Research article

Stubble burn area estimation and its impact on ambient air quality of Patiala & Ludhiana district, Punjab, India

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A B S T R A C T

Stubble burning during October and November, results in the extensive formation of smoke cloud over the Punjab region, and maybe one of the main reasons behind the increase in air pollution levels in these areas. The manual detection and estimation are tedious, lengthy and unpractical, so several researchers have been using remote sensing and GIS technique to estimate stubble burn areas and forest fires. Thus, in the present study, an attempt has been made to detect and estimate the stubble burn area. Landsat 8 OLI images are used to detect the stubble burn area for the year 2014-18 for Patiala and Ludhiana, which are major rice producing districts of Punjab. Normalize Burn Ratio (NBR) index have been used to determine the burned area in an image using a statistical threshold technique (2σ approach). The results have been validated using available as well as collected Ground Control Points (GCPs) and accuracy assessment has been conducted by generating an error matrix. It has been estimated that the stubble burn area was reduced by 32% and 40% during the study period for Patiala and Ludhiana regions, respectively. The monthly variation for various pollutants (RSPM, NO_x and SO_2) during the study period has also been studied and analyzed. The distinct increase in pollutant levels has been observed during each stubble burning period. The results also indicate that the amount of emitted RSPM and NO_x was higher than the emitted SO_2 during stubble burning. The wind rose diagrams have also been plotted.

1. Introduction

Stubble burning is now recognized as one of the significant activities that degrades ambient air quality as it is one of the major sources of aerosol and gaseous pollution (Andreae and Merlet, 2001). A study has reported that humans are responsible for about 90% of biomass burning with a negligible percentage of natural fires contributing to the total amount of vegetation burned (Mittal et al., 2009). It has increased over the past decade due to excessive use of combine harvester that leaves stalks that are about one-foot tall and cannot be tilled back into the soil. The burning is considered as the easiest and economical option for management and removal of the stubble. Due to a lack of awareness or non-availability of suitable technologies, it is generally practiced in many countries. Annual biomass burned in Asia at an enormous scale, a residue of crop burning of India and China are 84.0 Tg and 110.0 Tg, respectively (Streets et al., 2003). The period of crop residue burning depends upon the harvesting period, and it varies from region to region. Various studies have shown that rice stubble burning produces a large number of

pollutants (RSPM, NO_x and SO_2) in a short burning period, resulting in a sudden environmental impact (Gadde et al., 2009; Mittal et al., 2009; Singh et al., 2015). The amount of RSPM produced and its impact is quite significant as it has greater residing time in the air because of the balance between the downward acting force of gravity and aerodynamic drag force (Singh et al., 2015). Moreover, the harvesting period of rice is winter season of the study region, the impacts of the emissions and the potential for health effects are pronounced due to the prevailing weather conditions (inversion condition) i.e., very poor dispersion and poor dilution of the smoke. The smoke plume emitted from the stubble burn area gets confined close to the ground and drifts almost intact, rather than dispersing and diluting itself downwind. That further deteriorates the ambient air quality impacts human health and surrounding. Thus the estimation of the burned area holds importance in quantifying total stubble burn and pollutant emitted (Levine et al., 1990). In the present study, estimation of stubble burn area (with the help of remote sensing) and its impact on ambient air quality due to various pollutants emitted has been found out.

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2. Role of remote sensing in estimation of stubble burn area

Remote sensing is defined as the collection of useful information from a distance. It is particularly important in collecting and processing data of the inaccessible areas. Over the last few years, the remote sensing field has seen enormous development in spectral and spatial resolution, which paved the way for better detection of individual field practices. Remote sensing with Geographical Information Syste (GIS) can be used as an effective method in determining the stubble burn area at regional and global levels (Escuin et al., 2008; Murphy et al., 2008; Pradhan, 2001). The burned area mapping aims at detecting and delineating the scars left by fires by the usage of their spectral signature. Over the past ten years, many studies (Badarinath et al., 2006; Escuin et al., 2008; G. Singh et al., 2009; Vadrevu et al. 2011; Sandhu et al., 2018) have been conducted for stubble burn area monitoring. Burning of crop residue leaves black coloration of the field, which can be picked up and assessed by remote sensing data (Singh et al., 2009). An attempt has been made for Punjab using coarse resolution AWiFS satellite data for the year 2005 (Badarinath et al., 2006). Similarly, Chuvieco et al. 2002 did burn land discrimination using multi-temporal sets of Landsat Thematic Mapper (TM) and NOAA Advanced Very High Resolution Radiometer (AVHRR) images. Studies have also been conducted on the use of MODIS satellite data to determine Fire Hot Spot (FHS) for burn area estimation (Smith et al., 2007). Due to the coarse resolution of MODIS (1 km^2), it cannot be used effectively in detecting small burnt areas on the field. Fine resolution of LISS III satellite images (23.5m resolution) had proved effective in tackling the problem (Singh et al., 2009), the images had also been used successfully in estimating burn areas. Landsat TM/ETM images have also been analyzed for fire severity assessment by (Escuin et al., 2008). The present study attempts to use Landsat 8 OLI (Operational Land Imager) images for the detection of small stubble burn areas. Impacts of air pollutants emitted from stubble burning on Ambient Air Quality has also been estimated and analyzed along with the wind direction and wind speed.

3. Study area

India has been dependent on its northern states of Punjab, Haryana, and western Uttar Pradesh for wheat and rice (paddy) production. Punjab has a total area under rice cultivation of about 26460 sq km. Patiala and Ludhiana districts (Figure 1) are two major rice cultivation district of Punjab, hence opted for study. Patiala district lies between 29° 49′ and 30° 47′ north latitude, 75°58′ and 76°54′ east longitude, in the southeast

Figure 1. Location map of the study area.

part of the state of Punjab, with a total geographical area of 3430 sq km. In contrast, Ludhiana district has total of 3767 sq km geographical area and lies between 30° 34′ and 31° 01′ north latitude, 75°18′ and 76°20′ east longitude. In Punjab, rice (kharif crop) is sown in months of May-June and its harvesting starts from the first week of October and continues up to mid-November every year. After harvesting a large amount of stubble approximately 1.5 times the yield, is produced and is left in the fields (Gupta and Sahai, 2004). This cannot be tilled back in the soil; therefore farmers are left with the only option of burning as fields are required to be cleared in a short time for sowing of next crop. It is reported that 70–80 million tons of rice straw is disposed of by burning (Badarinath et al., 2006). This burning results in the emission of a large number of pollutants.

