Spatio-temporal characterization of agriculture residue burning in Punjab and Haryana, India, using MODIS and Suomi NPP VIIRS data

Kiran Chand Thumaty*, Suraj Reddy Rodda, Jayant Singhal, Rajashekar Gopalakrishnan, Chandra Shekhar Jha, Gururao Diwakar Parsi and Vinay Kumar Dadhwal

National Remote Sensing Centre (ISRO), Balanagar, Hyderabad 500 037, India

Agriculture residue (in the form of stubble) burning is commonly practised in the northern states of India along the Indian part of the Indo-Gangetic Plains (IGP), predominantly in the states of Punjab and Haryana. In the present study, we characterize spatio-temporal patterns of stubble burning in Punjab and Haryana states of India, using active fire data from Moderate Resolution Imaging Spectroradiometer (MODIS) and Suomi National Polar-orbiting Partnership – Visible Infrared Imaging Radiometer Suite (Suomi NPP–VIIRS) for *kharif* cropping season (September–November) 2014. Analysis of active fire locations derived from MODIS and VIIRS during September–November 2014 suggest intense practice of stubble burning in the study area with total fire detections going up to 15,222 (MODIS) and 15,568 (VIIRS). Comparative analysis of MODIS and VIIRS active fire detections suggested that VIIRS is more sensitive with higher detection capability. Further, grid-based (5 × 5 km) analysis of fire patterns, viz. total fire detections, fire frequency and total fire intensity using temporal (*kharif* season for 2004–2014) MODIS active fire locations suggest intense burning activity in the central and southern districts of Punjab during the study period. Temporal analysis of MODIS active fire locations (2004–2014) suggests a transition of decrease-to-increase in the total number of fire detections during October to November respectively, during 2004 through 2014.

Keyword: Active fires, agriculture residue burning, five patterns, spatio-temporal characterization.

AGRICULTURE residue burning is commonly practised in the Indian part of the Indo-Gangetic Plains (IGP)–Indus (Punjab, Haryana) and Gangetic Plains (Uttar Pradesh, Bihar and West Bengal), primarily to clear the waste after harvesting and for preparing the field for the next cropping cycle in a short time. The predominant cropping system in this region is rice–wheat rotation, accounting for about 10 million hectare[1,2]. Mechanization of conventional methods in seed-bed preparation and harvesting (like combine-harvester) in the recent past and selection of certain crop varieties by the farmers (e.g. using coarse rice varieties over fine grain) in the region has resulted in large crop biomass leftover in the form of straw and stubble[3–5]. According to the Indian Agricultural Research Institute (IARI), New Delhi, cereal crops generate a maximum residue of 352 Mt, of which rice and wheat contribute to 34% and 22% respectively[3,6]. The surplus residues (total residues generated minus residues used for different purposes) of cereal crops in India which amount to 82 Mt are typically burnt in the farm, of which 44 Mt is from rice and 24.5 Mt is from wheat[3]. According to another study, 84 Tg of crop residue is burnt in India[7]. While burning of crop residue is an economical way of clearing a field in the farmer's perspective, the resulting effects on air pollution, health and atmosphere are alarmingly dangerous. Agriculture residue burning is a global concern and is widely studied scientifically with respect to the emissions into the atmosphere, viz. aerosols and particulate matter[8–11] and greenhouse gases (GHGs)[8,12–17]. These emissions are believed to alter the atmospheric physics and chemistry, thereby contributing to climate change[18,19]. Many countries have banned the practice since 1990s by legislation policies, but the continuing practice in many developing countries still poses a global threat.

