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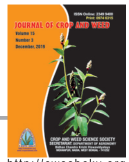

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Paddy crop acreage assessment using Sentinel-1 (C-band) SAR data in Andhra Pradesh state, India

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ABSTRACT

In monsoon season, identification and mapping of paddy rice under cloud cover using microwave remote sensing is vital for precise paddy crop acreage estimation. During the cloud cover, the assessment of paddy rice acreage through optical sensor data is impractical. Synthetic Aperture Radar (SAR) signal has the capability to infiltrate the clouds and receive the signal generated from the objects. Sentinel-1, C-band SAR data with VV (vertical transmit & vertical receive) polarization with Interferometric Wide (IW) swath mode was used to estimate the paddy crop area in Andhra Pradesh, India. In Andhra Pradesh, Srikakulam, Vizianagaram, Visakhapatnam, West Godavari, East Godavari, Krishna, and Guntur are the predominant paddy crop growing districts which contribute around 86% of the paddy area of Andhra Pradesh as per the paddy crop sown area in Kharif season 2018. The 88% accuracy was achieved for the paddy crop acreage map generated from Sentinel-1 SAR data. The Relative deviation (RD) was assessed by using estimated paddy crop area from Sentinel-1 SAR data with statistics from the Agriculture Department of Andhra Pradesh. Srikakulam, Vizianagaram, Visakhapatnam, West Godavari, East Godavari, Krishna, and Guntur districts showed the significant RD -7.1%, -5.3%, 10.9%, 0.37%, 3.6%, -7.9%, and 6.7%, respectively. The overall RD was -0.2%. of seven major paddy rice-growing districts of Andhra Pradesh.

Keywords: Acreage, microwave, paddy, sar, sentinel-1.

Traditionally, countries in Asia have the largest share in world rice (paddy rice) production. India is the second-largest producer of rice in the world (India at a glance, FAO, 2020). Andhra Pradesh is the fourth-largest producer of rice in India and one-fourth of the total cropped area of Andhra Pradesh state is under rice cultivation. It is important to monitor and estimate the acreage of paddy rice. Optical remote sensing sensors *i.e.,* MODIS, AWiFS, LISS-III, Landsat, and Sentinel-2 are typically cloud contaminated during vegetative crop growth stages (tillering, panicle initiation, and flowering stage) of paddy crop; thus, hampering mapping efforts (Whitcraft *et al*., 2015). Sentinel-1 (C-band) microwave sensor can penetrate cloud and have being utilised for timely mapping of paddy rice. Previous studies on mapping paddy rice using SAR data was initiated in 1990 with ERS-1 (C-band) microwave data of 12.5–30m spatial resolution with a repeat pass of 35 days (Paudyal and Aschbacher, 1993; Aschbacher *et al*., 1995; Chakraborty *et al*., 1997; Panigrahy *et al*., 1999; Liew *et al*., 1998), another study with C-band RADARSAT data of 10–100 m spatial resolution with a repeat pass of 24 days (Yun *et al*., 1997; Panigrahy *et al*., 1999). These pathfinder studies were thwarted as those days not have the quality ground-truth data and only the single-polarization was available to study. Due to high data values only small scale studies were possible. Later research studies were started focusing on multi-temporal RADARSAT SAR data to generate more accurate rice acreage map for large areas (Shao *et al*., 2001; Lee and Lee, 2003; Inoue, 2002; Chen and McNairn, 2006). The SAR multi-date data was used during crop establishment, vegetative growth, and grain development stages for in-season rice area estimation in India (Panigrahy *et al*., 1999). After the launching of the RISAT-1 C-band (5.35 GHz) satellite by India, the SAR data viability was increased. In continuation to strengthen the SAR data availability, Sentinel-1A was launched on 3rd April 2014 further Sentinel-1B was launched on 25th April 2016 by European Space Agency. Sentinel-1 is the first of the Copernicus Programme satellite constellation for Land and Ocean monitoring, and composed of two polar-orbiting satellites (Sentinel-1A and Sentinel-1B) operating day and night and acquiring imagery despite of the weather which shares the same orbital plane and it has a constellation of sun-synchronous, near-polar orbit and the orbit has a 12-day repeat cycle. Sentinel-1 has four operational modes: (1) SM (Strip Map) mode has 5X5 meter spatial resolution with 80 km swath (2) IW (Interferometric Wide Swath) mode has 5X20 meter spatial resolution and a 250 km swath (3) EW (Extra

