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Rice Cultivation Monitoring and Acreage Estimation using RADARSAT SAR images in Jharkhand, India

Narayan Kumar Mishra[1], Rahul Kumar Singh[2], Amit Kumar[3] and A. T. Jeyaseelan[4]

[1]Jharkhnad State Watershed Mission, Department of Rural Development, Govt. of Jharkhand, Ranchi, INDIA
[2]Jharkhand Space Applications Center, Department of Information Technology, Govt. of Jharkhand, Ranchi, INDIA
[3]Centre for Land Resource Management, Central University of Jharkhand, Ranchi, INDIA (ORCID: 0000-0002-4582-5677)
[4]National Remote Sensing Center, Department of Space, Hyderabad, INDIA

*Corresponding author: mishrank14@gmail.com (+91 94315 74367).

ABSTRACT

The present study involves analysis of multi-date RADARSAT ScanSAR narrow beam data during the rice crop growth period for acreage estimation for 2008. In the present study, RADARSAT data up to mid July as first date (7th July and 17th July 2008), up to mid August as second date (31st July and 10th August 2008) and up to early September as third date (24th August and 3rd September 2008) was used. Ground truth data was collected in order to build model for classification using Geomatica software. Sample segment approach was adopted for rice acreage estimation, which was then extrapolated to the entire state using simple random sampling method. The initial acreage was estimated using two-date and three-date data set, which exhibits 1.385 million hectares during the first estimation and 1.45 million hectares during the final estimation. The study shows the RADARSAT based rice acreage estimation was very high correlation and useful for mapping and concurrent monitoring of rice cultivation in spatio-temporal framework using space based technologies.

Keywords: *Acreage Estimation, Crop Productivity Monitoring, RADARSAT*

INTRODUCTION

Rice (*Oryza sativa*) is the most important food crop in the world, because it is the staple food of over half the world's population (Ribbes and Toan 1999; Khan *et al*. 2007). Rice has always been relevant to global food security and socio-economic stability (Zeigier and Barclay 2008). This crop has been the most traditional land use and the main economic variable that has historically shaped social relations (Narayanan 2006). It is the major food grain grown in almost all states in India mainly during Kharif season (June to October). It is a heat and water favorite crop (Shao *et al*. 1999). Now, rice has adopted in wider range of agro-climatic conditions. Thus, rice has been regarded as the principal food grain and estimation of rice acreage as well as production could emerge the key area of management. Information such as rice fields acreage, number of crops per year, rice growing conditions which are essential for decisions concerning crop monitoring, yield prediction or water distribution is often absent or inexact (Malingreau 1986). The monitoring of rice crop growth is vital for food management planning and one of the monitoring methods is through the use of remote sensing from space (Choudhury and Chakraborty 2006).

The major stumbling block in the development of an accurate rice monitoring programme is to gather data require for forecasting. Use of remotely sensed data has proven to be very effective method of gathering this type of information for a wide variety of crops around the world (Chen and Mcnairn 2006). Different satellite data for example Landsat MSS and TM data (Morain and Williams 1975; Oettera *et al.* 2000; Blaes *et al.* 2005), SPOT (Buttner and Csillag 1989; Hanna *et al.* 2004), Advanced Very High Resolution Radiometer (AVHRR) imagery (Paliouras and Emery, 1999), Indian Remote Sensing (IRS) satellite data (Dutta *et al.* 1994; Panigrahy *et al.* 1997; Panigrahy and Sharma 1997) and Quickbird (Yang *et al.* 2007) have been used to estimate the crop yield. But in rainy seasons due to cloud cover, the crop acreage and yield production is difficult to estimate due to limitations of optical remote sensing sensors (Bhatt 1996). Here, Synthetic Aperture Radar (SAR) has emerged as a valuable tool in kharif rice monitoring, which is independent of the meteorological conditions (Ribbes and Toan 1999), having cloud penetrating capability and larger coverage area. Hence, the rice field can be easily detectable by SAR due to its unique temporal SAR backscatter (Aschbacher *et al.* 1995, Chakraborty *et al.* 1997, Panigrahy *et al.*1999[a], Li *et al.* 2003). Studies were carried out to understand the signature of rice crop at different stages of growth. In this context, accurate, reliable and consistent production monitoring and yield prediction systems are needed. Carrying out an efficient inventory of rice cultivated areas has therefore become a prime concern for local authorities. (Ribbes and Toan 1999).

