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CONTENTS

Mapping rice residue burning in Punjab state using Satellite Remote Sensing

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ABSTRACT: The Punjab state, is among the major bread providers over the Indo-Gangetic Plain (IGP) region with its dominant cropping system being Rice-wheat. Due to large scale adoption of combine harvesters by most of the farmers in the state, huge amount of crop residue is left behind which is subjected to open field burning; so as to catch the next season crop. The resulting smoke act as a serious human health hazard and also pose a major threat to environment over the adjoining cities like Delhi-NCR. In this study, the major focus is on extent analysis and mapping the rice residue burning in Barnala and Sangrur districts of Punjab state for the year 2017 using Sentinel-2 satellite data. A multi-temporal, pre and post burn, vegetation and burn indices based threshold algorithm was used for estimating the rice crop and residue burnt area in ENVI 4.8 software. Sentinel Application Platform (SNAP) toolbox and Sen2Cor processor was used for format and atmospheric correction, respectively. The Normalized Difference Vegetation Index (NDVI), Normalized Burn Ratio (NBR) and difference NBR (dNBR) approach on pre-defined threshold were used to categorize the pixels as crop, non-crop, burnt and unburnt. The results indicated that out of the total geographical area of 505'000 ha, 382.94'000 ha has been estimated under the rice crop in the year 2017-18. Further, 8.65 % and 59.38 % area was mapped as burnt on 20th October 2017 and 30th October 2017, respectively. It was also observed that a total of 68.08 % of total rice crop area got burnt till 30th October 2017. The study concluded that maximum residue burning events took place towards the end of October and starting of November in the study region.

Key words: Area estimation, mapping, NBR, NDVI, residue burning, Sentinel-2

India has witnessed, significant increase in the occurrence and extent of biomass burning (including forest fire and crop residue) during the past decades. Crop residue burning is becoming an important global environmental issue, especially occurring in countries with rice-wheat cropping system like India (Lohan *et al.*, 2018; Choudhary *et al.*, 2021) and its neighbours (Gadde *et al*., 2009; Azhar *et al*., 2019; Yin *et al*., 2021). In India it occurs over the Indo-Gangetic Plains (IGP), covering almost whole of Punjab, Haryana, Uttar Pradesh, Bihar and Madhya Pradesh (Lohan *et al.*, 2018; Verma *et al.*, 2019; Liu *et al.*, 2020). As per the records of Indian Ministry of New and Renewable Energy (MNRE), the average annual crop residue production of India is about 500 million tons, majority of this crop residue is used as fodder, fuel for other domestic and industrial purposes. However, there is still a surplus of 140 million tons out of which 92 million tons is burned each year (NPMCR, 2014). Wheat and paddy residues constitute 27–36 % and 51– 57 % of crop residue production of the country, respectively (Lohan *et al.*, 2018). Punjab ranks third in the row after West Bengal and Uttar Pradesh in rice production (2019-20), having about 2920'000 hectare area under paddy cultivation and a total production of 11779.28'000 tons with an average productivity of 4034 kg/ha (APY State). In one of the reports by The Energy and Resources Institute, New Delhi, it is mentioned that the total paddy straw generated in Punjab state is around 23.07 million tons, of which 16.78 million tones are surplus biomass. The districts such as Sangrur, Ludhiana, Patiala, Moga and Ferozpur have large amount of crop residue surplus in the State (TERI, 2018). Such residue burning events in Punjab and Haryana during October and November months account for over 90% of total cases in the country (Liu *et al.*, 2020).

