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Research Article

Soybean Acreage Estimation using Temporal Microwave and Optical Remote Sensing Data: A Case Study in Nizamabad District, Telangana

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ABSTRACT

Soybean is a high economic value oilseed crop, mostly grown in the *kharif* season in India. The persistent cloud cover during this season makes the soybean crop acreage estimation complicated using space-borne remote sensing. Microwave remote sensing can help in resolving the problem, owing to its capability toacquire images in cloudy condition. The current study utilized temporal Sentinel-1B SAR and Sentinel-2A/2B optical data to discriminate the soybean crop from other competing *kharif* season crops in the Nizamabad district, Telangana, in the year 2019. Multi-temporal VH backscatter intensity and Normalised Difference Vegetation Index (NDVI) data were used to characterize backscatter and greenness behaviour of soybean crop, and to frame the rules for classification of the soybean crop. The rule-based classifier could achieve the overall accuracy, and Kappa coefficient as 80.7%, and 0.71, respectively, to assess the spatial distribution of soybean crop in the Nizamabad district.

Key words: Rule-based classification, Soybean, Normalised Difference Vegetation Index (NDVI), SAR

Introduction

Soybean (*Glycine max*), a high economic value crop, is fairly easy to grow and produces more protein and oil per unit of land than almost any other crop (Singh *et al*., 2005). In India, the area under soybean cultivation has been increased significantly in recent past as compared to any other oilseed crop. The spatial information on the soybean crop distribution is noteworthy due to several: (a) there is requirement from the government of India to increase the number of crops for operational crop inventory; (b) economic values of soybean crop are very high; and (c) soybean crop map is very much required from the crop insurance perspective. Therefore, a reliable soybean crop map is a key input parameter for the decision makers for the planning purposes and policy making related to its production.

As soybean is mostly grown as the kharif crop with the onset of monsoon in a rainfed agro-ecosystem where uncertainty in the rainfall pattern (onset, amount, frequency, dry spells) is high, the soybean acreage varies significantly from year to year. Crop acreage estimation using traditional practices are very time consuming, labour intensive and expensive. Moreover, these methods

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do not provide reliable and spatial information, space-borne remote sensing can help in synoptic data collection in more cost and time effective manner (Shewalkar *et al.,* 2014, Forkuor *et al*., 2014). As soybean is a short duration *kharif* crop, use of remote sensing data in optical spectrum is often limited by persistent cloud cover. In this scenario, microwave remote sensing is the only option to resolve the problem related to soybean crop mapping in tropical and sub-tropical country like India (Kumari *et al*., 2019). Synthetic Aperture Radar (SAR), a form of microwave remote sensing, can be used to map the *kharif* season crops owing to its capability to acquire image in all-weather condition (Liao *et al.,* 2018; Koppe *et al*., 2013). However, use of SAR data is also limited due to its intricacy, salt and pepper noise and difficulty in data understanding for agricultural applications (Li *et al*., 2010). The C-band SAR Sentinel-1 which was launched recently by European Space Agency's (ESA) and are available free of cost, has unlocked the opportunities to produce crop type map, operationally. It has the advantage of high spatial and temporal resolution which can be used to derive a crop map based on differential phenological growth stage. Crop mapping has already been widely tested and used operationally using temporal moderate spatial resolution optical images (Zhang *et al*., 2003, Clark *et al*., 2010, Korets *et al*., 2010, Kontgis *et al*., 2015), high resolution optical images (Yan and Roy, 2016), SAR images (Dave *et al*., 2017; Raman *et al*., 2019) or a combination of SAR and optical images (Veloso *et al*., 2017; Brinkhoff *et al*., 2020; Laurin *et al*., 2013). Nevertheless, most of the studies has exploited the SAR data for operational mapping of rice crop (Son *et al.,* 2018; Nguyen *et al.,* 2017) and a smaller number of studies have utilized the SAR data for mapping of other kharif season crops (McNairn *et al*., 2014; Verma *et al*., 2019).

