

## Estimation of biophysical parameters of rice using Sentinel-1A SAR data in Udham Singh Nagar (Uttarakhand)

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**सार** – उधम सिंह नगर उत्तराखंड राज्य का प्रमुख चावल उत्पादक क्षेत्र है, और तराई क्षेत्र में पड़ता है। यूरोपीय संघ के कॉपरनिकस कार्यक्रम के हिस्से के रूप में 2014 में लॉन्च किया गया सेंटिनल -1 ए उपग्रह सिंथेटिक एपर्चर रडार (एसएआर) डेटा प्रदान करता है। एसएआर छवियां मौसम की स्थिति और सौर रोशनी से स्वतंत्र होती हैं और पृथ्वी की विभिन्न विशेषताओं के अवलोकन की अनुमति देती हैं। दोहरी ध्रुवीकृत (वीएच और वीवी) प्रहरी 1ए डेटा का उपयोग चावल के जैव-भौतिकीय मापदंडों का अनुमान लगाने के लिए किया गया है जो लीफ एरिया इंडेक्स (एलएआई), प्रकाश संश्लेषक रूप से सक्रिय विकिरण का अंश (एफपीएआर), फसल की ऊंचाई, बायोमास और जल सामग्री हैं। प्रहरी 1A का पुनरीक्षण समय 12 दिन है और 20m का उच्च रिज़ॉल्यूशन है। SAR डेटा को यूरोपीय अंतरिक्ष एजेंसी के सेंटिनल एप्लिकेशन प्लेटफॉर्म (SNAP) को लागू करके पूर्व-संसाधित किया गया था। चावल की फसल के विभिन्न जैव-भौतिकीय मापदंडों (लीफ एरिया इंडेक्स (एलएआई), प्रकाश संश्लेषक रूप से सक्रिय विकिरण का अंश (एफपीएआर), फसल की ऊंचाई, बायोमास और जल सामग्री) के लिए एसएआर मानचित्र ईएनवीआई- 4.8 में विकसित किए गए थे। सेंटिनल -1 ए बैकस्केटरिंग गुणांक  $\sigma_{0VV}$ ,  $\sigma_{0VH}$ , और  $(\sigma_{0VV} / \sigma_{0VH})$  के बीच संबंध का विश्लेषण किया गया था, इसके लिए सेंटिनल -1 ए के बहुकालिक डेटा को जून 2017 से सितंबर 2017 तक उधम सिंह नगर, उत्तराखंड में लिया गया था। प्रतिगमन मॉडल बायोफिजिकल मापदंडों और बैकस्केटरिंग गुणांक  $(\sigma_{0VV} / \sigma_{0VH})$  के अनुपात के बीच विकसित किए गए थे। लीफ एरिया इंडेक्स (एलएआई), प्रकाश संश्लेषक रूप से सक्रिय विकिरण का अंश (एफपीएआर), फसल की ऊंचाई, बायोमास और जल सामग्री के निर्धारण के गुणांक का मूल्य क्रमशः 0.53, 0.47, 0.50, 0.63, 0.34 पाया गया जो दर्शाता है कि ये बायोफिजिकल पैरामीटर हैं प्रत्यारोपण, जुताई और शीर्ष से सभी विकास चरणों में बैकस्केटरिंग गुणांक  $(\sigma_{0VV} / \sigma_{0VH})$  के अनुपात के साथ महत्वपूर्ण, लगातार और सकारात्मक रूप से सहसंबद्ध। प्राप्त परिणामों के आधार पर यह निष्कर्ष निकाला जा सकता है कि प्रहरी-1ए एसएआर डेटा में चावल की फसल के जैव-भौतिकीय मापदंडों के आकलन की काफी संभावनाएं हैं।

**ABSTRACT.** Udham Singh Nagar is the major rice producing area of Uttarakhand state, and falls in Tarai region. Sentinel-1A satellite launched in 2014 as part of the European Union's Copernicus program provides Synthetic Aperture Radar (SAR) data. SAR images are independent of weather conditions and solar illumination and allow observations of different features of earth. The dual polarized (VH and VV) sentinel 1A data has been used to estimate the rice biophysical parameters which are Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (fPAR), Crop Height, Biomass and Water Content. The revisit time of Sentinel 1A is 12 days and a higher resolution of 20m. SAR data were pre-processed by applying European Space Agency's Sentinel Application Platform (SNAP). The SAR maps for various biophysical parameters (Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (fPAR), Crop Height, Biomass and Water Content) of rice crop were developed in ENVI- 4.8. The relationship between Sentinel-1A backscattering coefficients  $\sigma_{0VV}$ ,  $\sigma_{0VH}$  and  $(\sigma_{0VV}/\sigma_{0VH})$  were analyzed, for this multitemporal data of Sentinel-1A were taken from June 2017 to September 2017 over Udham Singh Nagar, Uttarakhand. The regression models were developed between biophysical parameters and ratio of backscattering coefficients  $(\sigma_{0VV}/\sigma_{0VH})$ . The value of coefficient of determination for Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (fPAR), Crop Height, Biomass and Water Content were found as 0.53, 0.47, 0.50, 0.63, 0.34 respectively which exhibit that these biophysical parameters are significantly, consistently and positively correlated with the ratio of backscattering coefficients  $(\sigma_{0VV}/\sigma_{0VH})$  throughout all growth stages from transplanting, tillering and heading. On the basis of results obtained it can be concluded that Sentinel-1A SAR data has great potential for estimation of biophysical parameters of rice crop.

