High $PM_{2.5}$ Levels in Delhi-NCR Largely Independent of Punjab-Haryana Crop Fires - An Analysis of Observations Across a Network of 30 Sites

International collaborative research led by Aakash Project[*] researchers at the Research Institute for Humanity and Nature (RIHN) show an unequivocal contribution of crop residue burning (CRB) to air pollution in the rural/semi-urban regions of Punjab and Haryana, and a relatively lower contribution than previously thought to the Delhi national capital region (NCR). We have installed 30 units of compact and useful $PM_{2.5}$[**] *in situ instrument with gas sensors (CUPI-Gs) and have continuously recorded air pollutants in 2022 and 2023. New analytical methods have been developed to assess and predict the formation and transport of air pollutants due to emissions from CRB.*

The adverse impacts of air pollution on human health, economic activities and lifestyle have been a major concern for decades as pollution at an alert level occurs each year during the October-November months in Delhi-NCR. One of the many hypotheses, to explain rapidly built-up and sustained high $PM_{2.5}$ concentrations in Delhi-NCR, implicates large contributions from the paddy CRB in Punjab and Haryana states of northwest India (Fig. 1). Burning of rice stubbles in the region is a common practice for land clearing since mechanised paddy harvesting is adopted and is thought to protect fields from pests and preserve soil fertility. Although this formation mechanism of air pollution in Delhi-NCR is debated till date (e.g., in media reports and research publications), policymakers at state and central government levels have targeted eradication of CRB by changing behaviour of farmers in land clearing. The debate continues mainly because of the lack of systematic measurements from the regions of concern. In this study, the research team used a combination of (1) measurements from the Aakash Project's low cost CUPI-G network, (2) analyses of air mass trajectories, fire counts and wind patterns, and (3) chemistry-transport simulations to assess the impact of CRB on $PM_{2.5}$ in rural, sub-urban and megacity regions.

