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Multi-Temporal Synthetic Aperture Radar Data for Paddy Crop Area estimation in Eastern Part of Godavari Delta, Andhra Pradesh, India

S.K. TIWARI* and G. PRASADA RAO

Andhra Pradesh Space Applications Centre, Government of Andhra Pradesh.

Abstract

In the present study, an attempt is made to estimate the area under paddy crop during Rabi, 2013-14 using Microwave satellite data in the eastern part of Godavari delta. Clouds veil nearly the entire sky in both (Kharif & Rabi) seasons of Andhra Pradesh and hinder the estimation of crop acreage through optical satellite sensors. Microwaves can penetrate clouds and be used to detect crops during the day and night, regardless of cloud cover. Radar Imaging SATellite-1 (RISAT-1), microwave sensor, dual-polarization Horizontal-Horizontal (HH), Horizontal-Vertical (HV), Medium Resolution scanSAR Mode (MRS) data (18 m pixel spacing and 37° incidence angle) of three different dates (in December, January, and February) with 25 days interval was used. The backscatter (dB) values of the early, mid, and late-season transplanted stages of paddy crop were used to estimate the paddy crop acreage coupled with ground truth information during different stages of the crop. It was observed that the dB values at the transplanting stage rapidly increased with plant growth in the early season sown areas and mid-season sowed paddy illustrate a dip in dB values in the second date due to change in transplantation and increased backscatter coefficient values in the third date because of crop growth after transplantation. The backscatter signature value of late sowing paddy crop showed first and second dates with high backscatter due to previous crop/vegetation and then a sudden dip in the third date as submerged field ready for transplantation. The dB values of the above stages were used in decision-based classifier to estimate paddy crop acreage. The paddy area was compared at Mandal (sub-district level) estimates observed the significant coefficient of determination ($R^2 = 0.89$) between traditional estimates and Synthetic Aperture Radar (SAR) data assessment. This study robustly suggests the utilization of SAR data in agricultural crop monitoring during cloud cover.

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CONTACT S.K. Tiwari sudheer.apsac@ap.gov.in Andhra Pradesh Space Applications Centre, Government of Andhra Pradesh.

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Introduction

Andhra Pradesh state is one of the major rice-producing states in India, mainly cultivated in command areas (It is an area which can be irrigated from a scheme/dam and is fit for cultivation). Rice is the main food crop cultivated all over the state providing food for the growing population. The average area under rice (*Kharif* and *Rabi*) in the state is 23.46 lakhs ha and 21.05 lakhs ha in the cropping year 2016-17.[1] Any decline in its acreage and production may have a perceivable impact on the state's economy and food security. Cloud coverage hinders optical sensors to sense the crop and microwave signals can penetrate clouds and offers great potential to monitor the paddy crop acreage. Particularly in monsoon, clouds are the hurdle to sense the object on the earth's surface optically. Thus, microwave remote sensing can be a potential option, as it can penetrate the clouds.[2] This technology uses microwave radiation using wavelengths from about one centimeter to a few tens of centimeters enables observations in all weather conditions without any restriction by cloud or rain. Microwave remote sensing has two types of sensing; active and passive. The active sensing receives the backscattering which is reflected from the transmitted microwave which is incident on the ground surface viz. Synthetic Aperture Radar, microwave scatter meters, radar altimeters.[3,4,5] Whereas passive sensing receives the microwave radiation emitted from objects on the earth's surface; the passive microwave sensor. Understanding about Different dependable parameters (System parameter-Wavelength, Polarization, Look angle, Resolution and Target parameters-Surface Roughness, Moisture, Slope, Orientation) are very essential.[6] RISAT-1 Synthetic Aperture Radar (SAR) is India's first indigenous, active, antenna-based microwave radar sensor in space, launched by PSLV-C19 flight on 26 April 2012. RISAT-1 satellite carries a multimode c-band (5.35 GHz) Synthetic- Aperture Radar.[7] The choice of the C-band frequency of operation and RISAT-1 SAR capability of imaging in HH, HV, VH, VV, and circular polarizations will ensure wide applicability in the thrust areas like flood mapping, Agriculture and Crop monitoring, generic vegetation, forestry, soil moisture, geology, and Sea Ice and coastal applications.[8] In agriculture cultivated fields, the condition of the crops changes regularly from sowing to harvesting stage diurnally, daily, and seasonally. Consequently, mapping and monitoring of crops through remote sensing satellites in the cloudy condition is a challenge. Crop vegetation has linear features of length larger than the incident wavelength tend to generate larger reflections when the polarization alignment agrees with their structural alignment.[9] The polarization of the transmitted microwave (horizontal (H) or vertical (V)) also dictates which components of the vegetation contribute to the total amount of energy scattered back to the SAR sensor. The potential of Synthetic Aperture Radar (SAR) in discriminating among different agricultural crop types has been studied in previous studies[10,11] especially for paddy crop mapping and monitoring. Paddy crop is one of the key food grains linked to the food security of the rice feeding human population across the world. India has achieved the highest position in paddy crop cultivation and stands second in production in the world reported by USDA, Global Market Analysis in May 2020.[12]