Most paddies in India grow in warm, humid environment with heavy cloud cover and rainfall. Therefore, it is hard to analyze optical remote sensing data for kharif crop acreage estimation and production forecasting. Preliminary analysis of C band 23^0 incidence angle SAR data of ERS were carried out during 1992-93 for rice, sugarcane, cotton and groundnut grown under different agro-climatic conditions in India (SAC 1995). Synthetic Aperture Radar (SAR), with all weather, independent of illumination imaging capability and frequent revisit schedule, is anticipated to be the dominant data source for agriculture monitoring in tropical and sub-tropical regions. The typical signature of rice crop in multi-date SAR images was gainfully employed in its classification achieving over all identification and classification accuracy of more than 90% (Chakraborty *et al.* 1997). Rice monitoring and yield estimation has special significance to India, as rice is the staple grain and accounts for 42% of the crop yield for this country. Multi-date data acquired at critical bio-window of the crop growth was used to identify and classify rice fields with high accuracy (Patel *et. al.* 1995). Similar results have been reported from other Asian rice growing areas (Khusro *et. al.* 1993; ESA 1995). Systematic efforts on district level rice acreage estimation using multi-date ERS SAR data for selected districts of West Bengal and Orissa were carries out during 1994-95 kharif seasons (Panigrahi *et. al.* 1997). The objective of the present study is to analyze multi-date RADARSAT ScanSAR Narrow beam data during the paddy crop growth period (June to October) for acreage estimation for the Jharkhand State. The work was done under Crop Acreage and Production Estimation (CAPE)/ Forecasting Agricultural Output using Space, Agrometerology and Land-based observations (FASAL) programme, which uses microwave remote sensing technologies (RADARSAT) to forecast production of major cereals, oilseeds and fiber crops.

Jharkhand state is endowed with vast and rich natural resources mainly those of minerals and forest. The 80% of its population depend mainly on agriculture and allied activities for their livelihood. The food grain production is very low in the state and not meeting the basic requirement. The terrain is highly undulating, in the valley mainly paddy is being cultivated and in the upland maize, jowar, ragi, vegetables and other crops are cultivated. The annual average rain is about 1386mm, which occur mainly during the four months (June to September) of monsoon season. Though the monsoon rainfall is regular but due to their irregular temporal and spatial distributions, most of the agricultural area of about 92% is under rain fed condition (Jeyaseelan 2008). Large part of rice growing areas was followed a definite crop calendar and any major deviation from this results in loss of production as well as affects the crop rotation practice (Panigrahy *et al.*, 1999[b]). But in Jharkhand due to mono-cropping pattern, late transplantation was not affecting the crop rotation practice yet due to high variability in rainfall and poor irrigation facilities, the kharif crops are highly vulnerable to drought like situation or dry spells. Earlier due to non commercialization of agriculture in tribal dominated state, the low investment broadcasting method was traditionally used in Jharkhand and still in practice in few parts of the state.

STUDY AREA

The study area is whole Jharkhand state which lies between 21º 54' N to 25º 20' N latitude and 83º 22' E to 87º 58'E longitude (figure 1) and covers an area of 79,714 sq. km with the total population of 26.9 millions (Census of India, 2001). It was created as a ‘tribal state’ as it accounts for 28% of the states population (World Bank, 2004). The state is endowed with large mineral and forest resources. The state is situated in Chhotanagpur and Santhal Pargana plateau. Because of the undulating terrain in most parts of the state, 47% area (38 lakh hectares) is arable, 22.6% area is net sown and 8 % area is net irrigated in 2005. Hence one time cropping pattern is being followed in most parts of the state (Ministry of Agriculture, 2001).

