IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 09, Issue 1 (January. 2019), ||V (I) || PP 68-71

Modeling of rice crop biomass using Sentinel-1 backscatter coefficients: A Case Study

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Abstract: Agricultural crops are among the most important sources of food for human being. The monitoring of crop growth stages, discrimination among various crop types and crop yield estimation essential for crop health status, insurance and planning. SAR (Synthetic Aperture Radar) has tremendous potential to characterize vegetation due to higher sensitivity to vegetative structure, dielectric properties of the canopy, biomass There is wide gap exists to use SAR data for assessment of crops at local to regional scale. The optical domain has a severe limitation for agricultural monitoring in cloudy conditions and hence to overcome this limitations SAR is used for agricultural monitoring. The present study is carried out on multi-temporal Sentinel-1 data to estimate biomass. It was found that VH polarized sentinel-1 signals were more sensitive to change in phenological stages of rice crop as compared to VV polarized signals. The correlation of Sentinel-1 signal to biomass was found very high in VH polarization with r =0.8. Such results indicate that highly qualified Sentinel-1 radar data could be well used for rice biomass estimation.

Date of Submission: 26-12-2018 Date of acceptance: 09-01-2019

I. INTRODUCTION

Monitoring crop growth stages and biomass estimation at spatial scale are two important facets of season agriculture monitoring and prediction. This will guide us to know the spatial homogeneity and heterogeneity of various crops as well as their growth health during the agriculture season. In India, maximum net sown area falls under *kharif* season hence the usability of SAR data is quite high since the optical domain has a severe limitation for agricultural monitoring in cloudy conditions. Vegetation structure and canopy water content vary as crops evolve through a series of phenological growth stages from vegetative to reproduction, seed development, and senescence. Back scattering of crops and vegetation biomass depends on plant type and its growth stages Polarimetric data using empirical and semi-physical model plays a vital tool for crop biomass estimation ([1], [3], [4], [5], [6]). Multi temporal C band (4 GHz- 8GHz) ([2]) SAR gives appropriate results for low biomass crops but due to restriction in penetration depth high biomass crops are difficult to monitor.

II. MATERIAL AND METHODS

Nawagam (22.77 ^{0}N, 72.56 ^{0}E), also known as the Rice bowl of Gujarat is a rice cultivation farm under Anand Agriculture University, located in semi-arid region of west coast plains with rain-fed *kharif* rice and wheat in *rabi* as major crops. The soil at the station and its surrounding areas is medium black to very deep, poorly drained and salt affected. The annual mean temperature varies in range of 25^{o}C-40^{0}C. The annual precipitation is in range of 500 mm -750 mm. The study region receives 95–98% of annual rainfall from the south-west monsoon which generally starts in June and withdraws in late September. The Sentinel-1A IW Level 1 (L1) GRDH (ground-range detected, high resolution) product was used in this study. The Sentinel-1 C band (~ 5.40 GHz) SAR data has dual-polarization (VV and VH) with revisit time of 12 days. L1 data was pre-processed using ESA's open source 'Sentinel-1 Toolbox'. Pre-processing steps include orbit correction, geocoding, radiometric calibration and resampling (see https://sentinel.esa.int/web/sentinel/toolboxes/sentinel-1for a detailed description of the processing steps). Since this study is based on the investigation of (low-frequency) seasonal backscattering behavior, speckle filtering was performed for temporal data sets. In the present study, we report the initial observations of temporal variation in backscatter coefficients ($\sigma^{0}_{VH,}$ σ^{0}_{VV}), during different phenological stages of rice crop. Also, an attempt has been made to empirically model rice crop biomass using these data sets. Finally, all images are orthorectified into map coordinates by simulating SAR image from the SRTM DEM 30m and using it to do co-registration. The image pixel size of the final data is about 10 m. The present study is first of its kind over Nawagam region

