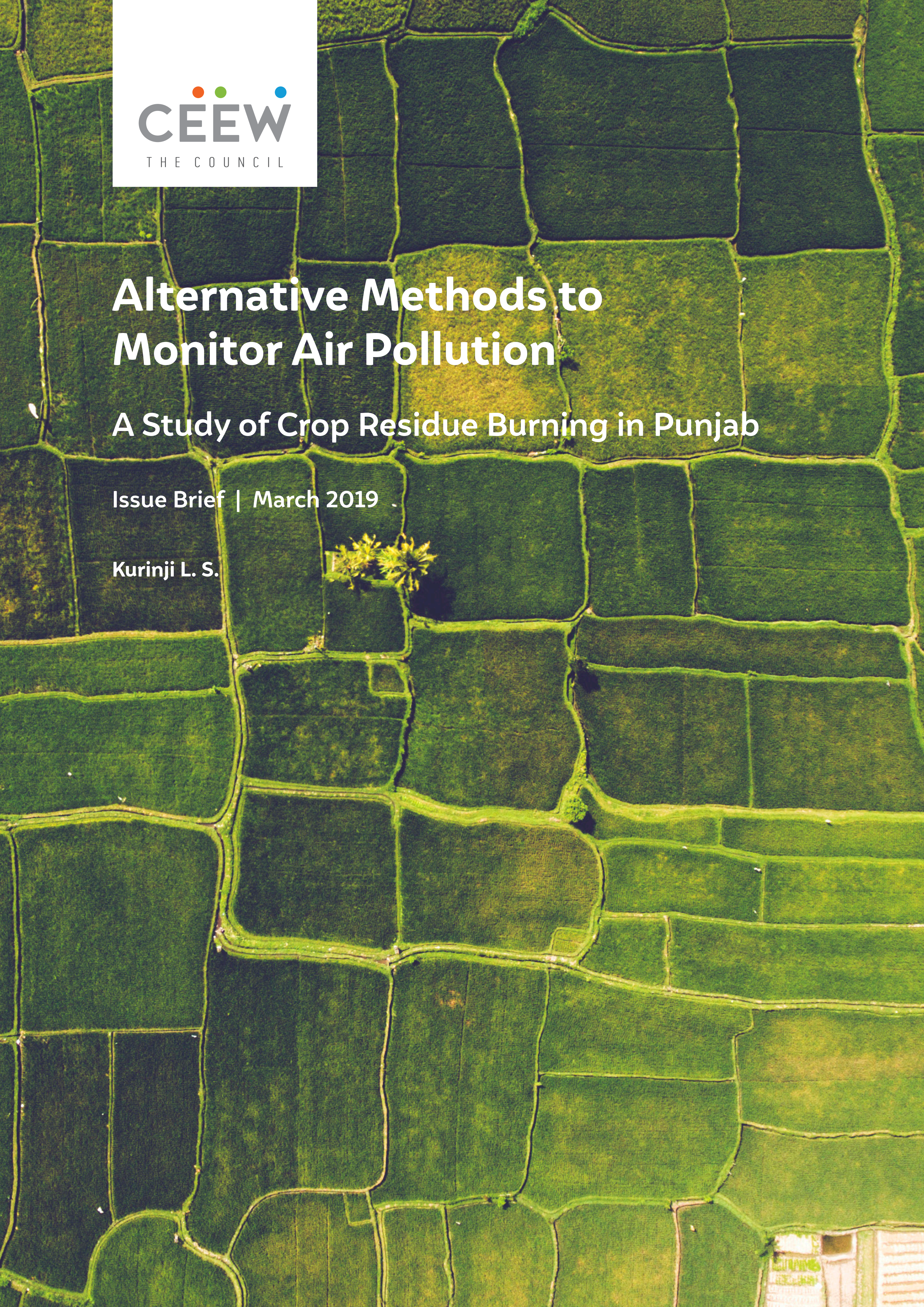

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Alternative Methods to Monitor Air Pollution

A Study of Crop Residue Burning in Punjab

Issue Brief | March 2019

Kurinji L. S.

Clearing land for the next crop cycle by burning the leftover paddy stubble is being practised by most farmers as it is the cheapest option for them given the lack of farm labour.

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THE COUNCIL

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The Council on Energy, Environment and Water (CEEW) is one of South Asia's leading not-for-profit policy research institutions. The Council uses data, integrated analysis, and strategic outreach to explain – and change – the use, reuse, and misuse of resources. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public.

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"Indian minds often frame the puzzle of air pollution as the problem of urban areas and neglect the rural areas. However, in most developing countries, the air is equally polluted both in urban and rural areas. Through this study, using technology, I hope to extend the pollution conversation towards rural areas. Being a techno-chauvinist, I strongly feel that science and technology will help us in finding solutions to understand and solve human problems."

Intensive paddy cultivation has led to massive ground water depletion in Punjab. As a result of the Punjab Preservation of Subsoil Water Act (2009) and shortened cropping cycles, farmers need to get their fields cleared fast to plant the next crop. This has led to large-scale crop residue burning in order to hasten land clearing.

Image: iStock

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ABBREVIATIONS

APEDA	Agricultural & Processed Food Products Export Development Authority
AQI	Air Quality Index
CPCB	Central Pollution Control Board
EPCA	Environment Pollution (Prevention & Control) Authority
ENVIS	Status of Environment and Related Issues
FIRMS	Fire Information for Resource Management System
GADM	Database of Global Administrative Areas
GST	Goods and Services tax
NAMP	National Ambient Air Quality Monitoring Programme
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NCAP	National Clean Air Programme
NOAA	National Oceanic and Atmospheric Administration
NPMCR	National Policy for Management of Crop Residues
PM	particulate matter
VIIRS	Visible Infrared Imaging Radiometer Suite

Satellite imagery can be used as a complementary tool to better monitor and measure crop residue burning over a large geographic area.

Image: iStock

Executive Summary

The National Clean Air Programme has set a modest target of 20 to 30 per cent reduction in pollution causing particulate matter by 2024. The government has also allocated an even more modest sum of INR 300 crore to implement the plan across more than 100 cities in the country.

To control air pollution, one needs to be able to measure it, identify and attribute proportions to various activities causing it, and ultimately clamp down on these activities. Frugal budgets and the need to increase ambition, require new approaches to make the best of the resources available to mitigate air pollution. We focus on one important contributor – seasonal crop residue burning in Punjab to establish the scale of activities, the drivers and the pollution that can potentially be attributed to it.

To measure pollution in Punjab, our study uses freely available data from satellite-based monitoring as well as data collected from a deployment of low-cost air quality sensors that make up for the lack of any significant ground monitoring effort (a total of four rural monitoring stations across the state and all being manual in nature, with no real-time data to drive action). Combining this data with ground information on changing cultivation patterns, agricultural statistics, and stakeholder consultations, we chart the trajectory of the problem and the severity of the issue for rural parts of Punjab.

Despite significant governmental efforts to clamp down on crop-residue burning and incentivise farmers to pursue alternative practices, the author finds little evidence that burning has reduced over time. Burning is still driven largely by the farmers' decision to cultivate non-Basmati paddy. In years when they choose to cultivate less of it, pollution shows a dip. Evidence of bans, fines, and alternative practices having worked on a large scale are limited.

Low-cost sensors indicate that the air quality in high-burning districts (Ludhiana and Sangrur) worsened during the peak burning period

Districts with larger land-holding size have increased their intensity of burning. Clearly, farmers with smaller land holdings have done more – inadvertently or otherwise, in reducing air pollution. Districts with higher incidents of crop residue burning demonstrated poorer air quality, notwithstanding the limitations to the approaches we have used. Low-cost sensors indicate that the air quality in high-burning districts (Ludhiana and Sangrur) worsened during the peak burning period. The maximum median concentrations of $PM_{2.5}$ observed during the peak burning season were 650.27 $\mu g/m^3$ in Sangrur, 343.53 $\mu g/m^3$ in Ludhiana, 153.78 $\mu g/m^3$ in Hoshiarpur, and 96.37 $\mu g/m^3$ in Pathankot. The air quality in some of these districts rival that of the National Capital Region, despite them not seeing the same level of other polluting activities such as use of private vehicles, construction, and industrial activity, to name a few.

The rural air quality monitoring network needs to be augmented to help record, understand, and communicate both the persistent as well as episodic incidents of air pollution. There is an urgent need to focus on the use of satellite-based data, especially from Indian satellites, to obtain much better resolution – spatial and temporal – of activities that have an impact on the environment. Ground truthing these data sets in order to increase more acceptability of these methods must be the immediate focus.

