RESEARCH ARTICLE

Investigating capability of open archive multispectral and SAR datasets for Wheat crop monitoring and acreage estimation studies

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Abstract

There is a necessity for new methods and technology for several agricultural applications and decision support systems. Technological development at the global, national, and regional level has shown a path for the application of spaceborne remote sensing for agriculture purposes. Remote sensing technology eases to detect areas within the plots for a reliable data supply to analyze the data. Spaceborne synthetic aperture radar (SAR) data are capable to provide a reliable data supply throughout the year. The global repetition rate is up to 12 days. The datasets acquired from the Sentinel-1 platform facilitates a ground resolution of 20×20 m and these sufficient for the synchronization of spaceborne multispectral and radar datasets for enhanced agricultural cropland monitoring applications and decision support systems. Sentinel-1 data is a C-band radar data sets in dual-polarizations. The signal intensity changes over according to humidity in the soil or vegetation cover and the surface structure. The variations in signal information being recovered at the sensor end help in the informed decision making. Besides, SAR datasets are capable to provide information on the phenological stage of agricultural cropland along with crop-type differentiation for specific use cases. The synchronous utilization of spaceborne multispectral and radar datasets for enhanced agricultural cropland monitoring applications and decision support systems can be transformed into informative map products for several processes. The same technology can be beneficial for monitoring crop conditions during any disaster and early warning systems for proper management of available resources.

Keywords Agriculture · Data fusion · Estimation · Monitoring · Multi-spectral · SAR

Introduction

During the last 40 years, the monitoring of agriculture crops with the help of a space-borne satellite system has moved from a research subject to an operational exercise. Most frequently, the normalized difference vegetation index (NDVI) is used as a proxy signature to showcase the presence or absence of vegetation health for determining variable growth rate or decline of vegetation cover (Chen et al. 2006; García-León et al. 2019; X. X. Zhang et al. 2010). We have shifted our attention towards agricultural crop monitoring, assessment, and yield estimation (Guzinski and Nieto 2019; Park et al. 2016; Potopová et al. 2020). It is a well-known fact that all traditional electro-optical satellite system applications are having certain limitations for frequent or continuous agricultural monitoring due to their incapability to look through the clouds. In this regard, there is ample space for synchronous use of multi-spectral and radar satellite datasets with global coverage and high spatial resolution to augment the current operations (Bassuk et al. 2015; Mermoz et al. 2015; Shastri et al. 2015). There has been long series of use of satellite imagery for monitoring agriculture all around the globe. Almost all agronomic service provider including agrochemical companies are marching towards the use of satellite images. They are typically translating the available information content to a vegetation index to derive the information on the state of the vegetation health for their business intelligence or passing this information's to agronomists and farmers for improvement in the agriculture processes (Barbosa et al. 2006; Blaschke et al. 2019; F. Zhang et al. 2019). This

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operational use of satellite images has more emerged and expanded in the last 7 years due to the launch of higher resolution, high-cadence, global multispectral datasets from several space agencies. *These* high-resolution panchromatic or multispectral data, along with SAR data facilitates the augmented information about the desired objects for feature extraction and land use classifications. The SAR images acquired from the space platform contain information on the small-scale surface roughness along with soil moisture. There is also potential to derive the height information with the interferometric SAR processing methods. A SAR image has a major advantage of its all-weather capability, and it allows the time series acquisition of satellite imagery under any climatic conditions. Synchronous application of multispectral along with synthetic-aperture radar (SAR) imagery can play a vital role for a wide range of applications in the environmental management and monitoring dimensions. The work tries to showcase the synchronous application of SAR and optical image data to better agricultural applications.

Agricultural monitoring with SAR datasets

There is some simple vegetation health metric analogous to NDVI and these could be derived from SAR datasets. There have been a few studies looking into whether SAR backscatter correlates with NDVI. Generally, radar vegetation index (RVI) is regarded as analogous to NDVI, and these could be generated from polarimetric SAR data. Some studies also investigate the "Cross-Ratio" and a normalized difference ratio of backscatter from VV and VH polarizations.

The study focuses on the wheat crop the second important cereal crop in India with 85 % of total area concentration in the north and central regions supporting the economy and out of them all, it has a major consumption by the population (Tukker 2015). Hence the rate of productivity should satisfy the rate of increasing demand in the market. This aspect leads to the use of various applications and remote sensing is of those. As the backbone of the Indian economy agriculture emphasises the regular monitoring of crop condition. With the advancement in science and technology, making use of remote sensing for the observation of agricultural land use and the type of crop cultivated and its efficient and dynamic monitoring to predict growth, acreage, distribution and management. The availability of soil moisture, plant health etc. are the different aspects to monitor the condition of the crop (Dutta et al. 2015). The yield of the crop can be reduced due to any hindrance in the normal growth pattern therefore, it is important to study the entire growth cycle of the crop right from the sowing and germination to crop maturity stage and harvesting (Sudha et al. 2007). Optical remote sensing techniques are widely used in monitoring the crop pattern and estimating acreage and health of the crop with certain limitations. On the contrary, the satellite-based imaging radar such

as SAR is not limited by cloud cover and has regular time intervals, Sentinel 1 carrying C-Band SAR sensor is well suited to capturing agricultural land use dynamics and for crop mapping (Blaschke et al. 2019). The structural components and moisture content of vegetation as well as the underlying surfaces which results in a complementary data source been used for identification, classification and monitoring purposes are reflected by the SAR imagery on the other hand (Onisi Kirubanandam and Raju 2019).

India has a very developed system for the collection of crop statistics consisting of more than 50 crops at the village level are covered and these are aggregated at different administrative levels(Wu and Pauw 2008). But after the years, it was strongly felt that there's a need for early and in-season forecasting of crop production. Crop assessment was carried out by many remote sensing studies since the space application in India began. In line with these, Crop Acreage and Production Estimation (CAPE) has been started by the Ministry of Agriculture, Government of India. The major crops being studied at the first level included wheat, rice, cotton etc. Satellite data visual mapping techniques as a supplemental aid for crops like wheat. The transition from visual to digital analysis is gradual. CAPE project focused on the efficient sample design, crop determining factors, spectral-yield relationships, and pre-harvest crop's accuracy forecast (Wheat et al. 2007). Furthermore, Forecasting Agricultural Output Using Space Agrometeorology and Land-based Observations (FASAL) aimed to meet the stringent requirement of multiple, nation-wide and multi-crop forecast. Research on the development of crop yield models under the Indian Remote Sensing Utilization Programme (IRS-UP) for wheat and paddy crops had shown that spectral vegetation indices at the maximum vegetative phase are highly related to the final yield of these crops (Rahman and Saha 2008). Much progress has been made through intensive studies on crop inventory and production. The study of the ranking of crops grown in the cropping pattern of a region/state/country becomes necessary because it focused on the significance of individual crop (Rahman and Saha 2008). From ranking, it can be understood the position of a crop in the given cropping pattern of a region. The alterations have occurred from 1970 to 2010 in the position of wheat cropping pattern. Even Michiels et al. (1992) had arranged the crops in ranking order for getting cumulative percentages for calculating the crop diversification index. Mishra and Singh (2019) had also used the ranking of the crops for calculating the crop diversification index. In 1970, the area under rabi crops was comparatively higher than the Kharif crops. Up till 1990, all the agricultural innovations like the adoption of increase in the extent of irrigation, the intensity of cropping, high yielding variety of seeds, factorization, the density of tube wells, etc., had been diffused in Punjab with an average of 43.54% area under Wheat cultivation in 1990. As a result, farmers were taking almost two crops in one agricultural year from the same

piece of land. In 2010, the per cent share under wheat to the total cropped area has increased from 40.49% to 44.45% from 1970 to 2010.

The several types of research for crop monitoring had documented radar as a better tool. As SAR instruments are capable provide enhanced information about the characteristics of crops along with the overcoming aspect of inherent limitations of optical sensors owing to its all-weather, day and night acquisition capabilities. This all been dominating in comparison to optical sensors (Fuller 1998). The extensive study of SAR data in recent years in agricultural monitoring has been applied for applications such as crop phenology monitoring (Bolton and Friedl 2013), assessment of productivity and retrieval of soil moisture content underneath crops (Robock et al. 2000). The present study tries to address the issues like (a) utilization of the potential of the Optical-SAR dataset for winter crop monitoring, (b) understanding the wheat crop phenology for better acreage assessment, (c) crop health assessment through health slicing and NDVI model, and (d) analyzing relationship between radar backscatter for NDVI values.

The MARS project (Monitoring agriculture through remote Sensing), a major operational programme in Europe was based on the objectives of rapid crop survey procedure using a sampling approach, identification of the multi-date crop and information of the field survey for making wide crop area estimates of Europe (Sharman and Whitehouse 1993). According to the study carried out by R.Fieuzal, B.Duchemin, L.Jarlan, M.Zirbi, F.Baup, O.Merlin and J.Garatuza-payan for better understanding of Radar Signals over the irrigated wheat fields and also to assess the potential of radar for various observations for monitoring of soil moisture in the Yaqui area, Mexico. The potential of SAR data for soil moisture condition monitoring for the agricultural lands March for wheat crops. Rie Sonobe, Yuki Yamaya, Hiroshi Tani studied six crop types Beans, Grass, Maize, Potato, Beetroot and Winter Wheat using five C-SAR (Sentinel 1A) (Facillity 2017) images and one MSI image (Sentinel 2A) of 2016 in the growing season. The objective of the study was to assess the potential for accurate classification of crop using the existing supervised classification models (Aher and Ph 2014). The four different approaches were attempted and compared by researchers namely, Kernel-Based Extreme Learning Machine (KELM), Random forest, feed foreword neural networks and support vector machine(Benz et al. 2004).

Present and future research

Recent research to assess relative classification accuracies of multi-polarized combinations for target crops using airborne data has been reported. In addition to identifying crop type and variety, identifying the crop growth stage is valuable. Crop condition, loosely defined as the vigour or health of a crop in a particular growth stage, is related to crop productivity and yield; however, the relationship is complex. Maincrop condition indicators include biomass, height, leaf area and contents of plant water, chlorophyll and nitrogen. Crop-type and crop-condition mapping are among the applications that are expected to benefit the most from the technical enhancements embodied by RADARSAT-2. The potential of RADARSAT-1 data for these applications has been rated as "limited", whereas for RADARSAT-2 data this potential is anticipated to be "strong". The Science and Operational Applications Research for RADARSAT-2 Program (SOAR) is promoting the evaluation of SAR capabilities by providing images to our project: N 2657 RADARSAT-2 for Corn Monitoring and Crop Yield in Mexico (Soria-Ruiz et al., 2009).