In the present study, we analyse the agriculture residue burning scenario, viz. spatio-temporal variability in the fire locations, fire frequency and intensity using space-based information derived from MODIS and VIIRS data, for two Indian states, viz. Punjab and Haryana, where

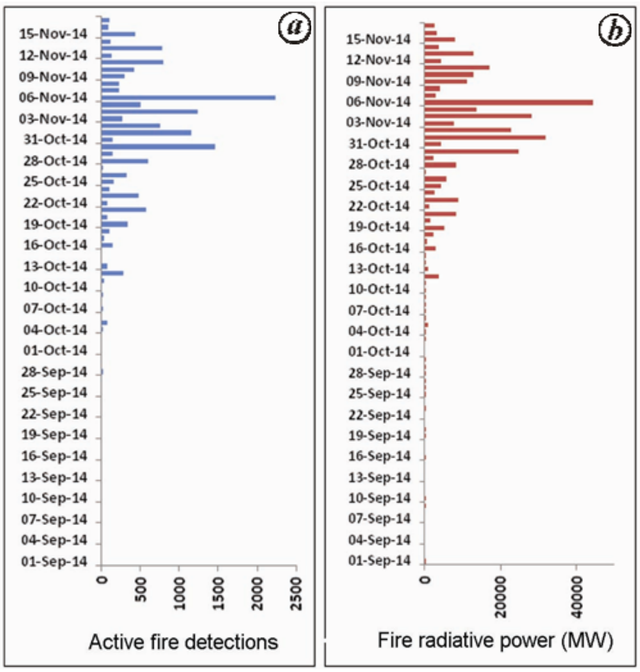

Figure 1. MODIS-based number of active fire detections (***a***) and fire intensity (***b***) during September–November 2014.

*For correspondence. (e-mail: trkchand@gmail.com)

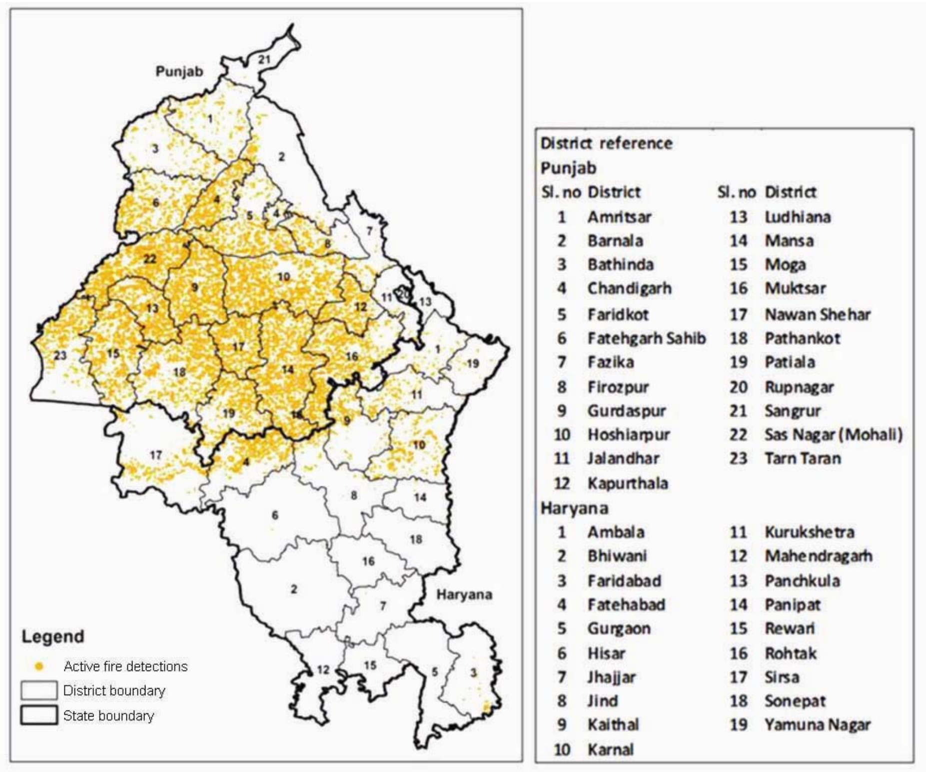

Figure 2. Spatial distribution of active fire locations (MODIS-based) in Punjab and Haryana during September–November 2014.