In Punjab, districts with higher incidences of crop burning demonstrated poorer air quality.

Image: iStock

The author recommends that improvements in the rural air quality network as well as near real-time information, can enable prompter mitigation measures. Further, there is a need to ground-truth satellite data with more on-ground monitoring for better understanding the transition of incidents of crop residue over time.

Crop residue burning is a large, seasonal contributor to air pollution in the north-western parts of India.

Image: iStock

1. Introduction

In India, the air pollution narrative has focussed largely on urban areas, especially Delhi (Khaira, 2018). Of the several contributors to pollution, crop residue burning is a large, seasonal contributor[1]. It is estimated that 22 million tonnes of rice straw surplus are produced in India each year, out of which 14 million tonnes (about 63 per cent) are burned, mostly in the north-western states of Punjab and Haryana (Gadde, et al., 2009). This impacts the airshed of Punjab and Haryana and also of Delhi (Cusworth, et al., 2018).

Crop residue burning emits trace gases like carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), other nitrogen oxides (NOx), sulfur dioxide (SO_2), and atmospheric particulate matter ($PM_{2.5}$), which adversely impact health. Exposure to emissions from crop residue burning leads to respiratory symptoms (Long, et al., 1998) and a corresponding increase in medical expenditure and workdays lost. In Punjab, around 40–50 per cent of the total medical expenditure is spent in the months of October and November, the peak period for burning crop residue (Kumar, Kumar and Joshi, 2015). This widespread phenomenon has several drivers.

In Punjab, 40-50 per cent of total medical expenditure happens in the months of October and November, the peak period for burning crop residue

Incentive structures following the green revolution have created a rice-wheat monocropping pattern in water-scarce states. Due to a healthy mix of institutional and technological factors, the state witnessed a tremendous increase in food grain production during the green revolution.[2] Productivity increases create large quantities of crop residue for farmers to manage. Also, policies to preserve groundwater have shortened the cropping intervals between rice harvesting and wheat sowing to 10–15 days and left farmers little time to manage the residue (Sidhu, 2014).

Increased use of mechanisation, particularly combine harvesters, to accelerate the harvesting process leaves behind a residue of 10–30 cm in the field, which was not the case earlier with manual harvesting (Kumar, Kumar, & Joshi, 2015); (Centre for Science and Environment, 2017). Labour scarcity, and programmes such as the Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA), have driven up costs and made it difficult for famers to hire labour (Jitendra, 2018).

1 Open burning of crop residue in rural areas contributes about 7 per cent to the total $PM_{2.5}$ emissions (Sharma, et al., 2016) (Ministry of Environment, Forest & Climate Change, 2019).

2 Punjab produces 20 per cent of India's wheat and 10 per cent of its rice (Kumar, Kumar, & Joshi, 2015); Table A1 of Annexure detail the area under, and production of, rice and wheat over the post–green revolution period. Punjab's contribution of wheat and paddy to the central pool over the past few decades are detailed in Table A2 of Annexure; it also provides the details of market arrivals of wheat and paddy.

Further, the lack of a viable market for crop residue, as well as perceptions that burning provides a quick way of controlling weeds, insects, and disease, have perpetuated the practice (Sidhu, 2014).

The large-scale burning of crop residue has been a serious threat to regional air quality (Cusworth, et al., 2018). To address it, the government has launched initiatives such as the National Policy for Management of Crop Residues, 2014 (NPMCR); there have also been directives from the National Green Tribunal to prevent crop residue burning.

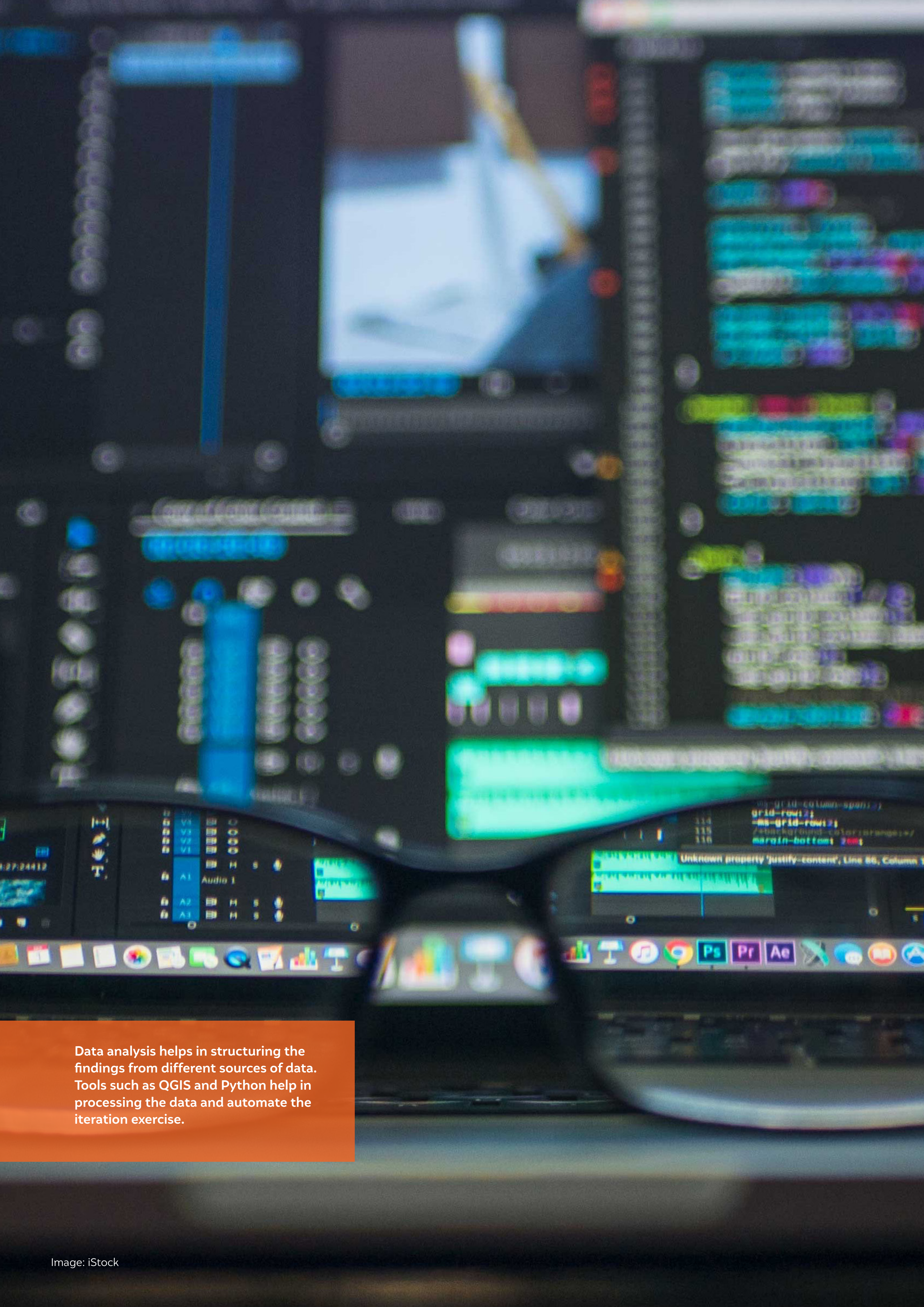
However, there have been gaps in understanding the impact of such initiatives. The first gap has been in assessing whether crop burning itself has been reducing over time. The second gap has been in understanding the impact on local air quality. Currently, under the National Air Quality Monitoring Programme, four monitoring stations are set up in rural Punjab, in the districts of Amritsar, Sangrur, Faridkot, and S. B. S Nagar (Punjab Pollution Control Board, 2018). But the number of monitors is inadequate, and real-time data are not accessible for meaningful action.

There are two knowledge gaps. First, has crop residue burning reduced over time? Second, what are the impacts on local air quality?

Beneficial insects such as grasshoppers that feed on harmful insects are often wiped out during crop residue burning.

Image: iStock

In this context, this study uses satellite information to analyse how crop residue burning has changed over time. It uses information from low-cost sensors to evaluate the ambient air quality in Punjab. This study highlights that well-established networks of air quality monitors are required to understand the quality of the ambient air in rural areas and make informed policy decisions.



Data analysis helps in structuring the findings from different sources of data. Tools such as QGIS and Python help in processing the data and automate the iteration exercise.

Image: iStock

2. Data and Methodology

2.1 Data sets

To investigate the linkages between crop residue burning and local air quality, this study uses ground-based measurements, data from satellite-based monitoring systems, and district-level agricultural statistics from various administrative and annual statistical publications on agricultural performance in the state of Punjab.