In this study, potential of time-series Sentinel-1 backscatter data in combination with Sentinel-2 data for the soybean crop mapping is explored. We analysed multi-temporal C-band VH polarized Sentinel-1 SAR data to evaluate the backscatter behaviour of soybean crop and 15-days maximum value composite (MVC) of NDVI values from Sentinel-2 optical data to fine-tune soybean map in Nizamabad district, Telangana state.

Materials and Methods

Study area

The Nizamabad district is second major district in area and production of soybean crop in Telangana state. The study area is situated in the northern Telangana zone with 18°40' N latitude and 78°06' E longitude. Total geographical area is about 4,288 km^2 (1,656 square meters) with 22 percent agriculture area in total geographical area of the district. The Godavari river separates the Nizamabad district from Maharashtra state in the west direction. The Nizamabad lies on 393m above sea level Nizamabad has a tropical climate, and most of the rainfall received from June to October month. The average annual rainfall is about 1108 mm. The average maximum temperature is about 46.1°C (115°F) and average minimum temperature is about 18°C (64°F). Most of the soils in Nizamabad district are red and black soils with sandy loam texture. Major *kharif* crops grown in study area are rice, soybean, maize, sugarcane etc. In study area, soybean is grown in rainfed condition. In year 2019, most of the soybean crop areas were planted late (mid-July) due to delayed onset of monsoon. This led to the late senescence and therefore, harvesting of soybean in study area.

Sentinel-1 SAR data

This study used time series dual-polarized (VV/VH) C-band imagery of Sentinel-1A from the ESA, covering 2019 soybean crop growing season. The Sentinel-1A operates at a radar wavelength of about 5.6 cm (corresponding to frequency 5.405 GHz; C-band), with a repeat cycle of 12 days. This study used the level-1 ground range detected (S1B_IW_GRDH) product, which provides multi-looked backscatter intensity normalized with respect to area in VH and VV polarizations, with a swath width of approximately 250 km and a spatial resolution of 10 m. Thirteen dates with a descending orbit during June to November 2019 were used in the analysis. The details of the Sentinel-1B data acquisition dates are given in Table 1.

Sentinel-2 MSI data

Sentinel-2 mission constellation with two satellites (Sentinel-2A and 2B) by ESA contains multi-spectral sensor (MSI) with thirteen spectral channels in the visible/near infrared (VNIR) and short wave infrared spectral range (SWIR) at spatial resolutions of 10m, 20m and 60m, respectively. The details of the Sentinel-2 data acquisition dates are given in Table 2.

All images from Sentinel satellite constellations are freely available and was downloaded at https://scihub.copernicus.eu/dhus/#/home.

Ground reference data

Field information (Fig. 1.) on the distribution of soybean crop and other competing *kharif* crops in particular, has been collected. A mobile application - FASAL app –developed by NRSC was used during field visit during *kharif* season, 2019. Various information such as crop type, crop sowing and harvesting dates, etc., were collected during field visit, using mobile app. This aided in

Table 2. Sentinel-2A and 2B acquisition dates and MVC NDVI at Fortnight (15-days) interval

S. No.	Sentinel-2A	Sentinel-2B	Maximum value NDVI composite
1	21-Sep-19	16-Sep-19	2 FN September
2	11-Sep-19	19-Sep-19	
3		26-Sep-19	
4	14-Oct-19	06-Oct-19	1 FN October
5		09-Oct-19	
6		16-Oct-19	
7	21-Oct-19	19-Oct-19	2 FN October
8	24-Oct-19	26-Oct-19	
9		29-Oct-2019	
10	03-Nov-19	05-Nov-29	1 FN November
11	10-Nov-19	08-Nov-19	

Table 1. Sentinel-1B acquisition dates and other specifications
Sentinel-1B: Descending pass

