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Analysing the Impact of the Southwest Monsoon on *Kharif* Rice Acreage in the Raipur District Using Microwave Remote Sensing

Gowtham S. [a++*], Gopi Krishna Das [a#], Prashant Kawishwar [b†], Harithalekshmi V. [a++] and Deepak Saran [c++]

[a] *Department of Agrometeorology, IGKV, Raipur, 492012, Chhattisgarh, India.*
[b] *Chhattisgarh Council of Science and Technology, Raipur,492014, Chhattisgarh, India.*
[c] *Department of Genetics and Plant Breeding, IGKV, Raipur, 492012, Chhattisgarh, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study utilized Synthetic Aperture Radar (SAR) data from Sentinel-1 to estimate the *kharif* paddy acreage in the Raipur district. The unique capability of microwaves to penetrate clouds enabled the mapping of paddy fields even during the monsoon season. Supervised classification based on training samples was employed to delineate paddy fields. The results demonstrated that the estimated paddy area closely matched the reported area, with error percentages of 5.3% and

[++]*Research Scholar;*
[#]*Professor;*
[†]*Scientist E-1;*
**Corresponding author: E-mail: somasundharamgowtham7120@gmail.com, professionalagrigowtham@gmail.com;*

8.6% in 2017 and 2019, respectively. The analysis of data from 2011 to 2019 revealed a consistent decline in both paddy acreage and rainfall during that period. Furthermore, the block-level analysis indicated significant spatial variations, with the Arang blocks having the largest paddy cover and the Raipur block the least. Moreover, a strong correlation was observed between southwest monsoon rainfall and the *kharif* rice cultivation, with paddy acreage decreasing during SW monsoon deficit years. These findings shed light on the impact of monsoons on rice cultivation and can guide agricultural planning and water resource management strategies in the region.

Keywords: Synthetic aperture radar (SAR); kharif paddy acreage; monsoon season; supervised classification; sentinel-1.

1. INTRODUCTION

Rice is one of the most important staple crops in India, providing sustenance to millions and contributing significantly to the country's agricultural economy. The productivity and cultivation of rice are highly dependent on the monsoon rainfall, especially during the southwest monsoon season, which accounts for the majority of India's annual precipitation. Understanding the relationship between monsoon patterns and rice acreage is crucial for effective agricultural planning and sustainable resource management.

The southwest monsoon, which typically occurs from June to September, is a critical climatic event that replenishes soil moisture, refills reservoirs, and sustains agricultural activities across India. It brings the majority of the country's annual rainfall, contributing significantly to the growth and productivity of the *kharif* crops, including rice. The success of rice cultivation during the monsoon season is directly linked to the distribution and adequacy of rainfall across different regions.

Remote sensing technologies, including optical and microwave sensors, have proven valuable tools in studying various aspects of agriculture. Optical sensors in Landsat and Sentinel, provide high-resolution imagery for monitoring land cover changes and crop health assessments. On the other hand, microwave remote sensing, which operates at longer wavelengths, offers unique capabilities, such as penetrating clouds, measuring soil moisture, and providing data regardless of weather conditions [1]. This makes microwave remote sensing particularly suitable for assessing rice acreage during the monsoon season when cloud cover can hinder optical sensor observations.

In recent years, remote sensing technology, particularly microwave remote sensing, has emerged as a powerful tool for studying and monitoring various agricultural parameters, including crop acreage, growth stages, and moisture content. The unique capability of microwave remote sensing to provide continuous observations regardless of weather conditions has made it an invaluable asset in monitoring agricultural activities on a large scale [2,3].

While numerous studies have explored the relationship between monsoon rainfall and rice cultivation at regional or state levels, there is a lack of block-level analysis within specific districts. Understanding the spatial variability of rice acreage response to monsoon variability is vital for implementing location-specific agricultural strategies.

Therefore, the primary objective of this study is to utilize microwave remote sensing data to assess the impact of the southwest monsoon on rice acreage in different blocks of Raipur district. The study examines rice acreage variations over multiple monsoon seasons and explores the correlation between monsoon rainfall patterns and rice cultivation at the block level.

All weather crop monitoring will capture the periodic changes in the crop and help to action prior. Early intimation of area coverage will help to predict the yield and take action at the decision-making level. It also enhances the utility of services like crop insurance, plant protection, and precision farming activities on a larger scale. Vulnerable crop zones can be figured out earlier so precautions and measures can be carried out.