2.1.1 Visible Infrared Imaging Radiometer Suite (VIIRS) Fire Product

The Visible Infrared Imaging Radiometer Suite (VIIRS) sensor aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite detects fire at 375 m nominal resolution. The VIIRS fire product algorithm is a hybrid thresholding and contextual algorithm that uses radiometric signals from the 4 micron band (M13), 11 micron band (M15), and additional bands. It also uses a suite of tests for internal cloud mask and rejection of false alarms. The VIIRS complements the Moderate Resolution Imaging Spectroradiometer, but the improved spatial resolution of the 375 m data allows for better response to fires over relatively small areas; it also has improved night-time performance (Vadrevu & Lasko, 2018).[3]

For the present study, the VIIRS Fire Product L2 data was accessed from the Fire Information for Resource Management System (FIRMS) of NASA. Each fire pixel detected by the algorithm is assigned one of the three confidence classes (low, nominal, or high), depending on its calculated confidence value (C). A confidence level helps users to scale the quality of individual fire pixels. To ensure fewer false detections of fire pixels, this study uses fire pixel data with C > 30 relating to the confidence level of 'nominal' and 'high' (Jethva, et al., 2018).

2.1.2 Ground-level $PM_{2.5}$ measurements

To understand regional air quality, CEEW in collaboration with Purelogic Labs has installed 48 low-cost air quality sensors across four districts – Pathankot, Hoshiarpur, Ludhiana, and Sangrur. Low-cost air quality sensors allow for coverage of a large spatial area (Gupta, et al.,

3 A detailed description can be found in VIIRS 375 m Active Fire Algorithm User Guide at https://viirsland.gsfc.nasa.gov/PDF/VIIRS_activefire_User_Guide.pdf last accessed 16 December 2018. The Suomi-NPP satellite is built by the National Aeronautics and Space Administration (NASA) for the National Oceanographic and Atmospheric Administration (NOAA).

2018). The $PM_{2.5}$ concentration of ambient air was measured from these low-cost sensors. Hourly $PM_{2.5}$ data were accessed from these sensors from 19 October 2018 to 31 December 2018. The sensors were distributed across the districts by sampling villages based on a probability proportional to size sampling technique. The sample size across the districts is not the same as logistical challenges prevailed and intended numbers of sensors across districts was not possible. The sampling strategy was not to make this representative of the state but capture the chosen districts.

The fire count (number of unique fire incidents) is directly determined by the area under non-basmati cultivation and the resultant crop cuttings that are rendered unusable

Low-cost sensors are installed in rural Punjab to obtain granular information on the spatial and temporal distribution of particulate matter.

The devices used the Plantower S7003 sensor – a popular optical sensor housed in a suitable assembly is able to transmit data at frequent intervals. The measurements control for variations in relative humidity and temperature. The data were aggregated to hourly averages for the purposes of the analysis. The sensors were calibrated at the time of manufacturing; and after the device was assembled. The efficacy of the sensor was not tested by co-locating it with a reference sensor as the timelines of the study did not permit that. This can be acknowledged as a limitation of the current set of monitors. To compare air quality data between rural and urban areas (primarily Delhi), air quality data on Delhi compiled by the Central Pollution Control Board (CPCB) was downloaded from Openaq.[4]

2.1.3 Agricultural statistics data

The secondary district-level data on the area under paddy and basmati cultivation of Punjab state were collected from the Basmati Survey Report, published by the Agricultural & Processed Food Products Export Development Authority (APEDA) in 2017, and the Statistical Abstract of Punjab (2012–2017).

4 Openaq (https://openaq.org) is an online platform where air quality data from public data sources provided by government, research-grade, and other sources are made available for public access.

Since the problem of paddy residue burning is associated with non-basmati cultivation, the district-level data on the area under non-basmati cultivation was calculated by subtracting the area under basmati cultivation from the area under total paddy cultivation.[5]

2.2 Analytical approach

2.2.1 Extraction of satellite derived fire incidence data

Quantum GIS (QGIS version 3.2.0-Bonn), an open source application, was used to process the fire detections acquired from satellite data in the study area. The raw file from 2012 to 2018 was downloaded from the FIRMS of NASA. Clip, a vector processing tool, was used to derive the fire incidence for the study area from the raw file. To merge the data with the Punjab shapefile, Union tool was used. The Punjab shapefile was extracted from the Database of Global Administrative Areas (GADM, www.gadm.org), version 3.6, released in May 2018.

2.2.2 Categorisation of districts of Punjab

The fire count (number of unique fire incidents) is directly determined by the area under non-basmati cultivation and the resultant crop cuttings that are rendered unusable, on account of current practices. Thus, fire counts are higher in districts with higher acreage under non-basmati rice. The author categorised the 22 districts of Punjab, through a derived variable, denoting crop residue burning intensity. The metric we choose is the number of fire counts per unit area (1000 hectares) under non-basmati cultivation (Annexure Table A 1). Districts with fire count intensity in the first tertile (< 33.3 percentile value) are considered low-burn; districts in the middle tertile are considered medium-burn; and districts in the highest tertile (> 66.6 percentile) are considered high-burn (Figure 1).

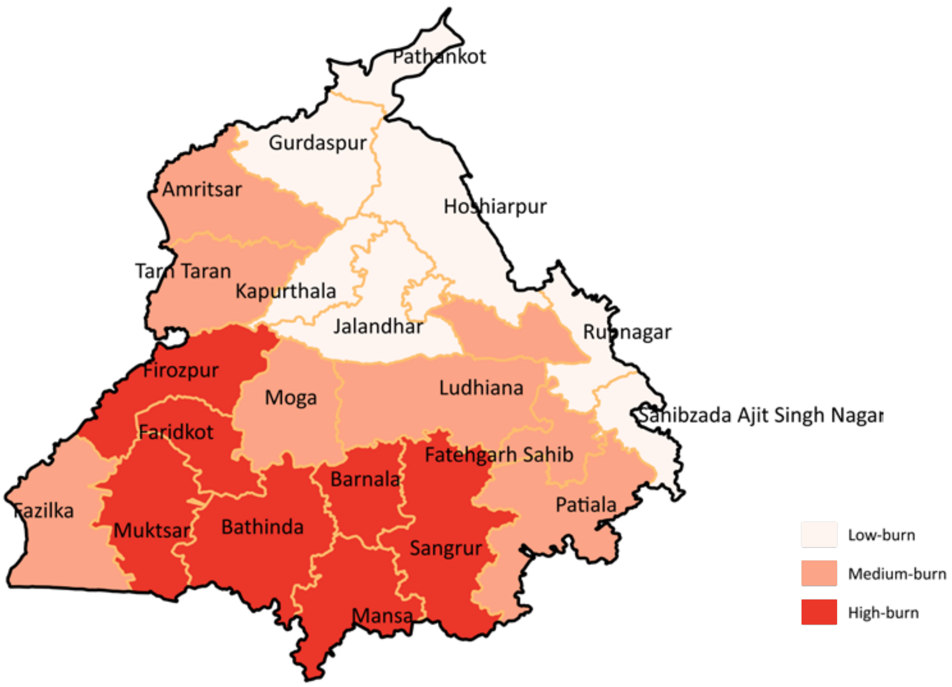


FIGURE 1: Punjab's districts categorised by number of open fires per 1,000 hectares under non-basmati cultivation

Source: CEEW analysis, 2019

5 Basmati is a variety of paddy crop that raises a superior price in the market. It is harvested manually to minimise grain loss; the loss is higher if combine harvesters are used (Gupta R. , 2012). Basmati residue, used as animal fodder, is not burned in the field.

Air quality in rural areas is worsened by activities such as crop residue burning and biomass burning for heating and solid fuel usage.

Image: iStock

3. Key Findings

This section highlights the key findings from the analysis on air quality as well as transition in crop residue burning.

3.1 Understanding the pattern of crop residue burning over time

The fire counts over Punjab detected by the VIIRS sensor from 2012 to 2018 are illustrated in Figure 2. More fires were observed during October and November, the season associated with paddy residue burning, than during April and May, the season associated with wheat residue burning. Conversations with farmers, and the existing literature, suggest that wheat crop residue is used as fodder for cattle while paddy (especially non-basmati) residue is not suitable.