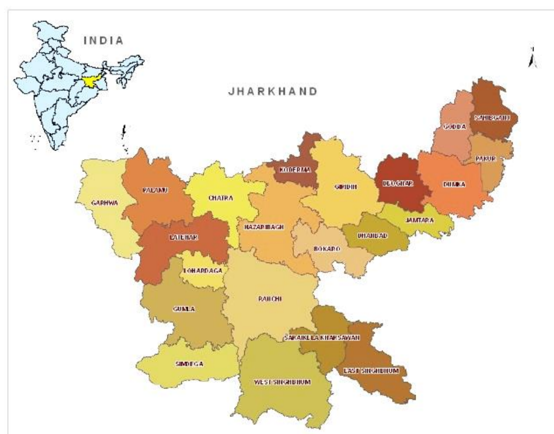

Figure 1. Study area

The major land covers are agricultural area (predominantly rice), forest, water bodies (river/ pond/ streams etc.) and urban. Agriculturally, the state is one of the most backward states in the country. The average yield of paddy in the state is around 9.6 quintals per hectare, which is half of the national average. The backwardness of agriculture in the state is contributed by poor water control strategy, largely characterized by erratic rainfall, coupled with low irrigation coverage in the undulating terrain of the state. The state receives 1386 mm of rainfall which however is very erratic and temporal, with 80 per cent of the rainfall taking place between the months of June to September. The present circumstances is indicating towards better management of agricultural land and regular monitoring of crops in the state.

MATERIALS AND METHODS

In the present study RADARSAT ScanSAR Narrow Beam (SCNB) data set were used to estimate rice acreage during kharif season in Jharkhand state. Three dates RADARSAT ScanSAR Narrow Beam (SCNB) data set (C band, HH-polarization and 31º- 46º incidence angles) were used. Two date satellite data acquired early in the season were used to assess the possible crop prospects based on puddling and transplanting activities. Three and four date data were used to estimate the acreage. A stratified random sampling approach was used to analyze sample segments and estimation of the rice acreage. Automated software – 'SARCROP' was developed for this purpose. RADARSAT data up to mid July as first date (7th July and 17th July 2008), up to mid August as second date (31st July and 10th August 2008) and up to early September as third date (24th August and 3rd September 2008) covering puddling/ transplanting to peak vegetative stages of kharif rice crop was used. The ground truth were carried out during kharif rice crop growing stage (viz, during puddling, transplantation, tillering, flowering stage). Kharif Rice coverage area and meteorological data collected from State Agriculture Department as well as State Agricultural Universities were used to validate the crop growth trend estimated based on digital analysis of RADARSAT data. The developed model was calibrated according to the nature of crop growing pattern in Jharkhand.

The RADARSAT ScanSAR is acquired in the form of coverage or scenes that are of 300 x 300 km area. The Jharkhand state is covered under 3 scenes i.e. 04, 22 and 23. Each of these scenes was acquired three times during June–September, matching the specific crop calendar of each of the areas. Image data from the CDs were downloaded using the CDSAR program of EASI/PACE. For ScanSAR data, flipping of data, speckle suppression; conversion to backscatter image and scaling back to 8 bit data format was taken care by the SCNLOAD.EAS programme. It creates the necessary 8-bit image channel of required image size. While downloading, east-west reversal of data for descending mode was carried out. All header parameters (geometric and radiometric) including satellite orbit information was loaded into the same image file. An enhanced Lee filter was used for speckle suppression. The downloading and processing

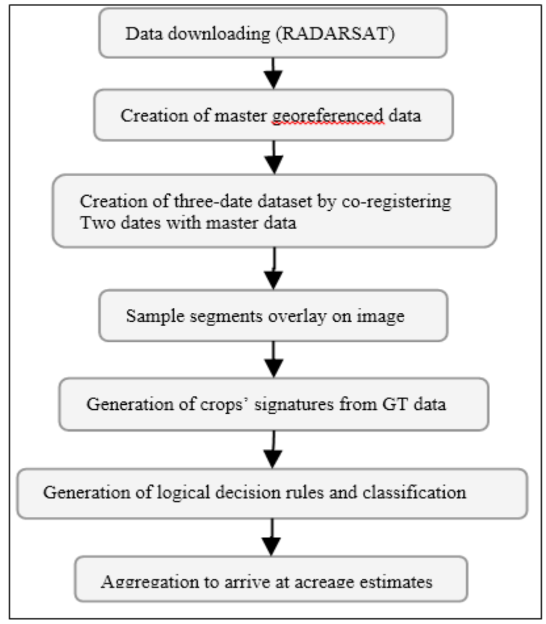

Figure 2. Methodology flow chart adopted to estimation rice acreage using RADARSAT SAR data

of data was carried out using Geomatica software.