Within this project, we are researching a) the use of RADARSAT-2 data, SPOT and Ikonos data to determine cultivated areas and monitor crop condition; b) relating polarization signatures from RADARSAT-2 data to corn Leaf Area Index and photosynthetic active radiation (PAR) parameters. The expected benefits of this project are: to obtain knowledge about crop type, crop condition and crop yield with better accuracy than with current methodologies; to support national corn farmers associations; to support the design of agriculture-related policies within state agriculture plans; to support the corn product industry and aid government decision making. Relevant results and economic impact will imply operational usage of RADARSAT- 2 data in the agricultural sector in Mexico (Soria-Ruiz et al., 2009).

Satellite imagery is an efficient method for mapping crop characteristics over large spatial areas and tracking temporal changes in soil and crop conditions. Some SAR sensors such as RADARSAT-1 acquire imagery with a single transmit-receive polarization, providing a single radar image. Therefore, more than one acquisition date is usually required to estimate meaningful crop information. With RADARSAT-2 several new features are expected to prove beneficial to the agricultural sector. These advancements include the availability of dual-polarization and quad-polarization modes, enabling the simultaneous acquisition of multiple polarizations on transmit and receive. In the quad-polarized mode, four polarization channels are acquired. Valuable crop information can be extracted from one RADARSAT-2 image, particularly if these data are integrated with optical or SAR data acquired at complementary (X and L-band) frequencies.

Crop type and crop condition mapping are among the applications together with crop yield that is expected to benefit the most from access to advanced sensors such as RADARSAT-2. The applications potential for RADARSAT-2 data is anticipated to be strong (Morena et al. 2004). Images acquired in the polarimetric and ultra-fine resolution modes are expected to contain moderately improved information in support of crop-yield mapping. For crop condition mapping, the improved potential of the polarimetric and ultra-fine resolution data products for crop

yield mapping can be explained by the increased sensitivity to crop structure and the capacity to obtain within-field zonal information.

Materials and methods

Study area

The current study was carried at in the Ferozepur district of Punjab State (India) which contributes towards the efficient production of wheat crop. Datasets are being collected with satellite observations through various surveying techniques for further analysis of the datasets. The current work tries to focus whole attention on monitoring of wheat crop at Ferozpur district of Punjab State (India) with the help of optical and radar-based SAR datasets. This study was carried out with the help of feature identification, classification, and extraction of wheat crop from open archive datasets to analyse the growth of crop through health slicing and the NDVI Model. In addition to the optical dada test, parallel SAR datasets from the Sentinel 2A satellite were used to utilise the capability of the radar imageries to evaluate the potential of SAR data for the study and analysis of the winter crop. For the current work, proprietary software like ERDAS Imagine, ArcGIS along with an open-source tool SNAP were used for the detailed processing of datasets. The study also summarises the fusion of optical-SAR datasets for the study of peak vegetative growth of the crop in the season. Ferozepur is the southwestern district of Punjab state. The total geographical of the district accounts for about 2820 sq. km with the latitudinal extent of 29°56′47″ to 31°07″ North and longitudinal extent of 72°52′04″ to the East. The district has flat terrain with a gentle slope towards the southwest direction.

Administrative set up The district is divided into three tehsils namely Ferozpur, Zira and Guru Harsahai. Talwandi, Mamdot and Makhu are the three sub tehsils. The district can also be sub-divided into six developmental blocks like Firozpur, Ghal Khurd, Zira, Guru Harsahai, Mamdot and Makhu which comes under the control of the Ferozpur division. About 966 villages are inhabited with a rural population of 1125 panchayats.

Topography The district has a flat topography, as it mainly constitutes the part of Punjab Plain formed due to the Indo-Gangetic alluvial depositions. The district elevation ranges from 230 m in the northeast and 175 m in the southwest with a gradient of one meter in four kilometres. The homogenous plain physiography of the district shows significant variations at local levels. The basic terrain units constitute *(a) the Satluj Floodplain, (b) the sand dune infested regions, and (c) the upland plain.*

Canal water irrigation Major source of irrigation in the area is the canal and water from the Eastern canal is utilized for irrigation. Important distributaries in the area are Jalalabad, Ladhuka disty, Golewala disty system (as per CGWB report 2017).

Rainfall and climate the climatic conditions of the region are primarily constituted arid, hot and tropical desert types. As shown in Table 1, the annual rainfall received is approximately 389 mm, which approximately covers the area in twenty-three days. 79% of the rainfall in the region is due to the southwest monsoon, which gradually decreases due to movement from northeast to the south-west. The probability of excess rainfall in the district is about 42%.

Soil Typically two types of soil are found in the district sierozem found in the northern part and desert soil in the southern parts, which supports the agricultural practices in the district. Also, the topography of the district is predominantly formed by the Indo-Gangetic plain and Indus basin with the gentle slope facing toward the southwestern direction.

Agriculture Being one of the major agriculturally important districts of Punjab, Ferozepur is also known for the cultivation of a variety of crops. Rabi and Kharif are the two main cropping seasons of the district. The Kharif crops include Rice, Moong, sugarcane, Groundnut, Cotton etc. and prominent Rabi crops constitutes Wheat, Barley, Gram, Lentil etc., and Table 2 shows the land utilization of the district for agricultural purpose.

Datasets

a) **Satellite Data Acquisition:** The current work utilised datasets acquired by United States Geological Survey, Earth Explorer, European Space Agency and Alaska Satellite Facility. The Sentinel 1A/B mission provides open-source microwave datasets in a high temporal and spatial resolution. It also can provide data during day/night regardless of weather condition. Sentinel-1 Level-1 SLC data are being generated by the operational ESA

Table 1 Rainfall pattern in the Ferozepur district of Punjab

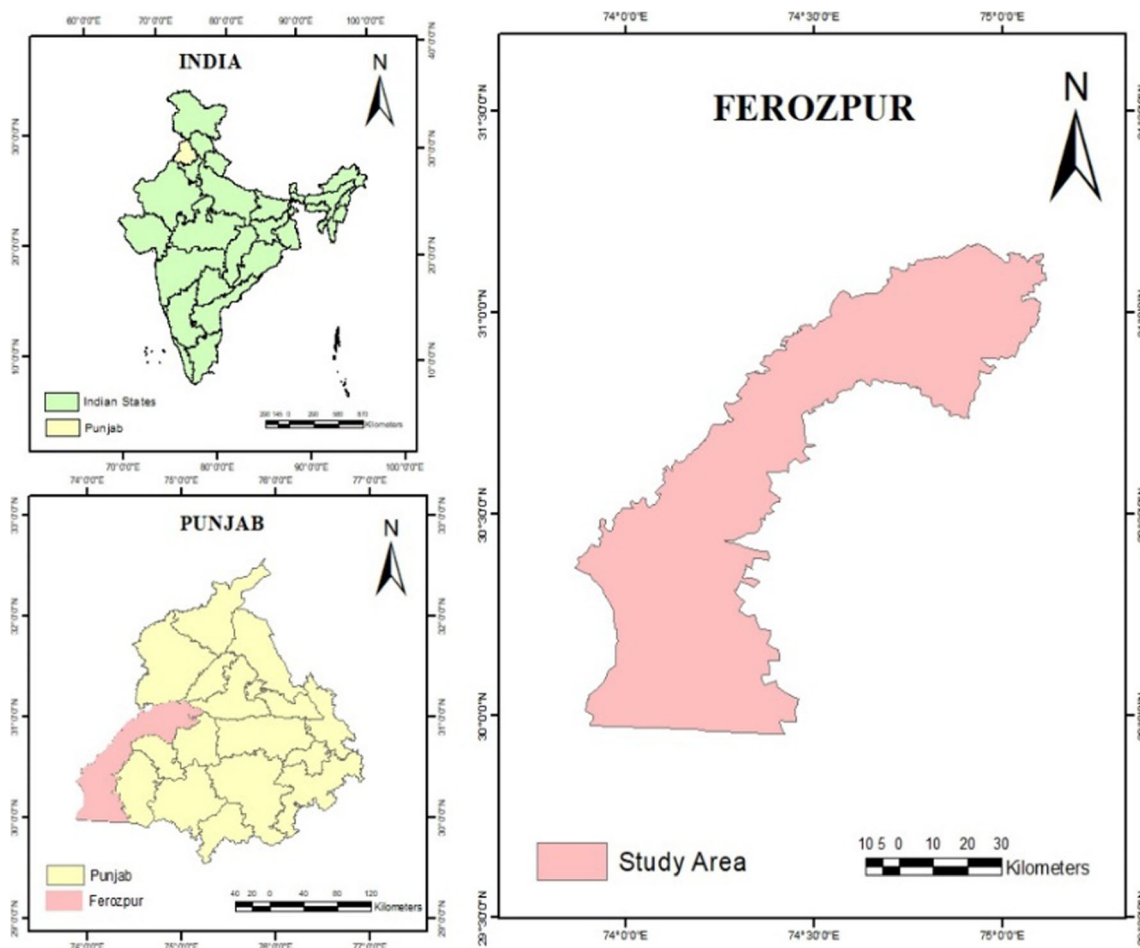| Normal Annual Rainfall	389 mm
Rainy Days	23 Days
Drought Frequency (1970–2002)	Moderate 5 Probability 0.15 Severe 1 Probability 0.03
Normal Monsoon Rainfall	79% of the total
Probability of Excess Rainfall	42%
Probability of Normal Rainfall	30%
Probability of Deficient Rainfall	27%

Fig. 1 Location map of Ferozepur district, Punjab State, India

Instrument Processing Facility (IPF). The SLC products are situated in slant range geometry. The slant range geometry is the natural radar one and is defined by the line-of-sight distance of the radar system to each reflecting object. The SLC product consists of focused SAR data in zero-Doppler orientation. Similarly, Sentinel 2A/B provides optical earth observation satellite datasets in 13 spectral bands, from visible and NIR to the short-wave infrared with a wide swath width of 290 km at high temporal resolution. Tables 3 & 4 shows the metadata of

sentinel datasets. Table 4 gives an overview of the radar data (Sentinel 1A) about data type, its acquisition, polarisation etc.

b) **Tools and Software:** ERDAS Imagine 2018, a raster graphics editor and remote sensing application used for sentinel 2A image processing and classification SNAP software have been used for SAR image pre-processing and further analysis of Sentinel 1A data of