Microwave Interaction With Agricultural Targets

The potential of radar remote sensing techniques has been shown in earlier studies.[13,14] In India, the Researcher has demonstrated the utility of temporal SAR data[15,16,17] Basically, physical and dielectric distinctiveness of crops influences the interaction of microwave and thus determines the backscatter response measured by the sensor. Crop phenology governs the plant water content and thus dielectric properties. As crop mature the water content decreases, which in turn reduces the contribution to radar backscatter from the plants. The present study covers Part of the East Godavari district of Andhra Pradesh. RISAT-1 C band SAR data HH polarization, MRS L2 data of three dates (sufficiently spaced-nearly 20 days to cover the variations from field preparation to planting growth stage) used to estimate Paddy crop acreage. In the Godavari region, Paddy is a major crop in both the seasons (*Kharif* and *Rabi*). The Radio Detection and Ranging (RADAR) sensors for agricultural applications have been diligently studied. Interaction of the radar signal with agricultural objects is affected by physical and chemical factors related to vegetation and sensor systems. Radar backscatter dependent on two types of parameters: (a) radar system parameters which affect radar backscatters - such as frequency, polarization, and incidence angle and (b) target parameters (dielectric constant, vegetation height, moisture content, shape and size of the leaf, soil moisture, roughness, etc.) that influence the scattering process. Target parameters are related to the dielectric and geometrical properties of the material in question. Dielectric properties are very strongly linked with the water content of the object while leaf shape and size are examples of geometrical characteristics. The aim of this study to map the paddy crop area during cloud cover using SAR satellite data in the Eastern part of Godavari Delta, Andhra Pradesh, India.