S.No.	Acquisition date	Product No	Minimum incident angle (degree)	Maximum incident angle (degree)
1	23-Jun-19	A97A	30.87	46.05
2	05-Jul-19	DD50	30.85	46.05
3	17-Jul-19	2239	30.855	46.05
4	29-Jul-19	7B6A	30.857	46.059
5	10-Aug-19	F6E3	30.839	46.297
		9F38	30.866	46.319
6	22-Aug-19	0C95	30.84	46.298
		D5FD	30.866	46.319
7	03-Sep-19	C002	30.841	46.427
		4D31	30.868	46.449
8	15-Sep-19	4071	30.841	46.427
		6CCD	30.868	46.449
9	27-Sep-19	BC9A	30.838	46.425
		D9F2	30.864	46.447
10	09-Oct-19	4E4E	30:842	46.044
		3F5E	30.872	46.059
11	21-Oct-19	A4F6	30.841	46.043
		8A51	30.871	46.058
12	02-Nov-19	8420	30.841	46.043
13	14-Nov-19	9189	30.841	46.044

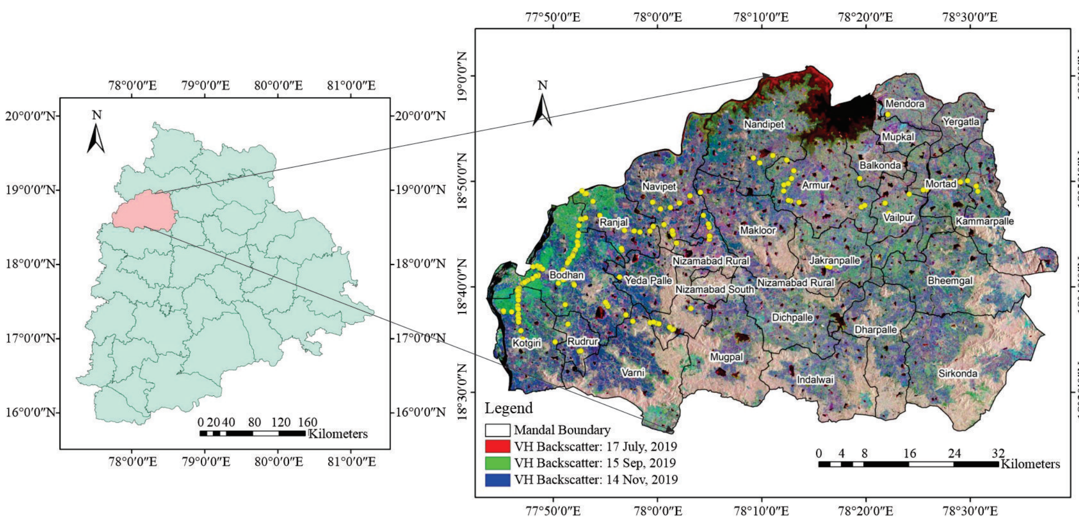

Fig. 1. Nizamabad district, Telangana (study area) with field points superimposed on colour composite of 03-dates of VH backscatter data

efficient collection of ground information about the crop along with field photographs.

Temporal Sentinel-1 and Sentinel-2 data were used to derive soybean crop map and schematic diagram of methodology is illustrated in Fig. 2.

Data pre-processing

Sentinel-1B SAR pre-processing includes radiometric calibration, speckle filtering, geometric calibration, carried out in SNAP software version 6.0.