Table 2 Agriculture - Land Utilization

Land utilization	Year	Area (in Hectares)
1. Total Area	2010–11	526,000
2. Forest cover	2010–11	12,000
3. Barren and uncultivable land	2010–11	–
4. Non-Agricultural land	2010–11	41,000
5. Misc. (cultivable waste and fallow land)	2010–11	–
6. Net area sown	2010–11	90,000
7. Area sowed more than once	2010–11	415,000
8. Total cropped area	2010–11	888,000

Table 3 Metadata factsheet for Sentinel 2A datasets along with band Details

Sentinel 2 Bands	Wavelength (micrometre)	Resolution(m)
Band 1 – Coastal aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 5 – Vegetation red edge	0.705	20
Band 6 – Vegetation red edge	0.740	20
Band 7 – Vegetation red edge	0.783	20
Band 8 – NIR	0.842	10
Band 8A – Vegetation red edge	0.865	20
Band 9 – water vapour	0.945	60
Band 10 – SWIR–Cirrus	1.375	60
Band 11 – SWIR	1.610	20
Band 12 – SWIR	2.190	20

the study area. ArcGIS 10.4 is used for post-processing and extraction of values from both optical and radar datasets for analysis and generation of map layouts. MS Word and MS Excel are used for preparing graphs and tables and for generating the outcome of the study.

c) **Methodology for Data Processing**

PRE—PROCESSING STEPS: The basic preprocessing for optical and microwave datasets includes

i) **Optical Data Processing and Analysis**

Figure 2 explains a detailed methodology for optical data processing and analysis for the wheat crop.

Layer stacking combines multiple bands into a single layer to prepare true colour composite or false-colour composite images. To prepare the false colour composite image from the Sentinal 2A/B satellite datasets, BLUE(B2) GREEN(B3), RED(B4), NIR(B4) and MIR(B11) bands were used.

Mosaicing aggregates Individual images requires to be combined to make a single image to cover the whole region.
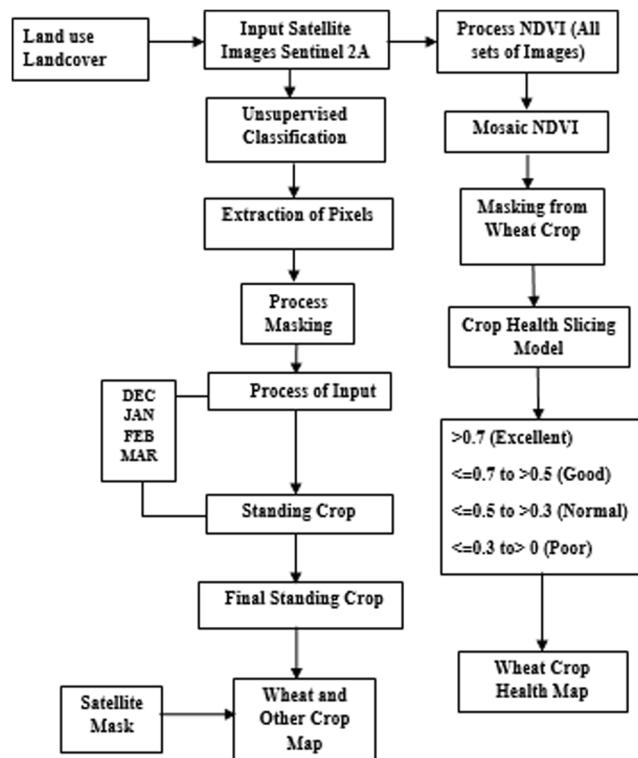
Subsetting of images are performed to clip the area of interest from the larger part of the image.

Table 4 Meta-information for Sentinel 1A datasets SAR datasets

PRODUCT TYPE	SLC (Single looking complex)
MISSION	SENTINEL-1A
ACQUISITION MODE	(Interferometric wide) IW
SWATH	IW2 (250 km)
POLARIZATION	VV and VH

ii) **SAR/Microwave Data Processing and Analysis**

Precise orbit file during the acquisition of Sentinel-1 data the satellite position is recorded by a Global Navigation Satellite System (GNSS). The orbit positions are later refined and made available as resituated or precise orbit files by the Copernicus Precise Orbit Determination (POD) Service.

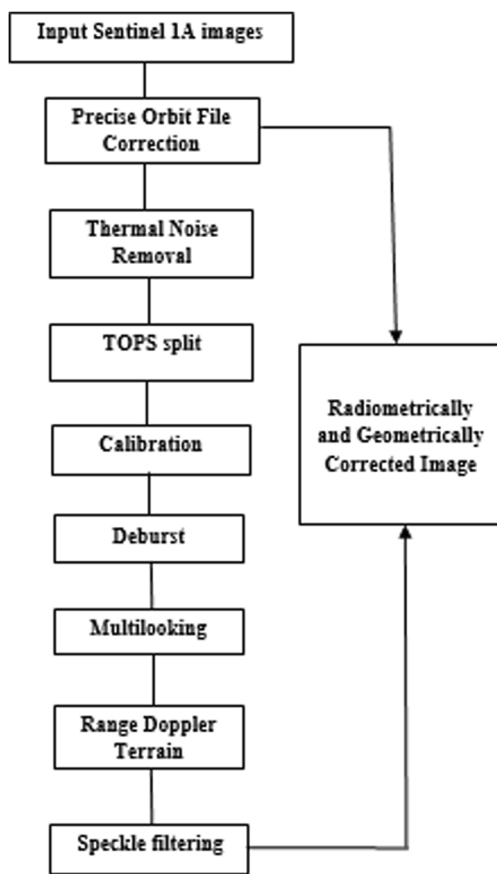**Fig. 2** Methodology Chart for Optical data processing and analysis for Wheat Crop

Fig. 3 Methodology chart for SAR data Preprocessing

the value of each pixel is directly related to the backscatter of the surface is an objective in performing calibration. Used to perform the conversion of DN to radar backscatter.

TOPSAR Deburst Sentinel-1 Level-1 SLC images acquired in IW or EW swath mode consists of one image per swath and polarisation. IW products are made up of three swaths which means three images for single polarisation and six images for dual-polarization. It is used to merge all sub-swath to retrieve one fluent image.

Geometric correction of the input data is performed by using the "Range Doppler Terrain Correction" method implemented in SNAP's S1TBX software. Data from the Shuttle Radar Topography Mission (SRTM) with a resolution of the 1-arc sec (30 m) is used for the necessary DEM.

Speckle Reduction, Speckle is a part of radar images that plays a significant role in making interpretation difficult because the "salt and pepper" effect is an aid to corrupt the information about the surface. Hence, we use speckle filters or multi look at the image.
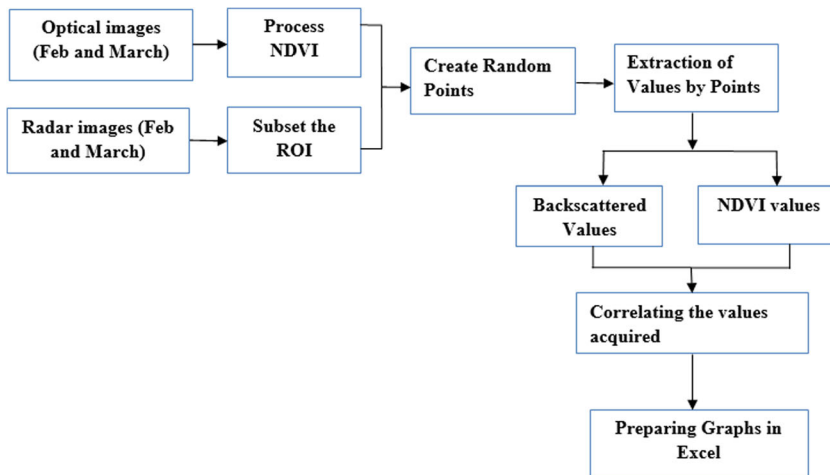
Classification Steps: It is the process of sorting the pixels into several finite classes of data based on the file values. For the study of wheat crop growth and acreage estimation unsupervised classification have been used for the extraction of various features specifically the crop grown in the study area from the satellite images of the cropping period. K-Means Clustering process has been used for classifying the data. The pixels of the image has been divided into 36 classes and later compiled and reclassified according to the purpose or requirement.

Figure 3 explains a detailed methodology for SAR data processing and analysis for the wheat crop.

iii)   **Optical- SAR Data Analysis**

Figure 4 elucidates a detailed methodology for Optical-SAR data analysis for the wheat crop.

Thermal noise removal Thermal noise is caused by the background energy of a SAR receiver and independent from the received signal power. Like some other noise factors, thermal noise appears randomly over the entire image. Thermal noise removal can only be applied on backscatter intensity therefore the phase information of the SLC data get lost.

Radiometric calibration to reduce and correct the errors in the digital numbers of the image. Creating an image where

Fig. 4 Chart showing the process of optical and SAR data fusion and analysis

Fig. 5 Raw Sentinel datasets for months of February and March. (a) VH Polarisation-February, (b) VV Polarisation-February, (c) VH Polarisation-March, (d) VV Polarisation-March

