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Assessment of paddy crop biomass using multitemporal sentinel-1 SAR data

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Abstract
In this study, Sentinel-1 SAR backscatter data were analyzed at different phenological stages throughout the growth period of rice during *kharif* 2021. Ground based observations of fresh biomass of rice crop was recorded at the corresponding phenological stages. The time series analysis of SAR backscatter and fresh biomass was performed. Both VV & VH polarized SAR backscatter were also correlated with fresh biomass at 90 DAT. The results indicated that SAR backscatter has smaller values in the beginning which increases rapidly during vegetative stages, attains a peak near reproductive stage and then decreases. Similar trend was observed for fresh biomass. Also, both VV and VH backscatter exhibited strong positive correlation with SAR backscatter with R^2 of 0.75 and 0.80, respectively. Hence, research for assessing the potential of SAR backscatter for obtaining rice biomass estimates should be performed by researchers.

Keywords: Paddy, Sentinel-1, SAR, biomass, correlation

1. Introduction

As the world population continues to grow, ensuring food security is becoming increasingly important. The increasing world population is putting a significant strain on the global food supply. Rice (Oryza sativa) is one of the most important staple foods for more than half of the world, that fulfils 27% of the global calorie requirements and 20% of dietary protein requirements (Redona, 2004) [14]. Notably, more than 90% of the world's rice is produced and consumed in Asia (UNDESA, 2013) [16]. Despite the impressive production numbers, productivity of rice in India (2.5 t/ha) is significantly lower than the world average of around 4.3 t/ha (FAO, 2020) [3]. Rice productivity in India can be improved by providing accurate information on crop growth and development in real time to optimize irrigation, fertilization, and pest management practices, ultimately increasing crop yields and improving food security.

Remote sensing provides an effective solution for crop monitoring (Karthikeyan *et al*., 2020) [7]. Optical remote sensing has been widely used for crop monitoring, however, heavy cloud cover during the rice growing season impedes its ability to capture accurate imagery of rice fields (Joseph, 2005) [6]. This is an important limitation of optical remote sensing, especially during k*harif* season, when a significant part of arable land in the country is under rice cultivation. Microwave or Synthetic Aperture Radar (SAR) remote sensing is a proven approach for effective crop monitoring because of its ability to penetrate clouds and vegetation. (Aher *et al*., 2014) [1]. The 'all weather' capability of microwave remote sensing makes it an ideal tool for rice crop monitoring which is often cultivated during the rainy season in most parts of the world (Zhao *et al*., 2022) [19]. Synthetic Aperture Radar utilizes backscatter values pertinent to biophysical parameters. SAR data have a proven ability for detection of rice through temporal signature of the backscatter coefficient (σ°) of the crop (Nelson *et al*., 2014) [13]. SAR observations in rice crop are sensitive to growth stage and biomass (Inoue *et al*., 2014) [4]. The temporal backscatter pattern during the growing season is unique in rice crops (Choudhury *et al*., 2007) [2]. Crop biomass is an important biophysical parameter that is related to crop growth status using SAR remote sensing (Yang *et al*., 2016) [18]. Inoue *et al*. (2014) [4] studied the relationship between SAR backscatter and paddy biomass. Choudhury *et al*. (2007) [2] utilized SAR backscatter obtained from ENVISAT and RADARSAT to study the relationship with paddy biomass. Correlation analysis between paddy biomass and SAR backsatter was performed by Wu *et al*. (2011) [17]. Jia *et al*. (2013) [5] employed RADARSAT-2 images to study the relationship between SAR backscatter and paddy biomass. Mansaray *et al*. (2020) [11] studied the temporal pattern of SAR backscatter and fresh biomass of paddy as well as the correlation between SAR backscatter and in situ biomass of paddy.

To fill the knowledge gaps, this study aims to establish a relationship of fresh biomass of rice with SAR backscatter data in both VV and VH polarizations. Results obtained from this study would be helpful for future research s of rice biomass estimation with SAR data.