From the orbit information contained in the header file of the full ScanSAR data, latitude / longitude values of first, middle and last pixels of each scan line of data were generated. These were used as header GCPs. The GCPs were edited and image-to-map and map-to-image equations are developed using second-order polynomial models (Figure 2). This image-to-map GCP segment and the fitting equations are used to georeference the image or to extract sample segments. In the sample segment approach, a georeferenced output image was not required as the image chips corresponding to the sample segments were extracted from the original image using the map-to-image transformation. The subsequent date data are co-registered to the first-date data, using an image-to-image registration procedure. A second-order transformation was used to create multi-date co-registered datasets using nearest neighbour resampling. Using standard procedure, the first date (D1) is assigned to red (R), second date (D2) to green (G) and third date (D3) to blue (B) to generate multi-date FCC calibrated georeferenced image.

The state was divided into 5 km x 5 km units aligned to the satellite pass (descending mode). All grids with more than 15% agricultural area were treated as the population. The population was then stratified based on various other criteria, often depending on crop proportion estimated from remote sensing data. Finally, 10-15% samples were randomly selected from each stratum. A database was prepared in a specific format, giving latitude and longitude information of each segment and its identification. In order to carry out the state-level classification and arrive at the acreage estimates, the district boundaries and sample segments was overlaid on the georectified image. The sample segments were classified with the help of model developed for the state. After the sample segment images were classified, calculation of crop proportion in each segment and finally crop acreage estimation were carried out for the state.

For classification of rice pixels, a three-date georectified dataset along with district and sample segment layer was used. Classification was carried out with a two-date dataset in order to arrive at first-level acreage forecast. Sample segment approach was used to arrive at paddy acreage estimation, which was then extrapolated to the entire state by simple random sampling method.

RESULTS AND DISCUSSION

Two date and three date ScanSAR data were processed to generate multi date calibrated georeferenced dataset. Based on the temporal behavior and the knowledge gathered while investigating SAR backscatter of rice crop, rice area was classified into different rice subclass areas *viz*., early, mid and late sown crop (table 1). The figure 3 (*a* and *b*) depicts the color combinations, which result from the signatures on the two dates and three dates respectively. The various shades indicate stages of transplantation *viz*., early, mid and late transplanted paddy. Based on these signatures, the pixels were classified as paddy and non-paddy area. The two date and three date data basically represents the crop growth status during the satellite data acquisition. The temporal variation of backscattering coefficient values, therefore, used for determining the crop phonological condition in comparative terms. In order to carry out classification, training sets are made for different features *viz*., water, settlements, fallows, forests and paddy (in various stages). The settlements, fallows, forests and water have similar backscatter values in all the dates. In case of paddy, the early, mid and late transplanted paddy was distinctly varying values in three dates.

Table – 1: The variation of DN values in Kharif Rice crop growing season

Color on the image	First Date	Second Date	Third Date	Classes
White	↑	↑	↑	Settlement, Fallows, Forest (with varying backscatter)
Black	↓	↓	↓	Water
Cyan	↓	↑	↑	Early-transplanted paddy
Magenta	↑	↓	↑	Mid-transplanted paddy
Yellow	↑	↑	↓	Late-transplanted paddy

↑ Represents increasing DN value.

↓ Represents decreasing DN value.

The kharif crop growth stages reflected on RADARSAT data were shown in the figure 4. The backscattering coefficient was stretched to 8-bit. The increasing trend of pixel values in very early and early transplantation stages reflects rice growing stages from puddling/ transplantation to tillering stage. While in case of mid transplantation stage, the higher pixel values during first date resemble the fallow land situation, which was under transplantation stage during second date (31st July and 10th August 2008) and tillering/ flowering stage during third date (24th August and 3rd September 2008) as observed through RADARSAT data. Whereas in case of late transplantation stage, the higher pixel values of first and second dates shows the current fallow situation of agricultural land, which decreased substantially in third date due to puddling/ transplantation stages of kharif rice crop.

Kharif Rice Acreage Estimation

The kharif rice acreage estimation was carried out using EASI/ PACE modeling in Geomatica software. Based on the specific stages of Kharif rice crop growth the rules were defined to classify the image data**.** The steps of the Kharif Rice Acreage Estimation are as follows:

1) Preliminary acreage estimation using two date dataset - For classification of rice pixels, a model was developed using Geomatica software the calculation of rice acreage is as follows:
   - Total no. of agricultural segments of Jharkhand = 2779
   - Average no of rice pixels in sample segments of Jharkhand (343) = 2000.72
   - Area of pixel (50 m x 50 m) = 0.25 Ha

   So total rice acreage area = 2779 x 2000.72 x 0.25 = 1390000.2 Ha i.e. 1.39 M. Ha.
2) Final acreage estimation using three date dataset - For classification of rice pixels using model using Geomatica software the calculation of rice acreage is as follows:
   - Total no. of agricultural segments of Jharkhand = 2779
   - Average no of rice pixels in sample segments of Jharkhand (343) = 8348.33
   - Area of pixel (25 m x 25 m) = 0.0625 Ha

So total rice acreage area = 2779 x 8348.33x 0.0625 = 1450000.57 Ha i.e. 1.45 M Ha.