(a) VH Polarisation-February

(b) VV Polarisation-February

(c) VH Polarisation-March

(d) VV Polarisation-March
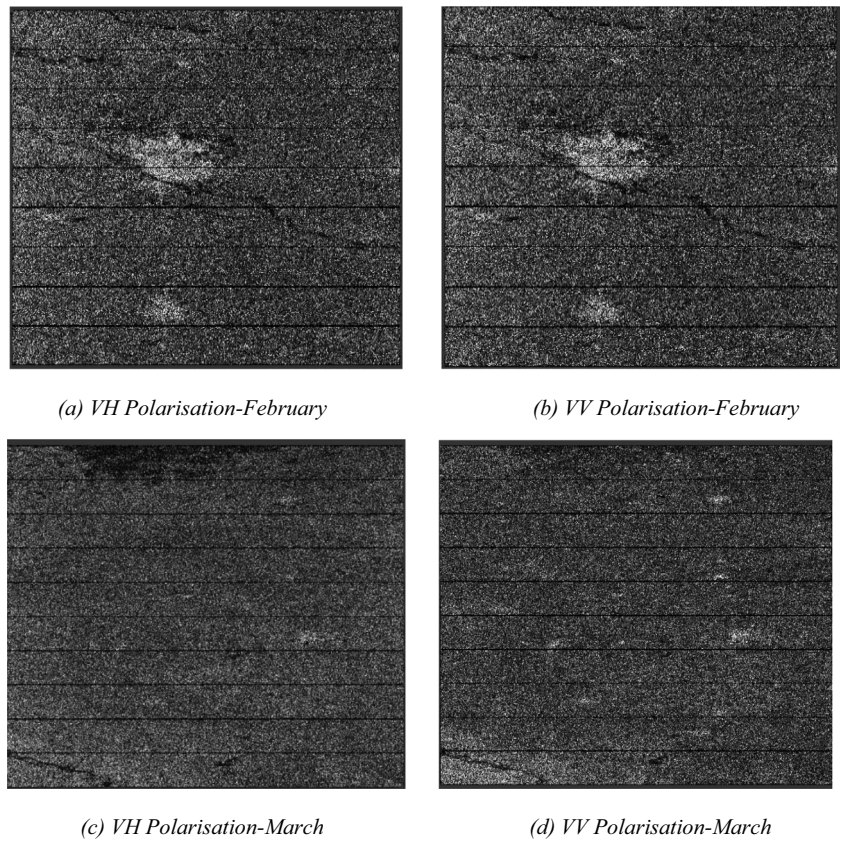
Fig. 6 Orbit corrected Sentinel 1A SLC IW datasets. a) VH Polarisation, (b) VV Polarisation
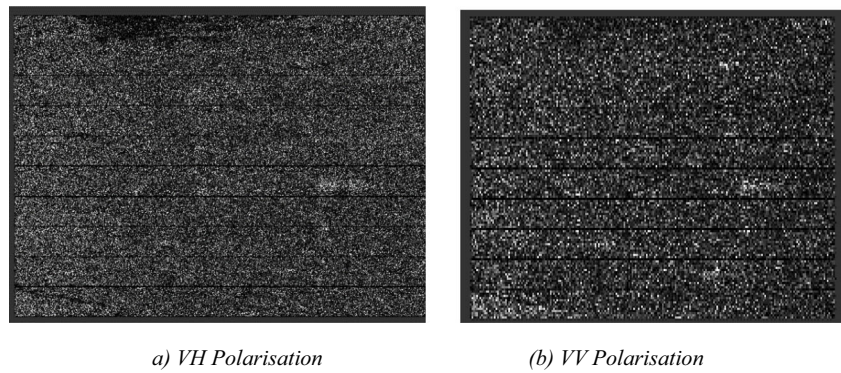
a) VH Polarisation

(b) VV Polarisation

Fig. 7 Thermal noise corrected radar datasets. a) VH Polarisation, (b) VV Polarisation
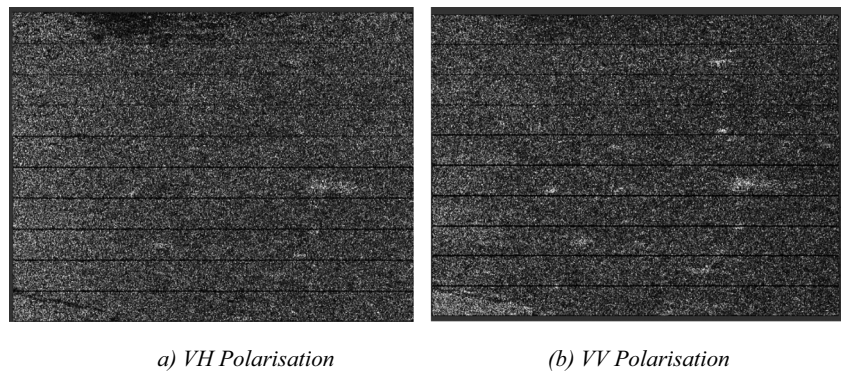
a) VH Polarisation
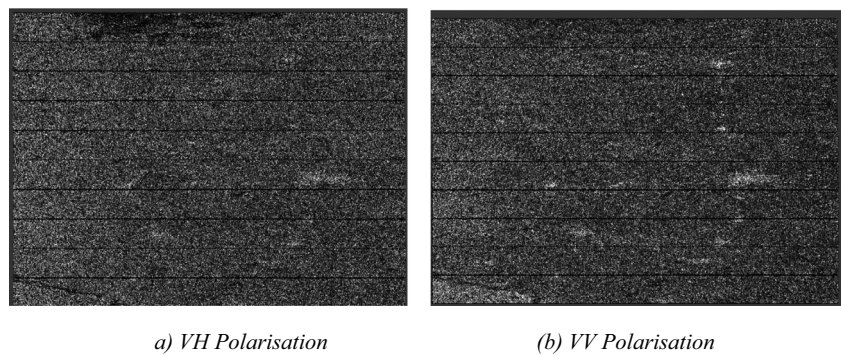
(b) VV Polarisation

Fig. 8 Radiometrically calibrated
radar datasets. a) VH Polarisation,
(b) VV Polarisation

a) VH Polarisation

(b) VV Polarisation

Results and analysis

As the current work attempts towards optical-SAR datasets processing to know the potential of the study for wheat crop in Ferozpur district of Punjab state, India based on the backscatter and NDVI values being generated. Typically various features in the radar or SAR image can be distinguished based on its backscattered values in terms of Decibels (dB). Hence, SAR data were preprocessed for quantitative analysis of vegetation and soil parameters over agricultural fields. Therefore, requisite geometric and radiometric corrections including speckle filter were applied.

Fig. 9 Sigma Naught Calibrated
Deburst Radar Datasets. a) VH
Polarisation, (b) VV Polarisation

a) VH Polarisation

(b) VV Polarisation

Fig. 10 Geometrically corrected
radar datasets. a) VH Polarisation,
(b) VV Polarisation
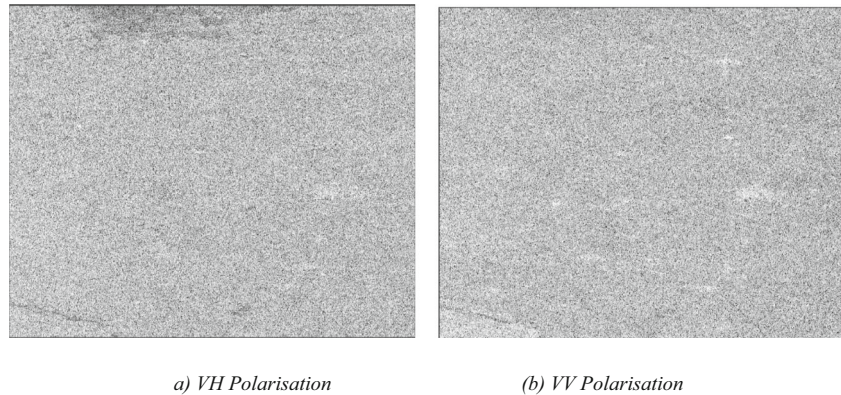
a) VH Polarisation

(b) VV Polarisation
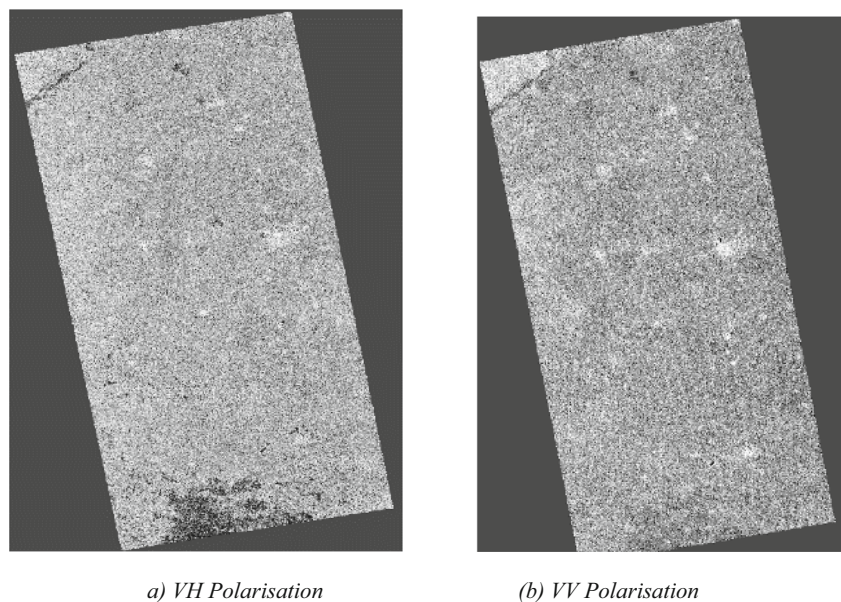
Fig. 11 Derived Results during Range Doppler Terrain Correction. (a)Derived DEM, (b) Derived Incidence angle from an ellipsoid

(a)Derived DEM

(b) Derived Incidence angle from an ellipsoid
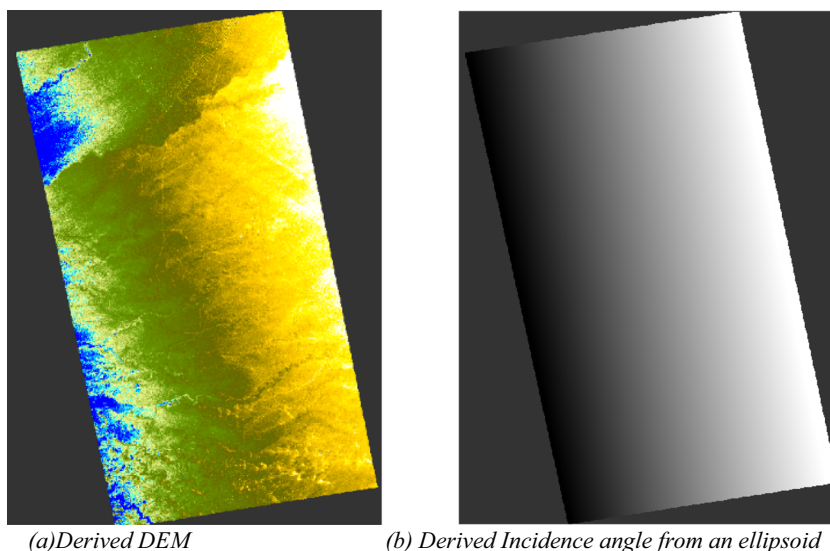
The corresponding SAR datasets of Peak Vegetative growth for the months of February and March of the wheat crop were taken into consideration for further analysis and interpretation. The Sentinel 1A raw images with polarization VH and VV are being shown in Fig. 5 and were further processed step by step with the help of the SNAP software for desired results.

a) ***SAR data Processing of Sentinel 1A SLC IW Datasets***

The first step is to apply **"Orbit File Correction"** to the raw sentinel 1A SLC IW images. It is used to update the orbit and velocity information within the SLC product. Precise orbit information can have a high influence on the quality of several pre-processing steps especially e.g. for the geo-referencing of the data.