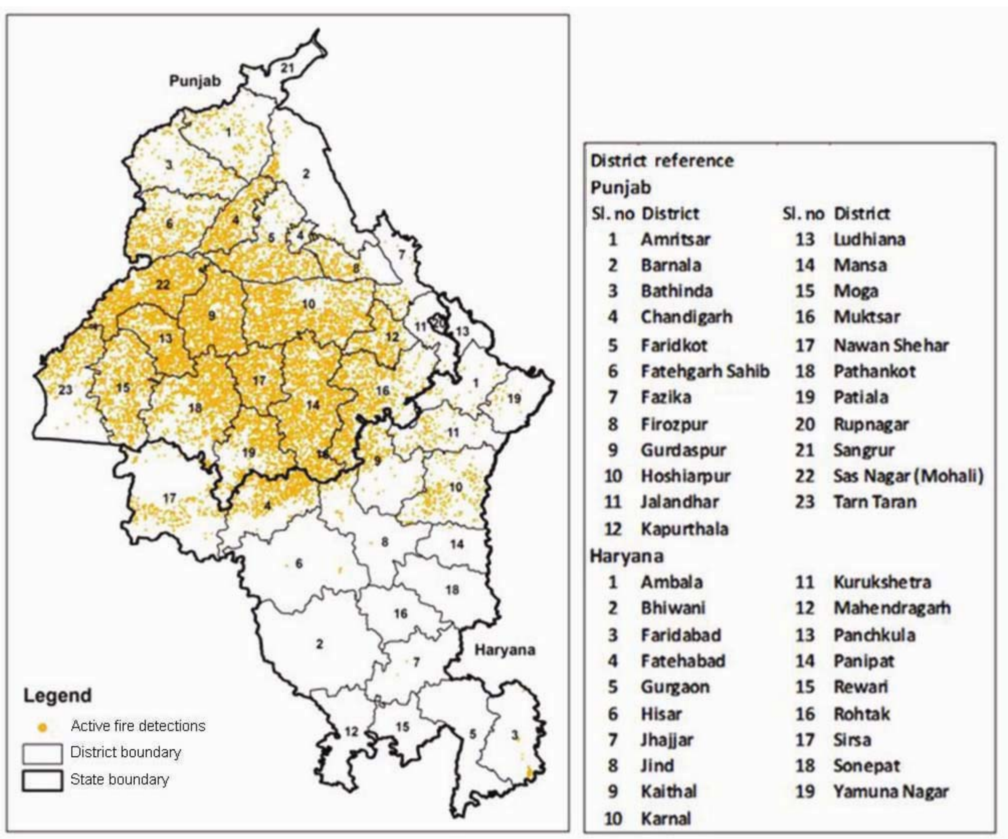

Figure 3. Spatial distribution of active fire locations (Suomi NPP VIIRS-based) in Punjab and Haryana during September–November 2014.