In Punjab, the harvesting of rice extends up to mid-November, as transplanting of rice before 15th June is not legal in Punjab as per "The Punjab Preservation of Sub-Soil Water Act-2009" (Punjab Remote Sensing Centre, 2015). At that point, farmers are unable to manage large amount of crop residues in a short time to comply with the land preparation operations for the next crop (*viz.,* wheat). Almost 85-90% of the paddy straw generated in the state is burnt in the fields by the farmers (Mukerjee, 2016), primarily due to short sowing window available for wheat crop and other reasons like; less usability as a fodder, costly-labour intensive, time consuming soil incorporation process, less market demand, poor accessibility of latest technologies by marginal farming community and cheaper rates of stubble supply by the biomass power generation units (Kaur, 2020). Moreover, poor storage facility, lack of market demand for further use, high labour wages and anxiety of the farmers to get the crop produce collected and marketed at the earliest; make the disposal of straw very difficult thereby subjecting it to get burnt in the open field. Consequently, vast cloud of smoke engulfs the whole of Punjab and nearby states of Haryana and Delhi during October–November; posing a serious threat to soil and environmental quality, and human health as well.

Agricultural crop residue burning contributes towards the emission of greenhouse gases (CO_2, N_2O, CH_4), air pollutants (CO, NH_3, NOx, SO_2, NMHC, volatile organic compounds), particulate matter and smoke; having a direct influence on global warming. Furthermore, it depletes the organic matter, major nutrients and reduces microbial biomass in the soil, thus impairing the efficacy of organic matter application in the next cropping season. It is reported that burning one ton of paddy straw, leads to a loss of almost 5.5 kg of Nitrogen, 2.3 kg of phosphorus, 25 kg of potassium,1.2 kg of Sulphur besides organic carbon from the soil and similarly, Carbon (C) present in rice straw is emitted as CO_2 (70%), CO (7%) and CH_4 (0.66%) whereas Nitrogen (N) is emitted as N_2O (2.09%) (ROTC, 2019).

Satellite data have been used to monitor biomass burning at both regional and global scales using algorithms; that can detect the location of active fires at the time of satellite overpass so as to map directly the spatial extent of the areas affected by the fire. It aims at detecting and delineating the scars left by fires using their spectral signature. The number of researchers in past has widely used MODIS data for assessment of agricultural residue burning (Singh and Panigrahy, 2011; Verma *et al*., 2019; Azhar *et al*., 2019; Liu *et al*., 2020; Yin *et al*., 2021). Burnt areas have also been mapped, using Landsat TM (Jha *et al*., 2019) and SPOT data (Pereira and Setzer, 1993). These sensors have a high temporal resolution due to wide viewing swaths (512km-3000km), while their spatial resolution varies between 250m (two bands in MODIS) and around 1 km (all other sensors) and include spectral bands of varying amount and widths (Eva and Lambin, 1998). Low spatial resolution (250m – 1000m) however restricts the capability to detect the small burnt areas, and therefore questions the reliability of large-scale burnt area mapping in areas where small burn scars strongly contribute to the total burnt area. The recent advancements in sensor characteristics at finer resolution gives the way out to resolve the shortcomings of coarse-resolution sensors. More recently the ESA's SENTINEL-2 with 10m, 20m, 60m spatial resolution and relatively high receptivity of 5 to 10 days can also be used for fire area mapping by the use of NIR and SWIR bands (Huang *et al.,* 2016; Roteta *et al.,* 2019; Roy *et al*., 2019; Singh *et al*., 2021). Therefore, by keeping in view the need of present alarming issue of residue burning, the present study was undertaken with the objective of "Mapping Rice Residue Burning in Punjab state using Satellite Remote Sensing".