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Wide Swath) mode has 25X100 meter spatial resolution with a 400 km swath (4) WV (Wave mode) has 5X20 meter resolution. Sentinel-1 has four types of data products: (1) Level 0-Raw data, (2) Level 1-Single Look Complex (SLC) data, (3) Level -Ground Range Detected (GRD) data, and (4) Level 2- Ocean (OCN) data. These data sets are available publicly for free online. The objective of this study to classify paddy rice pixel during cloud cover using Sentinel-1 SAR microwave sensing data.

MATERIALS AND METHODS

Study area

Andhra Pradesh is located on the southern coast of the India and covering an area of 160,205 km^2. Andhra Pradesh climate depends on the variation of geographical region of state. Monsoons of Andhra Pradesh have the significant role to define the climate of the Andhra Pradesh state. The main cropping season in the Andhra Pradesh state is the *kharif* season which starts from July to September with tropical rains. The state receives a plenty of rainfall during the southwest monsoon in the *kharif* season and slightly less rainfall occurs during the northeast monsoon. In October and November months, state receives heavy rainfall mostly in the southern and coastal regions due to sea low-pressure and also from tropical cyclones. The economy of the state is predominantly based on farming and livestock and most of the population is occupied in agricultural activities. Rice is the major food crop and state is also known as the "Rice Bowl of India". In addition to paddy rice, farmers also grow chili, cotton, maize, sugarcane, pulses, jowar, bajra, oilseeds millets, mango, tobacco, nuts and other crops in Andhra Pradesh. The study area is described in Fig. 1.

Data used

The Sentinel-1 (C-band) Synthetic Aperture Radar (SAR) data with a spatial resolution of 20 meter have been utilized in this study for paddy crop acreage estimation. Sentinel-1 is a space-borne mission which was funded by European Union and carried out by the European Space Agency (ESA) under the Copernicus Programme. Sentinel-1 is a constellation of two satellites (1A & 1B) with the payload of the C-band SAR for continuous earth observation (day, night, and all-weather) and the Sentinel-1A data used in this study is freely available to download from https://