**Key words** – Biomass, Crop height, fPAR, LAI, SAR, Sentinel-1A, Water content.

## 1. Introduction

Rice is not only the staple food for more than 50% of the world's population but it is also one of the most important agricultural crops (FAO, 2002). Rice is mainly grown in the *kharif* season and accounts for more than 54 percent of the total area under cereals in Uttarakhand state. The annual production of rice in the state is around 5.5 lakh tonnes from an area of about 2.80 lakh hectares. Rice is grown in all the 13 districts of the state, but the maximum area (33%) is under Udham Singh Nagar district which produces about 48% of the total rice produced annually in the state. (Mani *et al.*, 2014).

For planning and monitoring purposes, there is a need of up-to-date information on the area which comes under rice cultivation and any changes in the cultivated area is very essential for national policy decision-makers and also for international trade organizations. Synthetic Aperture Radar (SAR) sensors have a high potential for different types of agricultural operations, because of their capability of all-weather observation.

Sigma naught ( $\sigma^{\circ}$ ) exhibited by the crop is the unique temporal signature of the backscatter coefficient derived from SAR data which has an ability to detect rice systems. In nutshell, low frequencies like L and C band are able to penetrate deeper into the rice plant while high frequencies (X-band) interact with water content present in the grain and grain weight shows sufficiently a dual-peak signal in ( $\sigma^{\circ}$ ) during the rice season (Inoue *et al.*, 2002, Suga and Konishi, 2008, Kim *et al.*, 2009 and Oh *et al.*, 2009). X-, Ka-, Ku-bands are the short wavelengths at large incident angles, which are highly sensitive and enough to detect small rice seedlings which are just transplanted. The correlation between backscatter coefficient ( $\sigma^{\circ}$ ) and biophysical parameters of rice shows that low frequencies are strongly related to total fresh weight, leaf area index (LAI) and plant height than other parameters (Kim *et al.*, 2009). Backscatter coefficient ( $\sigma^{\circ}$ ) from X-band is weakly correlated with LAI and it is strongly correlated with biomass of the panicle indicating the suitability for a direct assessment of rice production (Inoue and Sakaiya, 2013 and Inoue *et al.*, 2014).

The main aim of this paper is to authenticate the potential of retrieving rice bio-physical parameters using Sentinel-1A SAR data. LAI, fPAR, plant height, biomass, and water content of rice crop were calculated over the test sites in Udham Singh Nagar. Three Sentinel-1A images were obtained during transplanting, tillering and heading stage of rice. The backscatter values of  $\sigma_{0VV}$ ,  $\sigma_{0VH}$  and ( $\sigma_{0VV}/\sigma_{0VH}$ ) acquired from Sentinel-1A was used to analyze the rice biophysical with the help of that regression models.

## 2. Materials and methods

The study was carried out at five sites out of which three were in the campus of G. B. Pant University of Agriculture and Technology, Pantnagar and two were in Sainik farm Udham Singh Nagar. This study was carried out in the *kharif* season of 2017. Geographically, Pantnagar is located at 29.0222° N latitude and 79.4908° E longitude and the elevation of this place from mean sea level is around 344 meter.

This region experiences all seasons which are summer, monsoon, winter. Rice is the main *kharif* crop grown in the monsoon season. Rice crop (*Oryza sativa*) is grown as a *kharif* crop in Udham Singh Nagar and it is sown in the month of June - July and harvested in the month of September - October. The duration of rice crop is almost 90-120 days and it is divided in 3 stages namely vegetative phase, reproductive phase and ripening phase.

The various biophysical parameters LAI, fPAR, crop height, biomass and water content were measured continuously at the time of vegetative phase, reproductive phase and ripening phase over five sites as mentioned in (Table 1). The locations of all the plots were marked with the help of Global Positioning System (GPS) for the data collection. The LAI and fPAR were measured with the help of LP-80 ceptometer.

Three fine dual polarized (GRD mode) Sentinel-1A SAR images with following characteristics as shown in (Table 2) were acquired on July 25, 26 August 18, 19 and Sep 11, 12 in 2017 with a 12-day repeat cycle as mentioned in (Table 3), however two images were taken on consecutive dates from July to September because whole area of Udham Singh Nagar couldn't be captured in a single scene, it could be only achieved by applying mosaicking on two different scenes. One image was taken on June 24 and 25, 2017 so as to depict zero bio-mass period.