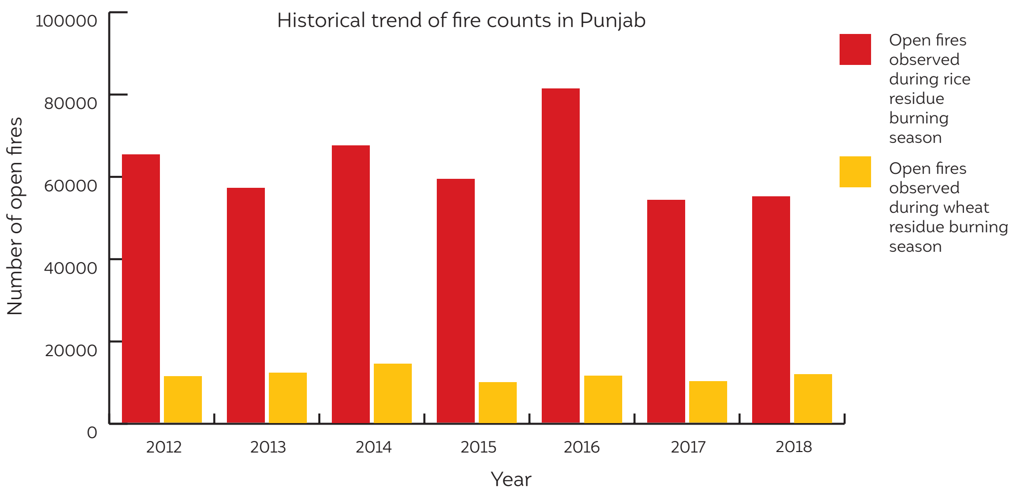


FIGURE 2:
No significant reduction in fire counts in Punjab in 2018 with respect to 2017

Source: CEEW analysis, 2019; NASA VIIRS 375 m

**Open fires from any burning detected by the satellite*

By and large, fire counts remained reasonably steady over the entire period. The variation in fire counts between various years can be explained by the interplay between area under non-basmati rice, basmati rice and cotton. 2016 saw a 37 per cent increase in paddy residue burning compared to 2015 and the most significant anomaly in fire count in the period under study. One of the reasons driving this is be the large (15.5 per cent) increase in area under non-basmati rice cultivation in 2016. Two factors contributed to this - the shift away from basmati and cotton by farmers. A 35 per cent decrease in acreage under basmati cultivation was on account of low market price for the commodity in 2015 (PTI, 2016). The damages suffered by cotton farmers on account of infestation by the white fly in 2015 resulted in a 16 per cent drop in acreage under cotton (Yadav, 2016).

In 2017, non-basmati acreage came down to 'normal' levels seen in earlier years. Low inventory of basmati rice, a fall in taxes on account of the new GST regime, coupled with rising exports demand and market price of basmati variety, drove farmers to increase the acreage under basmati cultivation (Das, 2017). This further resulted in a shift away from non-basmati rice. As a result, paddy residue burning fell 33 per cent over 2017. In the intervening period, the increasing realisation of the impacts of burning in Punjab, on the air quality in Delhi, bans and fines on burning were also introduced. This could have contributed to some of the reduction that was seen in 2017 (Haq, 2018). 2017 exhibited lower fire counts as compared to 2015, though the area under non-basmati paddy was higher in 2017. So clearly, the bans and fines did have some role to play in decreased burning.

No Significant decline in incidents of crop residue burning between 2017 and 2018 was observed

However, this drop from 2016 to 2017 did not accelerate any further in 2018. Statistical test suggests that the fire counts did not decline significantly between 2017 and 2018[6]. Conversations with farmers and relevant stakeholders suggest that there are slew of gaps in existing policies to mitigate crop residue burning. For instance, though we have the NPCMR policy, to promote agricultural implements – like Happy Seeder that can mix the crop residue with soil at a subsidised rate – not sufficient agricultural implements were available with farmers' co-operatives and unions in 2018. This was partially due to delay in sending out tenders for the production of implements. The manufacturers had enough capacity to supply the tenders, but they were given an inadequate three months.

Punjab has 3,200 farmers' cooperative societies and 12,000 villages. Farmers informed us that the availability of machines in Custom Hiring Centres (CHCs)[7] is limited and inaccessible to them. The rental cost of implements such as Happy Seeder ranged from INR 500 per acre to INR 1,500 per acre, prohibitive for some farmers; there was no standard rate set. The lack of awareness programmes and a resultant perception gap among farmers on the pricing of such implements was also observed.

Based on our discussion with relevant stakeholders, any intervention, to be successful, will have to be undertaken a few months ahead of the crop cutting season. Cognisant of this, the agriculture department has started accepting applications from farmers and manufacturers interested in subsidised implements. The tender process for manufacturers is expected to begin in June to avoid delays in 2019. This is to tackle the issue of crop residue burning in the next season and to encourage farmers towards mechanised paddy transplantation.

3.1.1 Temporal variation of open fires at the district level

In 2018, compared to 2017, fire counts dropped in all low-burn districts in Punjab except Pathankot (Table 1). Fire counts increased in medium-burn districts such as Amritsar, Moga, and Fazilka; in other districts, there was a decrease. All the districts under high-burn category show an increase in fire counts. Between 2012 and 2018, there was a decrease in fire counts observed during paddy residue burning (Figure 3). There was an improvement in low-burn and medium-burn districts (except Tarn Taran and Fazilka), but a deterioration in high-burn districts (except Barnala) over the past seven years.

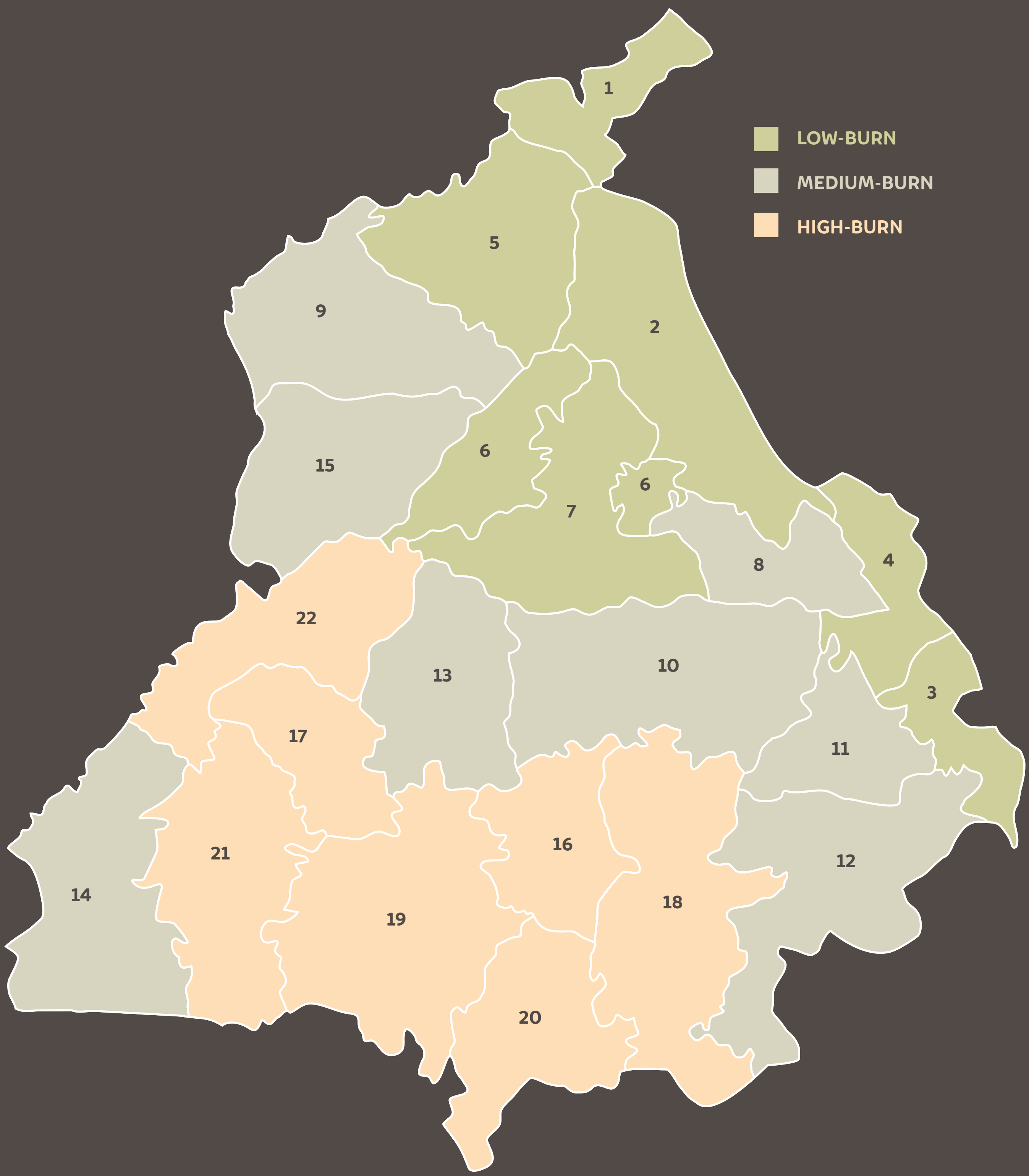
6 P-value for two-sample Kolmogorov–Smirnov test for the number of fires detections observed in 2017 and 2018 in Punjab is 0.3854, which is not significant.
7 CHCs comprise a set of farm machinery, implements, and equipment meant for custom hiring by farmers.