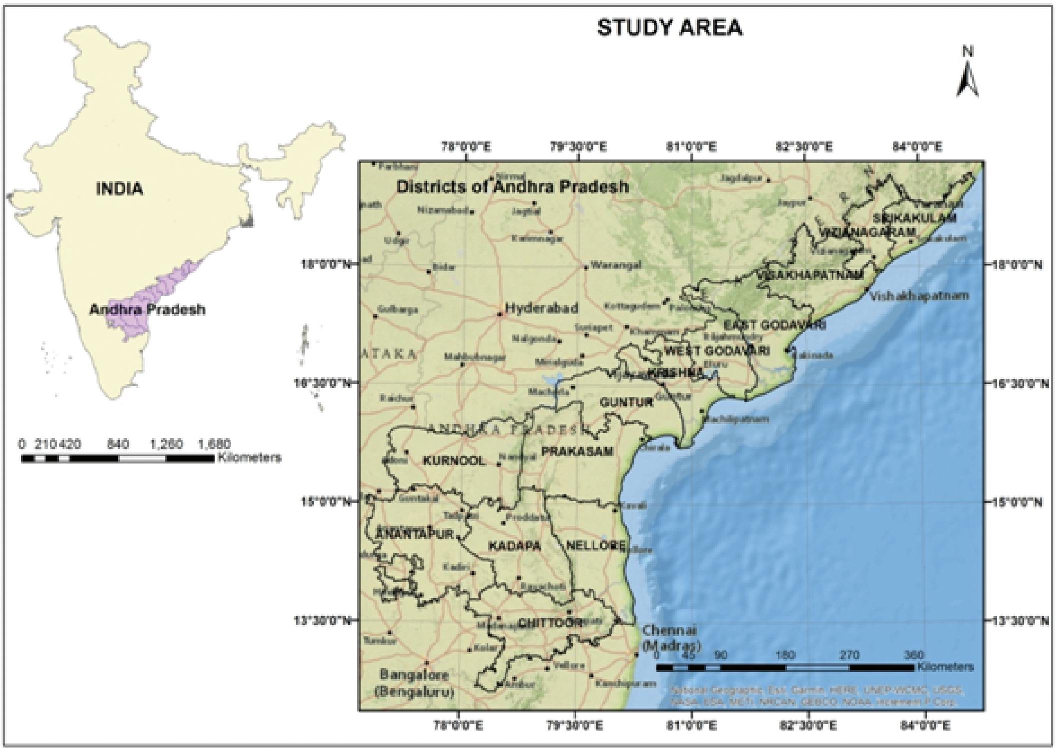

Fig. 1: Study area

Table 1: System specifications of Sentinel-1A data used in this study

S.No.	Attribute	Value
1	Frequency	5.3 GHz, C-band
2	Polarization	VV
3	Mode	Interferometric Wide
4	Product Type	Level-1, Ground Range Detected (GRD)
5	Incidence Angle (Central)	38.3°
6	Swath Width	251.8 km
7	Resolution (range * azimuth)	20.3 * 21.7
8	Repeativity	12 days

Table 2: The date of multi-temporal Sentinel-1A data collection (Strips as sown in Fig. 2)

	Strip wise data collection dates			
S. No.	**Strip(a)**	**Strip(b)**	**Strip(c)**	**Strip(d)**
1	22 June 2018	29 June 2018	24 June 2018	01 July 2018
2	04 July 2018	11 July 2018	06 July 2018	13 July 2018
3	16 July 2018	23 July 2018	18 July 2018	25 July 2018
4	28 July 2018	04 August 2018	30 July 2018	06 August 2018
5	09 August 2018	16 August 2018	11 August 2018	18 August 2018
6	21 August 2018	16 August 2018	23 August 2018	30 August 2018
7	02 September 2018	09 September 2018	04 September 2018	11 August 2018

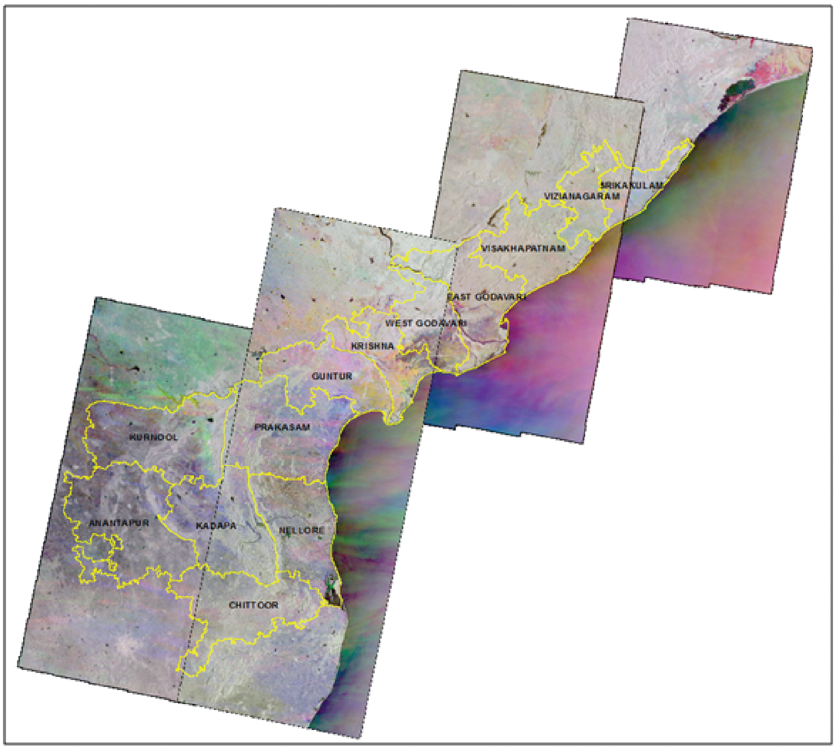

Fig. 2: Andhra Pradesh overlaid on multi-date Sentinel-1 data.

scihub.copernicus.eu. The specification of the Sentinel-1 data is given in Table 1. Three cycles of Sentinel-1 data of VV polarization was used to identify the paddy rice pixels. The date of acquisition of Sentinel-1A data is given in Table 2. The synoptic view of acquired Sentinel-1A data with strip number is shown in the Fig. 2.