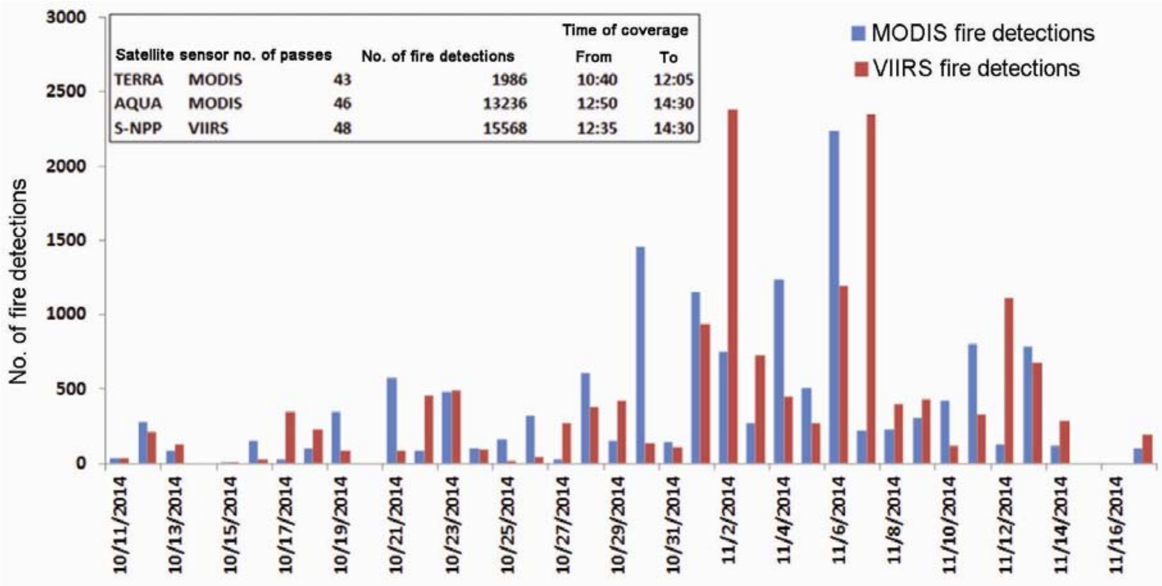

Figure 4. Comparison of MODIS and VIIRS-derived active fire locations for Punjab and Haryana during September–November 2014.

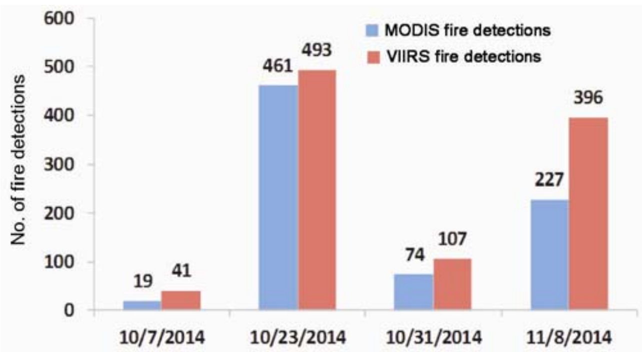

Figure 5. Comparison of number of active fire locations detected by MODIS and VIIRS sensors for dates with similar satellite overpass times.

stubble burning is practised[4,5,8,9]. Punjab and Haryana are considered as the rice and wheat bowl of India and are also accountable for the highest residue burning in the country. Apart from the local air pollution effects, stubble burning in the two states is also believed to contribute to the photochemical smog in the IGP, especially in the Indian capital city New Delhi[20]. As a step towards effective mitigation, in 2005 the state Government of Punjab banned the practice of residue burning and subsequently re-imposed the ban in 2013 along with the Punjab Pollution Control Board to prohibit indiscriminate burning of agriculture residue through Section 19(5) of the Air (Prevention and Control of Pollution Act), 1981. In the two states, the crop residues of rice are not used as cattle feed and large amounts of residues are burnt on field[3]. Further, the contribution of rice (*kharif* crop) residue burning was reported to be on the higher side compared to wheat (*rabi* crop) owing to the use of post-harvest leftover in the case of wheat crop[4]. In the present study, fire patterns during *kharif* season with specific reference to rice residue burning were taken into account for analysis.