Input: Sentinel 1A SLC IW Raw Image datasets for months of February and March and Precise Orbit File (Automatic download in SNAP).

Input: Sentinel 1A SLC IW Raw Image of February Month and Precise Orbit File (Automatic download in SNAP).

Output: Sentinel 1A SLC IW with updated orbit information.

Fig. 12 Radiometrically and geometrically corrected radar datasets. a) VH Polarisation, (b) VV Polarisation. **Note:** *The similar process were performed for pre-processing of March datasets in VV and VH Polarization*
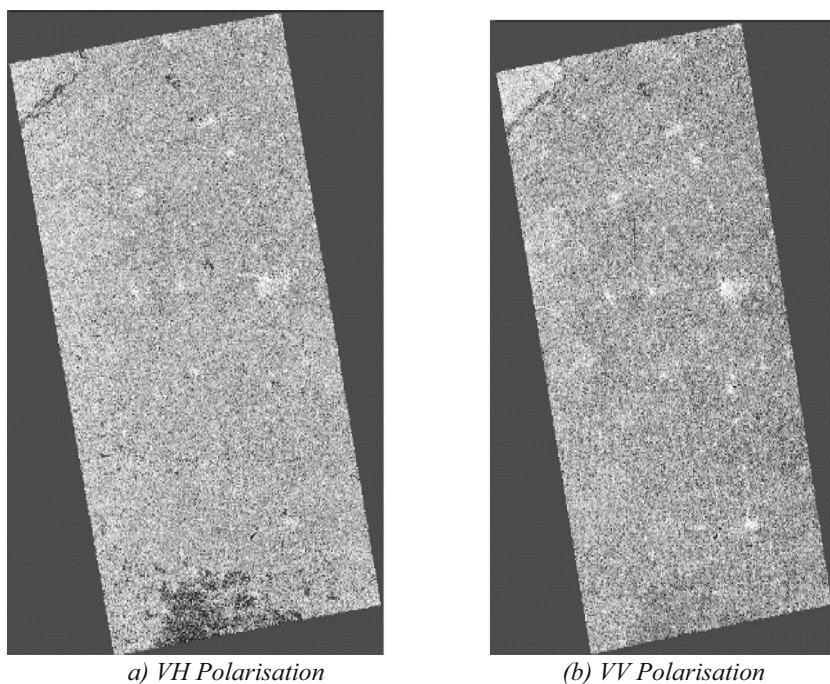

a) VH Polarisation

(b) VV Polarisation

Figure 6(a) and (b) shows orbit corrected Sentinel 1A SLC IW datasets. After that **"Thermal Noise Removal"** function is applied to the backscatter intensity therefore the phase information of SLC data get vanished. Figure 7 shows the thermal noise corrected datasets.

Input for Thermal Noise Removal function was Orbit corrected Sentinel 1A SLC IW datasets(Fig. 6).

**Output**: Sentinel 1A SLC IW corrected by thermal noise.

"Radiometric Calibration" was applied to Fig. 7 for quantitatively analysing the images. In our case, the output radar backscatter information is calibrated in Sigma nought. Figure 8 shows the radiometrically calibrated sentinel datasets.

Input for Radiometric Calibration included sentinel1 thermal noise corrected radar datasets (Fig. 7).
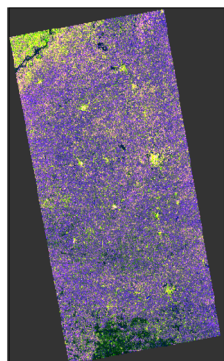
Output: Sigma nought calibrated radar backscatter Images.

"TOPSAR Deburst" operator was used to combine all the sub-swath (as shown with images as gaps) to recover as a single swath.

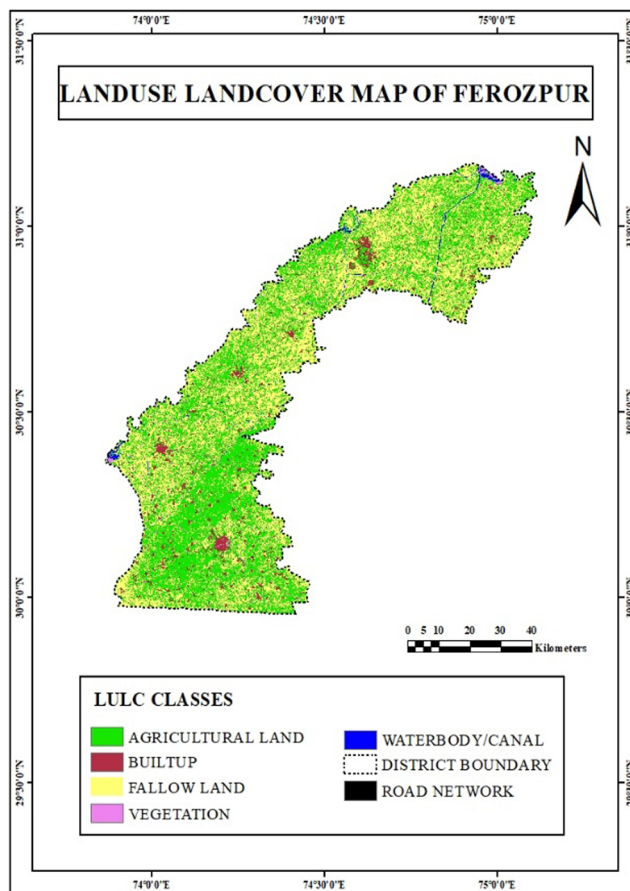**Input**: Sigma nought calibrated radar backscattered image (Fig. 8).
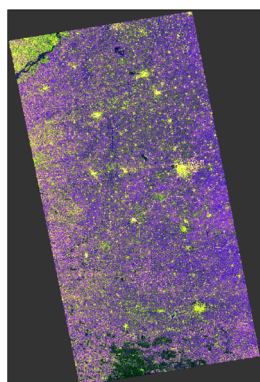
(a) False Colour Composite image for the month of February

(b) False Colour Composite image for the month of March

Fig. 13 False Colour Composite image. (a) False Colour Composite image for the month of February. (b) False Colour Composite image for the month of March

Fig. 14 Landuse land cover map of Ferozpur, Punjab State, India

Output: sigma nought calibrated radar backscattered image with fluent transitions.
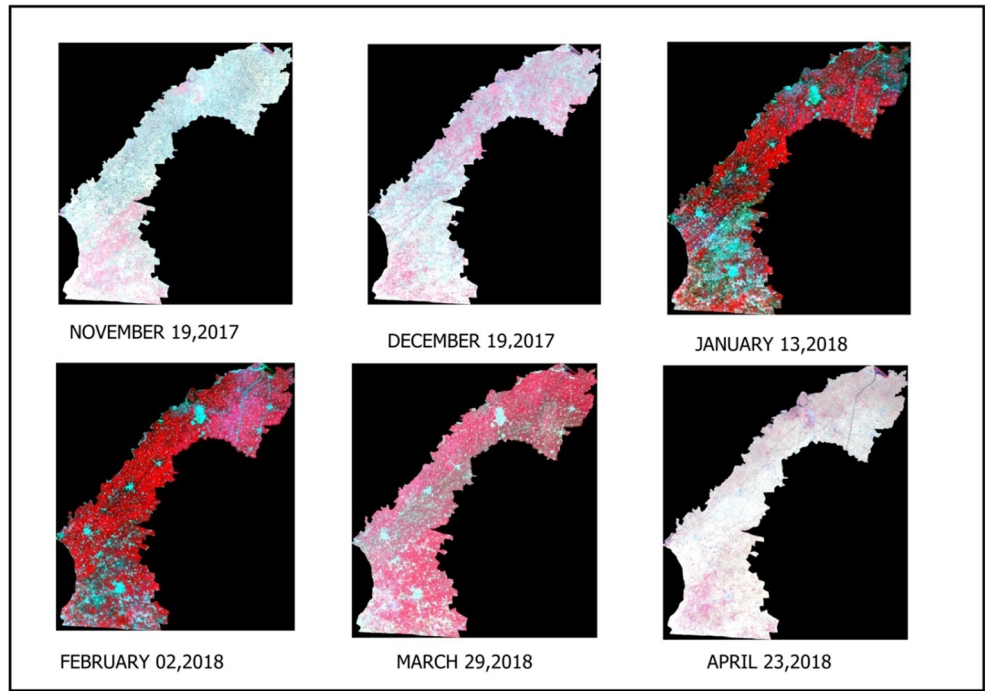
Figure 9 exhibits sigma nought calibrated TOPSAR Deburst SAR datasets. **Geometric Terrain Correction"** was performed through **"Range Doppler Terrain Correction"**. Figure 10 exhibits geometrically corrected SAR datasets.

Input: sigma nought calibrated deburst radar datasets (Fig. 9), and SRTM datasets (automatic download by SNAP).

Table 5 Summary of landuse-landcover classes with their area (in hectares)

LULC classes	Area(ha)
Agricultural land	246,393.7
Fallow land	247,608.3
Built-up	28,002.1
Vegetation/ trees	4452.93
Waterbody/ canal	4048.87
Road	1115.87
Total Area *(in hectares)*	531,621.8

Fig. 15 Sentinel 2A images of the study area showing the growth of wheat throughout the cropping period

NOVEMBER 19,2017

DECEMBER 19,2017

JANUARY 13,2018

FEBRUARY 02,2018

MARCH 29,2018

APRIL 23,2018

Output: Geometrically corrected sigma nought radar backscattered image, Incidence angle from ellipsoid, and Elevation.