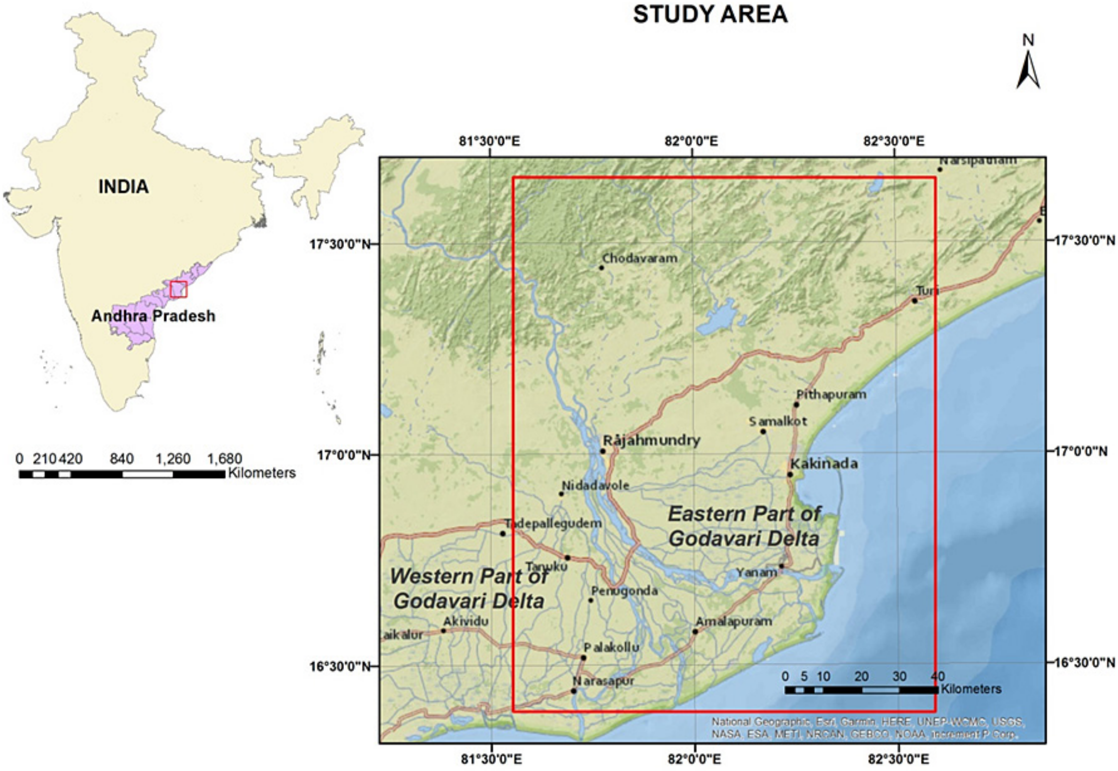


Fig.1: Study area (Eastern part of Godavari Delta)

Materials and Methods

Study Area

Sir Aurthur Cotton constructed the Godavari Delta System (GDS) across the river Godavari near Dowlaiswaram, East Godavari District of Andhra Pradesh, India. It is providing irrigation facility to an ayacut of 10.09 lakhs acres in East and West Godavari districts (Source: District irrigation profile, Water Resources Dept, Govt. of AP.). The study is focused in the Eastern part of Godavari Delta, it lies in between 16°23'57.6" to 17°39'05.2" N Latitude and 81°33'28.0" and 82°35'32.9" E Longitude (Figure-1). The principal irrigated crop in *Rabi*/ Dry season (November to April) is paddy. The paddy varieties mainly grown in East Godavari district are Vijetha (MTU-1001), MTU 1010, IR-64, Satya (RNR-1446), Vikas (IET-3116) (Source: Kisan, Nagarjuna Fertilizer and Chemicals limited).

RISAT- Data Processing

RISAT-1 operates in a sun-synchronous orbit at an altitude of 536 km with a revisit period of 25 days for MRS mode18. The multi-date satellite (L2) product(s) are Tiff format with a pixel resolution of 18 meters and an incidence angle of 37° was used in the study. The images were filtered using 5×5 enhanced Lee adaptive filter technique.[19] The pixel values were converted to the backscatter coefficient (dB) using equation (1).

dB (32-bit real channel) = $20\times\log_{10}$ (DN) calibration constan ...(1)

The filtered images were calibrated using calibration constant available in the metadata file (BAND_META.txt). The co-registered images of three dates of the same location were layer stacked. The sample points were collected accordingly for early sown, mid sown, and late sown paddy from different locations of the scene. The minimum and maximum dB values were found out to adjust the threshold and run the model maker tool in ERDAS Imagine software.[20] The methodology adopted for the analysis is depicted in the following flow chart (Figure-2).