2. Material and Methods

2.1 Study Area

The study area belongs to the Kichha and Rudrapur subdivisions of Udham Singh Nagar district in Uttarakhand, India. The area falls under humid subtropical climate and is situated in the "Tarai" belt of Himalayas at 29.02° N latitude, 79.48° E longitude and an altitude of 211.5 m above the mean sea level. The average annual precipitation in the area is about 1400 mm. The minimum temperature is usually recorded in the month of January and can be as low as 1.5±1.0 °C. However, maximum temperature may rise up to 45.5±1.5 °C during the month of May. The region's soil type is classified as alluvial, which is highly fertile and supports paddy cultivation. During *kharif* season, rice is the most dominant crop cultivated in the region. The transplanting of rice is performed around second fortnight of June and harvest in the second fortnight of October.

2.2 Ground Truth Data

The ground truth data was collected from 53 different locations and it was well distributed across the study area. The data included latitude and longitude of the field and fresh biomass of rice crop. The data were collected at 30, 45 60 and 90 days after transplanting (DAT). The fresh biomass time series was plotted to see its change over time.

2.3 Satellite Data

The Sentinel-1 SAR data was downloaded from European Space Agency (ESA) Copernicus Open Access Hub. The Sentinel-1 SAR imageries were acquired at 30, 45, 60, and 90 days after transplanting (DAT) for *kharif* rice during 2021. The scenes were then pre-processed (Fig. 1) using SNAP v 8.0.0 and the output after pre-processing is presented in Fig. 2. The GCPs were then identified using Google Earth Pro and vectors of 5x5 kernel size were created in ArcGIS (Fig. 3). These vectors were overlaid on the pre-processed SAR images in SNAP and the mean backscatter values in both VV and VH polarization were obtained for each vector polygon. The time-series of mean backscatter were then plotted for both VV and VH polarizations.

2.4 Correlation analysis between SAR backscatter and fresh biomass of paddy

The crop attains peak biomass nearly about 90 DAT. Therefore, fresh biomass at 90 DAT was correlated with both VV and VH backscattering coefficients and Karl Pearson's correlation coefficients were obtained.