METHODOLOGY

The multiple scenes of Sentinel-1 (VV) data were freely downloaded from https://scihub.copernicus.eu. The downloaded Sentinel-1A, VV polarization, GRD (Ground Range Detected) data was imported to the ESA's SNAP (Sentinel Application Platform) software. The software was obtained from https://step.esa.int/main/toolboxes/sentinel-1-toolbox/. SNAP software is mainly for radar data processing. SNAP is open-source software that has been developed to felicitate the utilization, viewing, and processing of remotely sensed data. The Sentinel-1 data processing functionality was accessed through the Sentinel Toolbox of SNAP software. The main component of the Sentinel Toolbox is to visualize, analyze, and process the Earth Observation (EO) data. The SAR data processing has been carried out for multi-temporal VV-polarization SAR data sets for each swath. However, the following steps were carried out in a batch processing tool available in SNAP after creating a Graph builder to process (Calibration, Speckle filtering, Multi-look, Terrain-correction, and Linear to dB) multi-scenes of Sentinel-1 SAR data. The processing steps of Sentinel-1 SAR data are given in Fig. 3. The radiometric calibration was applied in the linear domain. To reduce the speckle noise, a 2x2 multi-looking was done in range and azimuth direction. Furthermore, a Refined-Lee filter was applied to speckle suppression. For terrain correction, the Range-Doppler method was used with the help of external DEM (SRTM 30m) on auto download mode. The radiometrically ortho-rectified and terrain corrected data was converted from linear to decibels (dB) domain. These all steps (tools) were made available in a graph builder tool of SNAP software to apply a batch file in the auto mode. For the classification of paddy rice pixel, the data was scaled and converted into 8-bit integer (0 - 255) [DN = (25.5 + dB value)*10] for smooth selection of threshold values for classification. Date-wise scenes were mosaiced and layer stacked for each swath. Ground Truth (GT) points were used for training data collection. The average (at least four pure rice pixels) decibels