2. MATERIALS AND METHODS

2.1 Study Area

Raipur, the capital of Chhattisgarh, is situated in the central part of the state. It consists of four blocks: Arang, Abhanpur, Raipur, and Tilda, each displaying distinct land use patterns and agricultural practices. The region's elevation ranges from 244 to 409 meters above mean sea level (AMSL), covering an area of 2892 square kilometres. Raipur is a sub-humid region with an annual average of 1149 mm rainfall of which 1042 of the total rainfall was received during the southwest monsoon season. Which is 90% of the total rainfall [4].

The district is characterized by variations in topography, soil types, and land use patterns, which can influence the response of rice crops to monsoon variability. However, limited research has explored the impact of the southwest monsoon on rice acreage at the block level within the Raipur district, hindering the formulation of targeted strategies to enhance agricultural resilience.

2.2 Data Used

2.2.1 Meteorological data

India Meteorological Department's (IMD) gridded data of 0.25◦ x 0.25 ◦ was used for the rainfall analysis. These gridded data was weighted according to the area of the blocks and analysis was carried out.

2.2.2 Satellite data

Sentinel-1 is a dual-satellite Synthetic Aperture Radar (SAR) system, consisting of Sentinel-1A and Sentinel-1B, which provides continuous day and night all-weather imagery [5]. Launched under the Copernicus program by the European Space Agency (ESA) in 2014, it offers versatile polari metric capabilities. SAR employs linearly polarized waves that can be transmitted and received in horizontal (H) and vertical (V) orientations, resulting in four types of polarizations (HH, HV, VV, VH). Cross-polarization (VH, HV) has proven to be particularly sensitive to vegetated areas. This data was utilized for estimating paddy acreage. Detailed specifications of Sentinel-1A are provided in Table 1.

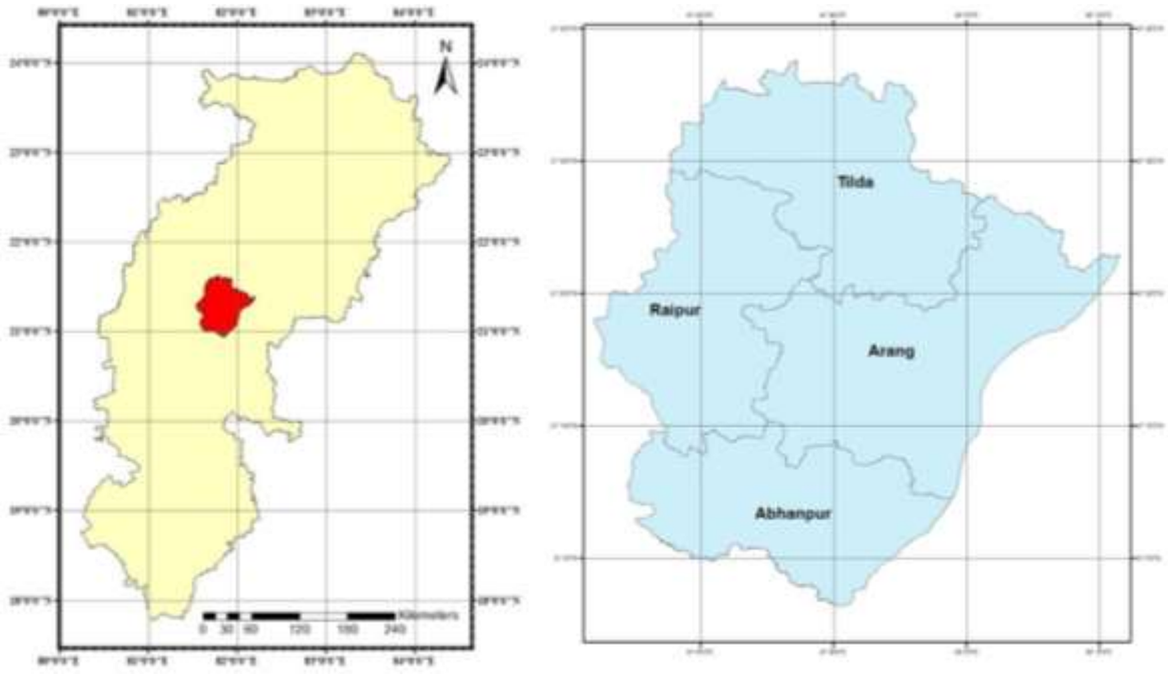

Fig. 1. Map of study area

Table 1. Specifications of sentinel-1A data

S. No	Attribute	Value
1.	Frequency/Wavelength	C- band (5.3 GHz)/ 5.6 cm
2.	Polarization	VH
3.	Mode	Interferometric Wide
4.	Product Type	Level-1, Ground Range Detected (GRD)
5.	Revisiting period	12 Days
6.	Resolution	10 m

