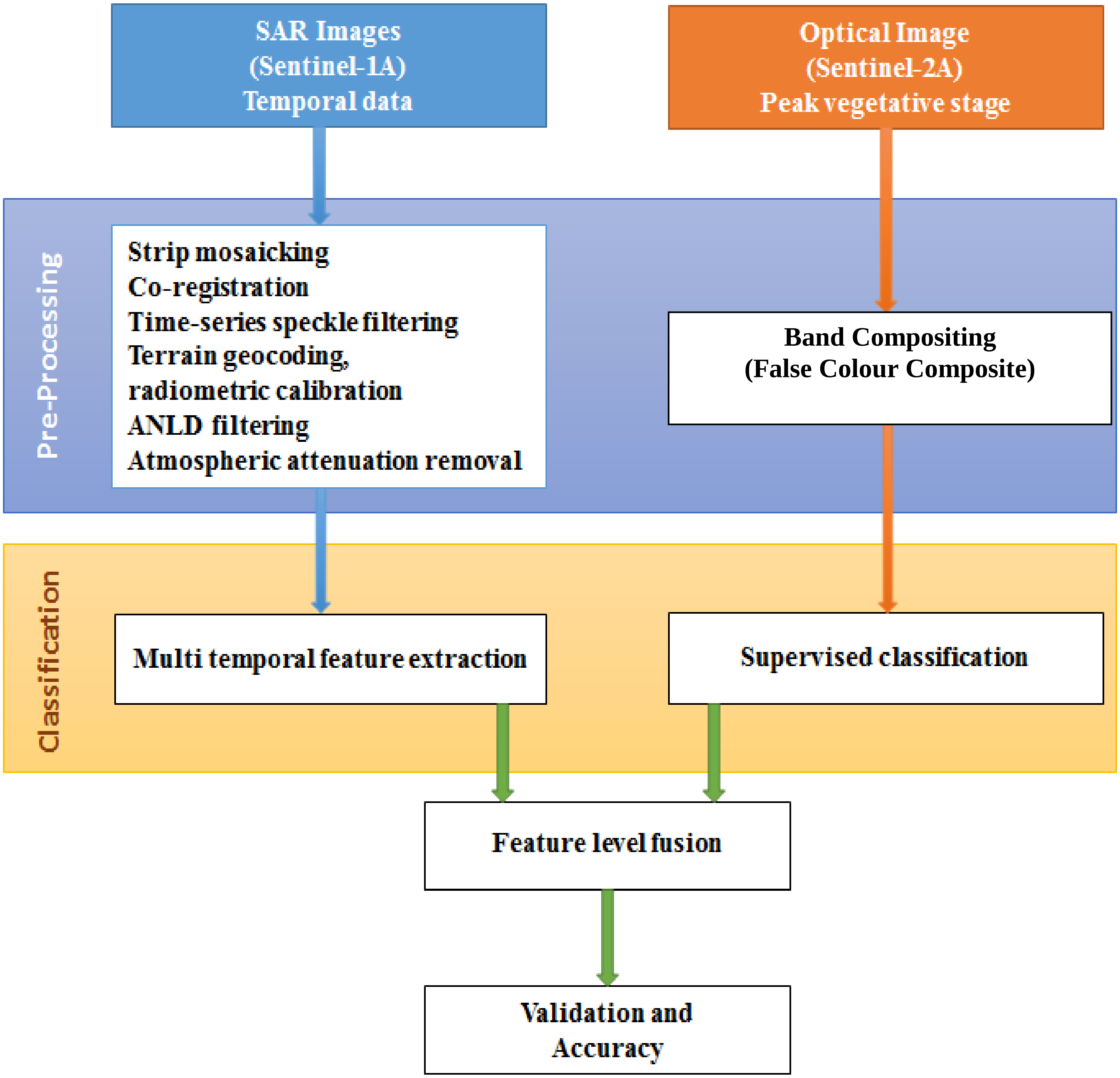

Fig.3 Methodology for integrating Optical and SAR images

Results and Discussion

Integration of SAR and Optical data

The combination of synthetic aperture radar (SAR) data and optical data helps in reducing the issues resulting from frequent cloud cover and yields supplementary information. Many works of literature show the advantage of integrating SAR and optical data in various fields land cover and land use mapping and monitoring (Joshi *et al.*, 2016), and most of the studies are described to perform a data-based combination, partly in a traditional sense of some kind of "pan-sharpening" approach followed by traditional image classification, partly using machine learning or decision tree algorithms. In recent studies, SAR data has only been used for stratification purposes (Chang *et al*, 2016), while the classification of the target class was based on optical data alone. Some studies focus on comparing the time series of Sentinel-1 features with Sentinel-2 or other optical data features (Notarnicola *et al*., 2017) and conclude with a recommendation to jointly use both data sources. Data-based combination methods are also used for biomass estimation, for which a multivariate regression model is built on both input data sets. Fusion is one method carried out for combining the SAR and optical data to derive higher accuracies (Zhang *et al*., 2018). Since different methodology was used to extract crop area information from Sentinel-1A SAR data and Sentinel-2 optical data, the fusion methodology was carried out in this study to integrate the products.