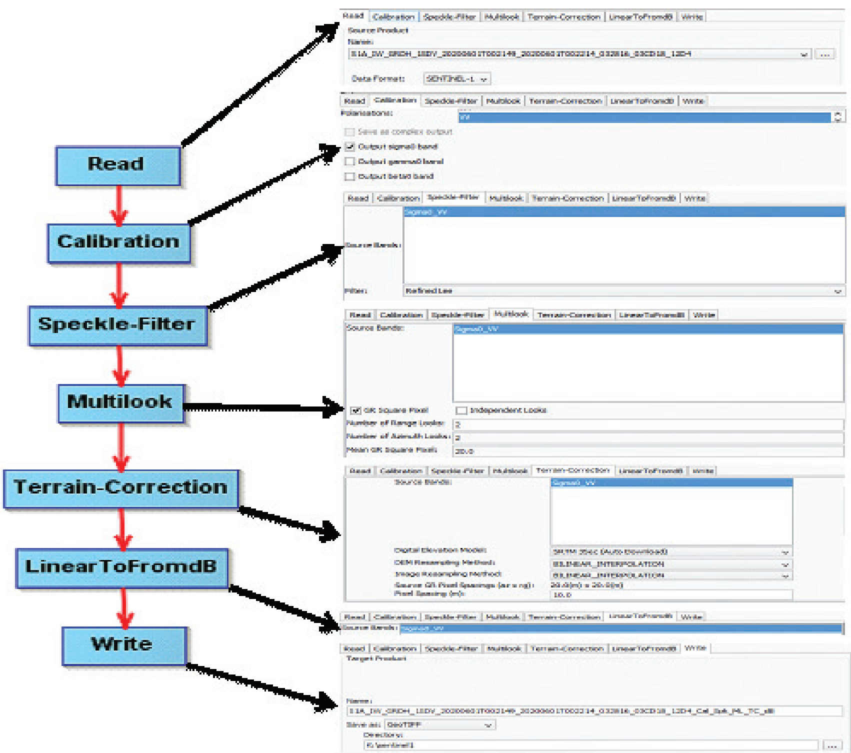

Fig. 3: Processing steps of Sentinel-1data in SNAP software

values (dB) as backscatter coefficient were calculated from the pixels using ground truth points. Moreover, the rice crop (early, mid, and late) signature was extracted with the help of these training locations. Based on signatures, the date of transplantation of rice crop for each date was identified and three processed Sentinel-1 data sets with a minimum 12 days gap have been selected for the decision tree-based classification and paddy acreage estimation. For classification, a hierarchical decision-rule-based classification model was created in the model maker toolbox of ERDAS Imagine software. The decision-tree classification model was fine-tuned with threshold values for each strip to estimate rice cropped area. To mask out the non-agriculture region, the agriculture mask layer was applied to the classified layer.

Accuracy assessment

The accuracy assessment of classified images is a structured way to examine the correctness of classification with ground truth data, etc. The data for the random points in the cell array can be saved in the classified image file for further reference, or to refine the past evaluation. In this study, 250 points were used randomly to check the classification accuracy.

RESULTS

The early, mid, and late sown paddy pixels were identified on multi-date layer stacked Sentinel-1 data. The early sown paddy rice was evidenced by the signatures of the different locations of early sown paddy rice scaled values were plotted on the graph (Fig. 4). Early sown paddy rice also appeared as cyan color on layer stacked image (Fig.7) and it was a signature to identify early sown paddy rice in other locations of multi-date layer stacked image. In mid sown paddy rice, the values of different locations of mid sown paddy rice were plotted on a graph. A dip was identified in the middle date of the Sentinel-1 data set (Fig.5). The pixel color appeared as a magenta color (Fig.7) on a multi-date Sentinel-1 image. The same process was applied for late sown paddy rice areas and identified a dip on scaled dB values in different locations of late sown paddy rice areas (Fig. 6) and pixel color was appeared as yellow (Fig.7). The patterns of VV signal of Sentinel-1 data weakened by the vertical geometry of paddy rice. The signals are depending on the cultivation field and the structure and geometry of a crop. The paddy rice mostly has the same cultivation procedure, from field preparation to harvest that gives a strong backscatter signature and that can be used for the identification of paddy rice pixels. The changes in scaled dB values of early, mid, and late sown paddy rice were recorded and the threshold of dB values was made to use in rule-based classifications. The strip wise classification was performed and further, the classified layer was mosaiced to complete the map at the district level. A mosaic classified layer of the East Godavari, West Godavari, Krishna and Guntur districts is showed in the Fig. 8.