III. RESULT & DISCUSSIONS

The temporal observation of rice growth is important for understanding the radar responses of rice plots at different stages of growth. There are three major periods of rice cultivation: the sowing period (starting according to the weather conditions from the end of May to mid-June), the growth period (up to September) and the harvest period (end of September to the beginning of October). Continuous water movement through irrigation compensates the variation of rainfall. VV and VH polarized backscatter coefficients (σ^0_{VV} and σ^0_{VH}) variation over selected rice fields during the study period are shown in figure1 together with ground images. After sowing (mid-June) it was observed that from bare soil surfaces, there was very low backscattering at VH polarization than at VV polarization. Figure1, shows the temporal evolution of the backscatter mean inside the rice fields. VV polarized backscatter is generally larger than VH polarized backscatter, and the backscattering coefficients (both polarizations) gradually increase during the growing period until they reach their maximum at the end of the reproductive state. This is followed by a significant backscatter decrease during the maturation state. While VV polarized backscatter reaches a first maximum after sowing, VH polarized backscatter shows a monotonic increase without such depression until it reaches its maximum on 250 DOY (approximately 70-80 days after sowing). However occasional depression in VH polarized backscatter between DOY 170- DOY 240 corresponds to rainfall events which leads to change in soil moisture. The depression in VV backscatter during maturation is probably related to the disappearance of standing water in this period, as it can be seen from Figure 1. The VH signal on the other hand seems to be less affected by such changes in standing water conditions and is thus expected to better represent the actual rice-growth cycle. We therefore limit subsequent analysis to VH backscatter measurements only.