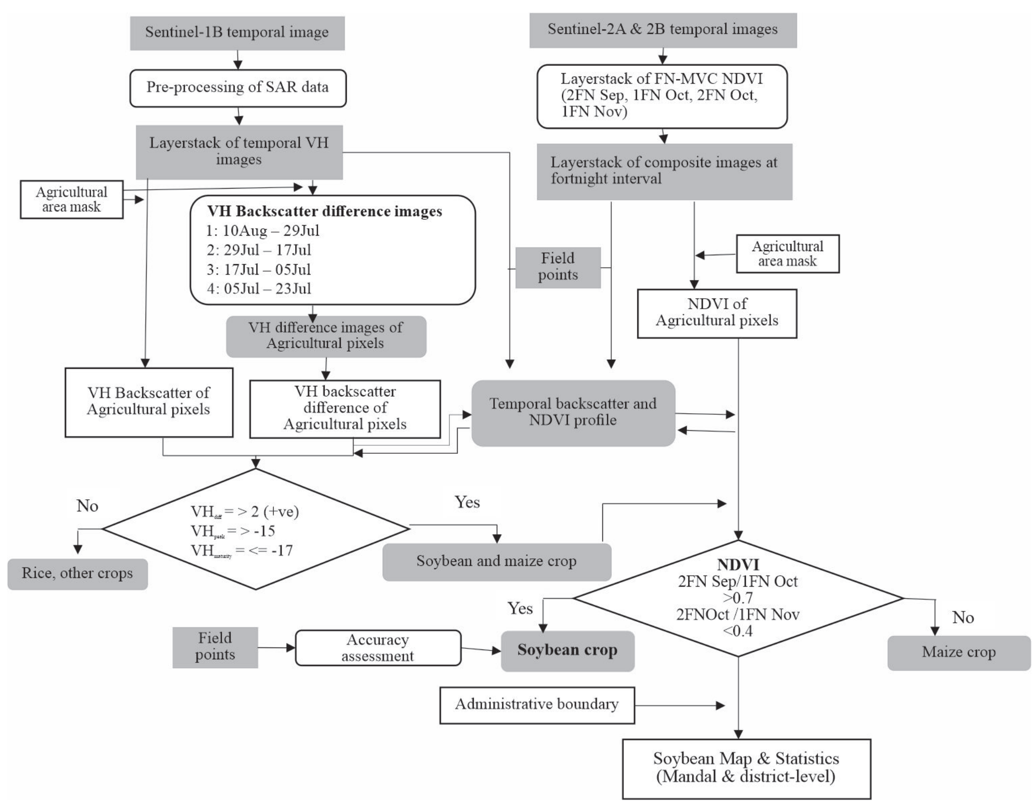

Fig. 2. Schematic diagram of methodology

Sentinel-2 data were used to calculate NDVI values using red band (B_2) and near- infrared band (B_8). In study area, the composite NDVI images of 15 days or fortnight (FN) interval (2nd FN September to 1st FN November) were prepared using maximum rule function to reduce the effect of persistent cloud during crop season. Four composite NDVI images generated using Sentine-2 data of year 2019 are: 2nd FN of September, 1st FN of October, 2nd FN of October, and 1st FN of November. These four composite NDVI images were used to fine-tune the soybean crop map derived using Sentinel-1B.

Agricultural mask from Land use/Land cover map were applied on both temporal SAR and NDVI data to restrict the study to the agricultural pixels of Nizamabad district.

Data analysis

Soybean crop phenological information were analysed using the temporal VH backscatter data. Here, identification of sowing time window, onset of peak growth stage and senescence stage, and length of growing period supported the discrimination of soybean.

Despite a logical requirement for a greater number of temporal optical data observations, only four fortnights NDVI data within a soybean crop cycle (during senescence phase) have been used for classification, largely because the prevalence of cloud cover has limited opportunities for their acquisition during crop growing season.

Traditionally, classifications of crop types have typically relied upon optical data or SAR data alone (Choudhury *et al*., 2006; Raman *et al*., 2019; Khabbazan *et al.,* 2019; Bazzi *et al*., 2019; Ashmitha Nihar *et al*., 2019) and very less studies have used both the data in combination (Denize *et al.,* 2019; Van Tricht *et al*., 2018). In this study, a rule-based classification was selected for several reasons. By combining the knowledge of crop phenology and the information content of satellite data, a threshold could be selected based on observed differences, and applied progressively to produce a classification. All rules could be refined with the full control of the user, at any time in the classification process and, in most cases, without changing the class allocation of other objects.

Seventeen data layers representing the thirteen dates of Sentinel-1 and four MVC NDVI value at fortnight interval of Sentinel-2 data were considered. However, only twelve were used in the final analysis, partly because of data redundancy between layers. Using these data, simple decision rules were developed to allow the progressive separation of soybean crop from non-soybean crop. For field locations corresponding to the crop types, image data were extracted and analysed. The basic rules were first developed from the statistical distributions of these data within the spectral feature space of each image, trends in these layers over time. Once established, the rule base was refined through reference to crop distributions observed within SAR and optical data. In all cases, the rules were based on the user's understanding of crop structure, phenology and dynamics and their manifestation within the SAR and optical data acquired.