4. Materials and Methodology

Landsat 8 (OLI) images were procured from the 1st of October to the 25th of November for the years 2014–2018 for the study region. Locations where stubble burninig incident took place were collected through field visits and from Punjab Pollution Control Board, Department (PPCB), for the verification of the area computed during the study. Ambient air quality data for the stubble burning period of relevant years were also collected from various departments of PPCB. The workflow of the study adopted to assess the relationship between the total burn area and its impact on ambient air quality is given in Figure 2, involving two main components; assessment of stubble burn area of five years and impact of emitted pollutants on ambient air quality.

4.1. Image processing

Landsat 8 OLI images with a resolution of 30 m has been procured from the USGS website. These geo-tiff images were stacked and clipped according to the study region using a complete enumeration approach as used by Yadav et al. (2014) for wheat and rice stubble burning. The non-agricultural area has been masked out from the clipped images, as shown in Figure 3.

4.2. Identification of burn area

For identification of stubble burn area Normalized Burn Ratio (NBR) has been used. NBR index has also been used successfully by various researchers in order to asses burn area (Singh et al., 2009; Godwin and Kobziar, 2011; Epting et al., 2005; Schepers et al., 2014). This index can effectively map burned areas in many different landscapes across the world (Koppmann et al., 2010). It utilizes the Near Infrared (NIR) and Short Wave Infrared Bands (SWIR) of the remote sensing data. It has been observed that healthy vegetation shows a very high reflectance in NIR band and low reflectance in SWIR band, whereas recently, burn areas show low reflectance within NIR band and high reflectance in SWIR region of the spectrum. This distinction between the spectral responses of healthy vegetation and burn area reach their peak within the NIR and the SWIR regions of the spectrum. NBR index is based on the difference in the magnitude of spectral responses. A high NBR value indicates healthy vegetation, whereas low value indicates bare ground and recently burn areas. NBR index may be calculated by the following equation (i).