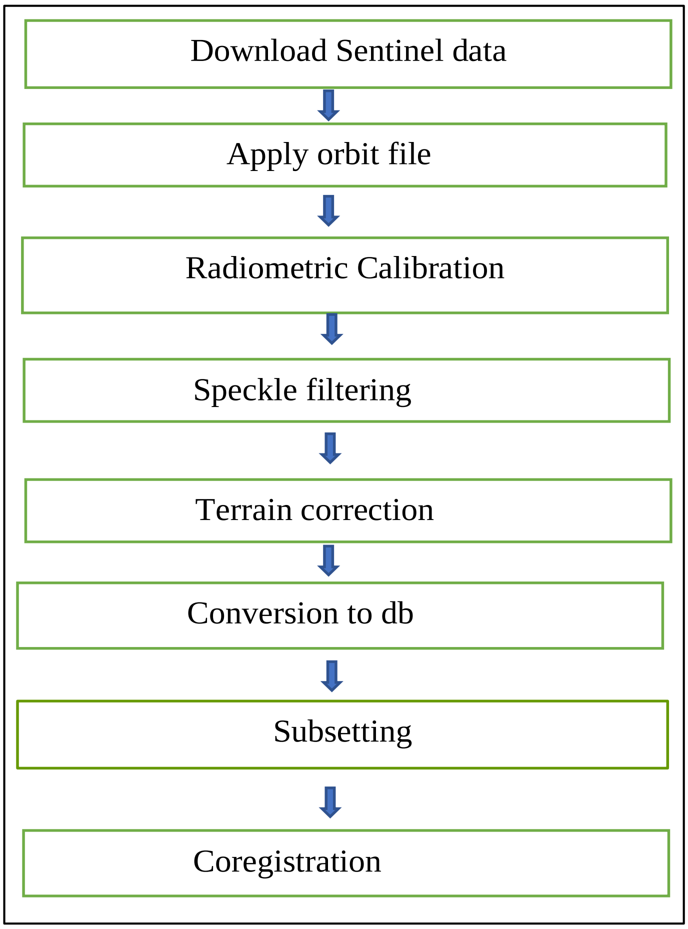

Fig 1: Flowchart representing pre-processing of Sentinel-1 data

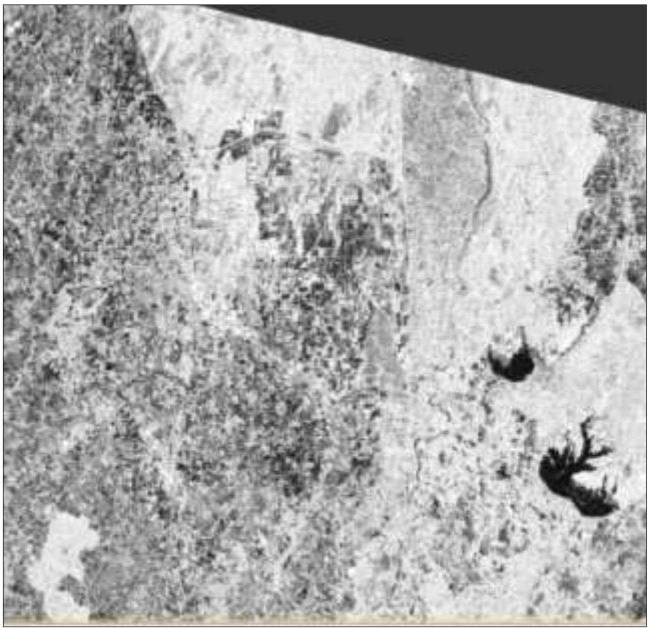

Fig 2: Final SAR output after pre-processing

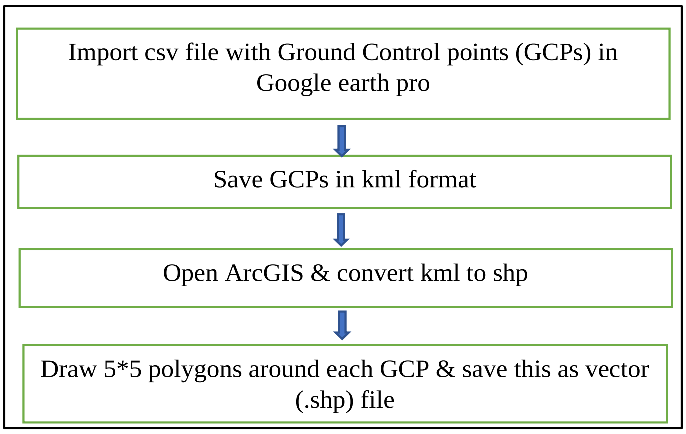

Fig 3: Identification of rice fields through GCPs & creation of vector file

3. Results and Discussions:

3.1 Temporal pattern of fresh biomass of paddy

The crop remained in vegetative stage nearly up to 60 DAT and then entered reproductive stage. The phenological stages of paddy at 30 DAT corresponds to the tillering, 45 DAT to maximum tillering, 60 DAT to stem elongation to booting. At 90 DAT, the crop phenological stage corresponds to flowering to milking and thereafter it enters ripening stage.

The fresh biomass of the paddy increases rapidly from the beginning to the reproductive stage and then decreases slowly near ripening stage (Fig. 4). The increase in fresh biomass can be attributed to the fact that the dry matter and total moisture content increases in the vegetation increases up to initial reproductive stages. The decrease during ripening stage is characterized by decrease in moisture content in the plant thereby leading to an overall decrease in the fresh biomass. Similar results were obtained by Mansaray *et al*. (2020) [11].

3.2 Temporal pattern of SAR backscatter

The results indicate that backscatter signal in both VV & VH polarizations are very small in the beginning. During the growth stage of paddy rice, the backscattering coefficient increases continuously up to vegetative stage and then, it attains plateau until flowering stage. During ripening stage, the backscatter value decreases in both VV and VH polarizations (Fig. 5 and 6). Similar trends were observed by Kurosu *et al*. (1995) [8], Le Toan *et al*. (1997) [9], Ndikumana (2018) [12] and Mansaray *et al*. (2020) [11].