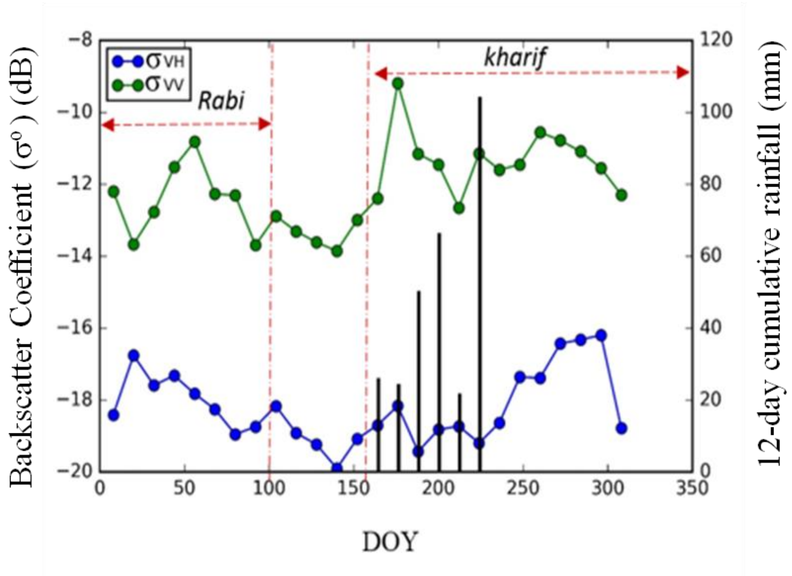

Fig 1: Temporal variation of backscatter coefficient over Nawagam, Gujarat

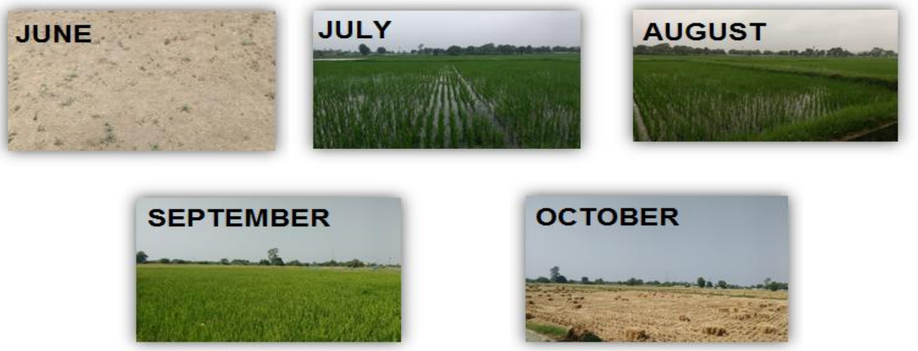

Fig 2: Ground conditions during study period

Ground truth measurements of rice biomass were conducted in ten reference plots at Rice Research Station (RRS) at Nawagam. A plot survey was carried out from May 2017 to November 2018 on the ten rice reference plots selected to cover the variability of agricultural practices in this area. The reference plots were chosen in such a way that they could represent the rice fields in Nawagam area and were not adjacent to each other. The ground surveys were conducted based on the Sentinel-1 data acquisitions to measure rice biomass through the full rice growth cycle. In that respect, the following measurements were made every ten days. We took five samples per plot. We could not take more samples since it would be a waste and it would have had an impact on the production. The biomass was dried to have the dry biomass that is used in our analysis. The empirical model was developed using the relation between ground measured biomass and Sentinel-1A backscatter. It was found that, backscatter coefficients (σ^0_{VV} and σ^0_{VH}) have good correlation with ground observed biomass with the correlation coefficient of (r=0.8) (see fig.3). The developed model was validated using independent dataset of ground measured biomass for the year 2017 for the same region. It was observed that, the error in the estimated biomass was about 26%.

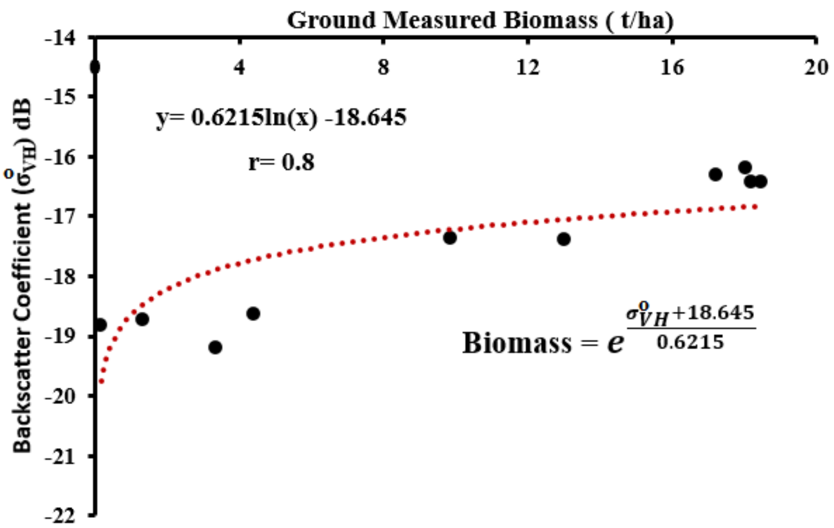

Fig 3: Relation between ground measured biomass and Sentinel-1A backscatter (σ^o_{VH})

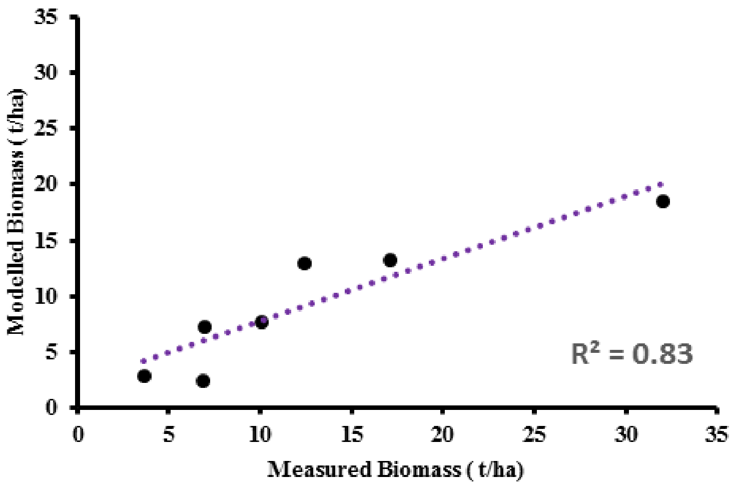

Fig 4: Validation of biomass model over Nawagam, Gujarat

IV. CONCLUSION

This study gives a beautiful insight on application of SAR data for monitoring crop phenology and biomass estimation in rice agro ecosystems. Further, attempt will be made to craft similar models for other crops such as wheat, sugarcane. This kind of approach will help us to overcome the constraints faced by optical data sets for biomass modeling during monsoon seasons.

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Devansh Desai. “Modeling of rice crop biomass using Sentinel-1 backscatter coefficients: A Case Study.” IOSR Journal of Engineering (IOSRJEN), vol. 09, no. 01, 2019, pp. 68-71.