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \qquad \text{(i)}$$

where Band 5 (NIR) has a wavelength of 0.845–0.885 μm and band 7, SWIR (Short Wave Infrared) has a wavelength of 2.100–2.300 μm in Landsat 8 OLI sensor. A model has been generated in image processing software to superimpose the NBR index on the images, which has been used further to determine the threshold value. In past studies, the threshold value of NBR index has been useful for differentiation burned and unburned pixels. This value can be identified from field validation,
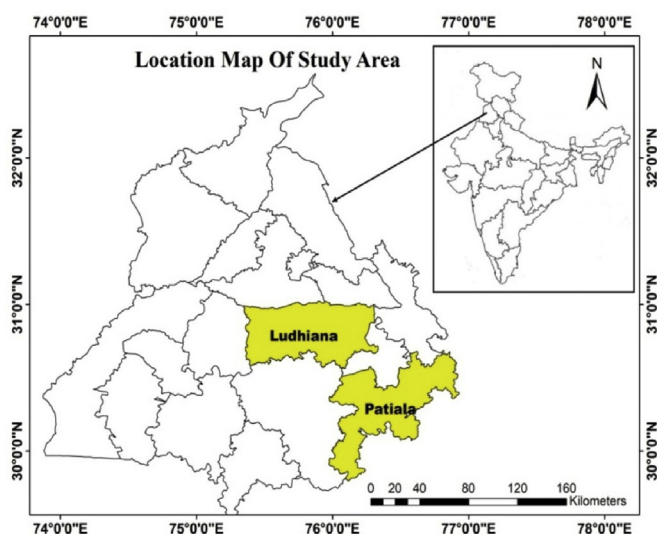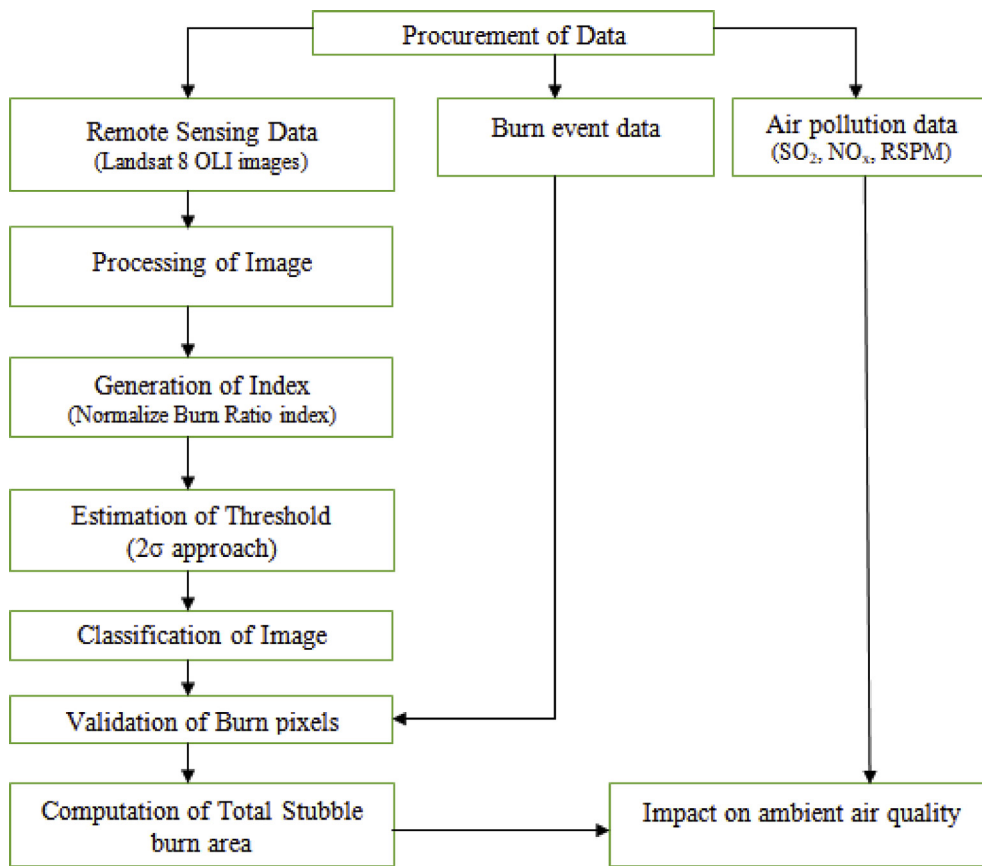
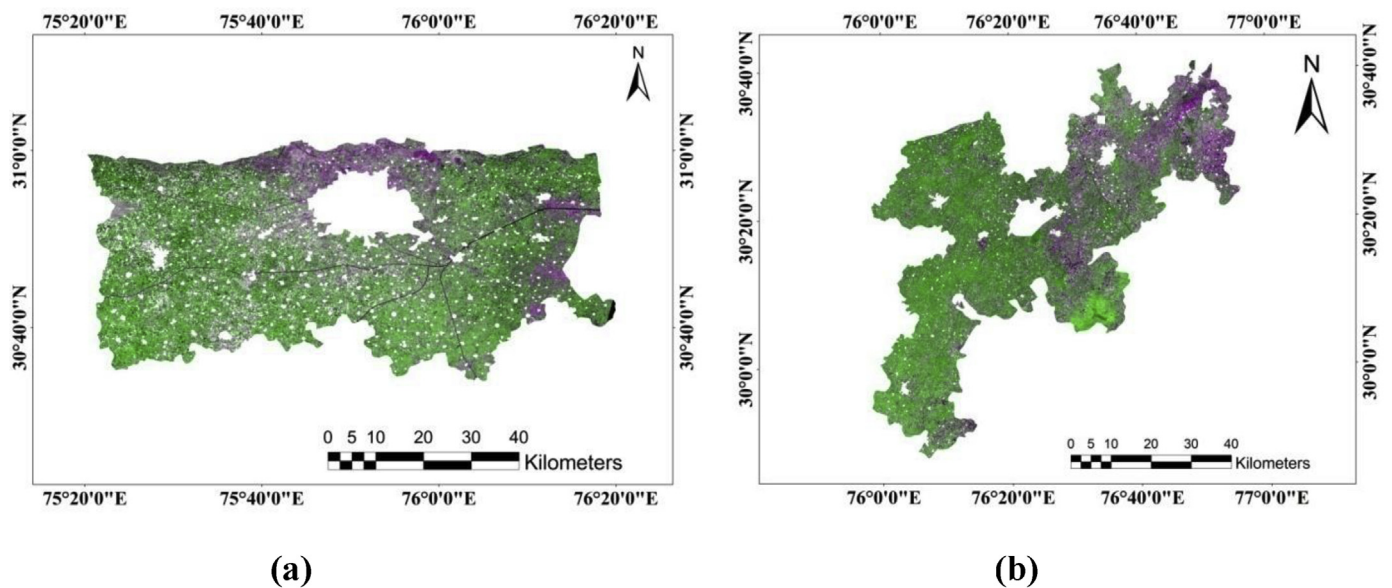**Figure 2.** Methodology flow chart.

Figure 3. Masking out of Non-Agricultural area (a) Ludhiana (b) Patiala.

by applying statistical techniques (Singh et al., 2009), taking fixed threshold value (McCarty et al., 2009) or by visual interpretation (Godwin and Kobziar, 2011). Although visual determination is regarded as the best technique to determine threshold value (Godwin and Kobziar, 2011; Singh et al., 2009) it has limitations if images have clouds, haze and smoke. As reported by McCarty et al., 2009, the fixed threshold value may be used for mapping burned areas due to forest fire only. Also, the

fixed threshold value of a specific region or condition cannot be generalized for other regions/conditions due to different atmospheric, land reflectance, and viewing conditions. A statistical approach is based on the probabilistic approach and regarded as one of the best methods to define threshold value, as relevant pixels are within the required confidence level. Threshold value (χ) has been determined with the help of equation (ii)

$$\mu \pm 1.96 \, \frac{\sigma}{\sqrt{n}} \qquad\qquad (ii)$$

where, μ = population mean, σ = standard deviation, n = total number of population.

In the present study, the 2σ approach has been followed that assumes a 95% confidence interval to estimate threshold value. Later this value has been used in the NBR model, and all the pixels were classified accordingly. Pixel values that lie in this range are considered as burned and rest all other as unburned.

4.3. Validation of burn pixels

Validation is a necessary step to assess the accuracy of the applied index and threshold values. Validation for burn pixels has been conducted using ground truth points. About 50 pixels were selected from each classification category from the processed image (whose co-ordinates were similar to that of ground truth points). Confusion matrices or error matrices have been plotted using classified pixels v/s the ground truth points to assess classification accuracy (Congalton, 2001). Overall accuracy and the Kappa statistic were then derived from the error matrices. The Kappa statistic incorporated the off-diagonal elements of the error matrices (i.e., classification errors) and represented agreement obtained after removing the proportion of agreement that could be expected to occur by chance (Yuan et al., 2005).