MATERIALS AND METHODS

Study area: Punjab, a northwestern Indian state is situated between 29º 30' N to 32º 32' N latitude and 73º 55' E to 76º 50' E longitude. The state has 22 districts and covers a total geographical area of 50,362 square kilometers which is 1.54% of India's total geographical area. (Fig. 1). Acreage wise Punjab accounts for 7.09% and 12.08% of wheat and rice, respectively and simultaneously contributes to 17.05% and 11.01% of wheat and rice produce in the country (Agricultural Statistics at A Glance 2019). The state has three distinct seasons, *viz.* the summer season (April to June), rainy season (July to September), and the winter season (October to March). The highest temperature in the state is recorded in June (44.2°C - 44.7° C) and the lowest (0°C-2.2°C in December.) The mean annual rainfall is 705 mm, which varies from 1200 mm at Pathankot to less than 300 mm at Abohar, representing the wettest and driest stations, respectively. Out of the 22 districts in Punjab, only two districts Sangrur and Barnala have been considered for the present study as these districts account for huge rice area in the state. Moreover, these two are amongst the worst affected areas by residue burning in the state approximating to 326'000 ha and 292'000 ha of burnt rice area during 2014 and 2015, respectively (Punjab Remote Sensing Centre, 2015). The districts fall in the southern part of Punjab. Cropping intensity of Sangrur and Barnala is 199% and 200%with an average rice productivity of 1353 and 567 kg/ha, respectively (Punjab at a Glance, 2019). The total area

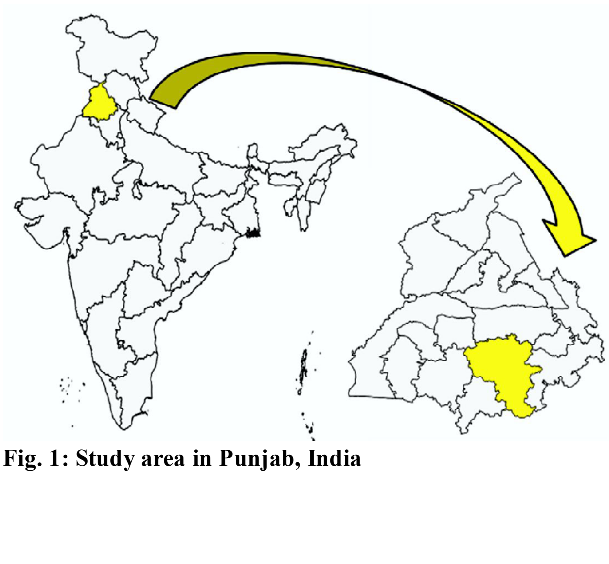

Fig. 1: Study area in Punjab, India

under rice cultivation for the year 2011-12 of both the districts (Barnala and Sangrur) has been obtained from government sources (Area and Production Statistics) so as to compare the estimates with actual for achieving higher estimation accuracy.

Satellite Data used: Multi-date multi-spectral remote sensing images from SENTINEL-2 satellite have been used in the study. The Sentinel-2 mission is capable of providing multi-spectral data with 13 bands in visible, near infrared, and short wave infrared part of the spectrum (Table 1). The study imageries were taken from the Copernicus Open Access Hub (previously known as Sentinels Scientific Data Hub) platform which provides complete, free and open access to all the sentinel user products. Open Access Hub, which could be accessed via https://scihub.copernicus.eu/ is an access point for all Sentinel missions with access to interactive graphical user interface. SENTINEL-2 products (Level-1B: Top of atmosphere radiances, Level-1C: Top of atmosphere reflectances and Level-2A: Bottom of atmosphere reflectances) are available for users (either generated by the ground segment or by the SENTINEL-2 Toolbox). The products are a compilation of elementary granules of fixed size, along with a single orbit, where a granule refers to the minimum indivisible partition of a product (containing all possible spectral bands). For Level-1C and Level-2A, the granules, also called tiles, are 100x100 km^2 ortho-images in UTM/WGS84 projection. For the present study S2A-L1C product has been used as it is available for the users on the open access hub.