Figure 11(a) & (b) exhibits derived results during range-Doppler terrain correction (*i.e. Derived DEM, and derived incidence angle from ellipsoid).* Derived DEM after the
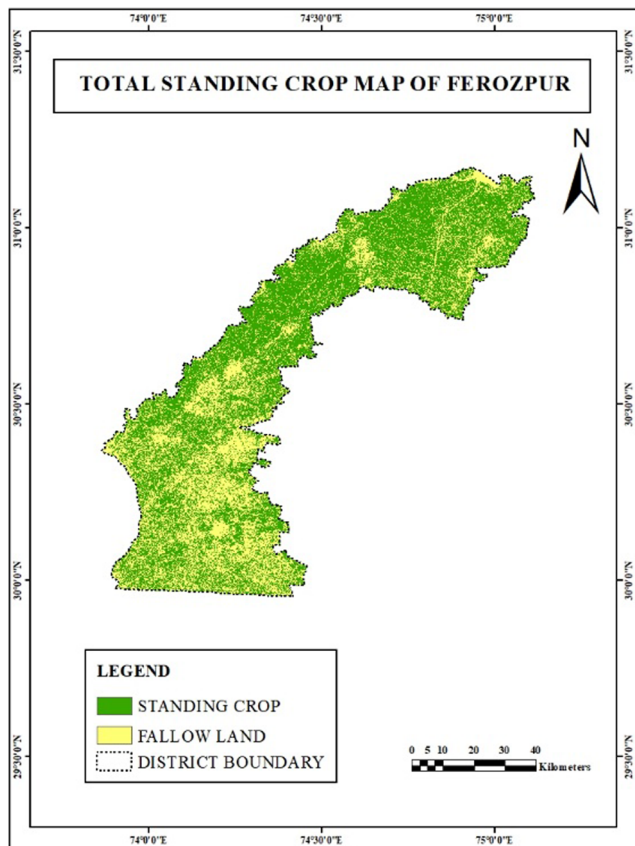
Fig. 16 Total standing crop in Ferozpur
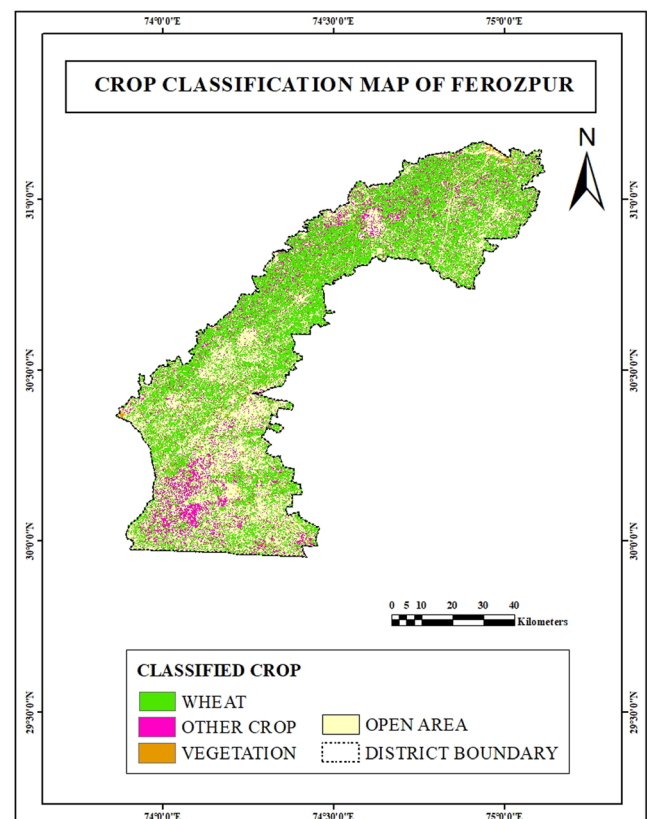
Fig. 17 Crop classification map showing wheat and other crops in Ferozpur

Table 6 Acreage of wheat

CROP (Acreage)	AREA (ha)
WHEAT	26,120,543
OTHER CROP	5,626,222
TOTAL STANDING	31,746,765

geometric correction helped to understand the topography of the study area, it was observed that the Firozpur district have a flat topography which is a prerequisite for efficient agricultural practices. On the contrary, the derived incidence angle from the ellipsoid helped to visualise the orientation of the topography.

"Speckle Filter" was used to reduce the noisy appearance of homogeneous areas of the scene. To enhance the image, a single product filtering technique with a "Lee Sigma" type filter was used to geometrically corrected the image.

Input: Geometrically corrected sigma nought radar backscattered image (Fig. 10).

Output: Radiometrically and Geometrically Corrected Speckle Reduced sigma nought radar backscattered Image.

The radiometrically and geometrically corrected image was visualised as RGB or False Colour Composite image for a better understanding of features. Figure 13(a) & (b)

were generated as False Colour Composite image with the band ratio of VV and VH polarization. The Bright yellow colour visualises habitation whereas the green and pinkish colour denotes vegetation or agricultural areas as the image acquired belongs to the area with peak vegetative growth of the wheat crop. Hence more of the area is governed by agricultural growth and represent soil moisture. Water can be easily assessed in SAR images as it shows higher negative backscattered values about $\sigma 0 < -20db$ with high absorption with low echo and typically appears black in colour.

b) ***Landuse and Landcover Map of Study Area***

The study focuses on the monitoring of the wheat crop in Ferozpur in terms of its Growth, Health and Acreage. The study also focuses on how the Satellite-based Remote Sensing Technique is useful for monitoring Agriculture. The growth of wheat from the Sowing Period (November), Germination Period (December), Peak Vegetative Growth Period (February) to mature stage (March). Ferozpur is an agriculturally dominant district of Punjab and also ranks number one in the production of Wheat, Rice and other economically important crops. The landuse landcover map of Ferozpur provides a brief introduction of the region. The table below shows the various classes along with the area. Based on
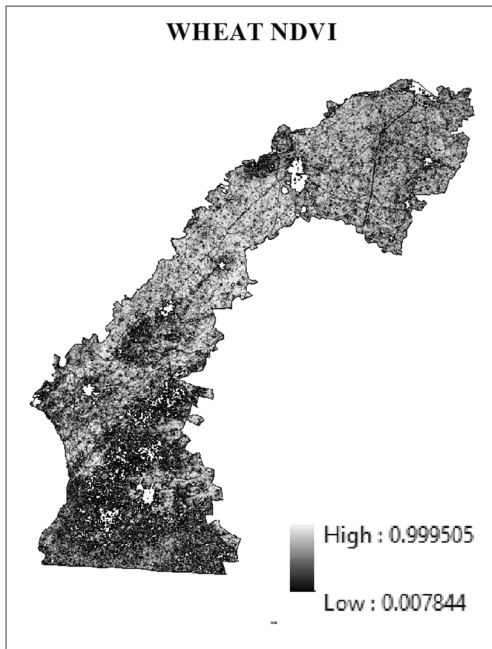
Fig. 18 Block Diagram for NDVI model

Normalized Difference Vegetation Index
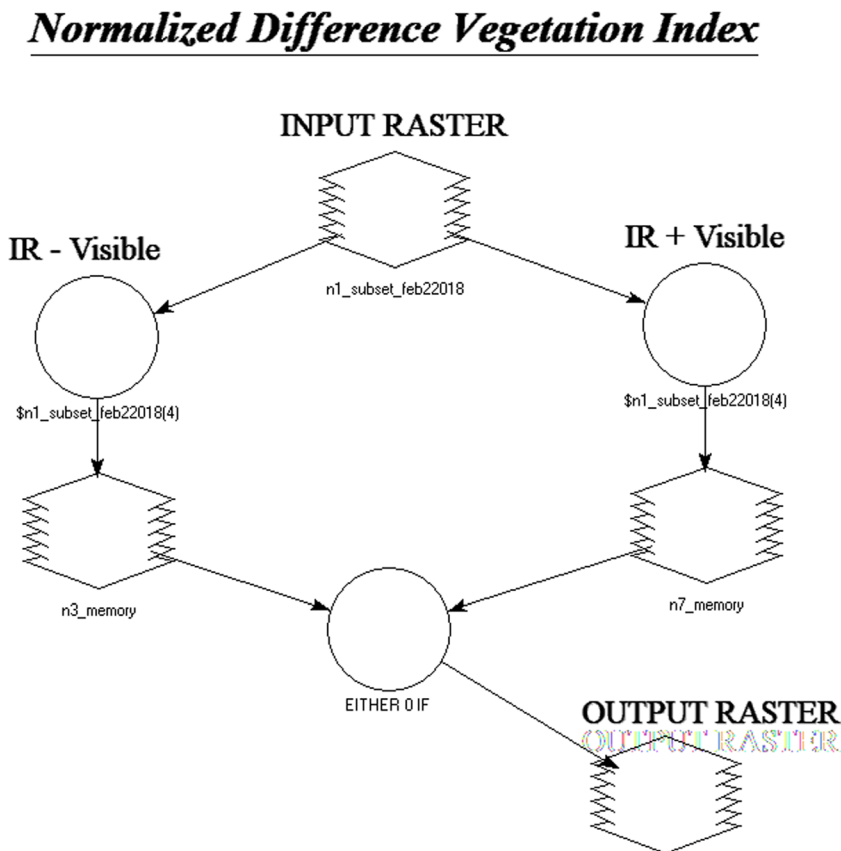
Fig. 19 NDVI of the wheat crop in Firozpur

the area calculated one can conclude that the district agriculturally dominated district supported by an efficient canal system for irrigation.

Table 5 summarises the allocation of land with various land use and land cover classes.

Figure 15 summarises the crop condition in the area (in 6 months) ranging from November 2017 to April 2018. Figure 15 also exhibits the cropping pattern of the wheat crop in Ferozpur district for a complete period ranging from

sowing period to harvesting period of the crop. The images were used to extract the total wheat in the region acreage estimation.

iii) ***Crop Estimation***

Figure 16 exhibits the area total standing crop in Firozpur throughout the cropping period of the wheat crop. The area covered by the standing crop was 317('000″) hectare in contrary to fallow with 214 ("000″) hectare. The total standing crop was extracted using the unsupervised classification technique and picking the red pixels representing the agricultural growth in the region and recorded over the other. The continuously growing pixels were studied in terms of their change in colour and reflectance pattern and taken into consideration while overlaying them over one another to extract the crop grown in the area. The data were further used to extract wheat from total standing crop and for crop classification map generation as shown in Fig. 17. It shows the area under total wheat cultivated in the region for other crop and natural vegetation. The total standing crop of the region was masked with the fallow region in April the continuous pixels are considered as wheat while the remaining red pixels were reclassified as other crops.