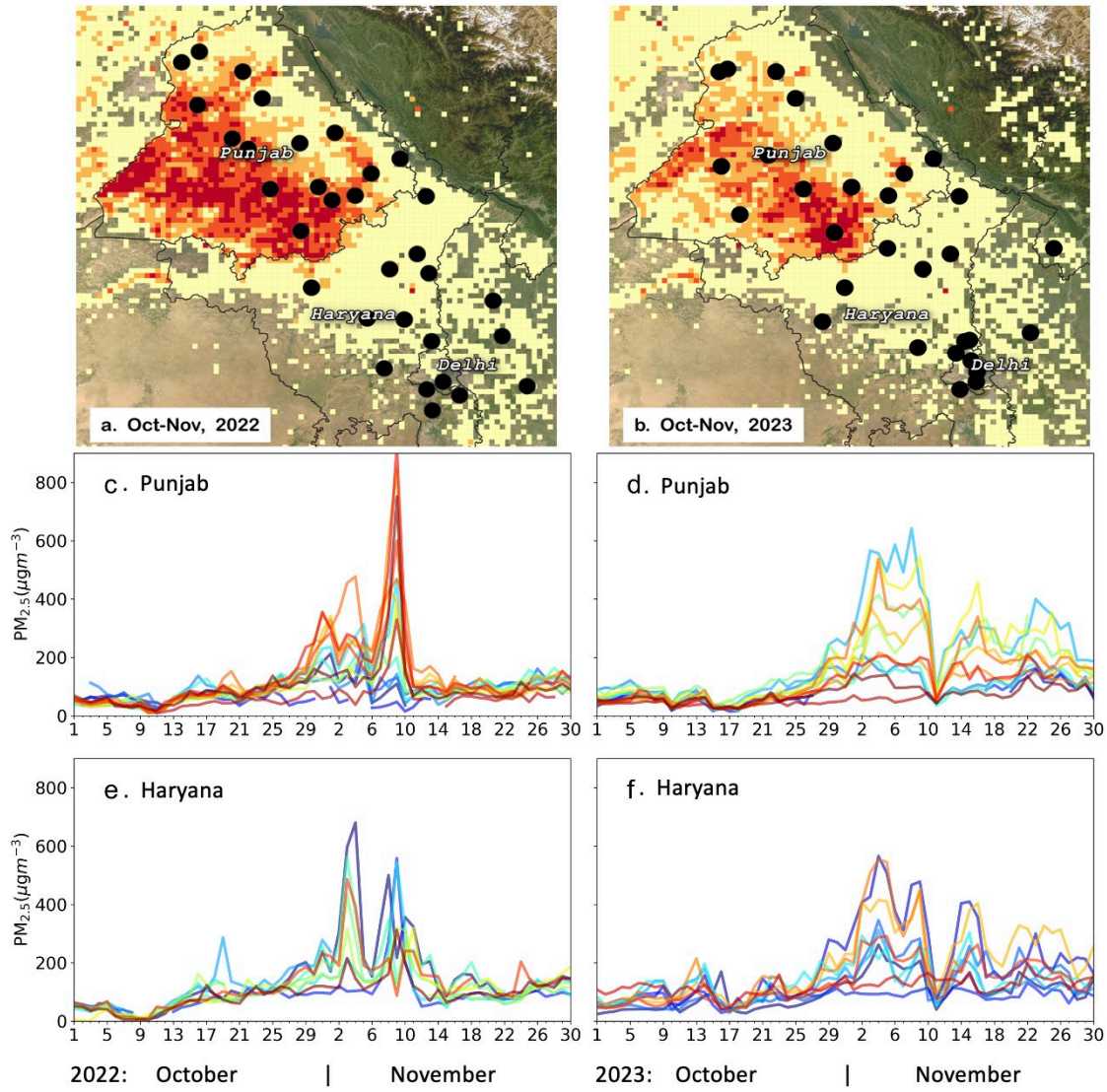

Figure 1. Soon after the kharif/summer crops (mainly rice paddies) are harvested, large number of farm fires are detected from the satellites in late October to November over northwestern India (a:2022, b:2023; top row). A network of about 30 low-cost sensors has been deployed during the intense CRB period since 2022 (black circles in a, b). Our measurements show rural area air pollution in Punjab (c, d; middle row) and Haryana (e, f; bottom row) was significantly caused by paddy crop residue burning in the October-November months for both 2022 (left column) and 2023 (right column). The FDC maps, at 0.05×0.05 degrees grid resolution, are created from Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the SNPP and NOAA20 satellites hotspot detections. The background shows the visible image of earth's surface.

The research findings highlight that, despite a significant reduction in the satellite fire detection counts (FDCs) over Punjab and Haryana from 2015 to 2023, $PM_{2.5}$ concentrations in Delhi have remained high. The $PM_{2.5}$ concentrations showed large day-to-day fluctuation from site-to-site in both 2022 and 2023 (Fig. 1). Both years saw significant fire counts in southwest Punjab with

daily-mean $PM_{2.5}$ exceeding 300 μg m^{-3} in Delhi, but the meteorological conditions were markedly different for the peak CRB days of November 1st – 12th of 2022 and 2023. November 2022 witnessed a prevalence of northwesterly winds allowing the transport of airmass from Punjab and Haryana to Delhi-NCR on two occasions. However, in November 2023, a southwesterly low wind condition with speed <1 m s^{-1} limited air movement causing an accumulation of local pollutants in Delhi-NCR (Fig. 2). Our analyses showed that the buildup and sustenance of $PM_{2.5}$ in the Delhi-NCR is primarily of local origin and can be inferred from the rise/drop in concert with implementation/revocation of Graded Response Action Plan (GRAP) stages as administered by the Commission of air quality management (CAQM) (Fig. 2).