The increase in backscatter during vegetative stage can be explained by the fact that as the rice plant develops and biomass increases, the area available for radar wave reflection also increases, leading to an increase in measured backscatter. As the crop progress towards the ripening phase the plant water content decreases, which lowers the steam and leaf densities (Lim *et al*., 2008) [10]. This results in decline of the backscatter coefficient starting from ripening to harvesting stage.

3.3 Correlation analysis of SAR backscatter with paddy fresh biomass

The results of correlation between SAR backscatter with fresh biomass at 90 DAT are presented in Fig. 7 and 8. The results indicated that both VV & VH have strong positive correlation with fresh biomass. The Karl Pearson's correlation coefficient for VV & fresh biomass was 0.75 and that for VH and fresh biomass was 0.80, respectively. Inoue *et al*. (2014) [4] reported similar findings in VH polarization.

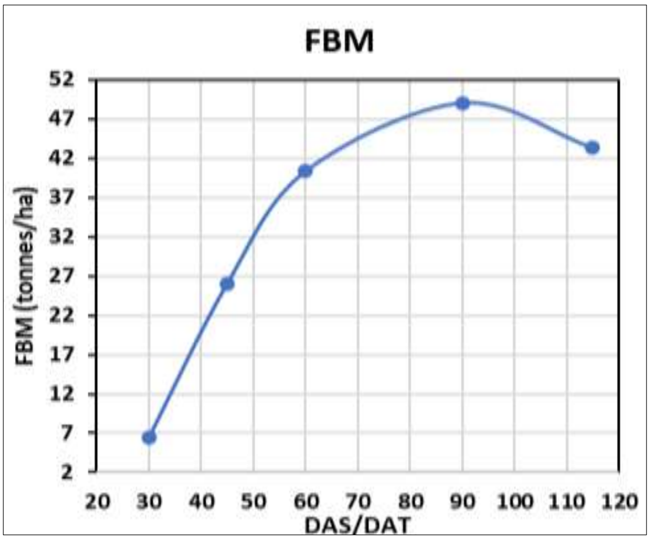

Fig 4: Fresh biomass time series for paddy crop during *kharif* season