4.4. Total stubble burn area and impact on ambient air quality

To compute the total stubble burn area from 2014-2018 for rice harvesting season, all the images acquired were classified and verified by the above-stated method. Individual polygons (burn pixels) of these classified images were then clustered together, and the total stubble burn area has been calculated. Due to stubble burning large amount of pollutants like CO_2, CO, NO_x, SO_x, PM_{10} and $PM_{2.5}$ are released. These pollutants remain in the atmosphere for extended period due to adverse dispersion conditions during the harvesting period, i.e. winter season, as inversion conditions prevail at that time and these pollutants affect not only human health but also degrades ambient air quality. It has been observed that there is a strong correlation between stubble burn and emitted pollutants (Simmonds et al., 2005; Cao et al., 2008). The second aim of the study was to calculate the impact of stubble burning on ambient air quality for this the monthly variations of the pollutants emitted has been plotted during 2014–2018 for the study region. These graphs help in estimating the difference in the level of pollutants during burning and non-burning periods.

5. Results and Discussion

5.1. Accuracy assessment and total stubble burned area

For classification (burned and unburned) accuracy assessment error matrix has been prepared for all year 2014–2018 for both the districts with the help of ground truth points or ground control points (GCPs). Figure 4 shows the burned pixels along with ground truth points for the Patiala district. The summary of classification accuracy has been given in Table 1 for Patiala and Ludhiana districts. The overall accuracy values varied from 93% to 96%, whereas the variation of 0.817–0.90 in kappa values has been observed.

Stubble burn area has been estimated with the help of above-stated methodology. Total rice stubble burning area along with the net culti-vable area in the two districts of Punjab, Patiala, and Ludhiana during the study period; have been presented in Table 2. It has been observed that the stubble burn area declined by ~32% in the Patiala district, whereas it decreased by ~40% for the Ludhiana district. The results also indicate that the burning of rice stubble takes place during the third week of October, and there is negligible burning during the third week of
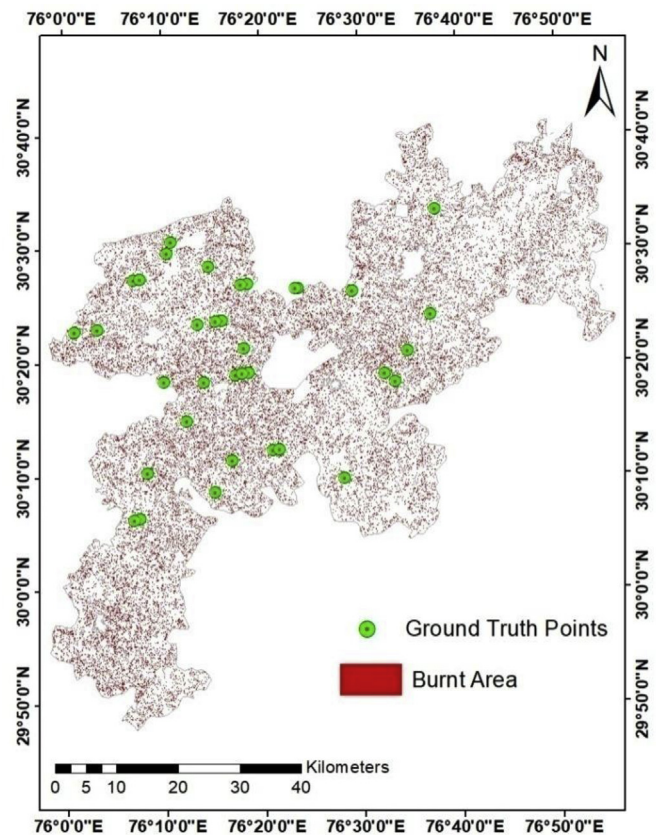

Figure 4. Burn pixels and Ground truth points, Patiala.

Table 1. Summary of classification accuracy for Patiala and Ludhiana districts.

Year	Patiala		Ludhiana	
	Overall Accuracy	Kappa Value	Overall Accuracy	Kappa Value
2014	96%	0.90	94%	0.835
2015	94%	0.848	95.7%	0.883
2016	94%	0.864	94%	0.862
2017	93%	0.817	93%	0.850
2018	95.7%	0.893	94%	0.848

November for Patiala district, whereas, for Ludhiana, district burning starts from the first week and lasts up to the third week of November. It has also been observed that the stubble burning increases in the year 2017 by ~4% as compared to the year 2016. Stubble burning for the year 2017 decreased by ~13% and ~7% as compared to the years 2014 and 2015, respectively. In the year 2018 least burning took place as compared to previous years; this may be due to strict policies, awareness among farmers, proper disposal of stubble, or tilling back in soil with the help of subsidies machinery like happy seeder. These results are promising and

**Table 2.** Stubble burned area and net cultivated area for years 2014–18, Patiala and Ludhiana.

Year	Percentage burn area	
	Patiala	Ludhiana
2014	70	64.2
2015	64.4	60
2016	53.3	46.5
2017	57.4	48.8
2018	48.7	40

show that remote sensing data may be used for estimating and detection of stubble burning.