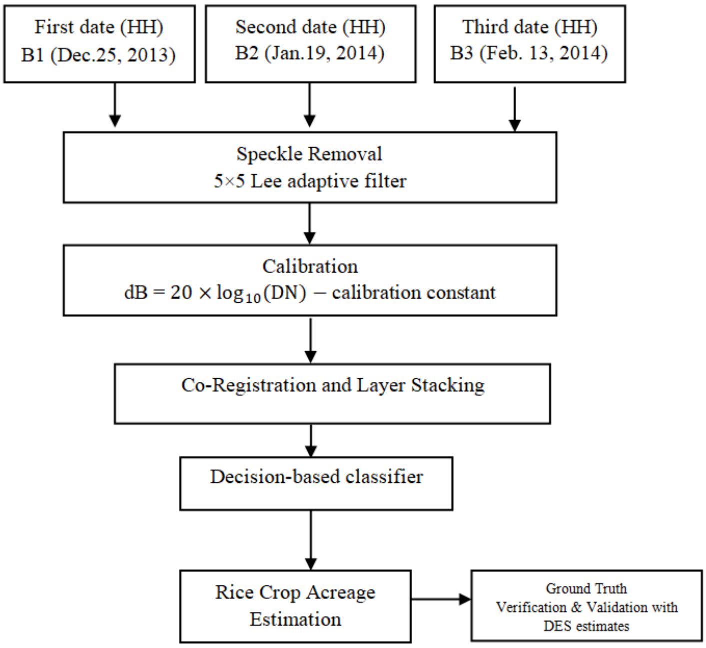
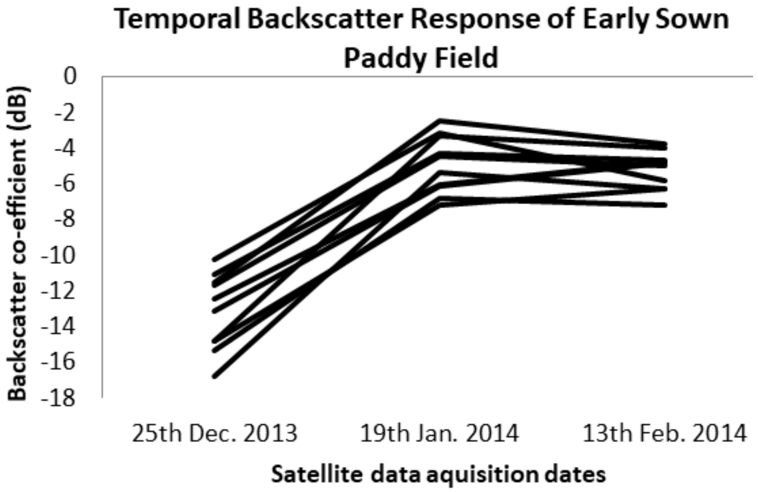


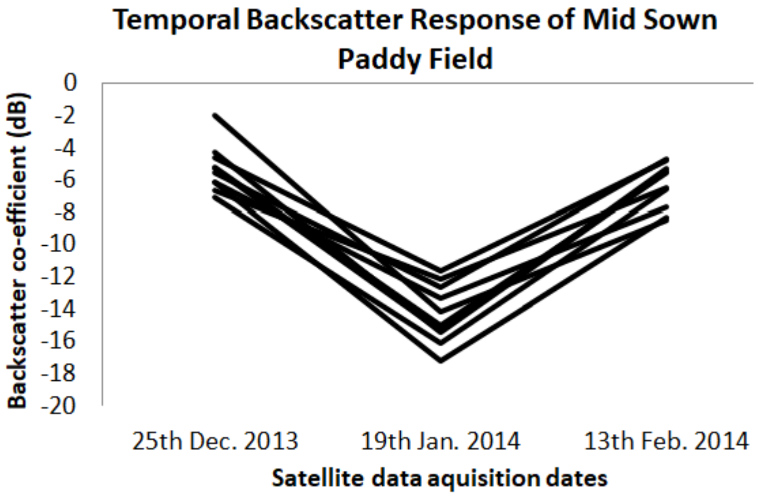
Fig. 2: Methodology

Radar images have dark pixels known as speckle noise these speckle noise must be lessening before the data use. However, the technique used to reduce speckle noise also produces changes in the image. The Lee adaptive filter[21] was used as it is based on the multiplicative speckle model and uses local statistics to preserve details. The Lee-Sigma filters utilize the statistical distribution of the DN values within the moving window to estimate what the pixel of interest should be. The Lee adaptive filter assumes that the mean and variance of the pixel of interest is equal to the local mean and variance of all pixels within the user-selected moving window. Calibration of RISAT-1 SAR data was done to convert DN values to dB values using equation (1) and backscatter values (dB) were used for classification of paddy crop. Co-registration is a process of pixel to pixel matching with a reference image. In this study LISS-III, the master image used as a reference image for rectification of RISAT-1 data (first cycle), and the remaining two cycles were co-registered using the first rectified image. Three co-registered imaged were stacked to perform the rule-based classification based on the variations identified in dB values during the transplantation and plant growth stages.