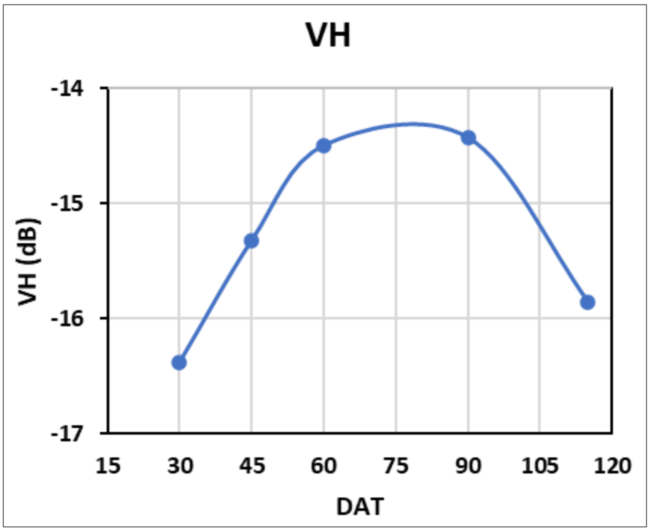

Fig 5: VH time series for paddy crop during *kharif* season

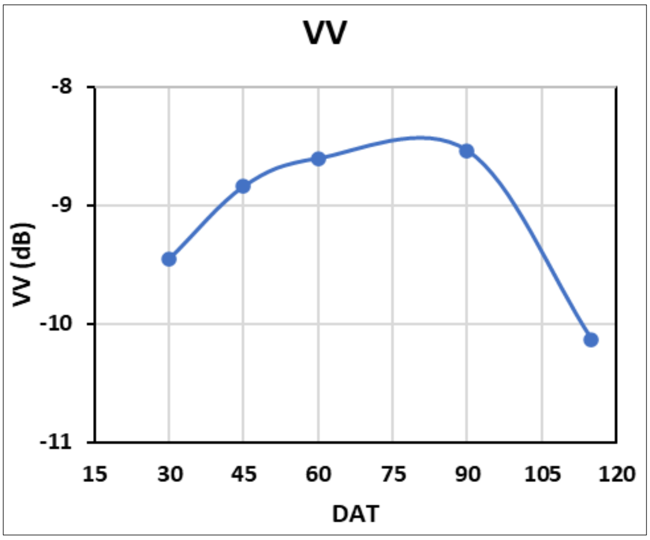

Fig 6: VV time series for paddy crop during *kharif* season

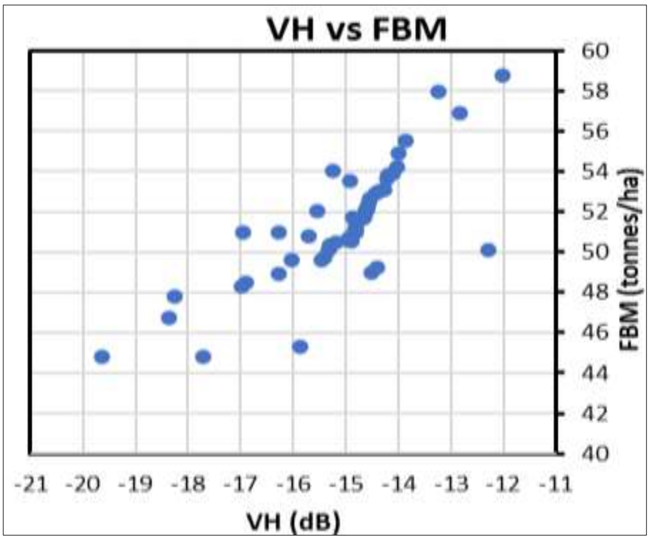

Fig 7: Scatterplot of paddy fresh biomass with VH at 90 DAT

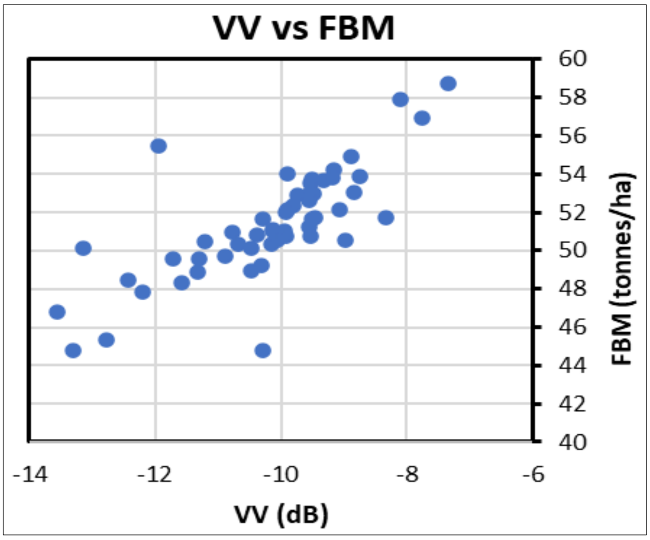

Fig 8: Scatterplot of paddy fresh biomass with VV at 90 DAT

Conclusions

This paper presents a preliminary investigation to establish a relationship between paddy fresh biomass with Sentinel-1 datasets (VH and VV polarized. When the entire rice growth profile of the crop during *kharif* season is investigated, the SAR backscatter in both VV and VH polarizations showed similar temporal profile as fresh biomass of paddy crop. Also, VV and VH polarizations possessed a strong positive relationship with SAR backscatter. The findings of this study may be helpful in assessing the potential of SAR backscatter for estimating rice biomass.

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