5.2. RSPM, NOX, and SO2 concentration during stubble burning periods

Emission of pollutants from stubble burning depends on the composition, soil moisture condition, stubble moisture content, and ambient conditions i.e. wind speed and temperature (Jenkins et al., 1996). The monthly variation of pollutants of years 2014-18 for Patiala district is shown in Figure 5 (a to e) and for Ludhiana district is shown in Figure 6 (a to e). It can be observed that there was not a proportional increase in SO_2 levels, because there is hardly any source of sulfur (S) in the crop residue stubble. The increase in NO_2 is expected because of the use of nitrogen (N) based fertilizers in both crops. Patiala and Ludhiana district ambient
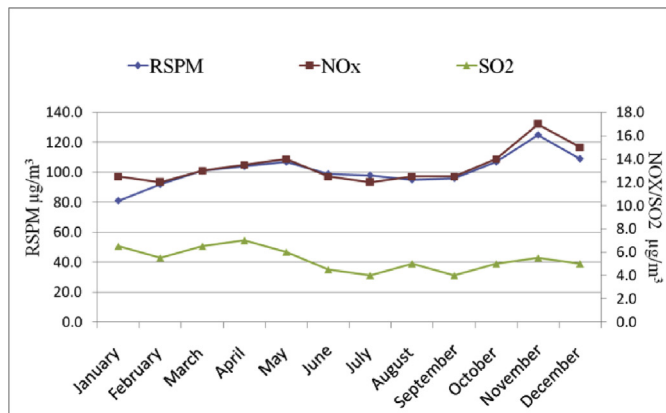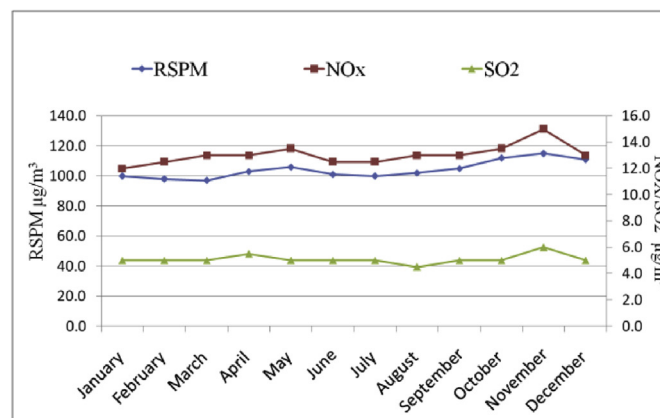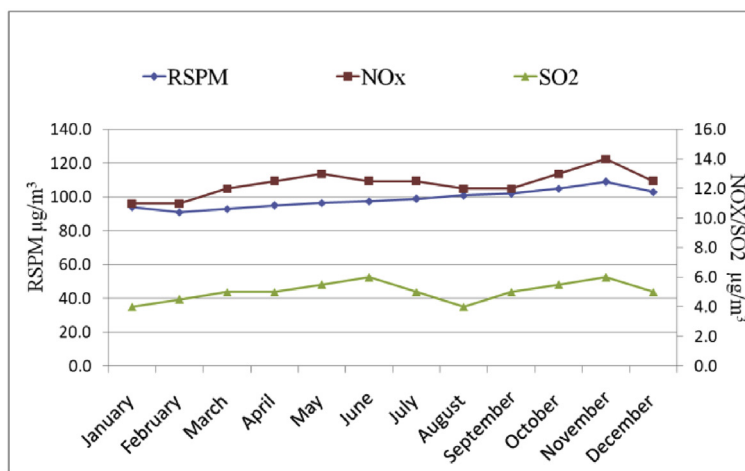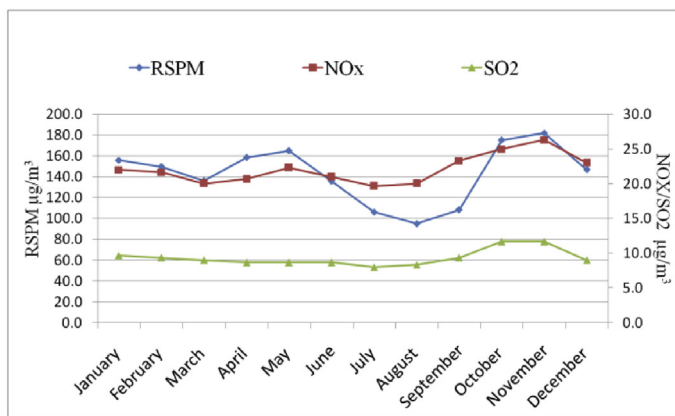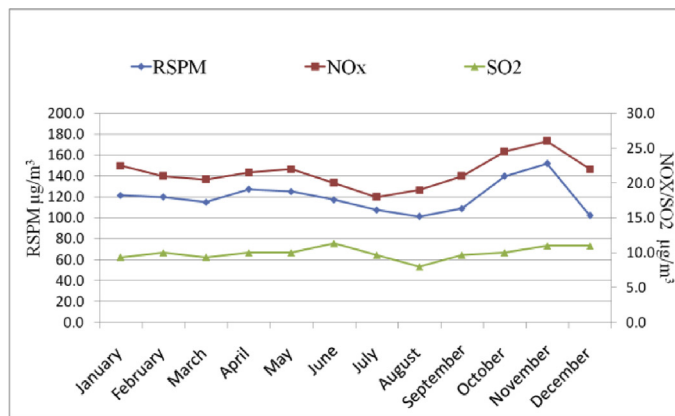

(a)
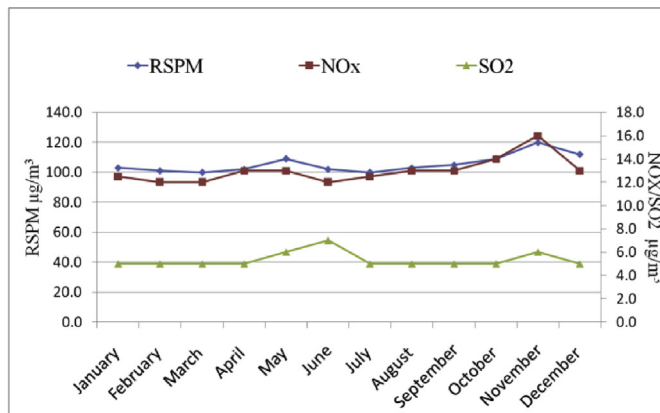
(b)
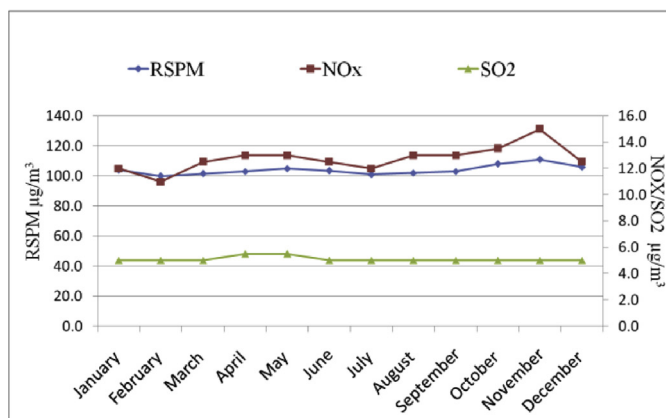
(c)