Active fire products from MODIS (on-board TERRA and AQUA platforms) for September–November 2014 (*kharif* season) were primarily considered for analysis in the present study. The MODIS active fire products carry, for each fire pixel, valuable attribute information on the location of fire, acquisition date, confidence of fire detection and fire intensity in terms of fire radiative power (FRP)[21–23]. Active fire products of VIIRS[24] were also used to analyse the spatio-temporal distribution of residue burning for *kharif* 2014. VIIRS is a successor to MODIS in the earth observation era and has been providing data on active fire locations globally apart from other land, ocean and atmospheric applications since 2011. The algorithm theoretical basis of fire detections for both MODIS and VIIRS is similar for generation of the respective products[24]. While MODIS fire pixels are at 1 km pixel spacing (spatial resolution), VIIRS products are delivered at 750 and 375 m spatial resolutions and are believed to be more sensitive for smaller and cooler fires[24,25]. For the present study, however, VIIRS 750 m active fire products available at the National Aeronautics and Space Administration (NASA) – 'Level 1 and Atmosphere Archive and Distribution System' (LAADS) Web were used. Information on active fire locations and relevant attributes from both MODIS and VIIRS sensors for the study area was transformed to point shape files and subsequently masked for agriculture sector alone using a spatial layer of total cropped area from a standard land-use/land-cover reference map for further analysis.