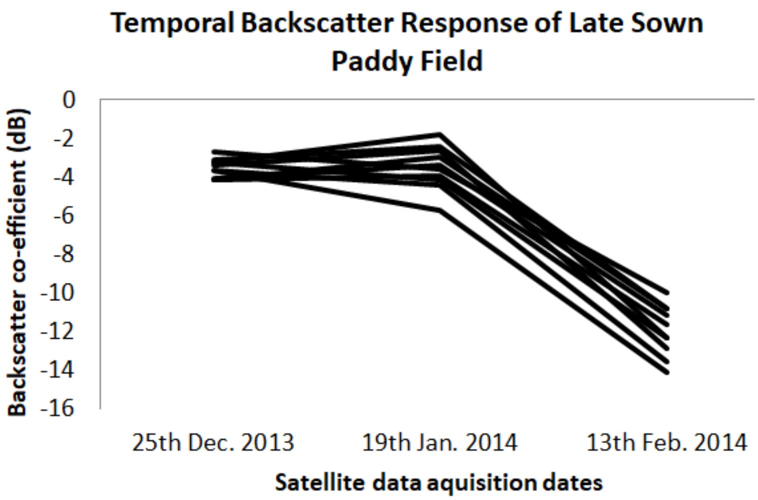
The Godavari delta which is a paddy crop dominant region, farmers cultivates *Kharif* and *Rabi* paddy crop in both seasons. The eastern part of Godavari delta which was studied by using RISAT-1 SAR data for the feasibility of paddy area estimation in cloud condition. The typical temporal changes (i.e., crop growth, and flood condition of paddy crop field during transplantation), resulting in strong interaction mechanisms (SAR signal-vegetation water), and the corresponding backscattering coefficient was the basis of the Rule-based model. A rule-based model was developed for classifications of multi-date microwave data.[22,23,24] ERDAS imaging Model maker tool was used and the function definition tool was utilized to write an algorithm for the classification. The sigma^0 values were observed based on the stage of the crop and given as input information in rule-based classification functions. Early, mid, and late-season sowing paddy cultivated areas were identified and classified into the spatial map. A masking operation was performed to generate the final map. The mask layers of forest, rivers, built-up, water bodies, wastelands were taken from the LULC (Land Use Land Cover) map of Andhra Pradesh. Finally, Sub-district (Mandal) level paddy crop map and statistics were generated and validated with DES estimates. The 25 locations in the study area were checked for classification accuracy of paddy crop acreage and observed that all the locations were correctly mapped.



3(a)



3(b)



3(c)

Fig. 3: dB response of early transplanted paddy 3(a), mid transplanted paddy 3(b), late transplanted paddy 3(c) of ten randomly selected location