Sentinel's Application Platform (SNAP) is a general platform to carry out preprocessing operations on Sentinel 1A data (ESA, 2017b). This software was used to convert SAR data into backscatter values, *i.e.*, sigma naught ( $\sigma_0$ ) values. The pre-processing includes calibration of SAR data followed by thermal noise removal with mosaicking. Thereafter, resampling was done at  $10 \times 10$  m<sup>2</sup> spatial resolution and multilook parameterization was done for both VV and VH polarization images. The effect of speckle which is an attribute of radar data that can manipulate the quality of radar images was balanced with the help of Refined Lee low-pass filter with a  $5 \times 5$  kernel that preserves the feature of edges by averaging the images (Wang, Ge, & Li, 2012). After getting the

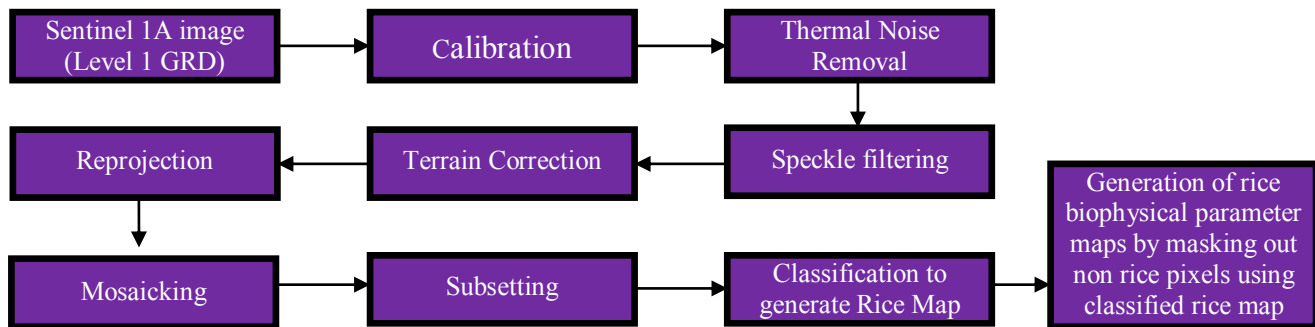


Fig. 1. Methodology for Pre-processing and generation of map using SAR data

TABLE 1

Biophysical Parameters with Backscatter Coefficient of SAR

Date	Place	$\sigma_{0VV}(\text{db})$	$\sigma_{0VH}(\text{db})$	$\sigma_{0VV}/\sigma_{0VH}$	LAI ( $\text{m}^2/\text{m}^2$ )	fPAR	Crop Height (cm)	Biomass ( $\text{g}/\text{m}^2$ )	WC (%)
25 Jul 2017	Sainik farm1	-8.54	-19.68	0.44	0.55	0.37	48.8	70.63	84.9
	Sainik farm2	-10.3	-15.74	0.65	1.51	0.72	62.9	258.33	72.1
	PCP	-9.14	-17.50	0.58	0.18	0.15	35.4	17.50	82.1
	Beni Field	-9.44	-16.52	0.64	3.19	0.93	77.3	390.00	75.0
	Near fisheries	-9.78	-17.12	0.57	2.09	0.82	61	258.33	78.5
17 Aug 2017	Sainik farm1	-11.11	-14.72	0.75	2.16	0.83	78	417.50	67.4
	Sainik farm2	-12.7	-15.44	0.82	3.18	0.90	81.7	1660.00	64.4
	PCP	-8.76	-14.94	0.58	1.48	0.74	72.5	162.50	73.9
	Beni Field	-10.6	-14.66	0.71	4.75	0.61	110.4	1150.00	74.1
	Near fisheries	-12.78	-16.14	0.79	3.63	0.96	81.6	790.00	88.8
12 Sep 2017	Sainik farm1	-11.32	-14.60	0.77	3.47	0.92	91.2	684.00	73.2
	Sainik farm2	-12.26	-14.72	0.82	3.55	0.90	102.4	2512.50	63.2
	PCP	-11.48	-16.10	0.71	3.35	0.88	99.2	1010.00	67.7
	Beni Field	-10.26	-15.24	0.72	4.75	0.96	123.4	2580.00	63.5
	Near fisheries	-11.96	-15.04	0.80	4.16	0.94	95	1925.00	55.9

\* $\sigma_{0VV}$  (db)- Backscatter Coefficient with vertical-vertical polarization

\*  $\sigma_{0VH}$  (db)- Backscatter Coefficient with vertical-horizontal polarization

\*LAI- Leaf Area Index; \* fPAR- Fraction of Photosynthetically Active Radiation

\*WC- Water Content

TABLE 2

Characteristics of Sentinel-1A Data (ESA, 2017a)

Parameters	Characteristics
Polarization	Dual (VV, VH)
Frequency	5.404 GHz
Wavelength	18 cm
Spatial Resolution (250 km swath)	$5 \times 20$ meters
Incidence Angle Range	$29.1^\circ$ to $46.0^\circ$
Pass	Descending

backscattered values ( $\sigma_0$ ) the data was transferred to ENVI-4.8 for sub setting, classification of images for generating rice map of Udham Singh Nagar. The developed rice map was used to mask out the non rice pixels so as to develop the maps of different biophysical parameters for rice crop. The methodology is shown in (Fig. 1).