As shown in the Table.6, the wheat crop in the region was predominant as compared to other crops based on which the acreage of the crop is estimated as 261 ("000′) ha as it is one of the major crops of Ferozpur. From 1970 to 2010 (as per land records, Punjab) wheat has been ranked first in Ferozpur in terms of production and growth. Monitoring of wheat in terms

Fig. 20 Health Slicing Model
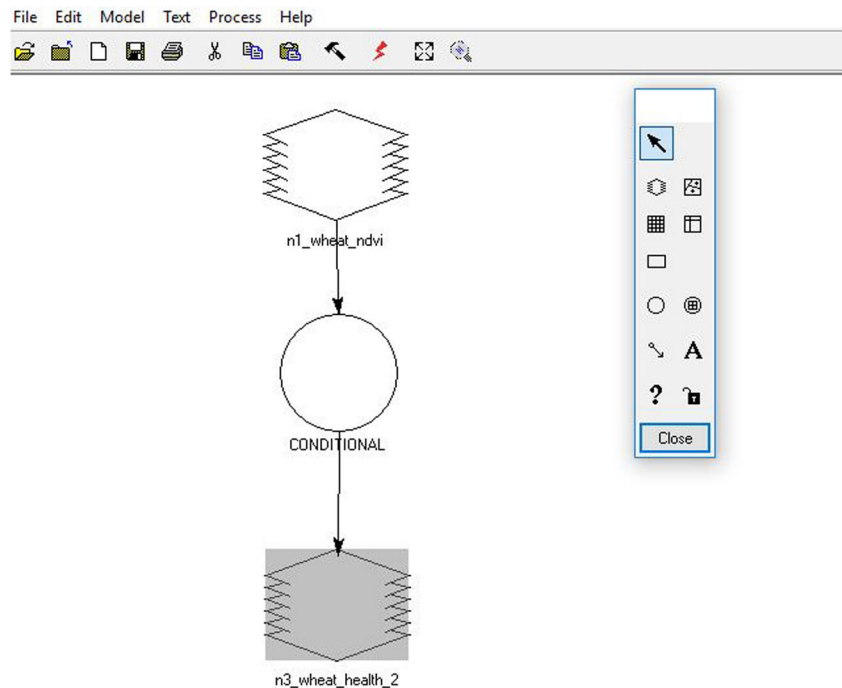
of its Growth and acreage work is useful for evaluating the past studies and estimating the future production and food security at the national and regional level. On the other, the health of the crop is also an important aspect in predicting the same, the health of the crop depends on the soil nutrient, water facility of the region. From the remote sensing perspective, the health of the crop can be evaluated using the Normalised Difference Vegetation Index Model.

iv) **NDVI Calculation**

NDVI is an image transformation technique that quantifies vegetation by measuring the difference between Near Infrared with high reflectance and Red band with high absorption (NIR-RED)/(NIR + RED). NDVI helps in monitoring the health of the crop based in the chlorophyll content of the crop as it changes from the germination phase to maturity. The NDVI of images from sowing to mature phase was generated and was mosaiced by applying maximum as an overlay function and at last masking, the NDVI with the total wheat extracted in order analyse the NDVI values of wheat only.

Figure 18 shows the block diagram for the NDVI model for vegetation quantification. Figure 19 shows the derived NDVI for vegetation quantification. Figure 20 shows the block diagram for Health Slicing Model.

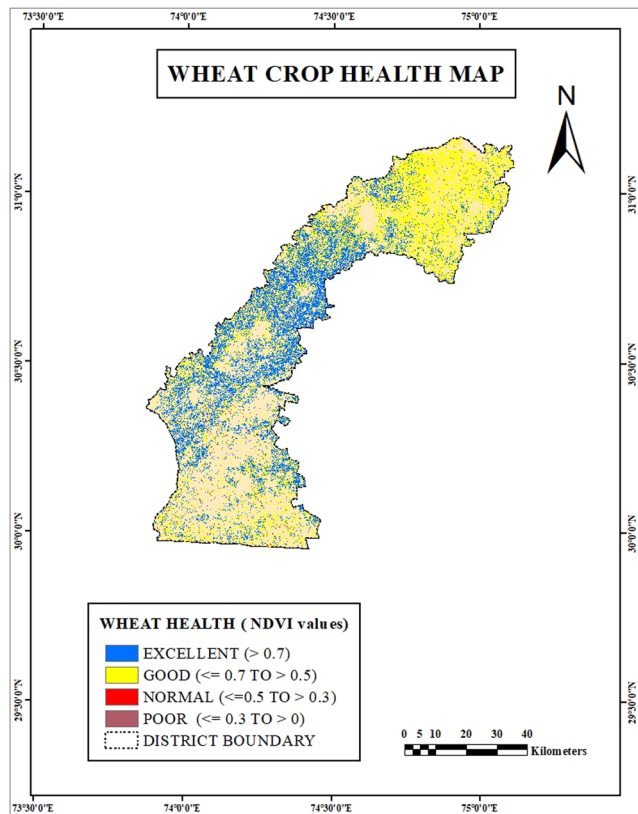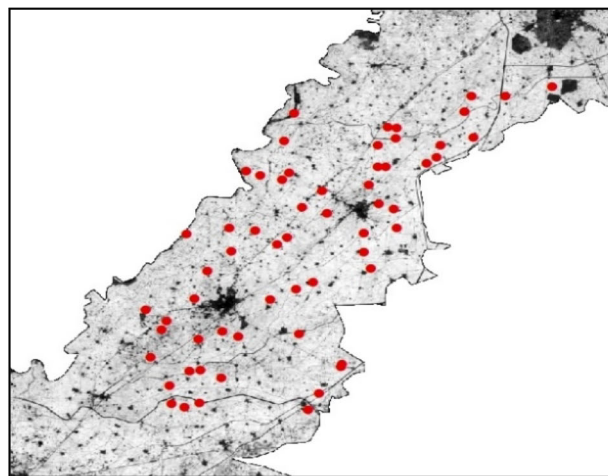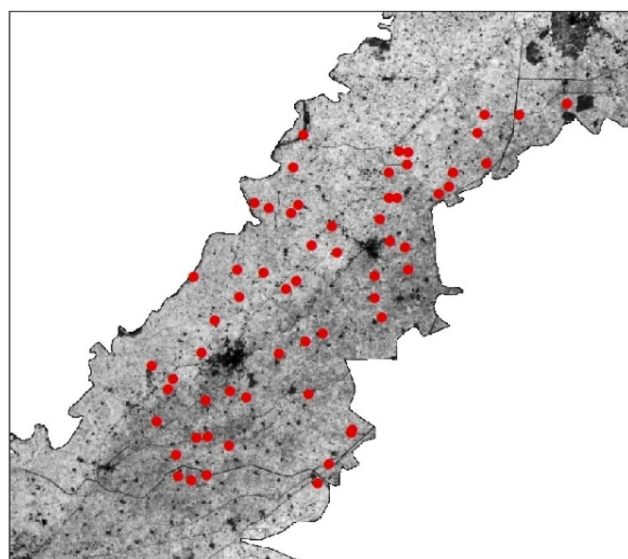e) **Crop Health Map Generation**

Fig. 21 Wheat Crop Health Map

(a) Region of interest with sample random points-February

*(b) Region of interest with sample random points-March*

Fig. 22 NDVI image of the study area with random points. (a) Region of interest with sample random points-February, (b)Region of interest with sample random points-March

The Health Slicing Model as shown in Fig. 20 was used to Slice the NDVI values into categories to represent the health of wheat crop in the study area ranging from excellent to poor. The Wheat Crop Health map represents the health of the crop in terms of the NDVI values Sliced down into four categories the maximum area of the crop falls under the excellent category of wheat which explains the good irrigation system and proper use of fertilizers and manure. A small fraction of wheat falls under the normal or poor category which could be due to water stress as they show low NDVI values.

f) **A meta-analysis of Optical-SAR datasets**

As the current study was focused on the application of optical-SAR remote datasets for agricultural applications. A

Fig. 23 Sigma Naught
Backscatter Image with random
sample points, (a) VH
Polarisation-Feburary, (b) VV
Polarisation-Feburary (a) VH
Polarisation-March, (b) VV
Polarisation-March

(a) VH Polarisation-Feburary

(b) VV Polarisation-Feburary

(a) VH Polarisation-March

(b) VV Polarisation-March
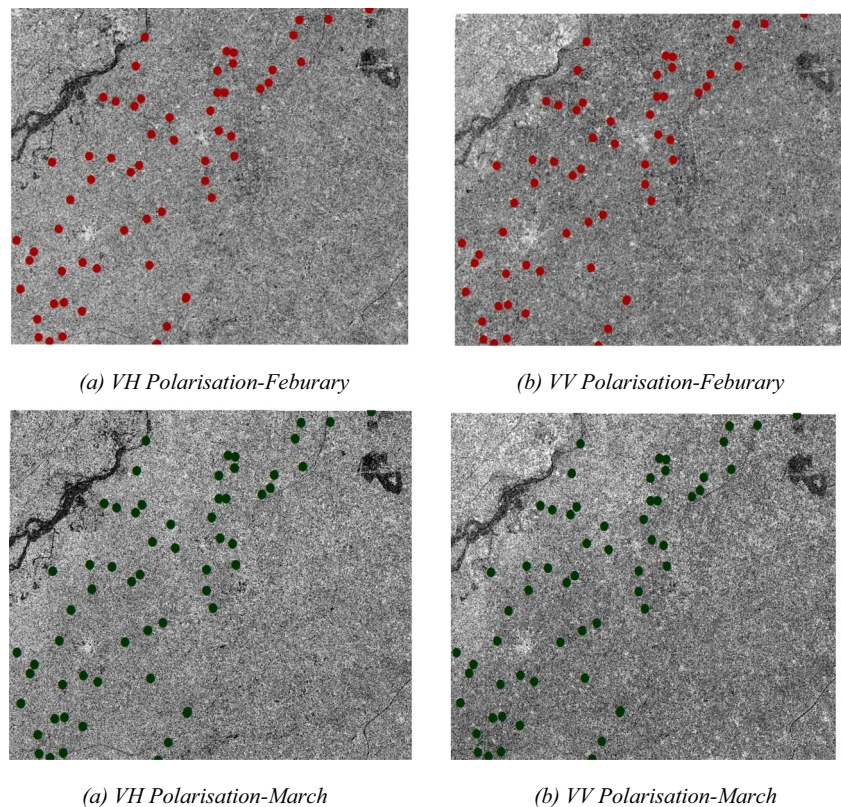
combination of datasets was tried for checking the capability in monitoring crop. It can reduce problems of data acquisition and processing, as SAR datasets are weather independent and can provide information with both day and night concerning optical data.

The meta-analysis of both the datasets combined can be studied with NDVI processed Images of Peak Vegetative Growth of the wheat crop for the months of February and March. Random Points were generated on both data to extract the values at the points. The NDVI values and the radar backscatter values were extracted for the area to develop a relationship of variation among them. Figure 22(a) & (b) exhibits the location of random points in the study area. Likewise, fgure23 (a) & (b) shows the location of random sample points over the area of interest.