Agreement between SAR and Optical data

Classification methodology followed to obtain *kharif* paddy area from Sentinel-1A SAR data was parameterized classification of multi-temporal features and maximum likelihood classifier of supervised classification from Sentinel-2 optical data. To assess the confidence level of the two methods, a preliminary agreement between the classification products was performed. A pixel-wise agreement analysis was carried out using the ERRMAT module of TerrSet software where the product from SAR was given as reference data since it had a higher accuracy level and the product from optical data was given as classified data to generate the error matrix as presented in Table 3.

The producer and user accuracies were 83.21 and 85.47 per cent respectively for rice classification and for the non-rice categories it was at higher ends. The commission and omission errors ranged from 14 to 16 per cent for the rice classification from the two products indicating the possibilities of getting higher accuracies on the fusion of the products (Carrara *et al*., 2008). The overall kappa value of 0.83 indicates the confidence level and reliability of the error matrix generated. With the results from the agreement between SAR and optical data with more than 83 per cent, it was decided to move further for the integration of the products using fusion methodology to increase the accuracy of the *kharif* paddy area estimation in the study districts.

Fused *kharif* paddy area estimation

A total of 86152.20 ha of *kharif* paddy area was recorded in the study area of the Cauvery Delta Region derived from the integrated product as shown in Fig. 4. Among the districts, Nagapattinam recorded the highest area of 41993.47 ha followed by Thanjavur and Thiruvarur with an area of 24025.69 and 20133.03 ha respectively as shown in table 4. Block wise area statistics in the three study districts were generated and the accuracy assessment was performed for validating the output paddy area.

Table.3 Error Matrix Analysis of SAR against Optical data classification

Class	Rice	Non-Rice	Total	Error % (Commission)
Rice	6134561	1237944	**7372505**	16.79
Non-Rice	1043276	72613055	**73656331**	1.42
Total	7177837	73850999	81028836	
Error % (Omission)	14.53	1.68		
Overall Kappa	**0.830871**			