### 3. Result and discussion

Sentinel-1A SAR backscatter ( $\sigma_0$ ) and its relationship with different growth stages of rice are shown in (Fig. 2). The backscatter values of the rice field during

**TABLE 3**  
Sentinel-1A Images Used in the Present Investigation

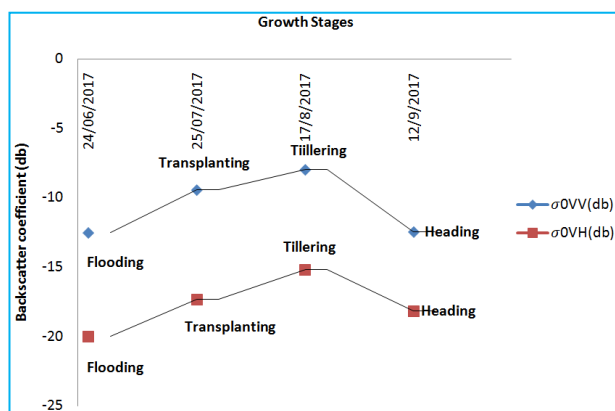
S. No.	Date of satellite pass	File specification	Polarization	Track	Orbit
1.	25 Jul 2017	S1A_IW_GRDH_1SDV_20170725T123830_20170725T123855_017628_01D810_8817	VV	VH	56 17628
2.	26 Jul 2017	S1A_IW_GRDH_1SDV_20170726T004330_20170726T004355_017635_01D848_43E6	VV	VH	63 17635
3.	18 Aug 2017	S1A_IW_GRDH_1SDV_20170818T123857_20170818T123922_017978_01E2B2_A309	VV	VH	56 17978
4.	19 Aug 2017	S1A_IW_GRDH_1SDV_20170819T004331_20170819T004356_017985_01E2EB_7024	VV	VH	63 17985
5.	11 Sep 2017	S1A_IW_GRDH_1SDV_20170911T123833_20170911T123858_018328_01ED70_333B	VV	VH	56 18328
6.	12 Sep 2017	S1A_IW_GRDH_1SDV_20170912T004332_20170912T004357_018335_01EDA9_810D	VV	VH	63 18335

\* IW- Interferometric Wide Swath

**TABLE 4**  
Pearson correlation coefficient between rice biophysical parameters and  $\sigma^0$  (July)

Polarization	LAI	fPAR	Crop height(cm)	Biomass	Water Content
$\sigma^0$ VV(db)	-0.193	-0.236	0.026	-0.175	-0.198
$\sigma^0$ VH(db)	0.009	0.000	-0.131	-0.028	-0.140
$\sigma^0$ VV/ $\sigma^0$ VH(db)	0.351*	0.441**	0.135	0.307	0.205

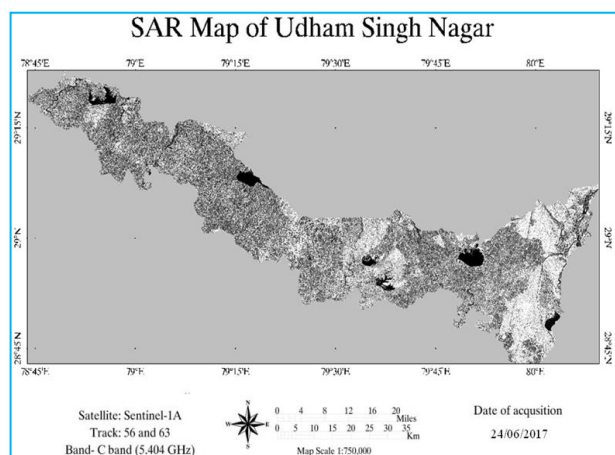
\*\*p<0.01, \*p<0.05, n=30



**Fig. 2.** Sentinel-1A SAR backscatter ( $\sigma^0$ ) response with growth stages of rice

zero bio-mass periods (June) were lying in the range of -12db for  $\sigma^0$ VV and -20db for  $\sigma^0$ VH due to flooding conditions in rice fields. The backscatter values for zero bio-mass period were derived from Sentinel 1-A SAR image for the month of June as shown in (Fig. 3).

The multi-temporal Sentinel-1A SAR backscatter ( $\sigma^0$ ) data with polarization VV and VH and their ratio was utilized on 30 samples from 5 testing sites (6 samples  $\times$  5 sites = 30 samples) which were used to estimate the relationship between biophysical parameters of rice and



**Fig. 3.** Sentinel-1A SAR image for zero bio-mass period (June)

Sentinel-1A SAR backscatter ( $\sigma^0$ ). The biophysical parameters which were taken into account were LAI, fPAR, Crop height, Biomass and water content. The relationship of biophysical parameters with Sentinel-1A SAR backscatters ( $\sigma^0$ ) and their ratio is correlated at different growth stages using Pearson correlation coefficient. It was noticed that with use of Pearson correlation coefficient at different growth stages the response of each polarization was different with rice biophysical parameters. Table 4 shows that from

TABLE 5

Pearson correlation coefficient between rice biophysical parameters and  $\sigma_0$  (August)

Polarization	LAI	fPAR	Crop height(cm)	Biomass	Water Content
$\sigma_{0VV}$ (db)	-0.357**	-0.447**	-0.002	0.205	-0.155
$\sigma_{0VH}$ (db)	-0.348*	-0.337*	0.106	0.089	-0.087
$\sigma_{0VV}/\sigma_{0VH}$ (db)	0.411**	0.475**	0.150	0.319	0.117

\*\*p&lt;0.01, \*p&lt;0.05, n=30

TABLE 6

Pearson correlation coefficient between rice biophysical parameters and  $\sigma_0$  (September)

Polarization	LAI	fPAR	Crop height(cm)	Biomass	Water Content
$\sigma_{0VV}$ (db)	-0.521*	-0.039	-0.105	0.256	0.041
$\sigma_{0VH}$ (db)	-0.544**	0.068	0.004	0.215	-0.107
$\sigma_{0VV}/\sigma_{0VH}$ (db)	0.578**	0.147	0.198	0.322	-0.227