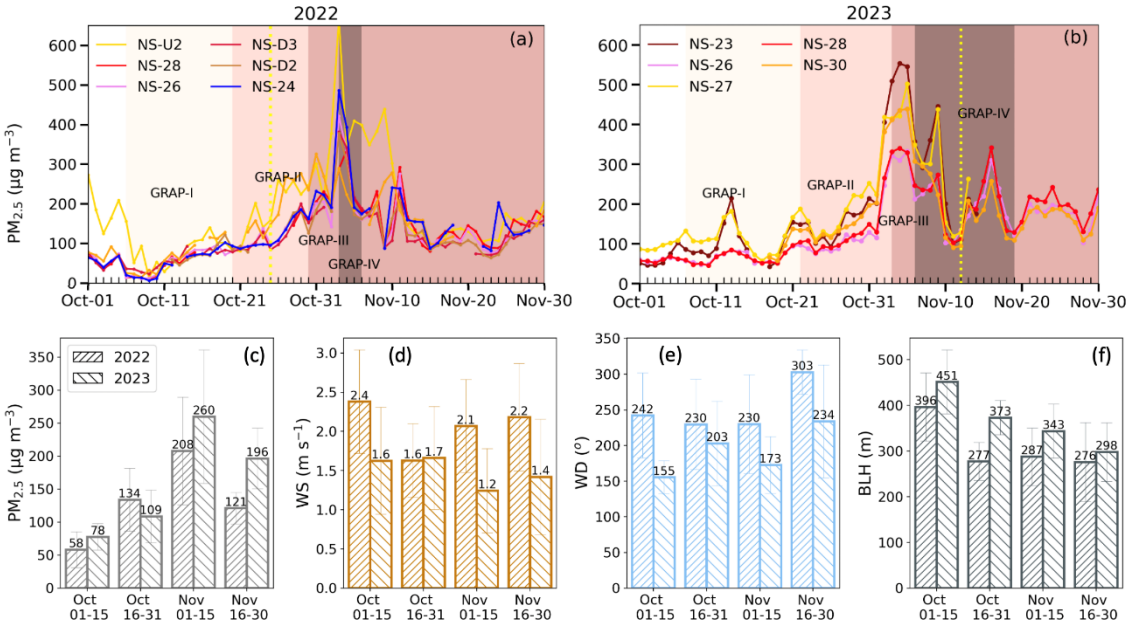

Figure 2. The $PM_{2.5}$ concentration in megacity Delhi and its neighbourhood are mainly dominated by local emissions and can be managed reasonably well through the GRAP implementation focusing on the NCR (top row). Strong meteorological influences at synoptic and interannual are also observed as summarised by the plots in bottom row, for mean $PM_{2.5}$ (c), wind speed (d; WS), wind direction (e; WD) and atmospheric mixing by boundary layer height (f; BLH) during the October-November period at an interval of 15 days.

"With the measurements at a network of about 30 sites covering Punjab, Haryana and Delhi NCR, we are able to separate the contributions of paddy straw burning to Delhi's $PM_{2.5}$ variations on the basis of characteristic $PM_{2.5}$ events and at week-monthly averages," says Prof. Prabir Patra, the leader of Aakash Project and principal scientist at Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Multiple years of data (2022-2023; now 2024) gathered by the project helps to confirm the findings and (in)validate the hypothesis (Fig. 3).

Based on several types of analysis as presented in Mangaraj et al. (2025), we have been successful in processing the observation data and model-based analysis in near real-time. These data and

plots have been shared online daily via the Aakash-RIHN website since 2023 (e.g., https://aakash-rihn.org/en/campaign2023-week13/). We have concluded that CRB in Punjab and Haryana cannot be made responsible for determining the air quality in Delhi-NCR, even during the peak rice stubble burning period (Oct-Nov). Apart from the fact that the horizontal wind flow is blocked by the Himalayas to the north (ref. Fig. 1a, c), the freshly emitted and photo-chemically formed $PM_{2.5}$ is randomly transported in the other 3 directions horizontally and is diluted vertically through the planetary boundary layer ventilation (Fig. 3). "Our study underscores the importance of continuous monitoring of air pollutions in both source (Punjab), receptor (Delhi-NCR) and intermediate (Haryana) regions for implementation of targeted mitigation strategies to combat persistency of harmful air pollution," says Dr. Poonam Mangaraj, the lead author of the article.