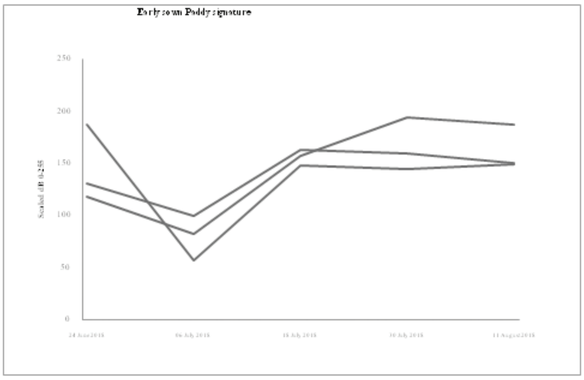

Fig. 4: Backscatter signature of early sown paddy

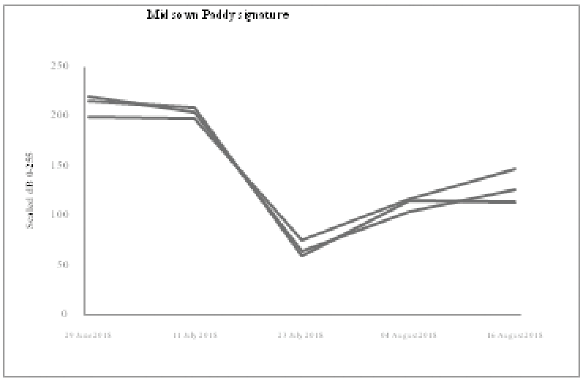

Fig. 5: Backscatter signature of mid sown paddy

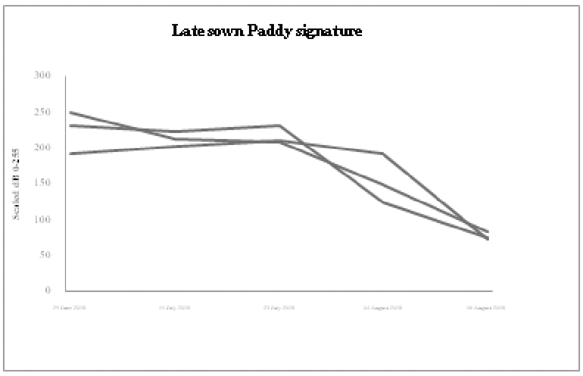

Fig. 6: Backscatter signature of late sown paddy

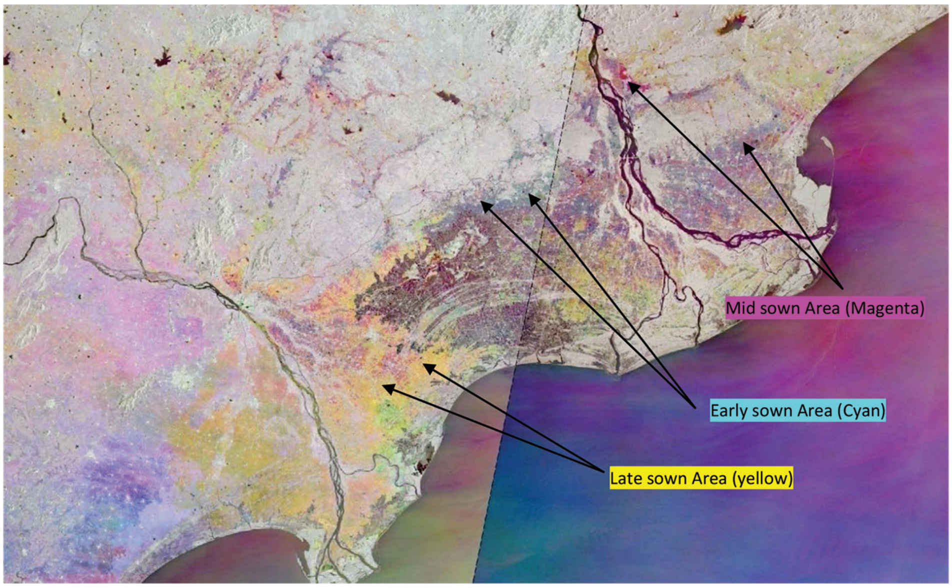

Fig. 7: Multi-date Sentinel-1 SAR data (Krishna and Godavari delta region)