\*\*p&lt;0.01, \*p&lt;0.05, n=30

TABLE 7

Pearson correlation coefficient between rice biophysical parameters and  $\sigma_0$  drawn from Sentinel-1A involving all 3 growth stages of rice

Polarization	LAI	fPAR	Crop height(cm)	Biomass	Water Content
$\sigma_{0VV}$ (db)	-0.619**	-0.625**	-0.523	-0.603	-0.637
$\sigma_{0VH}$ (db)	0.638**	0.612**	0.676	0.505	0.416
$\sigma_{0VV}/\sigma_{0VH}$ (db)	0.735**	0.690**	0.697	0.692	-0.586

transplanting to tillering (July) only LAI and fPAR were correlated progressively with ratio of backscatter  $\sigma_{0VV}/\sigma_{0VH}$  (db). The scattering from the rice canopy in between these two stages was limited because of the fact that water covers the field during these stages and influences the relation between backscatter values and rice biophysical parameters.

From tillering to heading stage during August all the biophysical parameters exhibited a strong correlation with the ratio of  $\sigma_{0VV}/\sigma_{0VH}$  (db) especially LAI and fPAR as shown in (Table 5). The strong correlation between ratio of backscatter values shows that the growth of rice progresses well.

In the month of September, from heading to maturity only LAI shows a promising relationship as shown in (Table 6) it may be due to the fact that when rice crop approaches its maturity from heading stage then there are vigorous changes occur in leaves, stem and panicle due to

which LAI responded well as compare to other parameters.

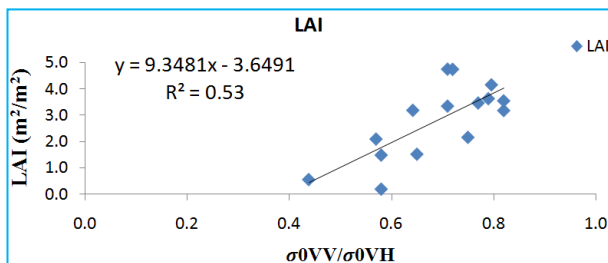
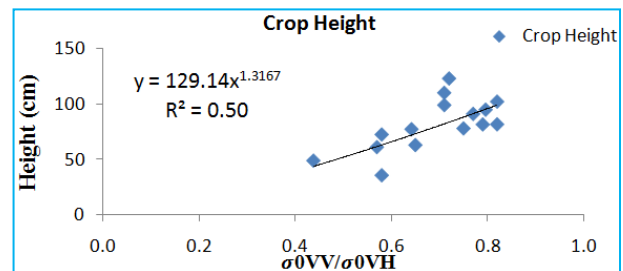
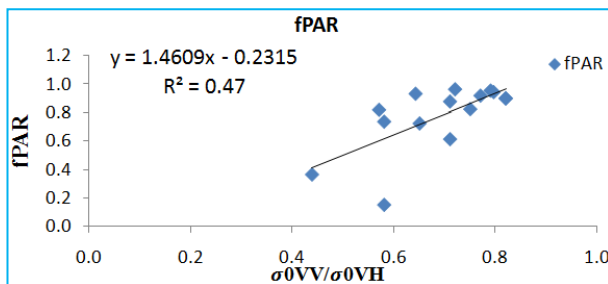
The Pearson correlation coefficients was drawn between  $\sigma_{0VV}$ ,  $\sigma_{0VH}$ , and ( $\sigma_{0VV}/\sigma_{0VH}$ ) ratio obtained from Sentinel-1A SAR image and rice biophysical parameters, *i.e.*, LAI, FPAR, Crop height, Biomass and water content for all three stages are shown in (Table 7).

It is clear from (Table 7) that the Pearson correlation coefficients obtained for  $\sigma_{0VV}$  (db) and  $\sigma_{0VH}$  (db) backscatter values are relatively weak as compare to ratio of  $\sigma_0$  (VV/VH) and their relationship with rice biophysical parameters. The most effective relationship that was found is relationship between ratio of  $\sigma_0$  (VV/VH) and biophysical parameters (except water content). The reason behind this when we use two bands combination (VV/VH polarized backscattered coefficients) the interaction of both bands is incorporated in one index (ratio).

TABLE 8

## Univariate statistical models for deriving different biophysical parameters

Biophysical Parameters	Developed Equation	R <sup>2</sup>
Leaf Area Index (LAI)	$(LAI) = 9.3481 * (\sigma 0VV / \sigma 0VH) - 3.6491$	0.53
Fraction of Absorbed Photosynthetically Active Radiation (fPAR)	$(fPAR) = 1.4609 * (\sigma 0VV / \sigma 0VH) - 0.2315$	0.47
Crop Height	$Crop\ Height = 129.14 * (\sigma 0VV / \sigma 0VH)^{1.3167}$	0.50
Biomass	$Biomass = 5695.2 * (\sigma 0VV / \sigma 0VH)^{6.3322}$	0.63
Water content (WC)	$WC = -47.159 * (\sigma 0VV / \sigma 0VH) + 104.85$	0.34

Fig. 4. LAI and  $\sigma 0VV/\sigma 0VH$ Fig. 6. Crop Height and  $\sigma 0VV/\sigma 0VH$ Fig. 5. fPAR and  $\sigma 0VV/\sigma 0VH$ 

Canopy water content was not significantly and consistently correlated with the ratio of  $\sigma 0VV$  (db) and  $\sigma 0VH$  (db) because water content status cannot be directly detected by Sentinel-1A in flooded irrigation condition. This problem could be overcome by removing the effect of standing water in field. However, this can be done with implementation of multi algorithm including visual interpretation, image texture analysis, edge detection analysis, histogram thresholding integrated approach etc. Among all the methods, thresholding method is very effective and efficient for flood mapping method (Schumann *et al.*, 2009).