There has been a change in the percentage contribution of each category of Punjab's districts to the fire counts observed overall during paddy residue burning from 2012 to 2018 (Figure 4). The percentage contribution of high-burn districts increased from 54.8 per cent in 2017 to 60.7 per cent in 2018. Medium-burn districts show a decrease from 35.55 per cent in 2017 to 32.91 per cent in 2018, as do low-burn districts, from 9.63 per cent in 2017 to 6.38 per cent in 2018. One of the possible reasons driving this could be the operational landholding of farmers in different districts. It was observed that the low-burn districts have a greater number of low and marginal landholding farmers than the high and medium-burn districts, which have a greater number of medium and large landholding farmers (Economic and Statistical Organisation, 2018). With increase in landholdings, high-burn districts experience higher fire counts. However, a more robust study is required to understand the reasons behind the trend in fire counts across districts.

One ton of straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg SO_2 (Gupta et all. 2004)

Image: Kurinji L.S./CEEW

Table 1
Temporal change of district-wise fire counts observed during paddy residue burning in Punjab



Source: CEEW analysis, 2019; NASA VIIRS 375 m

Category	Districts	2012	2013	2014	2015	2016	2017	2018	Status between 2017 and 2018
		Number of fire counts observed							
LOW-BURN	1 PATHANKOT	31	13	21	24	31	16	18	Worsened
LOW-BURN	2 HOSHIARPUR	749	515	649	441	735	410	193	Improved
LOW-BURN	3 S.A.S NAGAR	284	261	203	241	292	196	162	Improved
LOW-BURN	4 RUPNAGAR	563	560	454	436	653	278	101	Improved
LOW-BURN	5 GURDASPUR	1,403	1,102	1,219	983	1,802	1,318	1,059	Improved
LOW-BURN	6 KAPURTHALA	1,966	1,577	2,175	1,821	2,363	1,259	676	Improved
LOW-BURN	7 JALANDHAR	2,989	2,759	3,057	2,523	3,726	1,735	1,299	Improved
MEDIUM-BURN	8 S.B.S NAGAR	1,018	913	1,043	742	1,178	599	301	Improved
MEDIUM-BURN	9 AMRITSAR	1,121	859	953	1,353	1,677	1,049	1,254	Worsened
MEDIUM-BURN	10 LUDHIANA	6,495	5,833	6,608	5,102	7,452	3,780	2,750	Improved
MEDIUM-BURN	11 PATIALA	5,024	3,934	4,389	4,190	5,070	3,906	3,835	Improved
MEDIUM-BURN	12 FATEHGARH SAHIB	2,235	1,899	2,010	1,894	1994	1,469	1,024	Improved
MEDIUM-BURN	13 MOGA	5,802	4,728	6,226	4,909	7,325	3,427	3,854	Worsened
MEDIUM-BURN	14 FAZILKA	2,193	1973	2,697	2,515	3,064	2,393	2,677	Worsened
MEDIUM-BURN	15 TARN TARAN	2,296	2,095	2,538	2,537	3,497	2,610	2,401	Improved
HIGH-BURN	16 BARNALA	4,128	3,383	4,242	3,615	4,803	2,954	3,126	Worsened
HIGH-BURN	17 FARIDKOT	2,716	2,366	2,999	2,607	3,440	2,675	2,790	Worsened
HIGH-BURN	18 SANGRUR	8,365	7,267	8,296	7,132	9,605	7,179	7,197	Worsened
HIGH-BURN	19 BATHINDA	4,185	3,843	4,852	4,417	7,011	4,451	5,876	Worsened
HIGH-BURN	20 MANSA	3,017	2,758	3,121	2,652	4,414	3,596	3,974	Worsened
HIGH-BURN	21 MUKTSAR	3,596	3,561	3,959	4,117	5,178	4,161	5,115	Worsened
HIGH-BURN	22 FIROZPUR	4,991	4,801	5,668	4,924	5,873	4,642	5,311	Worsened
	TOTAL	65,167	57,000	67,379	59,175	81,183	54,103	54,993	Worsened

Improved / Worsened

LOW — HIGH

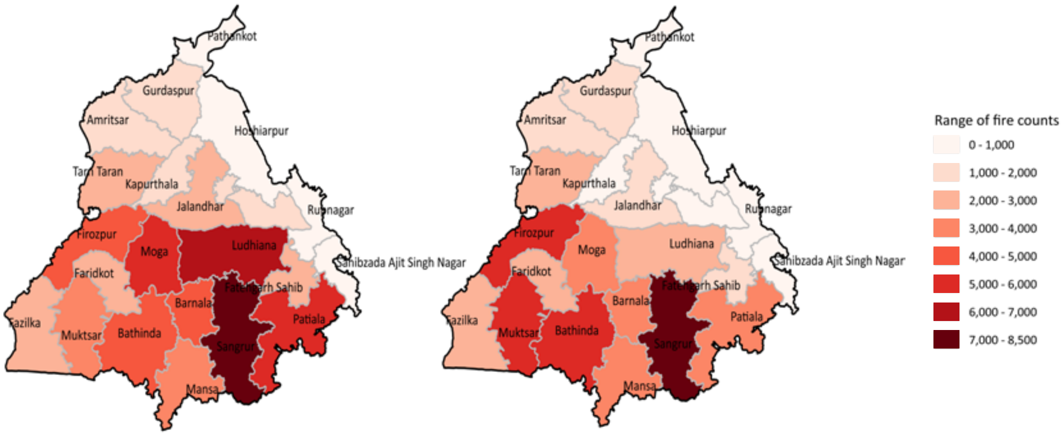


FIGURE 3: District-wise proportion of fire counts observed during paddy residue burning in 2012 and 2018 in Punjab

Source: CEEW analysis, 2019; NASA VIIRS 375 m

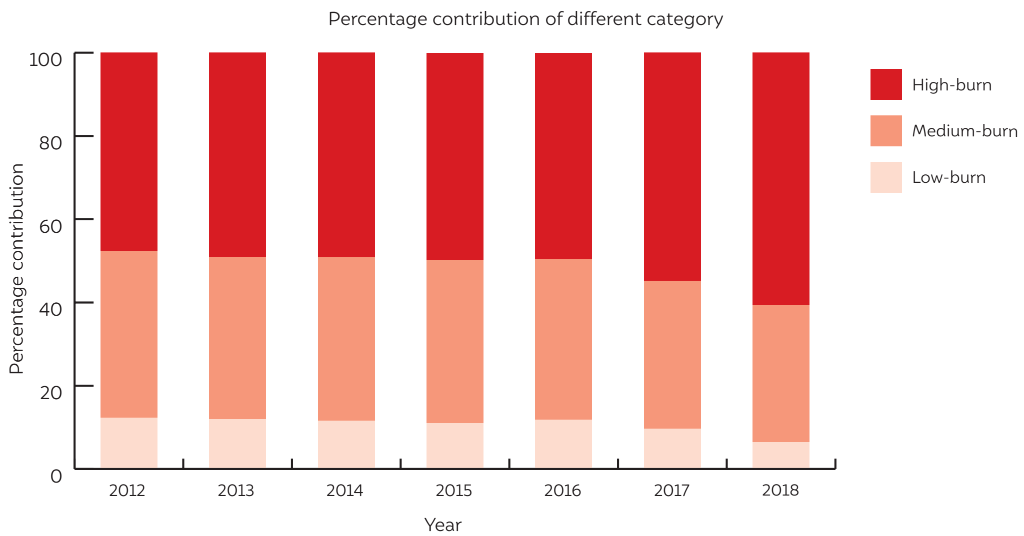


FIGURE 4: Temporal change of percentage contribution of different categories in Punjab's overall fire counts observed during paddy residue burning

Source: CEEW analysis, 2019

3.2 Disproportionate burden on local air quality

The spatial distribution of 48 low-cost sensors installed by CEEW across four districts of Punjab is shown in Figure 5. The daily average $PM_{2.5}$ concentration was compared with daily fire counts to understand the effect of burning crop residue on air quality. Data on fire counts was juxtaposed with data from the air quality sensors. A high correlation (0.72) was found between number of fire counts and $PM_{2.5}$ concentrations in high-burn districts (Sangrur) and medium-burn districts (Ludhiana), but no such significant correlation was found in low-burn districts (Hoshiarpur and Pathankot). A visual inspection suggests that $PM_{2.5}$ concentrations closely follow episodes of burning. However, a more robust study is required to establish a causal relationship.