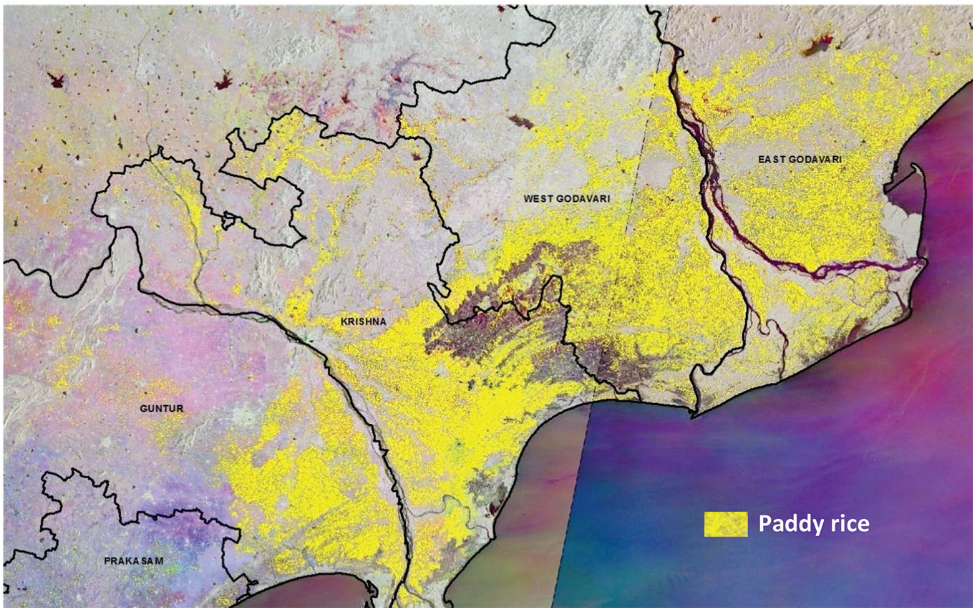

Fig. 8: Classified rice crop pixels overlaid on multi date Sentinel-1 data (Krishna and Godavari delta region)

The cyan, magenta and yellow color identified as early, mid and late sown paddy in Srikakulam and Vizianagaram districts of Andhra Pradesh is showed in Fig.9. The classified paddy rice of Srikakulam and Vizianagaram is showed in Fig.10. The classified paddy rice is validated using random sampling points. The district-wise rice cropped area was estimated from the decision tree classified image for the major paddy rice crop growing districts of Andhra Pradesh during the *kharif* 2018 season. The estimated rice acreage was compared with DES statistics as shown inTable 3. The rice classification results for all districts along with the multi-temporal RGB image are shown from Fig. The overall classification accuracy was consistently high (88%). The 250 validation points were used for accuracy assessment out of which 220 points correctly fallen on paddy rice area and 30 points on non-rice pixels.

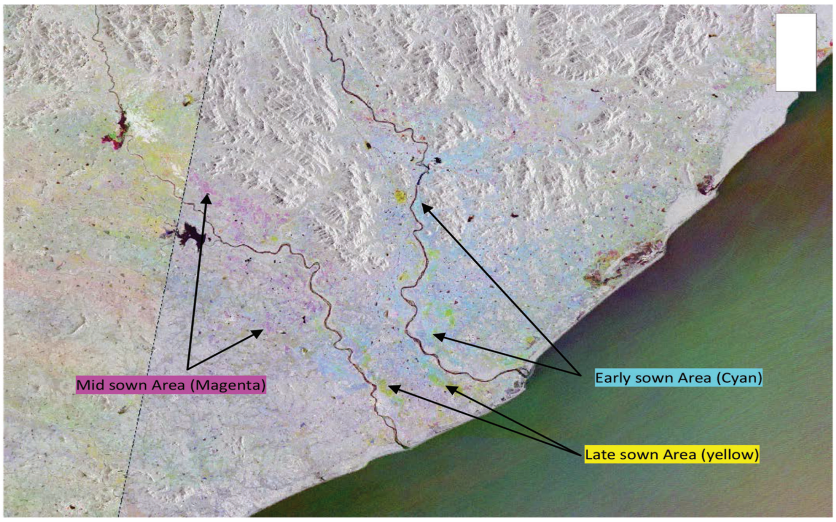

Fig. 9: Multi-date Sentinel-1 SAR data (Srikakulam and Vizianagaram districts)