Results and Discussion

The current study utilized temporal Sentinel-1B and Sentinel-2 data to discriminate soybean crop from other competing *kharif* season crops in Nizamabad district.

Temporal characteristics of soybean from Sentinel-1 SAR and Sentinel-2 NDVI Data

Fig. 1. shows the pseudo-colour composites, which are generated by using the temporal Sentinel-1B acquisitions in order to highlight the temporal characteristics within crops in study area. The red, blue, and green colours in the figure 1.0 correspond to the images acquired during the sowing (mid-July), flowering/pod formation (mid-September) and post harvested (mid-November) period, respectively.

Multi-temporal VH backscatter intensity images and maximum value composite of NDVI images (FN interval) were used in developing spectral profiles of soybean, maize, rice and other crops (sugarcane, turmeric). The backscatter and

NDVI values were extracted by overlapping filed point over these temporal images in *kharif* season, 2019. The temporal VH backscatter were analysed for sowing, maximum vegetative and maturity period. Most of the soybean crop were planted in 2nd FN of July and onset of peak growth stage were observed in 1st FN and 2nd FN of September. Soybean crop were harvested during 2nd FN of October and 1st FN of November. The VH backscatter intensities of soybean crop exhibited a gradual rise of backscatter values after planting and reached the maximum value during the pod formation stage. The backscatter intensities of soybean crop varied from approximately "20 dB during sowing to -15 dB during the pod formation periods.

Thus, the backscatter intensity exhibited a substantial rise during this vegetative phase due to the steep volume scattering within soybean plant canopies, clearly represented in temporal VH backscatter profile. At ripening period, there were decrease in the number of leaves of soybean plant which led to decline in VH backscatter intensity till harvesting stage. The backscatter values of rice crop were quite distinct from those of soybean crop due to water background. However, there was overlap of backscatter values between maize and soybean crop due to similar crop calendar. The long duration crops with entirely different crop calendar such as, sugarcane has shown different VH backscatter profile (Fig. 3).

We could construct the temporal NDVI profile from 2nd FN of September onwards due to effect of cloud on optical images (Fig. 3). The temporal NDVI profile showed the consistent lower NDVI values of maize than soybean crop even though both crops have the same phenological growth pattern.