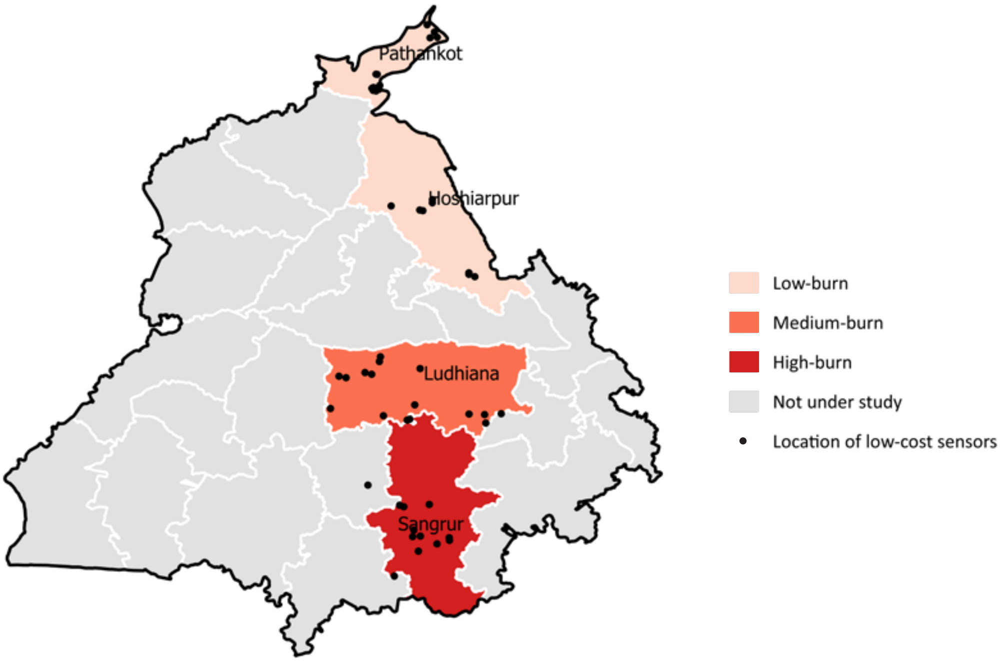


FIGURE 5: Location of low-cost air quality sensors installed by CEEW in Punjab

Source: CEEW analysis, 2019

Sangrur showed a significant increase in $PM_{2.5}$ concentration from mid-October 2018 to 15 November 2018 (Figure 6). This increase corresponds to the peak crop residue burning season. During this period, air quality in Sangrur was very poor and severe, according to the National Air Quality Index (AQI)[8] of the CPCB. The concentration of $PM_{2.5}$ decreased in end-November 2018 and remained almost constant until December 2018.

Similar to Sangrur, a significant increase in $PM_{2.5}$ concentration was observed in Ludhiana during the peak burning season (Figure 7). As per the AQI, the local air quality during these days was in the very poor and severe category.

Being low-burn districts, Hoshiarpur and Pathankot experienced a small increase in $PM_{2.5}$ during the peak burning season (Figures 8 and 9). As per the AQI, the local air quality during these days stays in very poor, poor, and moderate category.

The maximum median concentrations of $PM_{2.5}$ observed during the peak burning season were 650.27 µg/m³ in Sangrur, 343.53 µg/m³ in Ludhiana, 153.78 µg/m³ in Hoshiarpur, and 96.37 µg/m³ in Pathankot. The average median concentration of $PM_{2.5}$ during the peak paddy residue burning season (25 October 2018 to 20 November 2018) was 322.83 µg/m³ in Sangrur and 221.67 µg/m³ in Ludhiana. After the season, from 21 November 2018 to 10 December 2018, it fell about 47 per cent to 171.9 µg/m³ in Sangrur and about 21 per cent to 174 µg/m³ in Ludhiana. In Hoshiarpur and Pathankot, which are low-burn districts, no such significant variation was observed.

A high correlation between fire counts and PM2.5 concentration was found for high-burn (Sangrur) and medium-burn (Ludhiana) districts

8 The AQI categorises air quality into good, satisfactory, moderately polluted, poor, very poor, and severe. The proposed AQI will consider eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_2, NH_2, and Pb) for which short-term (up to 24-hourly averaging period) NAAQS are prescribed. Table A 4 in the Annexure details the AQI categories and the ambient concentrations of the identified eight pollutants. Table A 5 details the health impacts associated with the AQI.

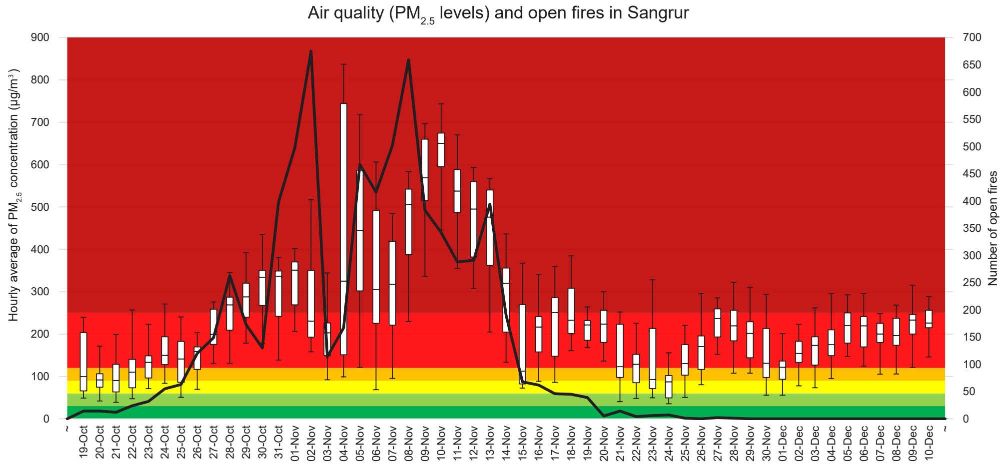


FIGURE 6: $PM_{2.5}$ concentrations during peak and post burning season in Sangrur (high-burn district of Punjab)

Source: CEEW analysis, 2019

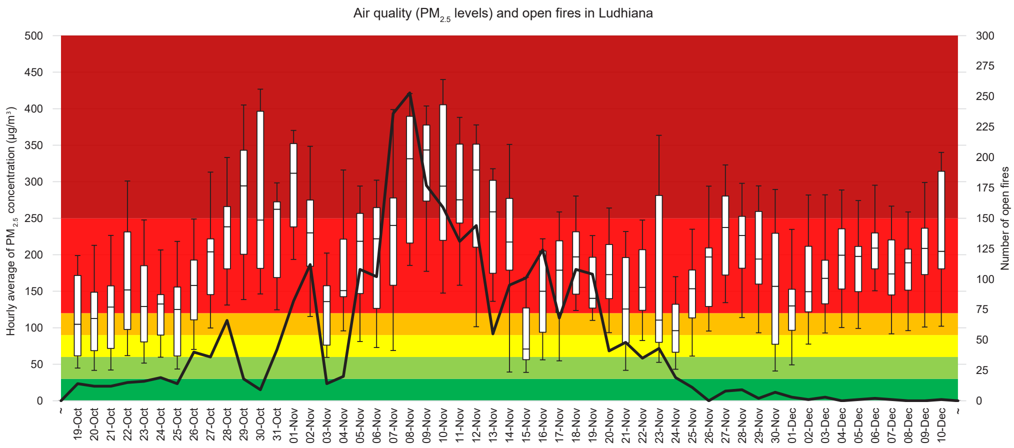


FIGURE 7: $PM_{2.5}$ concentrations during peak and post burning season in Ludhiana (medium-burn district of Punjab)