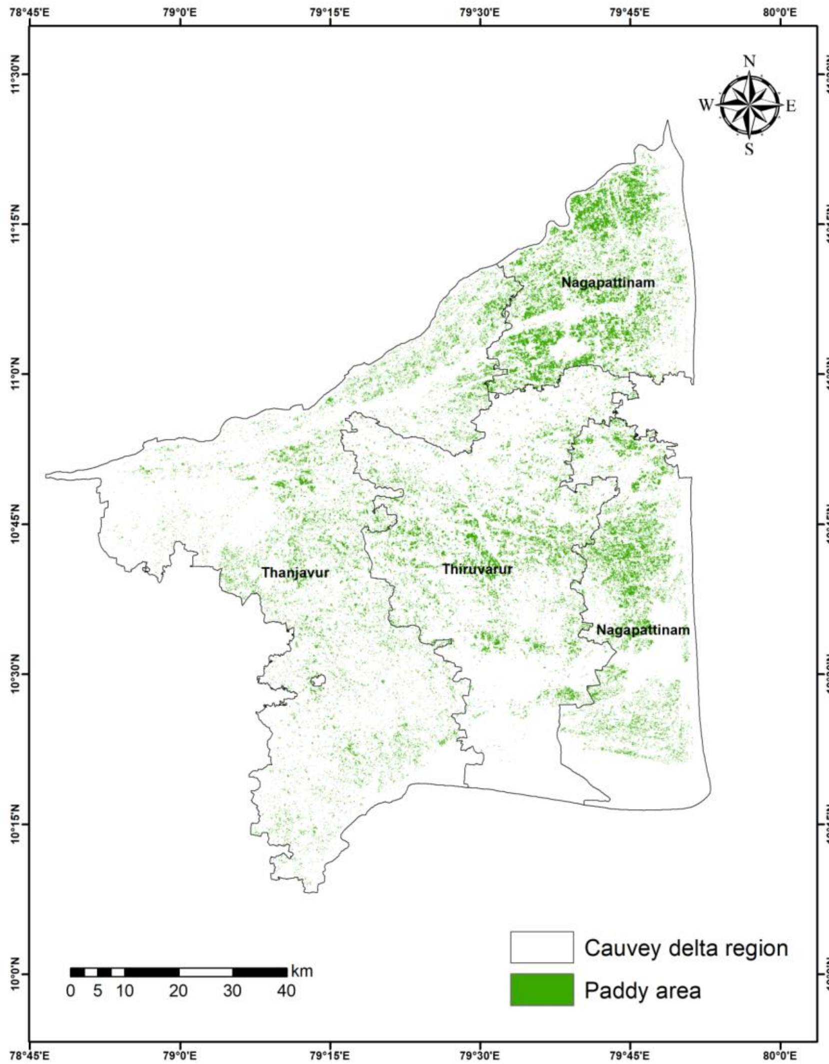

Fig. 4. Spatial distribution of *kharif* paddy generated by integrating Optical and SAR data

Table 4. District wise *kharif* Paddy area estimated in the study area (Area in ha)

Sl. No.	Districts	Integrated (SAR + Optical)
1	Thanjavur	24025.69
2	Thiruvarur	20133.03
3	Nagapattinam	41993.47
Total		**86152.20**

The results of the integrated product revealed that the estimate of *kharif* paddy increased over the individual products over an average of 14 per cent from Sentinel-1A and around 5.3 per cent from Sentinel-2 estimates.

Thanjavur district

Thanjavur district recorded a total *kharif* paddy area of 24025.69 ha. Block wise area statistics in the 14 blocks viz., Ammapettai, Budalur, Kumbakonam, Madukkur, Orathanadu, Papanasam, Pattukottai, Peravurani, Sethubavachatram, Thanjavur, Thiruppanandal, Thiruvaiyaru, Thiruvanam and Thiruvidaimaruthur was performed to understand the distribution of paddy area in the district. The area coverage is presented in Table 5.

Amongst the 14 blocks of Thanjavur district, the Orathanadu block recorded the largest area with 3870.93 ha containing 17.40 per cent of distribution and Budalur block recorded the least area of 436.76 ha with 1.96 per cent of total paddy area distribution. Blocks viz., Thanjavur, Ammapettai, Thiruppanandal and Thiruvidaimaruthur recorded an area of 2981.45, 2881.53, 2371.26 and 2184.54 ha, respectively followed by Pattukottai, Kumbakonam, Thiruvanam, Sethubavachatram and Papanasam blocks with 1791.72, 1572.76, 1443.25, 1331.35 and 1103.80 ha. Madukkur, Peravurani and Thiruvaiyaru had 684.53, 483.35 and 436.76 ha respectively contributing a total of 9.24 per cent area.

Table.5 Block wise based paddy area in Thanjavur district – Integrated

Sl.No.	Block Name	Area in ha
1.	Orathanadu	3870.93
2.	Thanjavur	2981.45
3.	Ammapettai	2881.53
4.	Thiruppanandal	2371.26
5.	Thiruvidaimaruthur	2184.54
6.	Pattukottai	1791.72
7.	Kumbakonam	1572.76
8.	Thiruvanam	1443.25
9.	Sethubavachatram	1331.35
10.	Papanasam	1103.80
11.	Madukkur	887.67
12.	Peravurani	684.53
13.	Thiruvaiyaru	483.35
14.	Budalur	436.76

Thiruvarur district

Thiruvarur district registered a total *kharif* paddy area of 20133.03 ha. Block wise 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 is presented in Table 6. The largest paddy area of 4115.27 ha was documented in the Mannargudi block of Thiruvarur district with 21.87 per cent of its total paddy area distribution and the least paddy area of 639.88 ha with 3.40 per cent of distribution was recorded in the Kudavasal block. Needamangalam block reported 3649.09 ha of paddy area, followed by Koradacheri, Thiruvarur, Kottur, Nannilam and Thiruthuraipoondi blocks with 2360.82, 2231.59, 1868.24, 1620.25 and 1523.12 ha. An area of 1301.84 and 828.28 ha respectively was found in Valangaiman and Muthupettai blocks.

Table.6 Block wise paddy area in Thiruvarur district – Integrated

S.No.	Block Name	Area in ha
1	Mannargudi	4115.27
2	Needamangalam	3649.09
3	Koradacheri	2360.82
4	Thiruvarur	2231.59
5	Kottur	1868.24
6	Nannilam	1620.25
7	Thiruthuraipoondi	1523.12
8	Valangaiman	1301.84
9	Muthupettai	828.28
10	Kudavasal	639.88

Nagapattinam district

The total *kharif* paddy area of 41993.47 ha was estimated in the Nagapattinam district. In the 10 blocks, block wise area statistics viz., Keelaiyur, Kilvelur, Kollidam, Kuthalam, Mayiladuthurai, Nagappattinam, Sembanarkoil, Sirkali, Talanayar, Thirumarugal and Vedharanyam were carried out to understand the distribution of the district's paddy area. The area statistics is presented in Table 7.