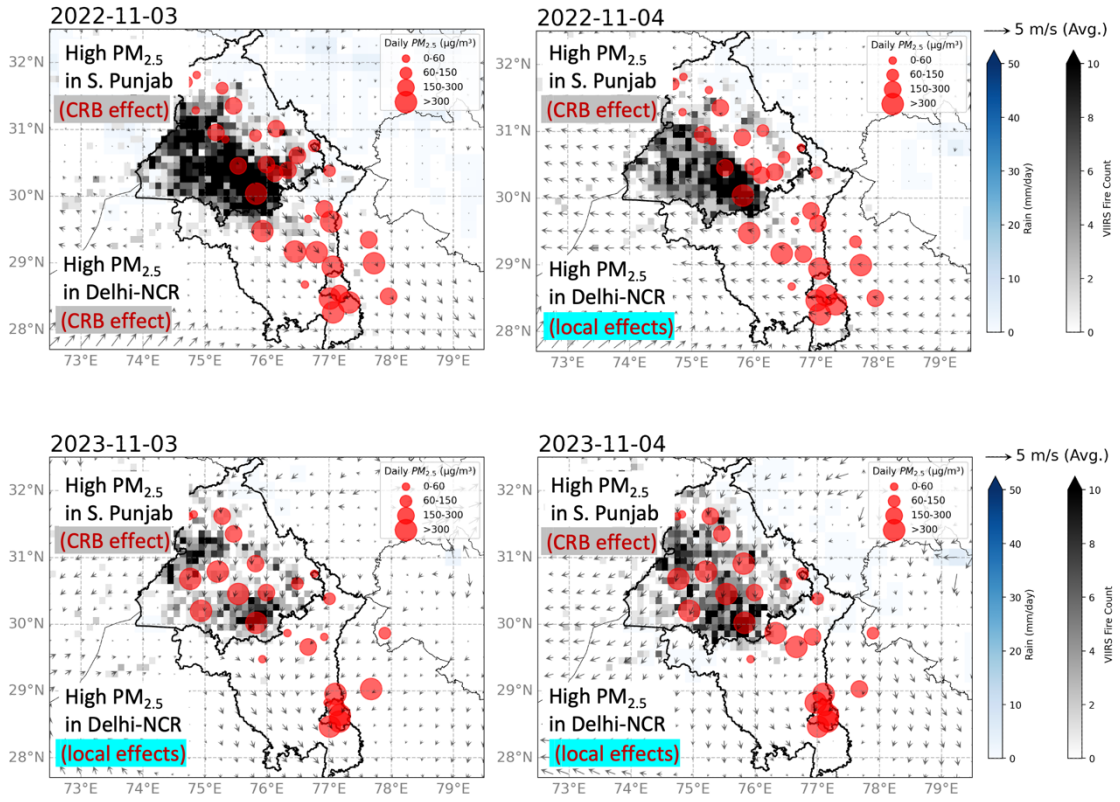

Figure 3. Diagrams showing that Aakash/CUPI-G ground-based observation network allows us to track the movement of plumes from Punjab to Delhi. Four days of high $PM_{2.5}$ in Delhi-NCR are shown in 2022 (top row) and 2023 (bottom row). The CRB effect always elevates the daily mean $PM_{2.5}$ concentration (red circles) in South Punjab, while the direct effect of CRB rarely reaches to Delhi-NCR. The CUPI-Gs recorded $PM_{2.5}$ continuously, even under hazy and cloudy conditions when satellites cannot detect CRB or related information.

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The measurement data of $PM_{2.5}$ are made available from the RIHN database with open data sharing policy (https://aakash-rihn.org/en/data-set/).

*The Aakash project is exploring ways to shift people's behaviour to sustainable agriculture in the Punjab region to reduce the health hazards caused by air pollution, by clarifying observation-based relationship between straw burning and local air pollution; raising awareness of the importance of maintaining clean air among residents; and proposing the effective and beneficial use of rice straw by farmers.

**$PM_{2.5}$: particulate matter less than 2.5 μm in diameter (popularly known as $PM_{2.5}$). These fine particles can be inhaled during human breathing. Depending on chemical composition, defined by oxidative potential (OP), they damage the pulmonary cells. The particulates from materials burning usually have greater OP than those from natural sources, e.g., mineral dusts or secondary organics.

Article information

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