The Kharif rice acreage estimation of Jharkhand for 2008 using two date data and three date data is 1.385 M ha and 1.45 million hectares respectively. In 2007, it was 1.03 million hectares and 1.44 million hectares respectively for two date and three date data. The final rice acreage of both the year was similar as the rainfall

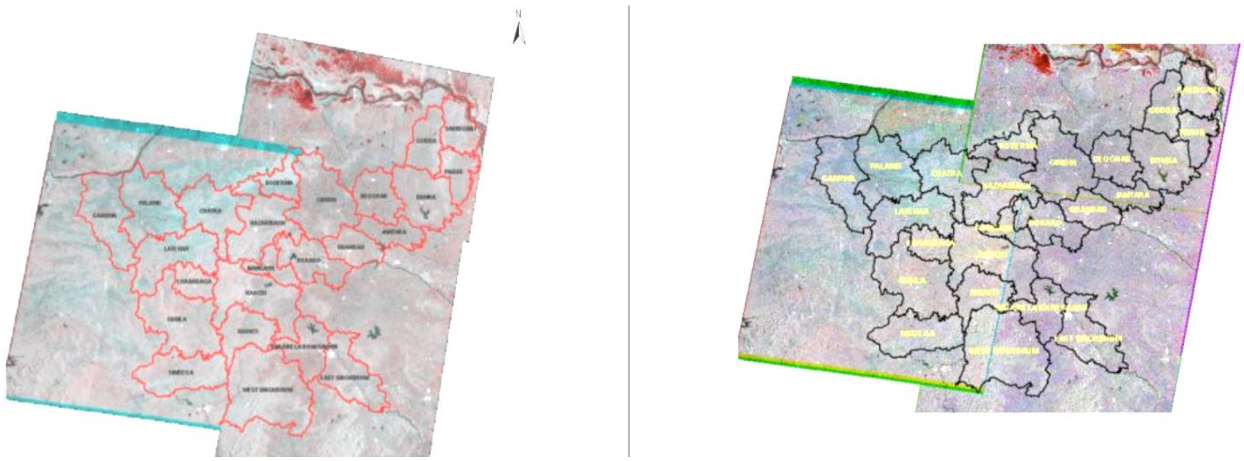

Figure 3: (a) Two date data, and (b) three date data of RADARSAT

pattern of both the year was almost same. The slight increase of rice acreage in three date data as compared to two date data was because of inclusion of some area in three date data under mid and late transplantation stage. This study showed that around 85% of the kharif rice transplantation was occurred in early and mid transplantation stage. Using this result, SAC Ahmedabad forecasted rice production (2008) for Jharkhand State, which is 2.13 million tons for 2008. Earlier in 2007, the estimated production was 2.43 million tons. The forecasted production of 2008 was less as compared to 2007 because of partial drought occurred in parts of Palamu, Garhwa and Latehar district in 2008. The kharif rice acreage estimation based on RADARSAT data (1.45 million hectares) had 90.23% accuracy when compared with the data of State Agriculture Department (Directorate of Agriculture 2008) (1.607 million hectares) for the year 2008. The reason of less rice acreage estimation through RADARSAT data may be attributed to limitation of coverage period (*i.e.*, 24 days repeativity) as well as time constraints for analysis of RADARSAT data during very late transplantation stage for the present study.

COMPARATIVE STUDY

The comparative study of rice acreage estimation, production using RADARSAT with State Agriculture Department, Govt. of Jharkhand (GoJ) were correlated (table 2), which exhibits that the RADARSAT based rice acreage estimation was highly correlated with the actual rive coverage (R^2=0.99) (Figure 5a), whereas the production estimation based on RADARSAT and actual production based on GoJ was less correlated (R^2=0.56) (Figure 5b). The productivity estimation by RADARSAT was limited, which can be attributed to the methodological limitation of using RADATSAT data for acreage estimation, in which data up to last week of August to first week of September (24th August and 3rd September in the year 2008) were used. This period in special reference to Jharkhand is under late/ very late transplantation period of rice due to erratic and deficient rain.