Methods of estimating burnt area extent: The pre and post burn analysis for monitoring residue burning (McCarty *et al.,* 2009; Singh *et al.,* 2009; Punjab Remote Sensing Centre, 2015) and threshold-based detection algorithm (Vafeidis and Drake, 2005) for active fire detection has been adopted in the present study. As the study is concentrated on estimating area under paddy straw burning, multidate images of S2A L1C for the three dates

Table 1: **Sentinel-2 wave-band's wavelength and spatial resolution**

Band	Band	Central wavelength (nm)	Bandwith (nm)	Spatial resolution (m)	Objective
B1		443	20	60	Aerosol Correction
B2		490	65	10	Aerosol Correction, Land Measurement Band
B3		560	35	10	Land Measurement Band
B4		665	30	10	Land Measurement Band
B5		705	15	20	Land Measurement Band
B6	VNIR	740	15	20	Land Measurement Band
B7		783	20	20	Land Measurement Band
B8		842	115	10	Water Vapor Correction, Land Measurement Band
B8a		865	20	20	Water Vapor Correction, Land Measurement Band
B9		945	20	60	Water Vapor Correction
B10		1380	20	60	Cirrus Detection
B11	SWIR	1610	90	20	Land Measurement Band
B12		2190	180	20	Aerosol Correction, Land Measurement Band

i.e., pre-burning period (30th September, 2017) and post burning period (20th October, 2017 and 30th October, 2017) have been acquired. After incorporating required atmospheric image corrections, the study area was masked with the help of administrative boundary layers in GIS environment. Consequently, the vegetation and burnt area indices were worked out along with other spectral bands for burnt area estimation. Further, the non-agricultural areas were also masked out to improve the classification accuracy and the total area was assessed by figuring pixels under the masked classified image for each category following Yadav *et al.* (2014). The flow diagram of methodology followed in the study has been depicted in Fig. 2.

Image Analysis Software Used: Sentinel Application Platform (SNAP), developed by ESA is a toolbox used for processing Sentinel products. This was used to change the format of satellite images and for resampling of images at 20 m resolution as sentinel 2A is a multi-resolution sensor which needs to be brought down at a particular scale for further image processing. Sen2Cor, a processor for Sentinel-2 Level 2A product generation and formatting; it is primarily used for performing atmospheric-terrain and cirrus correction of Top-Of- Atmosphere Level 1C input data (Huang *et al.*, 2016). It also creates Bottom-Of-Atmosphere, optionally terrain and cirrus corrected reflectance images; and additionally, Aerosol Optical Thickness, Water Vapor, Scene Classification Maps and Quality Indicators for cloud and snow probabilities. The output product format of Sen2Cor is equivalent to the Level 1C User Product: JPEG 2000 images at three different resolutions, 60, 20 and 10 m. ENVI 4.8 software was used for generation of different indices for estimation of burnt area extent over the study area.

Generation of Indices for detecting burnt pixels: In the present study, mainly two indices were used to estimate

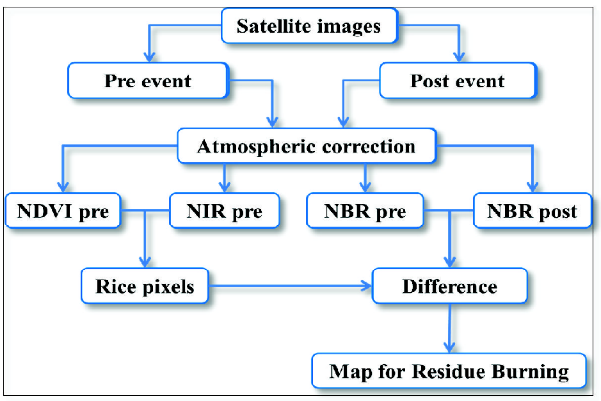

Fig. 2: Flow diagram of methodology followed in the study

the area under residue burning. These indices were selected on the basis of previous work done by various researchers for detecting the burnt scars (Chuvieco *et al*., 2002; McCarty *et al*., 2009; Singh *et al*., 2009; Yadav *et al.,* 2014).