Table 7 summarises NDVI values at random samples points for both months at peak vegetative phase for the wheat crop. The values in the month of February varies from 5.4 to 0.7 and in March, it varies from 0.3 to 0.6. The variation in the highlighted values indicates the transformation in the crop growth and its phenology, due to which crop reaches to mature stage (therefore NDVI values decreases). The values are further displayed using a scatter diagram (Fig. 24 and 25).

Figures 24, 25 exhibits the trends of NDVi with respect to backscatter values (in both polarisations). The NDVI and the Backscattered values were plotted along the y-axis with respect to sample points on the x-axis. The

Values acquired in February appear to show a the linear relationship of NDVI in form of $(y = 0.0004x + 0.6548)$, whereas the backscatter values in VV polarization exhibits trend with $(y = -0.0035x - 13.861)$ and for VH polarization it exhibits trend of $(y = -0.0261x - 17.492)$. Likewise for the month of march NDVI shows the trend with $(y = 0.0001x + 0.4564)$, and the backscatter values in VV polarization exhibits $(y = -0.0194x - 12.425)$ and VH shows $(y = -0.0193x - 17.037)$.

The NDVI values confirmed that the vegetative growth in the area ranges from −1 to +1 whereas the backscatter values vary with reference to features. Agricultural vegetation typically exhibits backscatter values from $-20 \, dB < \sigma0 < -10 \, dB$. The values having high variation shows better results compared to values with low variation, as they represent compressed datasets. The intercept of NDVI values for both months shows slight variation as the crop reaches the mature stage, the chlorophyll content decreases the same.

Conclusion

Crop yield is a key element in rural development and an indicator of national food security. Optical and radar RS have been used separately in most cases for agriculture applications. Increased exploitation of SAR data is expected as these data become more readily accessible and as users become

**Table 7** NDVI values extracted in the month of February and March

Random Points	NDVI FEB	NDVI MARCH
0	0.508104742	0.448780477
1	0.585652769	0.370485693
2	0.705069125	0.507206559
3	0.744572163	0.537788868
4	0.624783635	0.552034795
5	0.687079191	0.573163986
6	0.684687257	0.327419966
7	0.745005608	0.405526996
8	0.731678486	0.577902913
9	0.568376064	0.499593824
10	0.696892023	0.549850762
11	0.694512188	0.399613887
12	0.708901107	0.546860754
13	0.651352227	0.415017068
14	0.717233658	0.323770493
15	0.746234357	0.531326771
16	0.746993721	0.364202321
17	0.653210998	0.347022593
18	0.690347254	0.514792919
19	0.62472409	0.452380955
20	0.709163368	0.611382127
21	0.400897533	0.460267991
22	0.681276798	0.68925184
23	0.707033634	0.514510274
24	0.680586576	0.387769789
25	0.554973841	0.360091746
26	0.671303809	0.51221019
27	0.620797038	0.380189598
28	0.682897151	0.547122836
29	0.405186385	0.366900861
30	0.731240034	0.39729923
31	0.777491391	0.353635788
32	0.577089787	0.308289349
33	0.665040672	0.575545847
34	0.755540907	0.344599545
35	0.671668649	0.377857149
36	0.649833679	0.311525524
37	0.744616926	0.553626776
38	0.175851569	0.162768722
39	0.696903288	0.492456257
40	0.74718529	0.36142391
41	0.712183654	0.348101258
42	0.765951931	0.548520684
43	0.745482683	0.529602051
44	0.68102169	0.43608281
45	0.728530288	0.616140723
46	0.659127116	0.487057418
47	0.759355783	0.473717749
48	0.666858435	0.496774197

Table 7 (continued)

Random Points	NDVI FEB	NDVI MARCH
49	0.720136523	0.337340355
50	0.754032254	0.52049762
51	0.657383442	0.475398481
52	0.759843469	0.573103011
53	0.471069366	0.343368351
54	0.710502028	0.601571262
55	0.756564438	0.452320993
56	0.742767096	0.562167227
57	0.621585608	0.382352948
58	0.610208809	0.567224085
59	0.701424479	0.537093818

more familiar with the processing and interpretation of these data. In addition, significant research is still required to advance methods and models to derive meaningful crop information from SAR data. Recent advances in the integration of optical and SAR data for agriculture applications are shedding more light on the communities understanding of how best to exploit both imagery sources. These advancements will assist in securing more accurate results to support day-to-day decision making. Optical and radar RS is based on different physical principles. Radar data are sensitive to water content in the vegetation and the large scale structure of the canopy. Optical wavelengths respond largely to the internal leaf structure and pigmentation. SAR data do not directly measure plant parameters, such as chlorophyll, important for plant photosynthesis. However parameters indicative of plant production, such as leaf area index, influence radar backscatter.

Vegetation type identification has been successful when multi-dimensional approaches have been applied, often with accuracies at or above operationally effective goals of 90% classification accuracy. As with optical imagery, quantification of crop condition is more challenging for SAR data, particularly because radar backscatter also includes scattering contributions for the soil. Nevertheless, the integration of SAR and optical imagery for crop condition and productivity estimation appears promising. Being an agriculturally dominant country India needs to utilise new technology and advancement in the field of agriculture with the increasing transformation of land use and food security. The current work tried to utilise the combined capability of optical and SAR datasets for analysing the potential towards the study of wheat crop monitoring with a prime focus on its growth, productivity and health. The results of the study exhibited and endorsed that both datasets can be utilised coherently with each other to increase the precision of estimation. The study summarises the
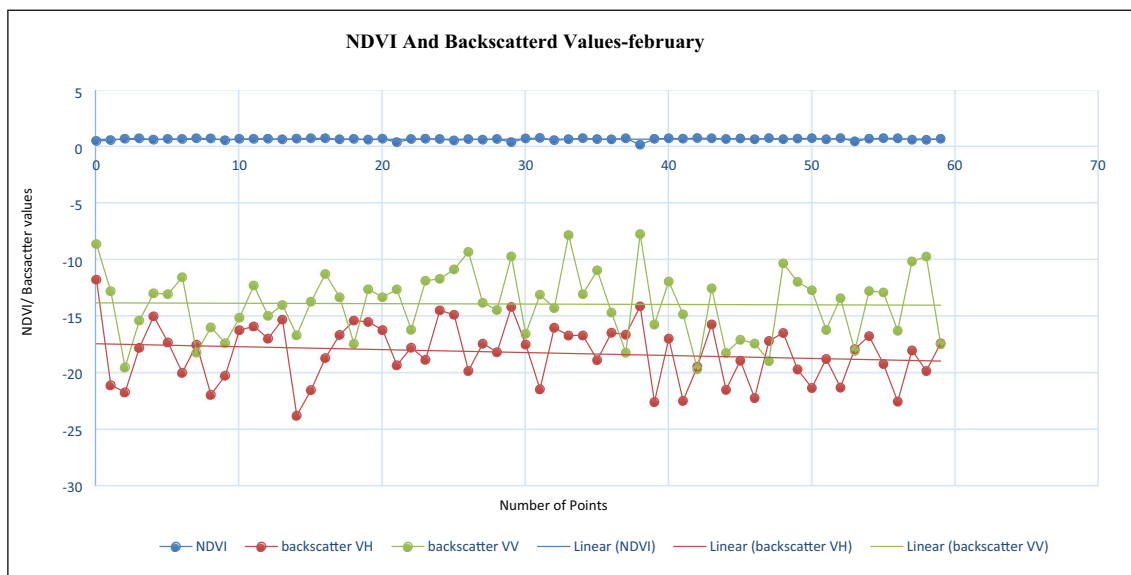
Fig. 24 Trends of NDVI and backscatter values (in VV and VH Polarisation) for February
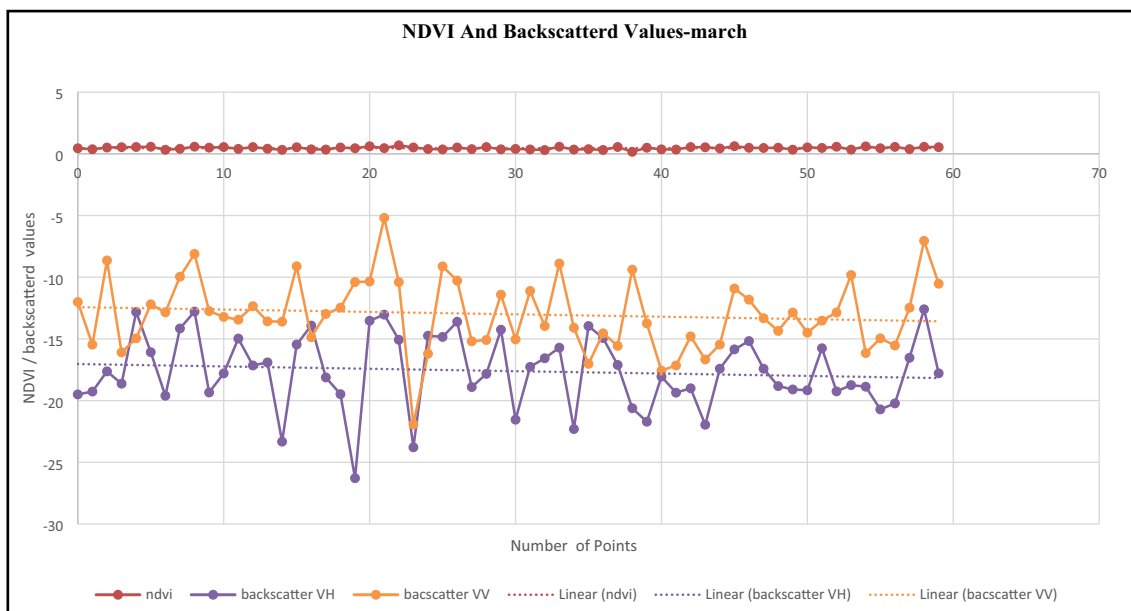
Fig. 25 Trends of NDVI and backscatter values (in VV and VH Polarisation) for March

use of remote sensing technology in the field of agriculture for estimating its acreage by extracting wheat with the help of satellite images with the application of NDVI values and Backscatter values. It also summarises the SAR data processing and utilisation capability of agricultural applications. Also, an attempt has been taken to showcase the coherent application of open archive Sentinel 1 and 2 datasets through an open-source SNAP toolbox.

Declarations

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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