Source: CEEW analysis, 2019

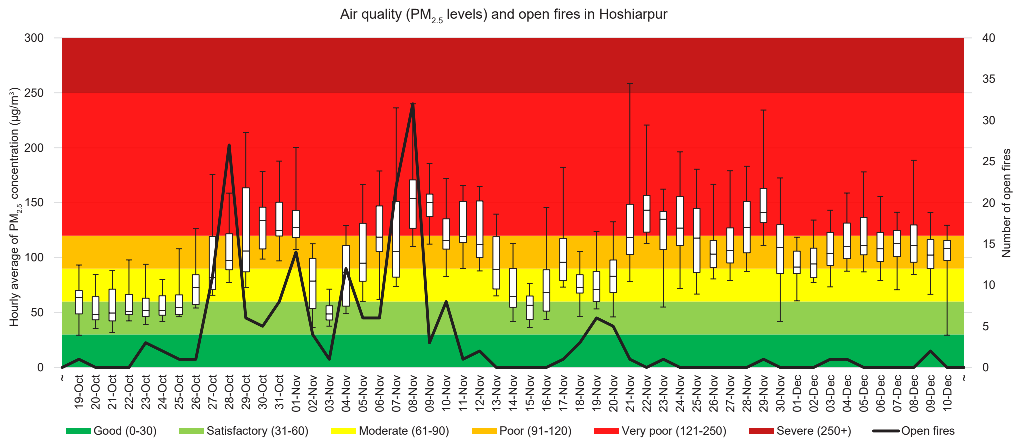


FIGURE 8: $PM_{2.5}$ concentrations during peak and post-burning season in Hoshiarpur (low-burn district of Punjab)

Source: CEEW analysis, 2019

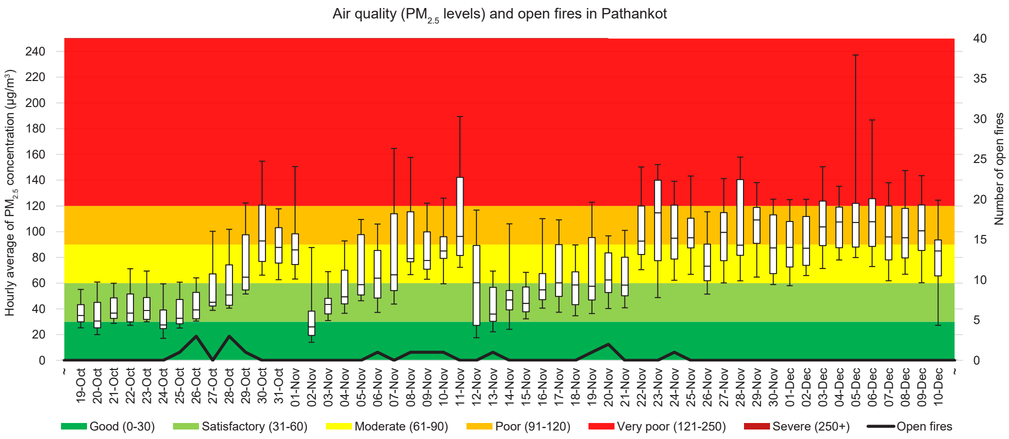


FIGURE 9: $PM_{2.5}$ concentrations during peak and post-burning season in Pathankot (low-burn district of Punjab)

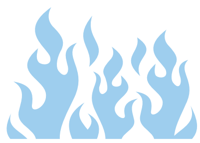
Source: CEEW analysis, 2019

Although crop residue burning is an episodic process, it creates a momentous increase in the concentration of particulates that cross the CPCB's National Ambient Air Quality Standards (NAAQS). The crop residue burned after paddy harvest leads to significant loading of particulates over the ambient atmosphere. In districts where much crop residue is burned, air quality is poor which may result in adverse health impact; in districts where no/little residue is burned, air quality is better.

3.2.1 Rural areas experience high levels of air pollution too

The 24-hour average $PM_{2.5}$ concentrations of Delhi and districts of Punjab (Sangrur, Ludhiana, Hoshiarpur, and Pathankot) was compared to understand the variation in air quality during and after the peak burning season. The low-cost sensors are installed primarily in open fields in the villages of Punjab, and the data mainly represents rural Punjab. Air quality data of Delhi was obtained from CPCB monitoring stations. A direct comparability of $PM_{2.5}$ concentration is strictly not possible, as the monitors used for Delhi and Punjab are not the same. However, the sensors used in the field in Punjab were tested in measuring air pollution in Delhi and are comparable with a margin of 20 per cent with the reference sensors, especially when concentrations in Delhi are high.

The air quality in rural Punjab was as poor as that of Delhi during and after the peak burning period (Figure 10). From this perspective, farmers also suffer the consequences of polluted air just as much as residents of Delhi. Along with the crop residue burning, biomass burning for heating and solid fuel usage worsen the air quality in rural areas, but there are no adequate monitoring networks to capture this on a continuous basis. There is interest in the area during the episodic incidents of burning but none beyond. Our sensors continue to remain deployed in the field and data suggests that in the low-burn districts of Hoshiarpur and Pathankot, air quality was worse in the period after the crop residue burning, as burning was warmth took hold in the colder days and resulted in high levels of particulate matter. This study does not document the various sources of air pollution in rural Punjab given the prevalence of biomass burning in the period of interest, the impacts are worrying. It is important to expand the air quality monitoring network in rural areas as well, to understand drivers of poor air quality throughout the year.



$PM_{2.5}$ values in Sangrur were similar to those observed in Delhi during the burning period

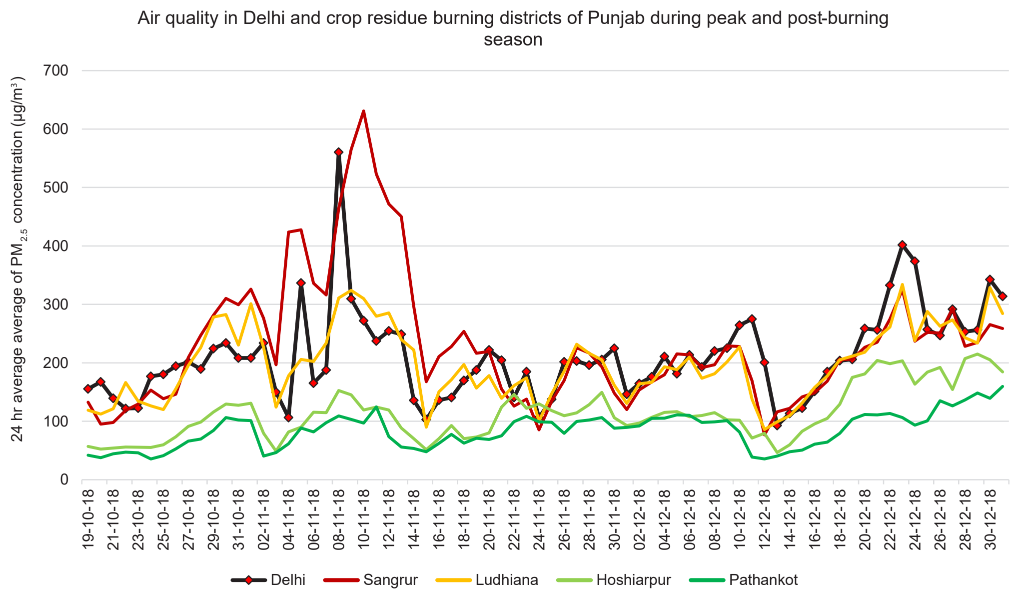


FIGURE 10: $PM_{2.5}$ Air quality in rural Punjab is poor and shows similar trends with Delhi

Source: CEEW Analysis, 2019; CPCB data from openaq

Low-cost sensors are an emerging alternative for air quality monitoring.

Image: Kurinji L. S./CEEW

3.3 Limitations of the study

We attempted to collect high-quality data to the best of our ability and performed rigorous analysis, but there are a few limitations.

Despite a high confidence level of fire counts data, fire counts derived from satellite data are not restricted to only crop residue burning. Our interpretation is that these are largely (if not entirely) associated with crop burning.

Deployment of low-cost air quality sensors, and use of their data to understand local air quality, may include uncertainties. However, in recent years, such low-cost sensors are widely used by citizen science groups and regulatory agencies to obtain granular information on the spatial and temporal distribution of particulate matter (Gupta, et al., 2018). The low-cost sensors were calibrated at the time of manufacturing; and after the device was assembled. However, the efficacy of the sensor was not tested by co-locating it with a reference sensor as the timelines of the study did not permit that.

Real time air quality monitoring and measurement helps to generate actionable information.

Image: iStock

4. Driving Policies – What is Needed?

The study yields insights that serve key stakeholders, policymakers, enterprises, and financiers that monitor crop residue burning and ambient air quality in rural areas. Based on the findings, the following key recommendations are made for the way forward.