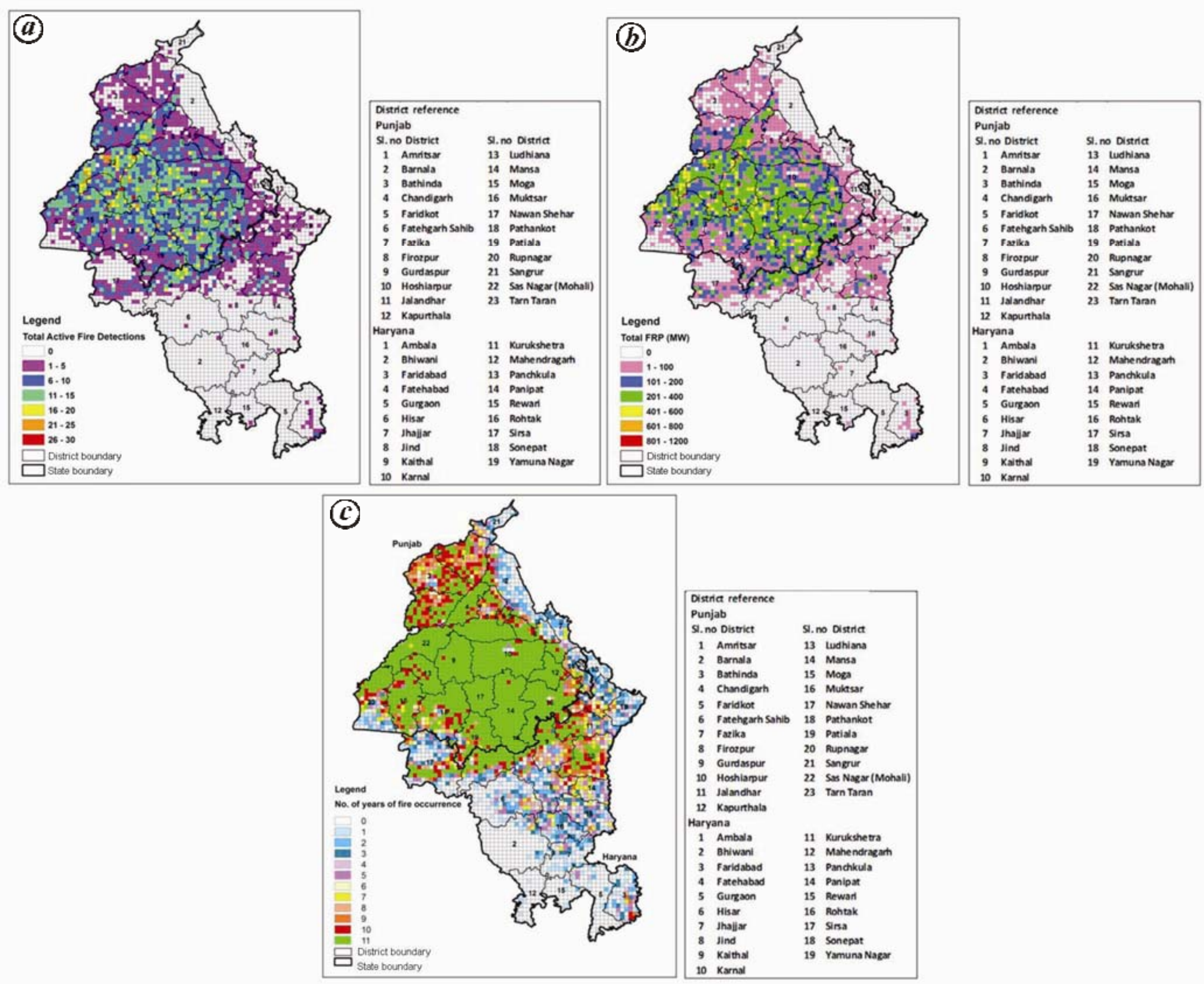

Figure 6. Grid-based (5 × 5 km) total number of MODIS active fire detections (***a***), total fire intensity (***b***) and fire frequency (***c***) during September–November, 2004–2014.

Figure 1 *a* shows day-wise total of number of active fire detections (pertaining to dates of active fire events) derived from MODIS data. Figure 1 *b* shows the corresponding day-wise total fire intensity (FRP in MW) during September–November 2014 in the study area. The number of fire detections and corresponding radiative power emitted show almost one-to-one correspondence for the study period. Figure 2 shows spatial pattern of MODIS-based active fire detections, while Figure 3 shows VIIRS-based active fires during September–November 2014 over the study area. Figure 4 shows a comparison of temporal fire detections of MODIS and VIIRS during the study period. Results suggest intense burning practice in Punjab and Haryana during September–November 2014. A total of 15,222 MODIS (TERRA = 1986 + AQUA = 13,236) and 15,568 VIIRS active fire detections were observed over the study area. Preliminary observation suggests higher number of fires being detected using VIIRS datasets. VIIRS is expected to be more sensitive to smaller and cooler fires[24,25] and may project detections in higher order compared to MODIS. In general, the active fire products of AQUA MODIS and VIIRS are comparable because of similar equatorial crossing times (1 : 30 am/pm) of the satellites. However, a number of factors need to be considered for direct comparison of fires detected by the two sensors. First, the time difference in the acquisition of signal (AOS) and loss of signal (LOS) of the two sensors may vary depending on individual satellite overpass times on any given day. This can result in time difference in the coverage of a given agricultural plot by the two sensors, sometimes by more than half an hour. Also, the duration or longevity of agricultural fires in the Indian context is expected not to last more than half an hour, in which case, any fire can

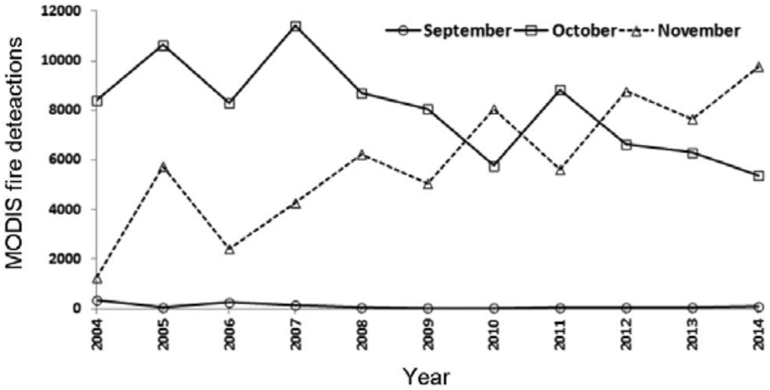

Figure 7. Temporal variability in the number of fire detections (MODIS-based) in Punjab and Haryana during September–November 2004–2014.