Based on the availability of satellite data, the study focused on the years 2017 and 2019 for analysis. IMD Gridded Rainfall data with a spatial resolution of 0.25° x 0.25° for the years 2017 and 2019 were downloaded and block-wise rainfall was estimated using the weighted average method. District-level crop area data was gathered from the ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) crop data portal.

2.2.3 Meteorological drought

It is generally rainfall deficiency based on the level of deficiency from normal rainfall it is classified into mild, moderate, and severe.

2.2.4 Acquisition of SAR data using Google Earth Engine (GEE)

Google Earth Engine is a cloud-based platform that makes it easy to access high-performance computing resources for processing very large geospatial datasets. It is accessed and controlled through an Internet-accessible application programming interface (API) and an associated web-based interactive development environment (IDE) that enables rapid prototyping and visualization of results [6].

The primary advantage of Google Earth Engine (GEE) lies in its Application Programming Interface (API), which eliminates the need to download and pre-process Synthetic Aperture Radar (SAR) data, significantly reducing internet data consumption, memory space, time, and the requirement for specialized tools to format the data [7]. SAR data in GEE is readily accessible through its codes. After preparing the data sets, samples were trained using the backscatter values of the data. Puddled rice fields are distinguishable by the presence of water stagnation, evident until the rice canopy develops and covers it. Water bodies exhibit very low decibel values in backscatter, making rice fields with consistently low decibel values likely candidates for water stagnation. As per the Raipur district majority of the cultivable rice fields were under low-land cultivation. So, this particular method of rice field mapping is suitable for the targeted area. Sentinel-2 optical images from September were employed to validate these findings, revealing agricultural practices or land-use patterns to further confirm the presence of agricultural activities in the identified areas. GEE facilitated direct access to Sentinel-1A data for analysis of rice cultivation in Chhattisgarh. The satellite data for the study was available for the year of 2017 and 2019 only. Multiple image dates were utilized to estimate the area due to varying sowing or transplanting dates influenced by monsoon onset and irrigation availability (Table 2). It was unable to take same date for the given years because of the non availability of satellite data.

Rice fields were classified using the backscatter coefficient [3]. The lowest values were observed during high flooding [8]. Optimal backscatter coefficients for flooded rice fields ranged from -35 dB to -25 dB [9]. Training samples with the lowest backscatter values from selected dates were used to create rice class signatures. Classification of rice was performed based on these signatures.

The agriculture shape file was used to delineate the agriculture area alone. So, the classification was carried out only in the agricultural land. This approach minimizes erroneous calculations of barren land and forest area, as water stagnation during monsoon months in open forest cover and barren surfaces can mimic puddle paddy fields, resulting in their inadvertent inclusion in the classification.

To check the variation between the estimated value and the actual value percent error method was used.

$$\textbf{Percent Error} = \frac{|\,Estimated\ Value - Actual\ Value\,|}{Actual\ Value} * \mathbf{100}$$

Drought analyses were made and correlations between drought year and area were made using correlation studies.

Table 2. Date of multi-temporal sentinel-1A data taken for this study

Dates	2017	2019
D1	June 10	June 12
D2	June 22	June 24
D3	July 04	July 30
D4	July 16	August 11

2.3 Correlation Analysis

The southwest monsoon rainfall amount of 2017 and 2019 has been taken and it is compared with the *kharif* rice acreage of the specified years. 2017 was a rainfall deficit year and many parts of the state have experienced meteorological during that year. A correlation analysis was performed to investigate the relationship between monsoon rainfall patterns and rice acreage variations at the block level.

3. RESULTS AND DISCUSSION

As per the data collected from ICRISAT, in 2017, Raipur district had 1,56,860 ha of the *kharif* paddy, which increased to 1,72,810 ha in 2019. The estimated area using SAR data was 1,48,880 ha and 1,63,180 ha, with reductions of 7,980 ha and 9,630 ha, respectively (Fig. 2).

The estimation of the *Kharif* paddy area at the district level for 2017 and 2019 showed percent errors of 8.3 and 5.6, respectively, both within the acceptable limit of 20%.