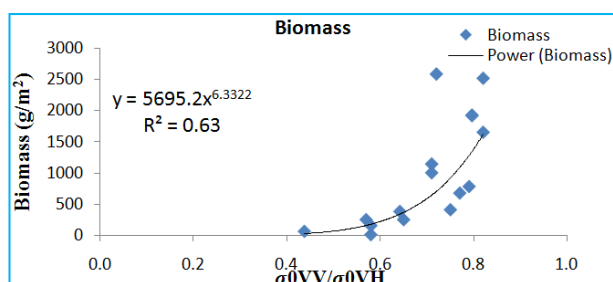
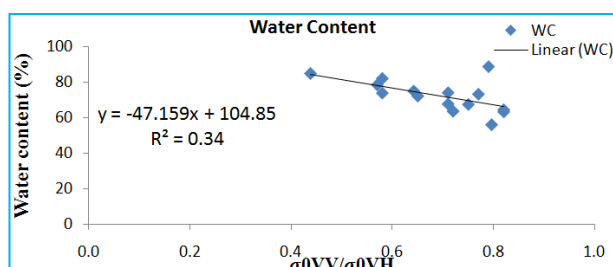
Simple univariate statistical models were developed in excel by creating scatter plot between ratio of backscatter coefficient ( $\sigma 0VV/\sigma 0VH$ ) and crop biophysical parameters of rice (LAI, fPAR, Crop height, Biomass and Water content). The scatter plots show that

there is consistently a good relationship between biophysical parameters and ratio of polarized backscattered radiation at all growth stages transplanting, tillering and heading. The resultant univariate models for different biophysical parameters are shown in (Table 8).

The scatter plot developed between the LAI and backscatter ratio ( $\sigma 0VV/\sigma 0VH$ ) showed a good agreement as evident from high value (0.53) of coefficient of determination ( $R^2$ ). The scatter plot shows that with increasing LAI the value of ratio of backscatter coefficient ( $\sigma 0VV/\sigma 0VH$ ) is also increasing (Fig. 4).

Similarly the fPAR is correlated with the backscatter values, which also showed a direct and consistent relation with the ratio of backscatter coefficient and produced linear relationship with  $R^2$  value of 0.47. The relationship is linearly positive and follows almost similar trend as was in case of LAI. This is due to the fact that fraction of photosynthetically active radiation (fPAR) is closely related with LAI. When LAI increases the canopy use to absorb more radiation for photosynthesis process thereby fPAR also increases with increasing LAI (Fig. 5).

The developed scatter plot demonstrated a good agreement between the crop height and ratio of backscatter radiation with coefficient of determination ( $R^2$ ) of 0.50. There exists a power relationship between backscattered coefficient and crop height (Fig. 6).

Fig. 7. Biomass and  $\sigma_{0VV}/\sigma_{0VH}$ Fig. 8. Water content and  $\sigma_{0VV}/\sigma_{0VH}$ 

Similar approach was adopted to find the relation between the biomass and ratio of backscatter coefficients. The developed scatter plot gives a very good relationship between biomass and ratio of backscatter coefficient with value of coefficient of determination ( $R^2$ ) as 0.63. This relationship is most strong relationship among all the biophysical parameters that were analyzed in the present study. There exists again a power relationship between the ratio of backscattered coefficient and rice biomass because initially the value of ratio of backscattered coefficient increases slowly with increasing biomass, however, it soon gets momentum and thereafter, it increases very sharply with increasing biomass (Fig. 7).

In case of water content, the relationship found with the ratio of backscatter coefficient is linearly negative. The value of coefficient of determination (0.34) is quite low as compared to the other biophysical parameters. Water content is the only parameter which did not exhibit good relationship with the ratio of backscatter coefficient due to the fact that Sentinel-1A SAR images cannot detect water content of the plant directly, however it may produce good relationship with total amount of water available in crop canopy and soil. As rice crop is grown in submerged conditions a lot of interference in the SAR data come from water beneath crop canopy. Thus, a relatively poor relationship is obtained between the ratio of backscatter coefficient and crop water content (Fig. 8).