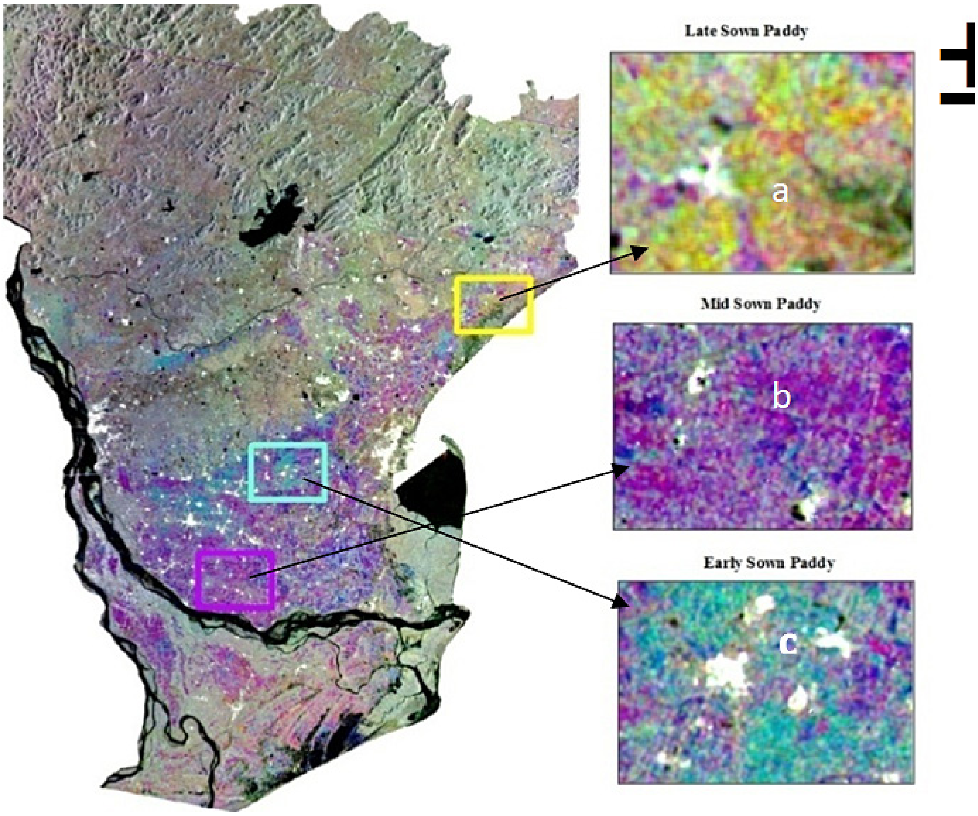


Fig. 4: Three-date RISAT-1 image covering a part of the paddy crop growing area of East Godavari district, Andhra Pradesh. a, Late transplanted area (yellow)in FCC. b, Mid transplanted area (pink). c, Early transplanted (cyan).

Results

Paddy crop generates a distinctive temporal backscatter signature, unlike other crops. During transplantation, backscatter is relatively low due to standing water conditions in puddle fields which reflects more energy in the forward direction and less in the back-scattering direction. The selection of the number of scenes depends upon the crop calendar. In the study area transplanting time differs from one place to another place, thus three dates were selected to cover the transplanting stage of the entire study area. In the three dates of FCC combination, early sown paddy crop appeared as cyan color, mid sown as pink, and late sown paddy crop appear as yellow color (Figure 4). At the transplanting stage, all the locations have shown low backscatter and it was subsequently increased in the growth stage. It can be noticed that there are a sudden dip and abrupt change in the backscattered coefficient. Backscatter (dB) values of the early, mid, and late transplanted stages of paddy crop were used to model the paddy crop acreage coupled with ground truth information during different stages of the crop. In Early sown areas the dB values ranging from dB -16.8 to -14.0 in the transplanting stage and dB values are rapidly increased ranging from dB -7.2 to -5.0 in plant growth (Figure 3a). Mid sown paddy with dip on second date values varies from dB -17.2 to -15.0 and increased backscatter coefficient values in the third date range from dB -8.4 to -4.7 (Figure 3b). The backscatter signature of late sowing paddy crop shows first date (dB -4.1 to -2.1) and second dates (dB -5.7 to -1.8) high backscatter and then a sudden dip (dB -14.8 to -12.0) in the third date (Figure 3c). Backscatter (dB) values of the above stages were used to model the paddy crop acreage estimation. The paddy crop classified map is shown in figure 5.