In the Mayiladuthurai block of Thiruvarur district, the highest paddy area of 6211.28 ha was recorded with 15.09 per cent of the total paddy area distribution and the lowest paddy area of 639.88 ha with 3.40 per cent of the distribution was recorded in the Talanayar block. Kuthalam block recorded 5393.59 ha of paddy area followed by Kollidam, Sembanarkoil, Kilvelur, Sirkali, Vedharanyam and Keelaiyur blocks with 5393.43, 4900.28, 4114.58, 3745.46, 3207.89 and 2659.39 ha respectively. Other blocks viz., Thirumarugal and Nagapattinam blocks recorded an area of 2497.80 and 2003.16 ha respectively.

Xin Zhang *et al*., (2018) have reported a similar outcome of obtaining good results on the rice estimates through the integration of optical and SAR data at 10 m resolution using a pixel-based classification approach with an accuracy of 90 per cent. The results from this study of integrating the optical and SAR data with 10 m resolution confirm the higher accuracies obtained.

Table.7 Block wise paddy area in Nagapattinam district – Integrated

S.No.	Block Name	Area in ha
1	Mayiladuthurai	6211.28
2	Kuthalam	5393.59
3	Kollidam	5393.43
4	Sembanarkoil	4900.28
5	Kilvelur	4114.58
6	Sirkali	3745.46
7	Vedharanyam	3207.89
8	Keelaiyur	2659.39
9	Thirumarugal	2497.80
10	Nagappattinam	2003.16
11	Talanayar	1854.76

Accuracy assessment

A confusion matrix was made to assess the accuracy of rice area maps generated using the integrated product with the ground truth data collection on a rice/non-rice basis. In total, 300 validation points covering 200 rice points and 100 non-rice points collected during 2019 were used for validation of the rice area map of the Cauvery Delta Region. Rice points were classified with an accuracy of 96.0 per cent while non-rice points were classified with an accuracy of 90.0 per cent (Xin Zhang *et al*., 2018). The efficiency of the methodology followed for mapping rice area with the integration of SAR and optical data was good with an overall accuracy was 94.0 per cent with reliability of 93.44 per cent (Table 8). The quality of the classification was assessed by the kappa index, which was 0.86 indicating good accuracy levels of the products.

The accuracy rates in estimating *kharif* paddy in the Cauvery delta have increased compared to the accuracies estimated individually for SAR and Optical data. Around a 3 per cent increase in accuracy was noted with the integrated product as that of the estimates from Sentinel-2 optical data, while the increase in accuracy level between SAR and the integrated product was only 0.7 per cent. The results of increased accuracy on the integration of SAR and optical data are in line with the studies conducted by Stroppiana *et al*, (2015) and Zhang *et al*, (2018).

Table.8 Confusion matrix for accuracy assessment of Integrated data

<table>
<tr><td rowspan="5">Actual class from the survey</td><td colspan="4">Predicted class from the map</td></tr>
<tr><td>Class</td><td>Paddy</td><td>Non-Paddy</td><td>Accuracy (%)</td></tr>
<tr><td>Paddy</td><td>192</td><td>8</td><td>96.00%</td></tr>
<tr><td>Non-Paddy</td><td>10</td><td>90</td><td>90.00%</td></tr>
<tr><td>Reliability</td><td>95.05%</td><td>91.84%</td><td>94.00%</td></tr>
<tr><td colspan="2">Average accuracy</td><td>93.00%</td><td colspan="2"></td></tr>
<tr><td colspan="2">Average reliability</td><td>93.44%</td><td colspan="2"></td></tr>
<tr><td colspan="2">Overall accuracy</td><td>94.00%</td><td colspan="2">Good Accuracy</td></tr>
<tr><td colspan="2">Kappa index</td><td>0.86</td><td colspan="2"></td></tr>
</table>