During the South West (SW) monsoon season in 2017 and 2019, the total rainfall recorded was 778 mm and 1107 mm, respectively. The mean seasonal rainfall was 1042 mm, while the annual average was 1149 mm. The SW monsoon rainfall trend is depicted in Fig. 3. In 2017, there was a seasonal deficit of 264 mm and an annual deficit of 303 mm compared to the normal average. These deficits account for *25%* and *26%* of the seasonal and annual totals, respectively.

Based on IMD criteria, when rainfall deficiency exceeds 26%, it indicates a moderate meteorological drought. Thus, 2017 qualifies as a moderate meteorological drought year. Table 3 demonstrates a significant correlation between SW rainfall and *Kharif* paddy acreage.

The correlation between SW rainfall and *Kharif* paddy acreage further underscores the positive influence of monsoon patterns on rice cultivation. The study's use of satellite data and GIS tools exemplifies the potential for remote sensing technologies in agricultural monitoring, especially during challenging monsoon seasons [3,5].

Satellite data accurately predicted the area of rice and various crops during kharif and rabi seasons which includes rice, wheat, cotton, maize, pigeon pea and vegetables Ashmitha et al., [10], Hudait et al., [11] and Parmer et al., [12], closely resembling the actual measurements. Though block-level data was unavailable, GIS