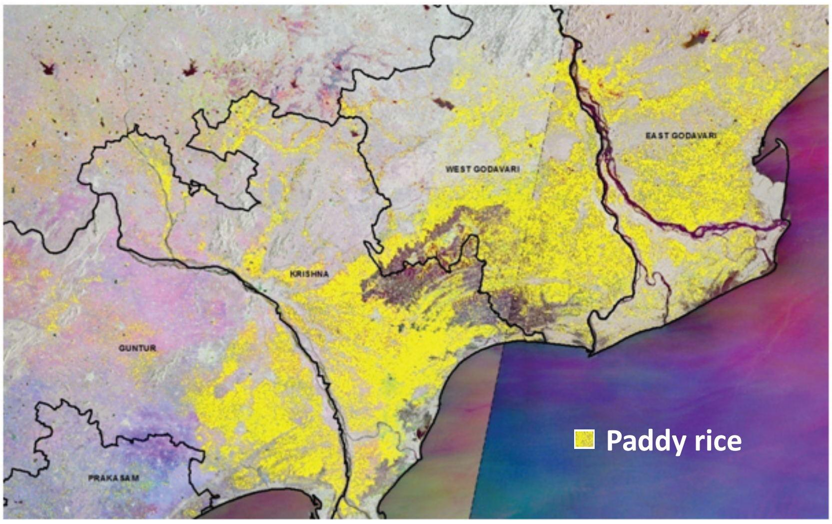

Fig. 10: Classified rice crop pixels overlaid on multi date Sentinel-1 data (Srikakulam and Vizianagaram districts)

Graphical signature of early mid and late sowed paddy crop area

Table 3: District wise rice crop area in ha

S. No.	District	Sentinel-1 Paddy rice Area (Ha.) 2018	Agri. Dept. Govt. of AP (as on 10-10-2018)	RD (%)
1	Srikakulam	196055	210025	-7.1
2	Vizianagaram	112749	118809	-5.4
3	Vishakapatnam	111591	99392	10.9
4	East Godavari	223608	222777	0.4
5	West Godavari	230627	222160	3.7
6	Krishna	226461	244495	-8.0
7	Guntur	208634	194485	6.8
	Total	1309725	1312143	-0.2

DISCUSSION

The results revealed the potential of Sentinel-1 SAR data towards generating accurate paddy rice spatial map. Sentinel-1 C band, VV polarization images were employed to access paddy crop acreage in major paddy growing districts of Andhra Pradesh. VV polarisation was used for this study as previous studies on comparison of polarizations (VV & VH) for flood map assessment and VV performed better than VH polarization, hence VV configuration was used for paddy rice area estimation. Since rice field preparation for transplantation (flooding) is a dynamic scenario to agronomic practices, therefore the satellite acquisition was organized separately to speck the evidence of water. The flooding dynamics (presence, start, and end dates) can be monitored significantly with frequency of Sentinel-1 observations. The 12 days repeativity has increased the monitoring mechanism. The total four strips were covering the entire Andhra Pradesh. The 7 dates from June to September 2018 were processed for paddy rice classification. The signatures of paddy rice were generated using training polygons. The threshold dB values were identified to classify the rice pixels. In early sown paddy rice areas, the low backscatter values were observed on Sentinel-1 data of 6th July 2018 and indicating flood conditions (field preparation for paddy plantation), and an enhance in backscatter values in next acquisition of SAR data due to the growth of the paddy crop. Mid-sown paddy areas have shown the low backscatter in the 23rd July 2018 acquisition which indicates the flooded condition and increase backscatter in the next succeeding acquisitions. In late shown paddy rice areas observed low backscatter on 8th August 2018 acquisition and increase backscatter values in succeeding Sentinel-1 observations which indicate the growth of paddy rice crop. Mansaray *et al*. (2017) has observed in their study that the flooded condition to crop growth govern the change of temporal backscatter of paddy rice were remarkable. During crop growth stage absence of water helps accurate discrimination of paddy rice crop pixel. The temporal signature SAR backscatters identify paddy rice from the other crop/objects. Furthermore, a comparison study was performed with statistics from the Agriculture Department which proved that the SAR data can provide high-resolution spatial explicit crop information in monsoon season, and during cloud cover. The results showed a good agreement between Sentinel-1 estimates and the traditional scale of estimation.

In this study, it is observed that the Sentinel-1 SAR data has showed potential for identifying and estimating paddy rice acreage. The relative deviation of selected seven districts has showed a significant correlation between Sentinel-1 SAR data estimation and statistics from the department (traditional method). The overall classification accuracy is admirable with 88% using Sentinel-1 SAR data during cloud affected condition. The overall relative deviation (RD) is -0.2% for seven major paddy rice-growing districts of Andhra Pradesh. It is also observed that the historical and current available microwave C band SAR data has proven capability to identify the paddy rice accurately.

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