go either detected or undetected by either sensors in case of time difference in coverage. This could be the probable reason for variation in the number of fire detections within a given day, as seen in Figure 4. Further, the average size of an agricultural burn (plot) is generally much less compared to the 1 sq. km MODIS or 750 sq. m VIIRS footprint and there can be more than one actively burning ground fire within the footprint of the respective sensors. The pixel aggregation scheme for differing scan angles from nadir of VIIRS and the corresponding spatial sampling are different from those of MODIS[24], which may also add to the difference in number of fire pixels detected by each sensor for the same area of interest. Furthermore, differences in the sensitivity of individual sensors to the size of area burnt, intensity of active fires during the satellite overpass and ground coverage (field-of-view) by the sensors themselves also contribute to an active fire on the ground being detected/undetected by them. To address this issue, in the present study we have considered AQUA MODIS and VIIRS data without time difference ($n = 4$ overpasses) for comparative assessment of fire detection capabilities of the two sensors (Figure 5). Figure 5 suggests higher number of fires as detected by VIIRS of the order of 7–116% compared to AQUA MODIS, which is primarily attributed to the relative fine spatial resolution of former compared to the latter. Similar observations have been reported elsewhere[24], wherein VIIRS produces 26–70% more fires compared to MODIS based on differing pixel aggregation scenarios.

Further, in the present study, temporal fire location information derived from MODIS during *kharif* season 2004–2014 was also analysed for gridded 5 × 5 km distribution over the study area to derive grid-based statistical information on total fires, total fire intensity and number of times of fire occurrence (Figure 6 *a*–*c*) respectively. Results suggest intense stubble burning practices in the entire Punjab and Haryana, predominantly in the central and south districts of Punjab during 2004–2014. Most regions show total fire pixel counts of 11–30 per grid (Figure 6 *a*) with fire intensity totals showing good correlation with the total fires (Figure 6 *a* and *b*). Similarly grid statistics suggest fire occurrence almost every year in more than 60% of agricultural land use in Punjab (Figure 6 *c*). A mean number of 14,017 MODIS-based active fire detections were observed during September–November for 2004–2014 in the study area. A decreasing trend in total fire detections was observed during September and October, while the fire detections were found to increase in November during 2004–2014 in the study area (Figure 7).

Despite several strict regulatory measures taken by the Government of India and the state Governments of Punjab and Haryana, the practice of stubble burning continues to add woes to the local and regional air pollution and health hazards of the region, and becomes a matter of serious concern even for navigation of rail, road and air travel. Effective implementation of such policy decisions requires periodic to continuous monitoring of the activity. In view of this, satellite data-based monitoring of agriculture residue burning is helpful in monitoring the activity in space and time. The present study presents a clear picture of the stubble burning activity in the study area and suggests potential use of satellite datasets in effective monitoring. More value-addition to the present study in terms of accurately estimating the total biomass and area burnt vis-à-vis emission constituents and relevant emission factors from the residue burning using ground inventory and space-based estimates at local and regional scales would effectively help in the mitigation policy.

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Assessment of human exposure to dissolved radon in groundwater around the uranium industry of Jaduguda, Jharkhand, India

N. K. Sethy[1,*], V. N. Jha[1], P. M. Ravi[2] and R. M. Tripathi[2]

[1]Health Physics Unit, Environmental Survey Laboratory, Jaduguda, Singbhum (E), Jharkhand 832 102, India
[2]Health Physics Division, Environmental Studies Section, Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, India

Measurement of dissolved radon and ^{226}Ra in groundwater was carried out in 30 different locations around the uranium mining and ore processing area of Jaduguda, Jharkhand, India. Activity concentration of ^{226}Ra was found to be very low, whereas dissolved radon was observed to be slightly elevated due to geological features of the area consisting of uranium mineralization. No definite relation was observed between radon and ^{226}Ra in groundwater. The annual dose due to ingestion of radon containing water estimated at 60% locations was less than 100 μSv. The maximum ingestion dose was found to be 300 μSv to adult members of the public. The average dose due to the ingestion of radon in water was 94 μSv, which is less than the stipulated limit of 1000 μSv prescribed by regulatory body.

*For correspondence. (e-mail: sethybarc@rediffmail.com)