(d)

(e)

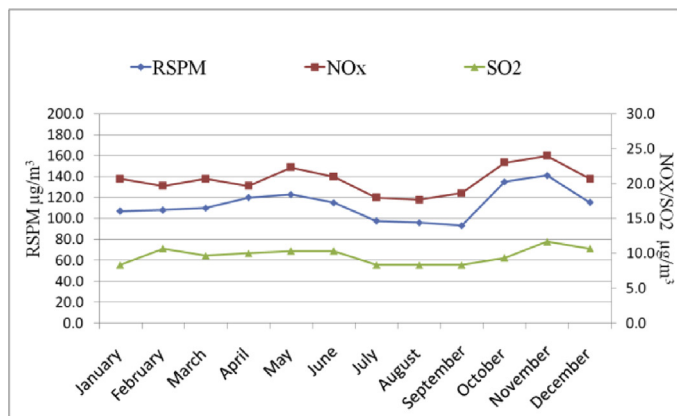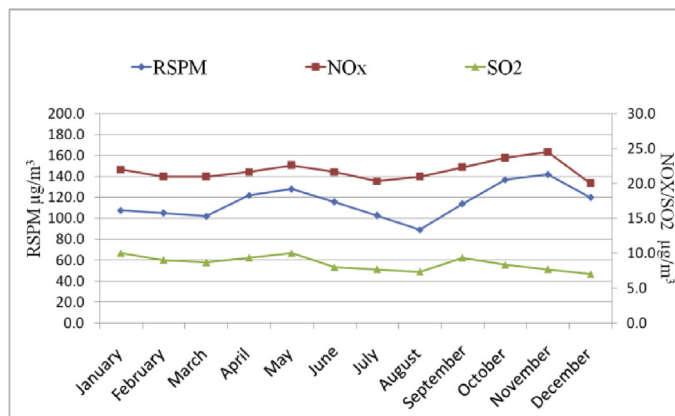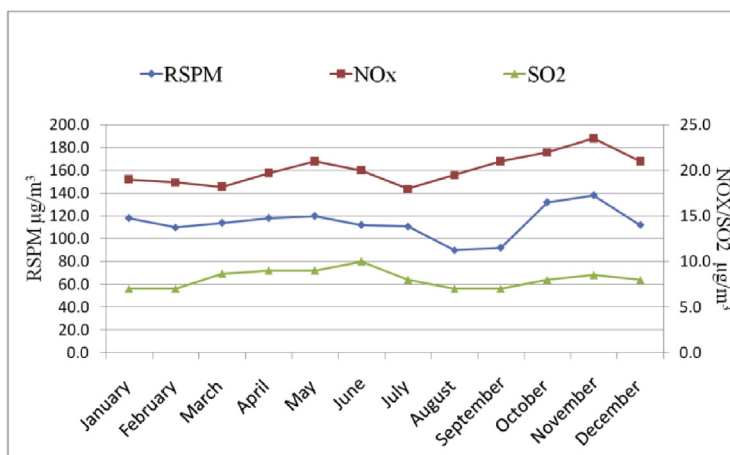**Figure 5.** Monthly variation in pollutant concentration for Patiala of year (a) 2014 (b) 2015 (c) 2016 (d) 2017 (e) 2018.

Figure 6. Monthly variation in pollutant concentration for Ludhiana of year (a) 2014 (b) 2015 (c) 2016 (d) 2017 (e) 2018.

air quality report shows that there is a sudden increase in the level of RSPM and NO$_x$ during the harvesting period.