Normalized Difference Vegetation Index (NDVI): The spectral contrast offered by red and near-infrared channels in case of healthy vegetation and burnt areas, provides the basis for using this technique for burnt area extraction. Healthy vegetation tends to give rise to high NDVI values, because it has a high reflectance in the near infrared and a low reflectance in the visible; on the other hand, burnt surface give rise to lower NDVI values because its reflectance is high in the visible spectrum and low in the infrared. The following equation was used for generating NDVI images.

$$NDVI = (NIR - R)/ (NIR + R)$$

Where, R and NIR are satellite reflectance in the visible (red) and in the near- infrared, respectively.

Normalized Burn Ratio (NBR): It is another band ratio similar to the NDVI, which utilizes the near-infrared and shortwave-infrared bands. Imagery collected over an agricultural area in a pre-fire condition will have high NIR band values and very low mid-infrared band values. Contrary to this, imagery collected after a fire incidence has low NIR band values and high mid-infrared band values. The USDA Forest Service and U.S Geological Survey uses the change in NBR (dNBR) between pre and post burning events method to map the extent of burning. The following equations were used for generating the pre-burn and post-burn NBR images and finally difference NBR (dNBR) image was generated.

$$NBR = (NIR - SWIR) / (NIR + SWIR)$$

$$dNBR = (NBR_{\text{pre-burn}} – NBR_{\text{post-burn}})$$

Where, NIR is the reflectance in the near- infrared and SWIR is the reflectance in the middle infrared.

Determination of Threshold values: The thresholds determination is very important to flag the pixels as crop area or non-crop area and burnt or unburnt pixels. Pixels whose values fall below or above the set thresholds are classified as burnt or unburnt. dNBR ranges which has been earlier used by Baloloy *et al.* (2016) were used to fix the threshold and mark a pixel as burnt in this study.

RESULTS AND DISCUSSION

It has been observed that the rice area has increased in Barnala and Sangrur from 105’000 ha to 114’000 ha and 274’000 ha to 287’000 ha, respectively from 2011-12 to 2018-19 (Table 2). Data records before 2017-18 were used for improving the estimation accuracy and to get a closer match with actual rice area. The FCC (False Color Composite) image of study area (Fig. 3). Similarly, the NDVI image of pre-burning period (30th September, 2017) was created to map the crop pixels in the study area, as during this time, rice crop is supposed to be at maximum growth in Punjab, giving a high value of NDVI. Later, the NDVI image in combination with the reflectance in NIR region was used to generate crop mask over Barnala and Sangrur (Fig. 4). As a result of hierarchical decision rule-based classification, the total rice area estimated for Barnala and Sangrur was 382.94’000 ha with a slight deviation of -3.54% of the actual total rice area for the year 2017, which was within the acceptable range (Table 3).

Spectral signatures of pre-burning period (30th September, 2017) and post-burning period (20th October, 2017 and 30th October, 2017) were studied and subsequently Normalized Burn Ratio images were created. It was observed that the pre-burning NBR image had high NIR band values and low mid-infrared band values for the crop pixels whereas, the post-burning NBR images revealed reverse band values (Fig. 5). These NBR images were used for calculating dNBR. One threshold value of dNBR was