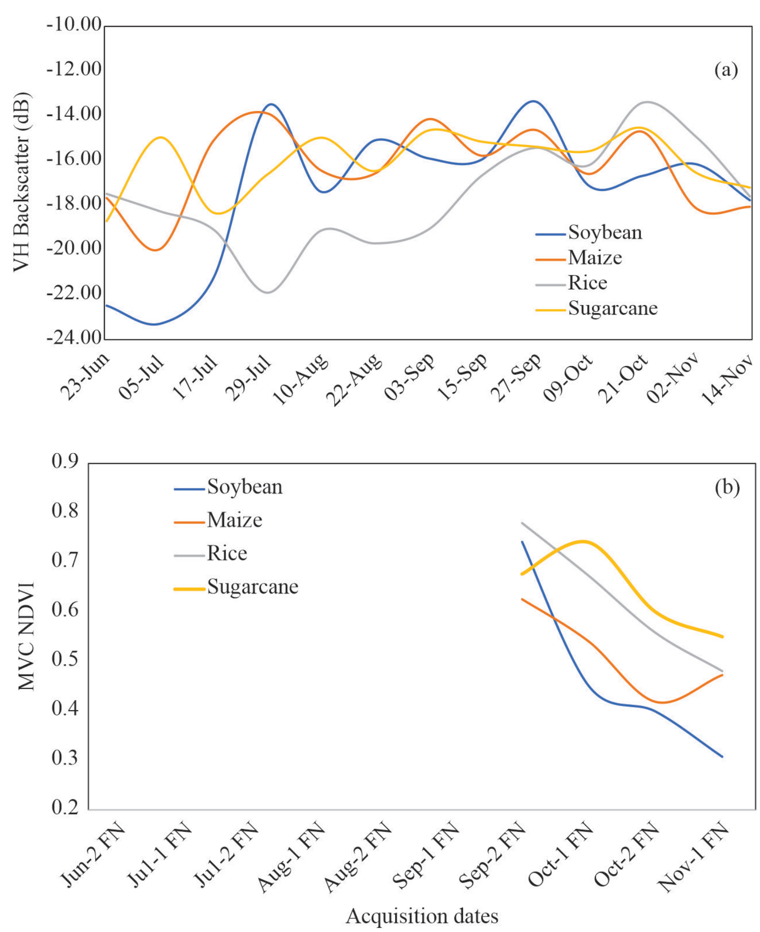

Fig. 3. Temporal profiles of different crops grown in study area (a)VH backscatter, and (b) MVC NDVI