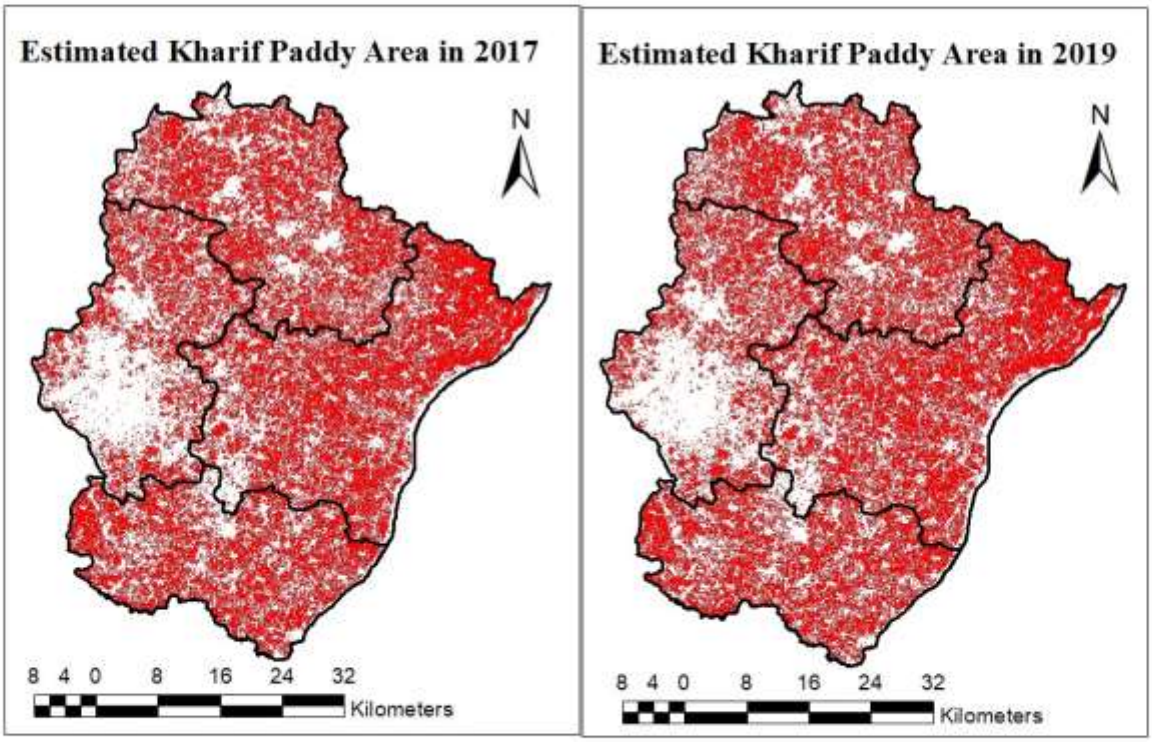

Fig. 2. Estimated *Kharif* Paddy Area in 2017 and 2019

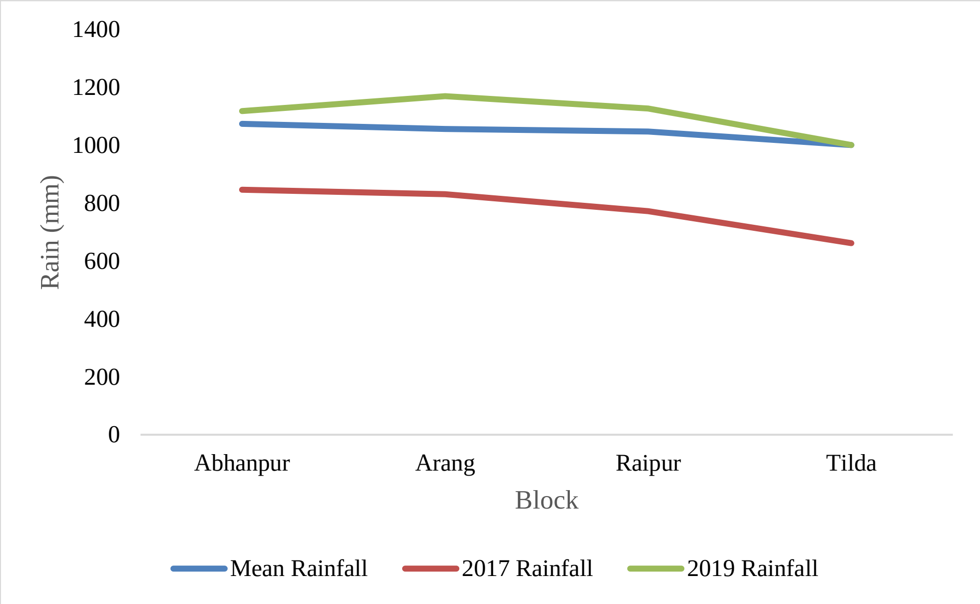

Fig. 3. South West Monsoon trends in the blocks

Table 3. Correlation report

S. No	Correlation between	Correlation Coefficient
1.	Area and SW rainfall	0.7
2.	Area and annual rainfall	0.7

Table 4. Block-level estimated area and rainfall

Blocks	2017		2019	
	SW rainfall	Area (ha)	SW rainfall	Area (ha)
Abhanpur	846	33233.9	1118	36600.4
Arang	830	53948.7	1169	57232.7
Raipur	773	23121.3	1127	26180.1
Tilda	661	38580.7	1015	43162.5

spatial tools were employed to derive block-level data from district data, serving as a proxy for real-time information. This is a common approach in remote sensing and spatial analysis studies [13-17]. The block-level data is presented in Table 4.

Among the four blocks, Arang has the largest area, followed by Tilda and Abhanpur, while Raipur exhibits fewer paddy fields due to extensive urban settlements. The observed spatial variations in paddy acreage among different blocks provide valuable insights for targeted agricultural planning and water resource management strategies. In 2017, all blocks in the Raipur experienced a moderate meteorological drought (*NLMT Report*). Despite a long-term increasing trend in the *Kharif* rice area [18], the drought year led to a significant reduction in rice acreage in Abhanpur (9.1%), Arang (5.7%), Raipur (11.6%) and Tilda (10.6%). Overall, the findings suggest that SW monsoon patterns play a critical role in shaping rice acreage, and the use of microwave remote sensing technology holds promise for accurate monitoring and assessment of agricultural activities during monsoon seasons.

4. CONCLUSION

Exploring the impact of the southwest monsoon on rice acreage in different blocks of Raipur district using microwave remote sensing is a crucial endeavour to improve agricultural practices and resource management in the region. The results demonstrated the effectiveness of SAR data in estimating *kharif* paddy acreage, with a close match to the actual reported area and low error percentages. The block-level analysis highlighted spatial variations, with Arang having the largest paddy cover and Raipur exhibiting the least. Correlation studies indicated a strong relationship between southwest monsoon rainfall and the *kharif* rice cultivation, with a notable 8% decline in paddy acreage with a 25% deficit of SW monsoon during 2017. These findings shed light on the impact of monsoons on rice cultivation and can guide agricultural planning and water resource management strategies in the region. The use of microwave remote sensing for such studies opens new avenues for precise and reliable monitoring of agricultural activities, especially during the monsoon season, and can contribute significantly to sustainable agricultural practices and food security in the region. Further research could extend the analysis to include more years and investigate other factors influencing rice acreage, providing a comprehensive understanding of the complex interplay between monsoons and rice cultivation in the Raipur district

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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