4.1 Improve the rural air quality monitoring network

Research already established that air quality in rural areas is impacted by the sustained usage of solid fuels (GBD MAPS Working Group, 2018). Episodic incidents of burning crop residue worsen air quality significantly and the impact on the local population is not well understood or communicated. Robust monitoring helps to keep a watch on extreme pollution events and initiate action.

Satellite feeds are not real-time and there is a delay in being able to act on incidents of burning. As a result, the ability to cut back on burning on specific days when downstream impacts can be significant is compromised. The present national air quality monitoring network is limited in its coverage. The assessment using low-cost sensors illustrates the gravity of the situation and also the ambient air quality even when burning does not occur. To make decisions that are sound and effective, policymakers need credible data; therefore, the extent and quality of the national air quality monitoring network needs to be improved (Mudur, 2018).

To make decisions that are sound and effective, policymakers need credible data; therefore, the extent and quality of the national air quality monitoring network needs to be improved

4.2 Transparency and capacity building in the use of satellite data

The use of satellite data for understanding incidents of crop burning is limited to the publicly available information published by NASA/ NOAA, both US agencies. Satellite data from EU satellites are also used in certain instances. With India attaining significant capacity in deployment of satellites, and given that all of it is publicly funded, more information from satellites of Indian origin is needed. Given that the foreign satellites do not offer a continuous view of any of these incidents, a dedicate satellite to cover the Indian landmass and the availability of such data for research and policy making is the need of the hour. The implications for these could be more far-reaching and enable a better understanding of open fires and with better resolution – spatial and temporal. Our attempts to use the INSAT 3DR product for getting more reliable estimates of fire counts were not successful.

More important than transparency and increasing the availability of such data is the need to develop capacity to use the data that is available to generate insights and develop methods to provide timely inputs by way of forecasts and estimates on the extent of crop residue burning likely, given the standing crop and other on-ground changes. Further, there is a need to ground-truth satellite data with more on-ground monitoring to minimise error and to improve the accuracy.

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Annexure

Year	Paddy		Rice	Wheat	
	Area (000' hectare)	Production (000' tonnes)	Production (000' tonnes)	Area (000' hectare)	Production (000' tonnes)
1960–61	227	342	229	1,400	1,742
1970–71	390	1,027	668	2,299	5,145
1980–81	1,183	4,975	3,233	2,812	7,677
1990–91	2,015	10,011	6,506	3,273	12,159
1995–96	2,184	10,507	6,840	3,221	12,517
2000–01	2,611	13,663	9,154	3,408	15,551
2005–06	2,647	15,234	10,207	3,469	14,497
2006–07	2,621	15,131	10,138	3,467	14,596
2007–08	2,609	15,651	10,486	3,488	15,720
2008–09	2,734	16,412	10,996	3,526	15,733
2009–10	2,802	16,770	11,236	3,522	15,169
2010–11	2,831	16,174	10,837	3,510	16,472
2011–12	2,818	15,829	10,542	3,527	18,012
2012–13	2,845	17,128	11,390	3,517	16,614
2013–14	2,851	16,943	11,267	3,512	17,620
2014–15	2,894	16,578	11,107	3,505	15,050
2015–16	2,975	17,647	11,823	3,508	16,077
2016–17 (estimated)	3,046	18,812	12,604	3,500	16,450
2017–18 (target)	2,845	16,985	11,380	3,480	16,360

TABLE A1:
Production and area under paddy and wheat in Punjab (1960–2018)

Source: CEEW compilation, 2019; Agriculture Database, ENVIS Centre: Punjab

Year	(000' tonnes)		Contribution to central pool (%)	
	Paddy	Wheat	Rice	Wheat
1970–71	846	3,121	16	74
1980–81	4,432	3,941	45	73
1990–91	7,894	6,367	41	61
1995–96	7,337	5,984	35	59
2000–01	11,542	10,579	33	58
2005–06	14,310	8,174	32	75
2006–07	14,002	7,911	31	61
2007–08	13,788	10,583	28	43.8
2008–09	13,488	11,018	25.1	42.3
2009–10	14,249	10,278	29	45.3
2010–11	13,136	11,094	25.3	38.7
2011–12	12,017	12,935	22.1	33.6
2012–13	13,375	11,117	25.2	43.4
2013–14	12,749	11,931	25.5	41.6
2014–15	11,840	10,507	24.2	36.8
2015–16	14,333	10,824	27.5	46.4
2016–17	16,588	-	-	-

TABLE A2: Market arrivals of wheat and paddy (1970–71 to 2016–17)

Source: CEEW compilation, 2019; Agriculture Database, ENVIS Centre: Punjab

TABLE A3: Categorisation of districts of Punjab based on number of open fires per 1,000 hectare under non-basmati cultivation

Source: CEEW compilation, 2019; Agriculture Database, ENVIS Centre: Punjab

Category	Districts	Area under non-basmati cultivation (*000 hectare) in 2017	Fire counts observed during paddy residue burning in 2017	Fire counts per 1,000 hectare under non-basmati cultivation in 2017
Low-burn*	Pathankot	23.29	16	0.69
	Hoshiarpur	55.42	410	7.40
	S.A.S Nagar	26.13	196	7.50
	Rupnagar	30.16	278	9.22
	Gurdaspur	127.05	1318	10.37
	Kapurthala	108.31	1259	11.62
	Jalandhar	148.59	1,735	11.68
Medium-burn	S.B.S Nagar	48.09	599	12.46
	Amritsar	74.00	1,049	14.18
	Ludhiana	226.32	3,780	16.70
	Patiala	201.24	3,906	19.41
	Fatehgarh Sahib	73.50	1,469	19.99
	Moga	156.94	3,427	21.84
	Fazilka	107.19	2,393	22.33
	Tarn Taran	99.40	2,610	26.26
High-burn**	Barnala	104.69	2,954	28.22
	Faridkot	88.48	2,675	30.23
	Sangrur	236.01	7,179	30.42
	Bathinda	139.40	4,451	31.93
	Mansa	90.15	3,596	39.89
	Muktsar	99.28	4161	41.91
	Firozpur	66.67	4642	69.62

Source: CEEW analysis, 2019

Note:

**33.3 percentile – 12.20*

***66.6 percentile – 26.91*

Any district having fire counts per 1,000 hectare under non-basmati cultivation in 2017 less than 33.3 percentile was considered low-burn.

Any district having fire counts per 1,000 hectare under non-basmati cultivation in 2017 between 33.3 percentile and 66.6 percentile was considered medium-burn.

Any district having fire counts per 1,000 hectare under non-basmati cultivation in 2017 more than 66.6 percentile was considered high-burn.

TABLE A4: Air Quality Index (AQI) categories and ambient concentrations of identified eight pollutants

Source: Ministry of Environment, Forest and Climate Change, 2014

**One hourly monitoring (for mathematical calculations only)*

AQI categories and ambient concentrations of pollutants								
AQI categories (range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/ m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0–50)	0–50	0–30	0–40	0–50	0–1.0	0–40	0–200	0–0.5
Satisfactory (51–100)	51–100	31–60	41–80	51–100	1.1–2.0	41–80	201–400	0.5 –1.0
Moderately polluted (101–200)	101–250	61–90	81–180	101–168	2.1–10	81–380	401–800	1.1–2.0
Poor (201–300)	251–350	91–120	181–280	169–208	10–17	381–800	801–1,200	2.1–3.0
Very poor (301–400)	351–430	121–250	281–400	209–748*	17–34	801–1,600	1,200–1,800	3.1–3.5
Severe (401–500)	430 +	250+	400+	748+*	34+	1,600+	1,800+	3.5+

TABLE A5: Air Quality Index (AQI) categories and associated health impacts

Source: Ministry of Environment, Forest and Climate Change, 2014

AQI	Associated health impacts
Good (0–50)	Minimal impact.
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people.
Moderately polluted (101–200)	May cause breathing discomfort to people with lung disease such as asthma, and discomfort to people with heart disease, children, and older adults.
Poor (201–300)	May cause breathing discomfort to people on prolonged exposure, and discomfort to people with heart disease.
Very poor (301–400)	May cause respiratory illness to people on prolonged exposure; effect may be more pronounced in people with lung and heart diseases.
Severe (401–500)	May cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.

It is estimated that 22 million tons of rice straw surplus is produced in India each year, out of which 14 million tons (about 63 per cent) is burned, mostly in the north-western states of Punjab and Haryana (Gadde, et al., 2009).

Image: iStock

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