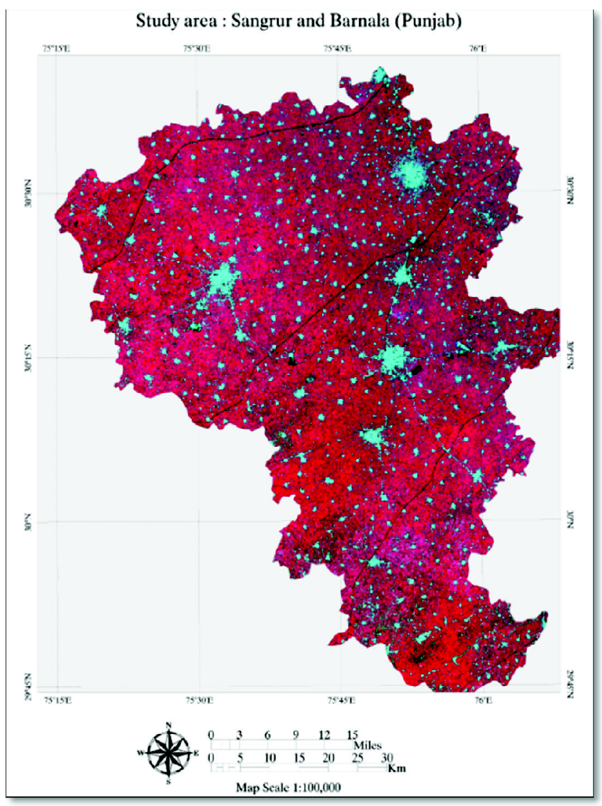

Fig. 3 : FCC satellite image of the study area

Table 2: Area under rice cultivation over study region.

Year	Barnala (000 ha)	Sangrur (000 ha)	Total (000 ha)
2011-12	105	274	379
2012-13	106	276	382
2013-14	107	273	380
2014-15	108	271	379
2015-16	110	274	384
2016-17	112	278	390
2017-18	113	284	397
2018-19	114	287	401

Table 3: Total area mapped by statistical analysis of images for the year 2017-18

Study Region	Sangrur and Barnala
Total Geographical Area- Reported (000 ha)	502
Total Geographical Area- Estimated (000 ha)	505
Total Rice Area- Reported (000 ha)	397
Total Rice Area- Estimated (000 ha)	382.94

Table 4: Estimated rice area burnt on two different dates

Particulars	Area ('000 ha)	Area (% of estimated crop area)
Estimated rice area burnt on 20th October 2017	33.33	8.65
Estimated rice area burnt on 30th October 2017	227.38	59.38
Total estimated rice area burnt in one month	260.71	68.08

decided and the pixels having values more than the threshold were mapped as burnt and below that were mapped as unburnt. Singh *et al.* (2021) also reported dNBR as the most practical tool (91.98 % accuracy) for discriminating and mapping of burnt and unburnt area in comparison to NDVI (75.86 % accuracy). The total burnt area for each date was calculated by carefully computing

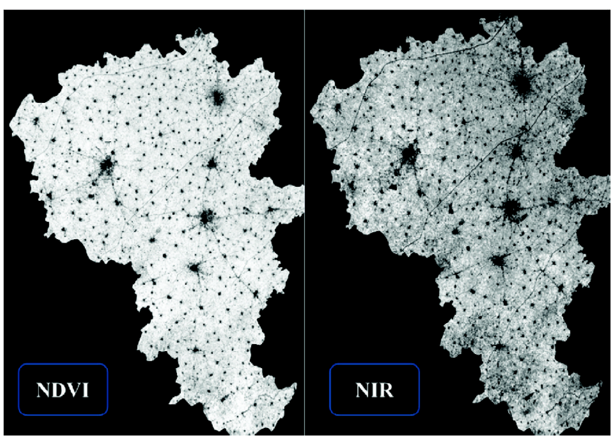

Fig. 4: Pre burning NDVI and NIR images for classification of rice area

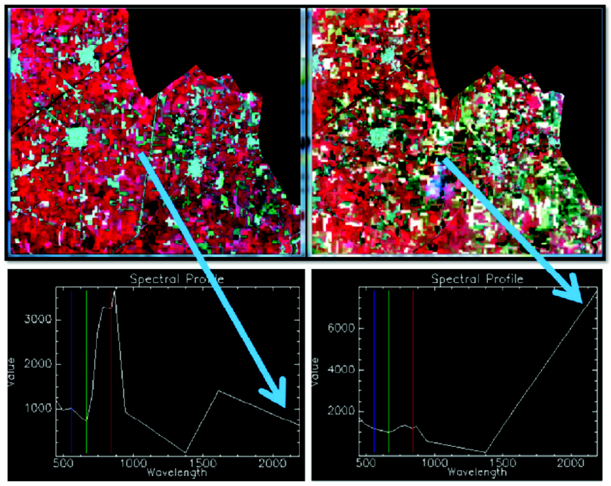

Fig. 5: FCC images and corresponding spectral curve of pre burn and post burn pixels