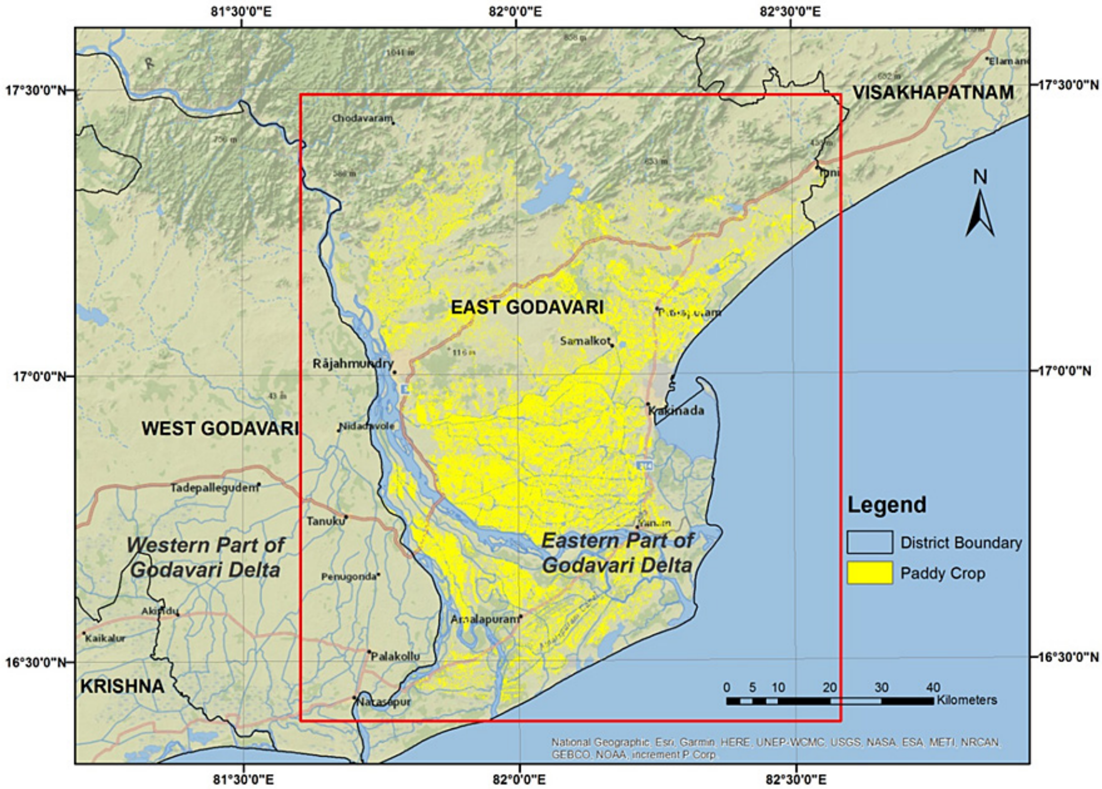


Fig. 5: Classified paddy crop segment in East Godavari district

Results Comparison with DES Statistics at Sub-District (Mandal) Level

The acreage estimates generated for sixteen sub-district (Mandals) of East Godavari district for *Rabi* 2013-14 season based on the classified image of multi-date RISAT-1 MRS data. The acreage was compared with sub-district (Mandals) level estimates of DES which is depicted in Figure-6 and the percentage of deviation is also shown in table- 2.

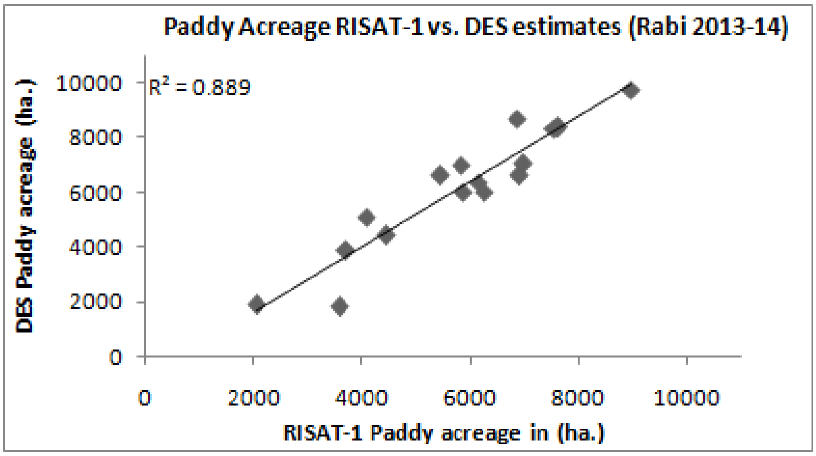


Fig.6: Paddy acreage comparison between RISAT-1 and DES estimates

Table 2: Evaluation of RISAT-1 assessment with Dept. of Economics and Statistics (DES) estimateof Rabi season, 2013-14