The pollutant level rises more during the harvesting period in both the district, which indicates the effect of burning. Emission from industries and stubble burning along with the emissions from firecrackers on the festive season during October and November make the scenario worst. Pollutant level falls by the end of December, but the percentage fall is very less, which indicates that the residing time of pollutants is more in the ambient air. This phenomenon can be due to the balance between the downward acting force i.e., gravity force due to the weight
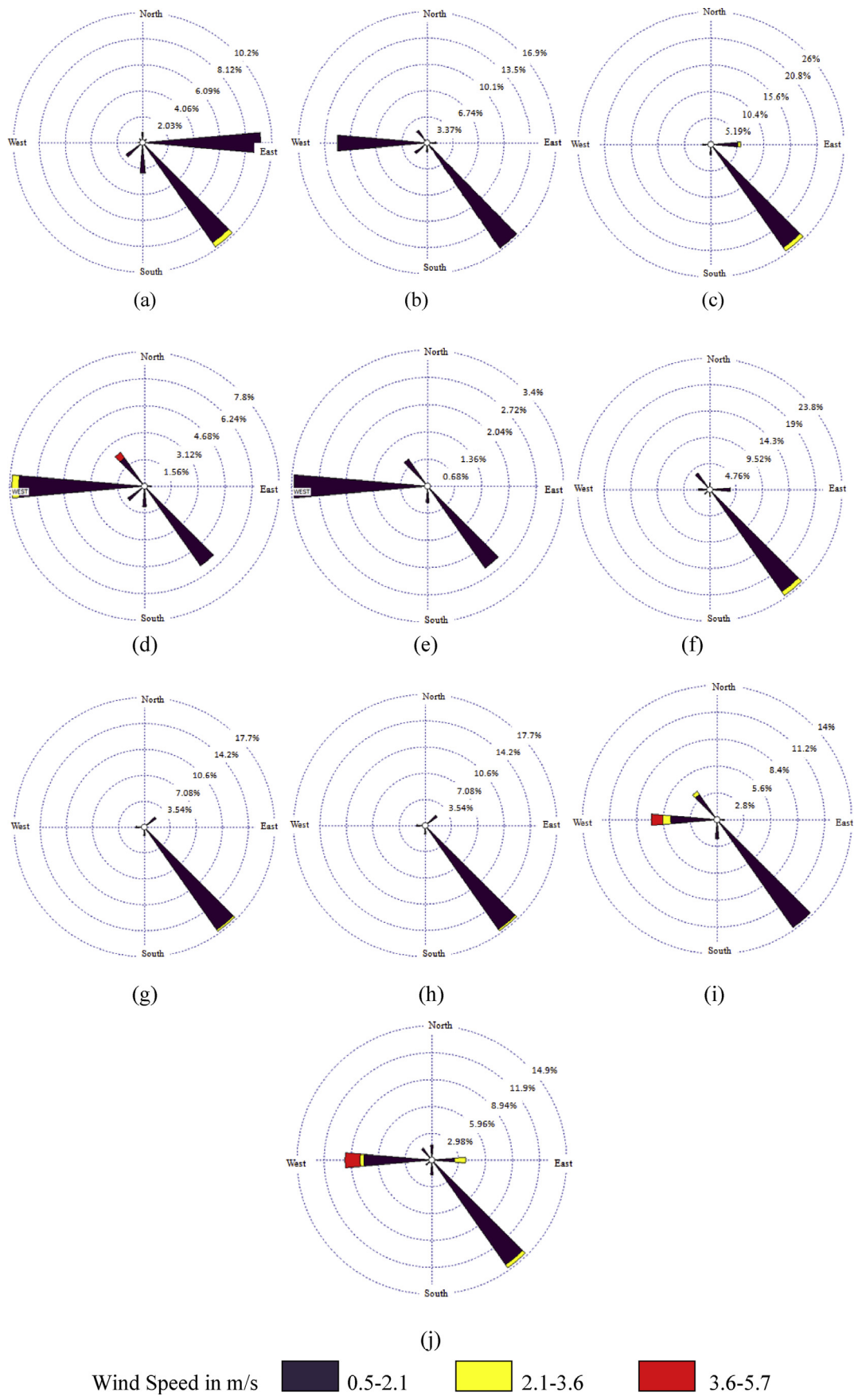
Figure 7. Wind rose diagram for Patiala district (a) October, 2014 (b) November, 2014 (c) October, 2015 (d) November, 2015 (e) October, 2016 (f) November, 2016 (g) October, 2017 (h) November, 2017 (i) October, 2018 (j) November, 2018.

Figure 8. Wind rose diagram for Ludhiana district (a) October, 2014 (b) November, 2014 (c) October, 2015 (d) November, 2015 (e) October, 2016 (f) November, 2016 (g) October, 2017 (h) November, 2017 (i) October, 2018 (j) November, 2018.
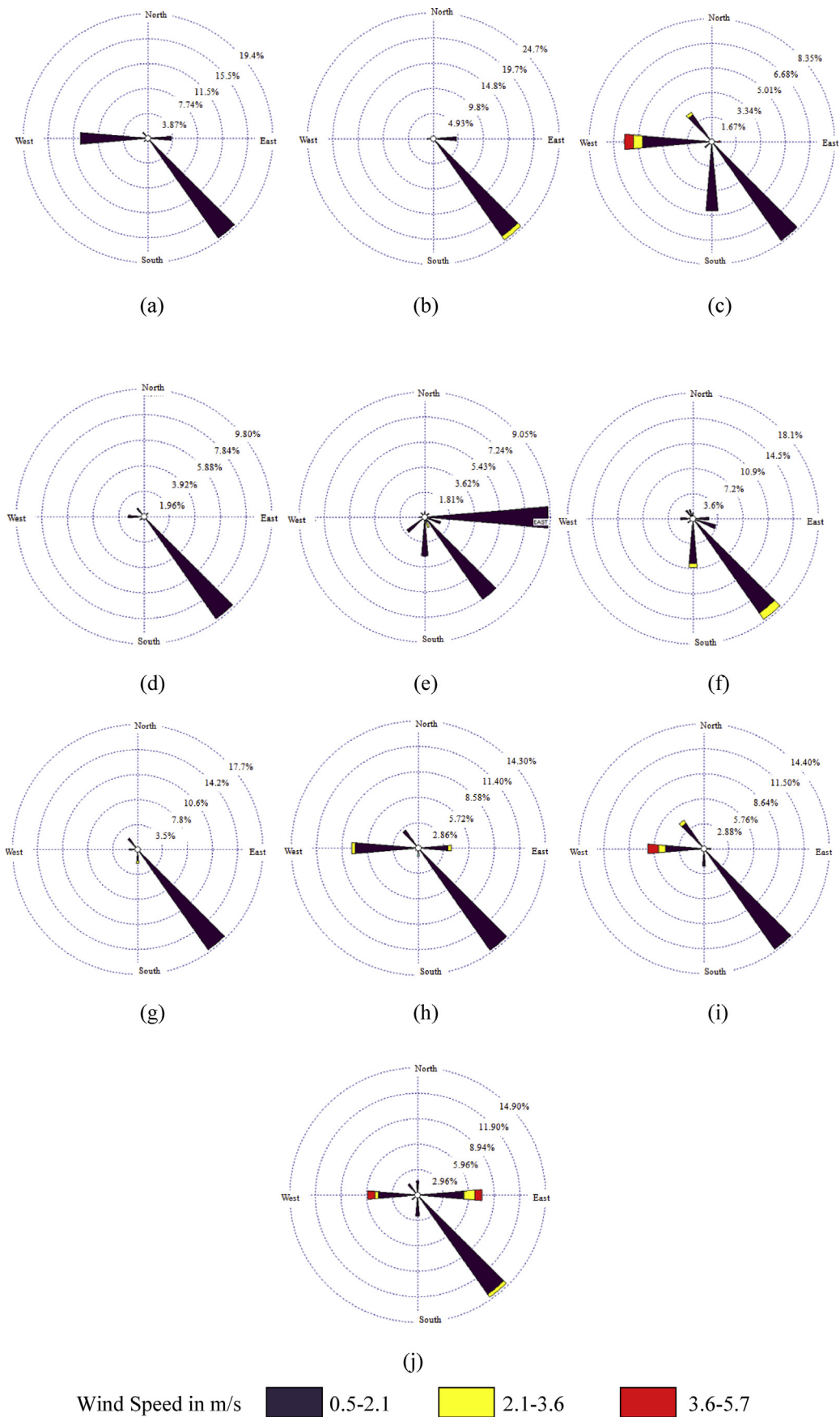
of particle and the upward drag force. Hence, pollutants from stubble burning not only have an adverse effects during the period of incident but have prolonged effects.