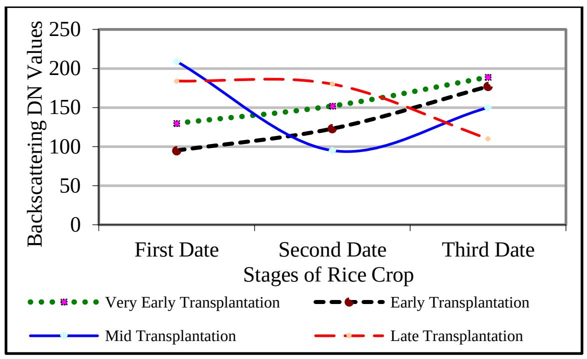

Figure 4: Temporal variation of Radar backscatter co-efficient of different land cover classes

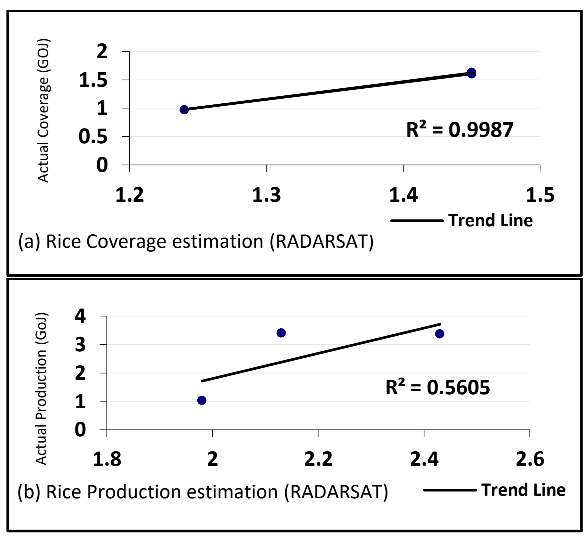

Fig 5: Correlation between the actual (Govt. of Jharkhand) and RADARSAT based estimation in (a) Rice Coverage, and (b) Rice Production

Table 2: Rice acreage and production details

Year	Rice Acreage (Million Ha)			Production (Million Tones)		
	RADARSAT (Final Forecast)	Govt. of Jharkhand	Accuracy	RADARSAT based Production Forecasting	Actual Rice Production-GOJ	Accuracy
2007	1.45	1.634	88.74	2.43	3.37	72.11
2008	1.45	1.607	90.23	2.13	3.4	62.65
2009	1.24	0.975	78.63	1.98	1.03	52.02

The accuracy of RADARSAT estimation of rice acreage and production when compared with Govt. of Jharkhand data, was found with decreasing in consecutive three years from 2007 to 2009. This may be attributed to crop damage due to typical drought stress in parts of Jharkhand. The year 2007 and 2008 was normal years, whereas 2009 was declared as '*typical drought year'*, where 11 districts were severely affected. This assessment was not observed and appropriately incorporated in RADARSAT based estimation due to limitation in data capturing in first week of September, whereas due to scantly rainfall, the crops were destroyed in major parts of the state.

CONCLUSIONS

This study revealed the advantage of RADARSAT data for kharif rice acreage estimation and production forecasting. The estimation done by State Agriculture Department through a traditional approach, was time consuming, whereas the analysis done using RADARSAT data was more reliable, comparatively accurate and less time consuming. The other crops having the similar growth trends as rice crop may also be considered as rice under RADARSAT analysis. Therefore extensive ground verification is essential for better accuracy. The average rainfall of Jharkhand state is more than that of national average but because of its erratic nature and highly undulating terrain (which leads to surface runoff), the rice coverage area was less as compared to other state. There are many challenges in providing the standing water for rice crops throughout the rice growing period in Jharkhand due to undulating topography and changing climatic conditions. The poor soil quality and soil depth in the regions also influencing the rice production and its productivity is. For enhancing rice coverage, there is a need of adoption of watershed management programme, so that most of the unutilized cultivatable land can be converted into paddy field along with maintaining the soil quality and soil moisture. The analysis of RADARSAT data also generates the spatial distribution of rice coverage in the state, which is helpful in local and state level agriculture management plans in the changing climatic scenario.

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