S. No	Sub-district (Mandal) name	Longitude (Degree Decimal)	Latitude (Degree Decimal)	Paddy acreage in (ha.) (RISAT-1)	Paddy acreage in (ha.) (DES)	Paddy acreage deviation in %
1	Alamuru	81.87066	16.81904	4441	4422	0.44
2	Anaparthy	81.96566	16.9101	3712	3865	-3.97
3	Biccavolu	82.02851	16.95338	5865	5989	-2.07
4	Kajuluru	82.16196	16.79867	6852	8698	-21.23
5	Kakinada (r)	82.24601	16.99995	2044	1892	8.04
6	Kapileswarapuram	81.94403	16.7602	6888	6605	4.29
7	Karapa	82.16321	16.88538	5834	6995	-16.59
8	Kothapalle	82.33201	17.11143	4070	5074	-19.78
9	Mandapeta	81.91084	16.89634	6975	7036	-0.87
10	Pamarru	82.05926	16.74146	6143	6346	-3.2
11	Pedapudi	82.12175	16.93737	7556	8360	-9.62
12	Pithapuram	82.22608	17.13772	5447	6611	-17.61
13	Ramachandrapuram	82.06106	16.81973	7625	8363	-8.83
14	Rayavaram	82.00401	16.8442	6256	6021	3.91
15	Samalkota	82.16303	17.02407	8973	9760	-8.06

During the current study, a significant coefficient of determination (R^2 = 0.89) was observed between cropped areas generated from RISAT-1 and DES. It is revealed that the deviation in areas in seven sub-districts (mandals) is less than -/+ 5%, between -/+ 6 to -/+ 10% in 4 sub-district (mandals), and remaining are above 10% as shown in table 2. Out of the 15 sub-district (mandals), very less deviation is noticed in Alamuru (0.44) and maximum in Gollaprolu (-21.23) sub-district-mandals.

Discussion

The study area in figure 1, selected as this area intensively occupied for paddy crop cultivation in both the seasons (*Kharif* & *Rabi*) and constantly covered with cloud, has to be observed by microwave sensing only. RISAT-1 has been observed a trend in figure 3, the variation in backscatter values corresponding to variation in crop stages (early, mid, and late sown paddy). The backscatter response has been studied and observed that the backscatter from crop canopy almost linearly increases with the increase in crop biomass until it reaches a saturation level that depends upon the radar frequency. Crop phenology governs canopy water content and thus the dielectric properties. As the crop matures, the water content decreases which typically reduces the response of backscatter.[25] The rule-based classification is a well-turned-out classifier for crop classifications. However, if the rules are applied in a structured way then definitely it is possible to build a knowledge-based classification tree. The advantages of this approach have been for instance recognition.[26] In this study, the threshold was collected randomly from the early, mid, and late sown pockets, and samples were used as a threshold to classify the paddy crop. Paddy crop is mostly grown as transplanting in swamped agriculture fields. Initially transplanted paddy crop provides a very low backscatter value due to specular reflection from flooding water in the field.[27,28] As the plant grows and expands tillers, the radar backscatter raises to the plant reaches the growth stage due to volume scattering from the vegetation and various reflections of vegetation/plant and surface of the water.[29,30] After the growth stage, the radar backscatter remains nearly constant up to crop maturity.[31] The classified paddy crop map (figure 5) was obtained from this study and was compared at the sub-district (Mandal) level to check the variation in acreage data collected from the traditional approach (DES). A significant regression coefficient (R^2 = 0.89) was observed when compared with DES estimated (figure 6). Sub-district (Mandal) level deviation statistics depict that most of the sub-district (Mandal) has variation within -/+ 5% which is considerable.

Conclusion

The study says that microwave satellite data (RISAT-1) has shown a significant role in the estimation of paddy crops. The coastal command areas have dominant paddy cultivation which is always covered with the clouds in both the seasons (*Kharif* & *Rabi* seasons). The available and upcoming high spatial resolution microwave satellite missions may be utilized for precise paddy crop acreage estimation and further enhance the monitoring of other crops in the future. The low data cost would be an advantage for the microwave remote sensing community globally in all areas of application.

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Conflict of Interest

The authors do not have any conflict of interest.

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