These emissions affect the local people most. Pollutants also tend to travel along with wind direction, affecting the surroundings as well. From these graphs, it can be concluded that the level of RSPM and NO_x increases during the months of April-May and October-November that are stubble burning months of wheat and rice, respectively. Higher peaks have been observed during October-November as compared to April-May, which indicates that stubble burning of rice has more impact on ambient air quality. This impact can be because of the higher percentage of rice stubble burn as compared to wheat, and secondly, rice stubble has higher ash content. However, the level of SO_2 does not change much. For all the five years the same trend can be seen in level of pollutants, but the amount of RSPM and NO_x during stubble burning period was lesser in 2018 as compared to the year 2014; this can be because of lesser burning in 2018 as compared to 2014. Graphs also represent that the pollutant level was little higher in 2017 as compared to 2016 but lesser than 2015 and 2014 which clearly indicate that there is a strong correlation between burned area and pollutants emitted, as the burning of the 2017 year was also more compared to the 2016 but lesser than 2014 and 2015.

The above graphs indicate the same trend as that was followed by the pollutant emission in Patiala district i.e., level of RSPM and NO_x increases during stubble burning months with no significant variation in the level of SO_2. The above graphs also depict that the value of pollutants emitted was higher by ~35% as compared to Patiala; this can be because of emission from various industries situated in Ludhiana.

5.3. Wind rose diagram

A wind rose diagram is a graphical representation of wind speed and wind direction at a specific location over a period. In this study, an attempt has been made to understand the distribution of wind speed, wind frequency, and wind direction during stubble burning months of the selected study regions. These plots give an idea about the direction in which emitted pollutants may travel. Strong winds (>2.5 m/s) can carry away the emitted pollutants in the downwind location (Nicolás et al., 2009). In the following paragraphs, the results of wind plots have been analyzed and presented for Patiala and Ludhiana districts. Wind plots for the Patiala district have been presented in Figure 7 (a to j). In this study, the wind rose plots were categorized into sixteen sectors, as reported by other relevant studies (Mittal et al., 2009). It has been observed that wind generally blows in Southeast direction in this district during stubble burning months (October and November). The variation in wind speed has been observed as 0.5–5.7 m/s, strong winds (>3.6 m/s) prevails for a lesser period, and dominant wind speed has been 0.5–2.1 m/s. Wind direction and wind speed play a vital role in deciding the concentration of pollutants at a particular place (where the burning incident occurred) and deciding the path in which these pollutants may be carried away. Kim et al. 2015 reported that the concentration of larger particles (10μm) increases in downwind location more as compared to smaller size (2.5μm) particles.

Wind plots for the Ludhiana district have been presented in Figure 8 (a to j). It has been observed that wind speed and wind direction for Ludhiana district was similar to that of Patiala district.

6. Conclusions

Increased mechanization i.e., uses of combine harvesters and un-availability of the economical viable solution have compelled the farmers to burn the stubble. This results in increased ambient air pollution levels that cause sudden impact on the environment. Remote sensing can be used as a useful tool to estimate the stubble burn area. From the above results, it can be concluded that:

- Rice stubble burning is a concerned issue as it takes place during the winter months; inversion condition is prominent during those months. Inversion condition does not allow the smoke emitted from burning to disperse in the atmosphere resulting in reduced dilution that further mixes up with fog and forms smog that is dangerous to human health and surroundings. It also decreases the visibility
- Burning of stubble produces a vast cloud of smoke consisting of pollutants like RSPM, NO_x, and SO_2, which are entrapped in the troposphere engulfing the whole region during October and November months every year. The level of these pollutants crosses the permissible limit as stated by the National Ambient Air Quality Standard.
- Higher peaks has been observed during October-November as compared to April-May, which indicates that stubble burning of rice has more impact on ambient air quality. These peaks can be because of the higher percentage of rice stubble burn as compared to wheat and secondly, rice stubble has higher ash content. Hence more concerned topic Graphs also represent that the pollutant level was little a higher in 2017 as compared to 2016 but lesser than 2015 and 2014, which indicate that there is a strong correlation between burned area and pollutants emitted.
- It was observed that the level of pollutants does not decrease suddenly after the burning period i.e., they remain in the atmosphere for more extended period. This was concluded from the monthly averaged value of the pollutants.
- The study regarding the comparison between the years 2014 and 2018 reveals that there is a decrease of ~32% and ~40% in the burn area from the year 2014 to the year 2018 for Patiala and Ludhiana district, respectively. These results are promising and show that remote sensing data may be used for estimating and detection of stubble burning. Although stubble burning has decreased, but the percentage decrease is very less, hence it needs more policies and innovations to find a feasible solution.

7. Limitations

The estimated areas are based on available satellite data. Due to excessive cloudy conditions, some of the images were not processed. Moreover, due to the matching of bare land signature with the burned signature, it may be possible that the rice stubble burning area of the period may be slightly overestimated. The satellite data taken was of every 15th day; it may also be possible that the rice stubble burn area may be re-sown for the next crop and not picked by the NBR index.

Declaration

Author contribution statement

Pratika Chawala: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Har Amrit Singh Sandhu: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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