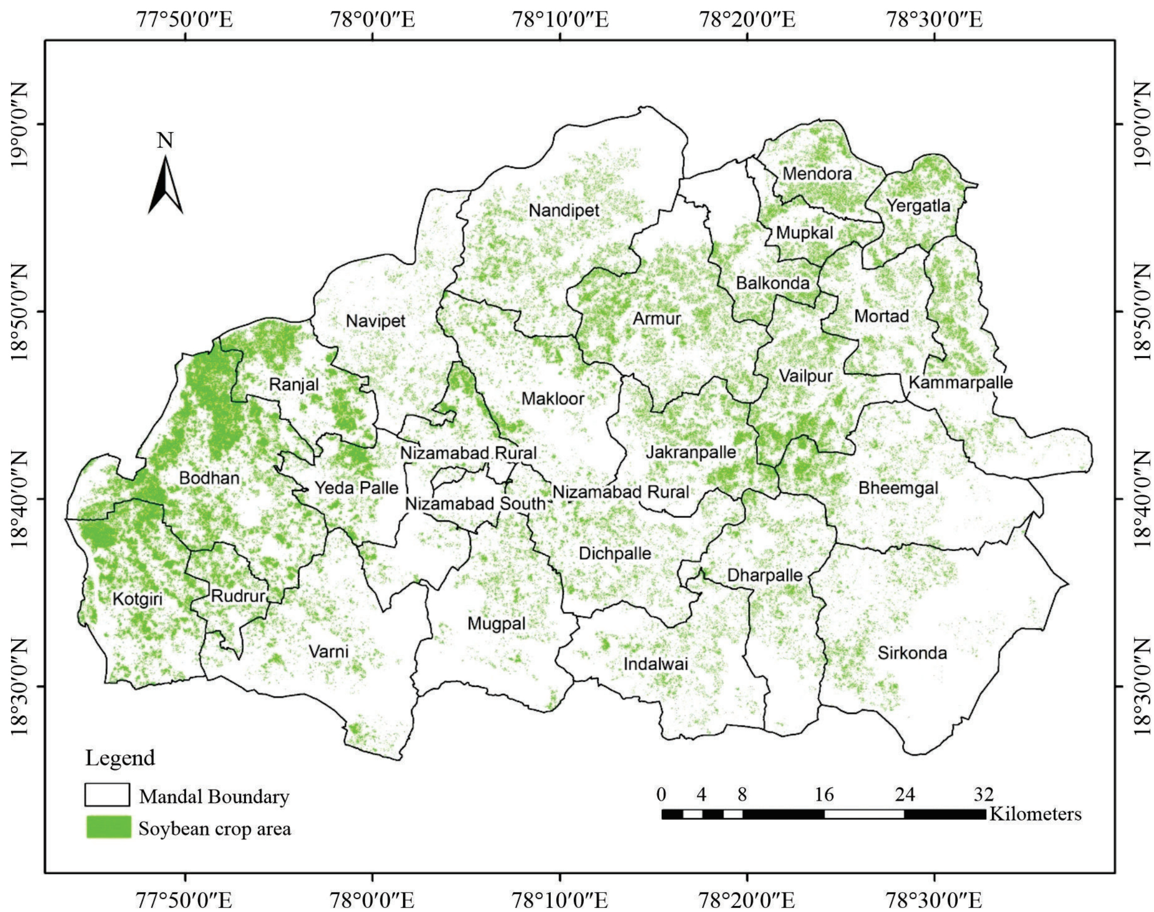

Fig. 4. Spatial distribution of the soybean crop in Nizamabad district

Soybean crop classification and accuracy assessment

The spatial soybean distribution map obtained using the rule-based classification of the temporal Sentinel-1B VH backscatter and Sentinel-2 NDVI data showed comparable results with reference to ground data. In study area, soybean crop was second most dominant crop in *kharif* season after rice, with large variability in planting time. The classified soybean map generated from rule-based classifier (Fig. 4) were assessed for its accuracy with the ground reference data (212 points). The results indicated that the overall accuracy and Kappa coefficient achieved were 80.7% and 0.71, respectively (Table 3). The soybean crops in study area were classified with user's accuracy of 82.2% and producer's accuracy of 81.4%.

There was some mixing of soybean and maize classes due to similar crop calendar. Both the crops were planted and harvested during same time window which made the discrimination between these two crops challenging. Moreover, the 12-day revisit cycle of Sentinel-1B is relatively long to capture phenological information of soybean crop (e.g. sowing and peak vegetative growth periods), which might lead to an increased uncertainty in soybean crop type classification, especially areas of high variability in sowing. Overall, the above problems caused the slight over-estimation of soybean crop acreage (64.8 lakh ha) in Nizamabad district.

These mapping results were confirmed by the Telangana government's soybean crop area statistics (57.5 lakh ha in year 2018-19) of Nizamabad district with the relative error in area values of 13%. Mandal-level soybean crop area statistics and its relative error with respect to government's statistics are given in Table 4.

Table 3. Confusion matrix showing classification accuracies of soybean and other crops

Ground reference data (pixels)	Classification results (pixels)			
	Soybean	Rice	Maize	Other crops
Soybean	83	5	10	3
Rice	4	37	2	1
Maize	11	1	32	2
Other crops	4	1	1	15
Producer's accuracy (%)	81.4	84.1	71.1	71.4
User's accuracy (%)	82.2	84.1	69.5	71.4
Overall accuracy (%)	80.7			
Kappa coefficient	0.71			

Table 4. Mandal-level satellite-derived soybean crop area statistics and its relative error (%) to Government's soybean area statistics

Mandal	Soybean area (ha)	Relative error (%)
Navipet	1424	24
Nandipet	3427	-20
Armur	4856	7
Balkonda	1672	38
Mupkal	1313	17
Mendora	1909	18
Yergatla	1837	36
Kammarpalle	2251	11
Mortad	1879	7
Vailpur	3479	9
Jakranpalle	3159	21
Makloor	2291	46
Yeda_palle	755	44
Ranjal	3536	30
Bodhan	10350	-16
Kotgiri	5778	11
Rudrur	1392	38
Varni	1848	17
Mugpal	1528	15
Dichpalle	2270	8
Indalwai	1625	-3
Dharpalle	2008	19
Bheemgal	2510	13
Sirkonda	1673	40
District total	64772	13

Conclusions

The present study explored the possibility of temporal SAR Sentinel-1B VH backscatter and optical sentinel-2 NDVI data for soybean crop classification in Nizamabad district, Telangana. The results indicated that VH backscatter profiles could characterize the temporal pattern of growth of soybean crop in the study region. It has shown a distinct response with reference to the crops with different growth pattern and phenology such as rice and sugarcane. However, maize crop has shown overlap in VH backscatter signature with soybean owing to similar phenology which has lowered the classification accuracy. Rule-based classifier was exploited to map the soybean fields with overall accuracy and Kappa coefficient achieved as 80.7% and 0.71, respectively. These results demonstrate the possibility for using temporal Sentinel-1/2 VH and NDVI data to soybean crop mapping framework at regional level.

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