The developed scatter plot equations were used to generate the images of different biophysical parameters by transferring these equations into the band math function

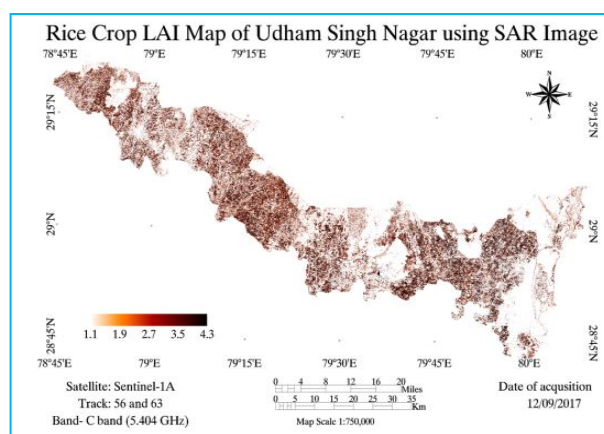


Fig. 9. Rice crop LAI map

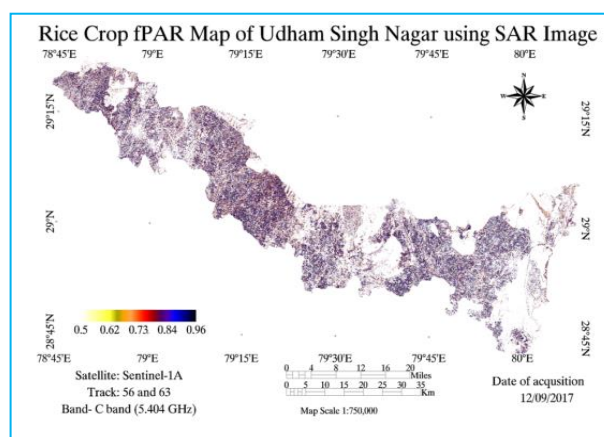


Fig. 10. Rice crop fPAR map

available with ENVI image processing software. The resultant images generated for LAI, fPAR, Crop height, biomass and crop water content for Udham Singh Nagar are shown in (Figs. 9, 10, 11, 12 and 13) respectively.

The LAI map of Udham Singh Nagar district derived using Sentinel-1 SAR image of 12<sup>th</sup> September, 2017 is shown in (Fig. 9). The value of LAI of the rice crop for the year 2017 at its reproductive stage varied from 1.1 to 4.3  $\text{m}^2/\text{m}^2$ . The low value of LAI at some places may be attributed to the pixel of mixed classes. The spatial resolution of Sentinel-1 SAR image available for download is at 10m. The border pixels of field often cover some portion of the fallow field or other land use categories resulting in the low aggregated LAI values. The higher values of LAI ranges from 4 to 4.3  $\text{m}^2/\text{m}^2$ , which are visible throughout Udham Singh Nagar district, represent the pure pixels of rice crop. Higher well distributed values of LAI in Udham Singh Nagar district signifies the good environmental conditions for growing of rice crop in the district.



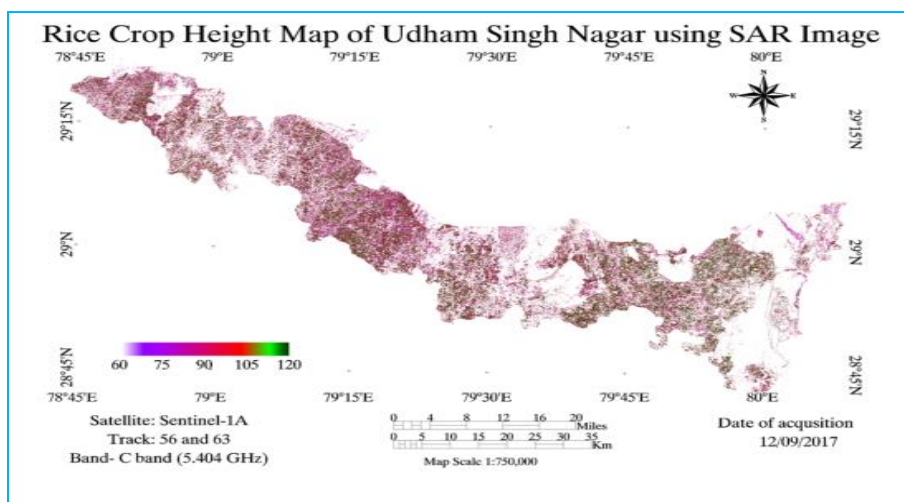


Fig. 11. Rice crop height map

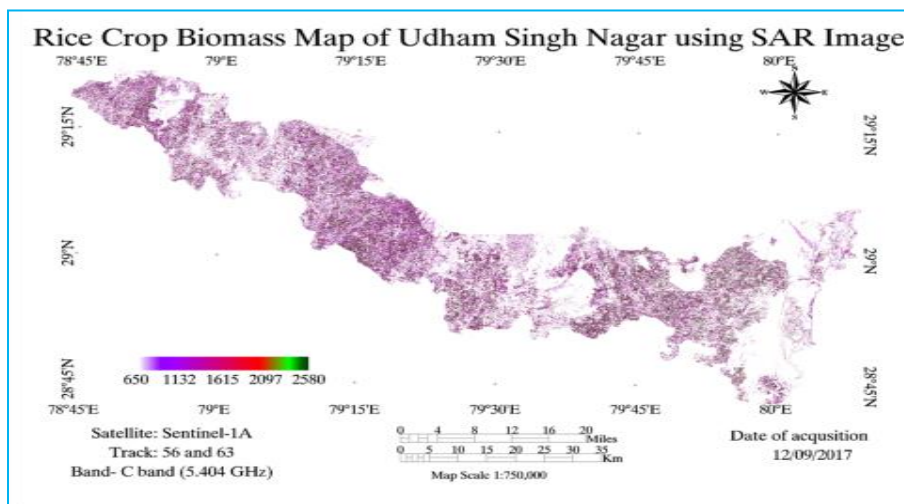


Fig. 12. Rice crop biomass map

Fig. 10 represents the map of fPAR pertaining to Udham Singh Nagar district for the rice crop at reproductive stage as on 12<sup>th</sup> September, 2017. Though the value of fPAR varied from 0.24 to 0.96, however a critical examination of the map shows that most of the rice growing regions of the Udham Singh Nagar district have higher values of fPAR (ranging from 0.80 to 0.96). Higher fPAR values signify that a good portion of the incident radiation is being absorbed by the rice crop. The higher value of fPAR may be attributed to active and higher amount of foliage available in the crop canopy at the time of satellite pass as on 12<sup>th</sup> September 2017.