the total number of pixels in each category (Table 4). As a result, it was noticed that 8.65 % of total rice area was burnt on 20th October 2017 which further increased to 59.38 % on 30th October 2017, within a very short time period (10 days only). It reveals that probably, maximum number of burning events in these two districts took place between 20th October to 30th October.

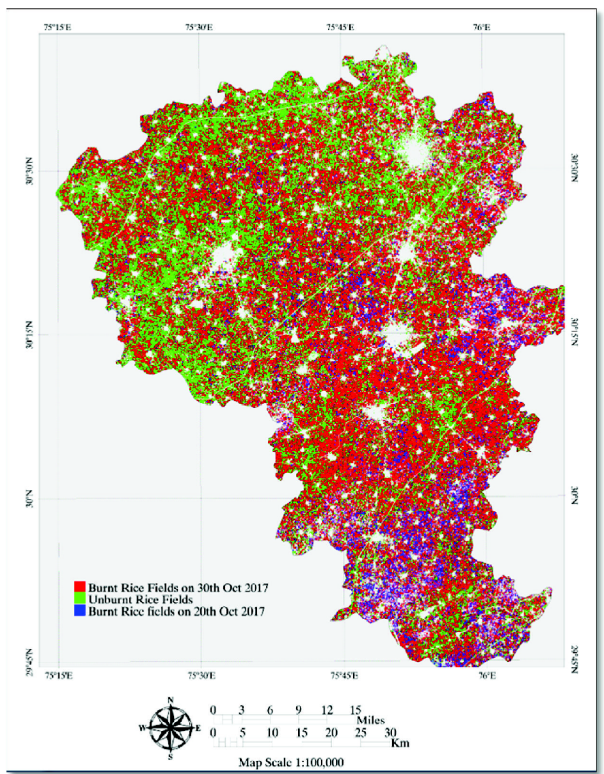

Fig. 6 : Map of area showing unburnt and burnt rice fields on different dates

Finally, a combined map was created, considering all the dates under analysis (Fig. 6) by using the band math function in ENVI. It was found that more burnt areas were captured between 20th to 30th October 2017. Statistical analysis also revealed that a total of 260.71'000 ha rice area had been burnt over the study region, which accounts for 68.08 % of total cropped area for that year. Punjab Remote Sensing Centre (2015) also reported that maximum burning events in Punjab takes place between 29th October – 11th November and by the end of the crop season. Around 75% of rice fields are put to fire in order to do timely sowing of next winter crop.

CONCLUSION

In context of environmental and agriculture sustainability, the area specific and need based cost-effective alternatives may be provided by the government and researchers that may suit to all socio-economic groups to stop the practice of residue burning. By that time, the real time monitoring of such fire events and its spatial extent analysis using satellite remote sensing is necessary to have a bird eye view on start, end and peak time of fire events. As the study revealed that nearly 68% of total rice area was burnt by 30th October in Barnala and Sangrur districts, possibly the same could be the condition of entire state. The maps prepared and information reported could form the basis for other studies on environment and land degradation. Nearly 382'000 ha area was reported under crop residue burning in two districts of the state but it may be a huge area in the state, and that too on highly fertile IGP land. Other researchers may take it forward on various aspects like, spatio-temporal change analysis of soil properties and loss of microbial biodiversity due to residue burning, quantification of pollutants generated and reduced radiation during such fire events, plant microclimate change detection and its impact on plant growth, etc. Quantification and pictorization or mapping of this will definitely attract the attention of researchers and policy makers, as it will raise the question on national food security as well.

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