Conclusion

The feature-level fusion method was adopted to integrate *kharif* paddy area derived from Sentinel-1A SAR data and Sentinel-2A optical data products for increasing the accuracy of the paddy area estimation. Pixel-wise agreement analysis was carried out using the ERRMAT module of TerrSet software with the product from SAR as reference data and the product from optical data as classified data to generate the error matrix. The producer and user accuracies were 83.21 and 85.47 per cent respectively for rice classification and the overall kappa value of 0.83 indicates the confidence level and reliability of the error matrix generated. A total of 86152.20 ha of *kharif* paddy area were recorded by integrating the SAR and optical data. Nagapattinam recorded the highest area of 41993.47 ha followed by Thanjavur and Thiruvarur with an area of 24025.69 and 20133.03 ha respectively. Rice points were classified with an accuracy of 96.0 per cent while non-rice points were classified with an accuracy of 90.0 per cent. The overall accuracy was 94.0 per cent with a reliability of 93.44 per cent and a kappa index of 0.86 indicating good accuracy levels of the products. Combined outputs of different methodology have been demonstrated to provide better results, rather than using a single methodology alone. Hence an attempt was made to delineate and estimate the area of the *kharif* paddy crop by integrating results of microwave and optical data, which was accomplished with good accuracies as evident from the validation of the products. A Higher accuracy of integrated products could be achieved as compared to the individual results. The availability of cloud-free optical data plays a vital role in crop area estimation for attaining a higher level of reliability.

References

Alganci, Ugur, Elif Sertel, and Cankut Ormeci. 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.

Carrara, Paola, Gloria Bordogna, Mirco Boschetti, Pietro Alessandro Brivio, A Nelson, and Daniela Stroppiana. 2008. "A flexible multi-source spatial-data fusion system for environmental status assessment at continental scale." International Journal of Geographical Information Science 22 (7):781-799.

Chang, Jisung, and Maxim Shoshany. 2016. "Mediterranean shrublands biomass estimation using Sentinel-1 and Sentinel-2." 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS).

Hirschmugl, Manuela, Carina Sobe, Janik Deutscher, and Mathias Schardt. 2018. "Combined use of optical and synthetic aperture radar data for REDD+ applications in Malawi." Land 7 (4):116.

Hong, Gang, Aining Zhang, Fuqun Zhou, and Brian Brisco. 2014. "Integration of optical and synthetic aperture radar (SAR) images to differentiate grassland and alfalfa in Prairie area." International Journal of Applied Earth Observation and Geoinformation 28:12-19.

Joshi, Neha, Matthias Baumann, Andrea Ehammer, Rasmus Fensholt, Kenneth Grogan, Patrick Hostert, Martin Rudbeck Jepsen, Tobias Kuemmerle, Patrick Meyfroidt, and Edward TA Mitchard. 2016. "A review of the application of optical and radar remote sensing data fusion to land use mapping and monitoring." Remote Sensing 8 (1):70.

McNairn, Heather, Catherine Champagne, Jiali Shang, Delmar Holmstrom, and Gordon Reichert. 2009. "Integration of optical and Synthetic Aperture Radar (SAR) imagery for delivering operational annual crop inventories." ISPRS Journal of Photogrammetry and Remote Sensing 64 (5):434-449.

Notarnicola, Claudia, Sarah Asam, A Jacob, Carlo Marin, Mauro Rossi, and Laura Stendardi. 2017. "Mountain crop monitoring with multitemporal Sentinel-1 and Sentinel-2 imagery." 2017 9th International Workshop on the Analysis of Multitemporal Remote Sensing Images (MultiTemp).

Olthof, Ian, and Simon Tolszczuk-Leclerc. 2018. "Comparing Landsat and RADARSAT for current and historical dynamic flood mapping." Remote Sensing 10 (5):780.

Stroppiana, Daniela, Ramin Azar, Fabiana Calò, Antonio Pepe, Pasquale Imperatore, Mirco Boschetti, João Silva, Pietro A Brivio, and Riccardo Lanari. 2015. "Integration of optical and SAR data for burned area mapping in Mediterranean Regions." Remote Sensing 7 (2):1320-1345.

Zhang, Hongsheng, and Ru Xu. 2018. "Exploring the optimal integration levels between SAR and optical data for better urban land cover mapping in the Pearl River Delta."

International Journal of Applied Earth Observation and Geoinformation 64:87-95.
Zhang, Xin, Bingfang Wu, Guillermo E Ponce-Campos, Miao Zhang, Sheng Chang, and Fuyou Tian. 2018. "Mapping up-to-date paddy rice extent at 10 m resolution in china through the integration of optical and synthetic aperture radar images." Remote Sensing 10 (8):1200.

How to cite this article:
Sugavaneshwaran Kannan, Ragunath Kaliaperumal, S. Pazhanivelan, R. Kumaraperumal and K. Sivakumar, K., 2023. Estimation of *kharif* Paddy area in Cauvery delta region by integrating SAR and Optical data. Int. J. Curr. Res. Biosci. Plant Biol., 10(5): 27-38. **doi:** https://doi.org/10.20546/ijcrbp.2023.1005.003