The height of the rice crop at its maximum vegetative / reproductive stage as on 12<sup>th</sup> September, 2017 is shown in (Fig. 11). The height of the rice crop ranged from almost 60 cm to 120 cm. However, critical

examination of the map suggests that the height of rice crop in most parts of Udham Singh Nagar district ranged from 90 to 120 cm. The variability in the rice height may be attributed due to cultivation of varying types of cultivar in the region. Some farmers are growing short varieties, while others are growing scented long varieties. The variation in the sowing time could be the second reason for attaining different height by rice crop on a given satellite pass date. The other reason for rice variability and especially the low values of rice height may be due to the fact that boarding pixels of rice fields (Sentinel-1A SAR image) may cover other land use categories resulting in low values of height.

The biomass map of the rice crop for Udham Singh Nagar at its peak vegetative/ reproductive stage is shown in (Fig. 12). The Value of biomass varied from 650 to



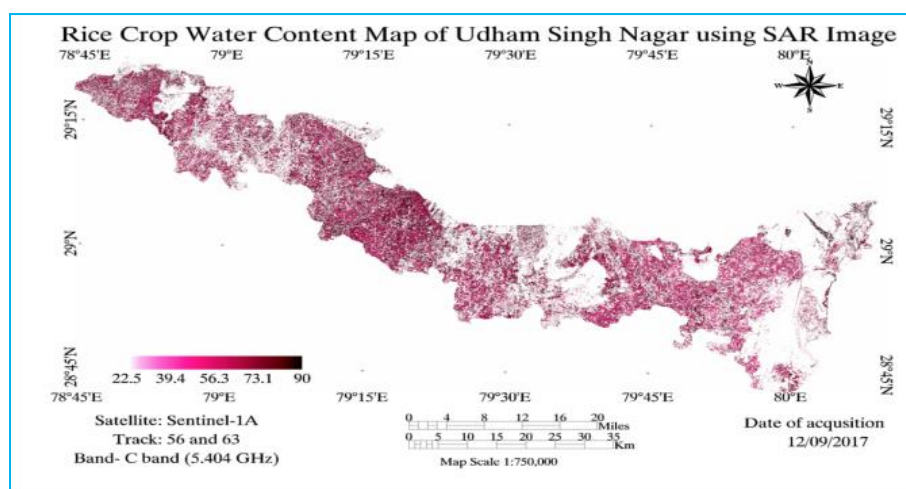


Fig. 13. Rice water content map

1850  $\text{g/m}^2$ ; however most of the area is covered by the higher value of rice biomass which ranged from 1935 to 2580  $\text{g/m}^2$ . The broad range of biomass may be attributed to varying management practices and a variety of rice cultivars being grown in the region. Varying soil, topography and microclimatic conditions are also responsible for varying amount of biomass across the regions. The lower values of biomass may also be reported due to merging of several other land use categories with rice in boarding pixels. The higher values of biomass in most parts of the districts signify that the environmental conditions are congenial for cultivation of rice in Udham Singh Nagar district. However, the average rice productivity of the district, which is just above 3000  $\text{kg/ha}$ , is cause of concern. This means that there are ample possibilities of increasing rice productivity in the district by adopting advanced technologies of rice cultivation with focus on plant protection and to adopt other high yielding varieties, which have higher dry matter partitioning to reproductive organs Setiyono *et al.* (2018).

The map depicting water content in rice plants in Udham Singh Nagar district has been figured in (Fig. 13). The water content map has been generated using Sentinel-1 SAR image of 12<sup>th</sup> September, 2017. The value of water content of the rice crop for the year 2017 at its peak vegetative stage / reproductive stage varied from 22 to 90%. The variability in the water content may be attributed to soil water status, and varying stages of crop. Though there will not be much variation in the phenological stages, however there are certain rice varieties like Pusa-1509, which mature quite earlier and at maturity the water contents of the crop drops very fast. Further, the map gives an approximate value of water content due to the fact that the effect of water beneath the crop cannot be separated. However, Di Baldassarre *et al.*,

(2009) used integrated multi-algorithm technique which includes visual interpretation, image texture analysis, edge detection analysis, histogram thresholding approach for estimation of water content which did fairly well.

#### 4. Conclusion

The regression models based on SAR Sentinel-1A data provide good estimates of biophysical parameters (Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (fPAR), Crop Height, Biomass and Water Content), which justify the high potential of use of statistical model for timely rice growth monitoring and estimation of rice based on SAR statistical model.

The preliminary results showed that the biophysical parameters can be retrieved over the rice growing season using high spatial resolution C-band SAR data but there is a need to conduct further research to separate out the effect of flooded water in the field to estimate crop water content more accurately.

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*Disclaimer* : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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