COVID-19 pandemic and sudden rise in crop residue burning in India: issues and prospects for sustainable crop residue management

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Abstract

The seasonal burning of crop residue significantly affects the environment, leading to poor air quality over Indo-Gangetic Plain (IGP) in India. Hence, there have been significant efforts to minimize crop residue burning through policy, innovations, and awareness measures. However, an abrupt increase in paddy residue burning was observed over IGP during 2020. Hence, the study explores the factors leading to this sharp rise. The business as usual trends analysis revealed that paddy crop residue burning activities increased significantly (60%) in 2020 compared to the previous year. The massive increase in crop residue burning consequently seems to be linked with the COVID-19 pandemic, which affected the farmer's income, including the poor compliance by the regulatory authorities. The study also highlights the issues and prospects for sustainable crop residue management and explores the solutions to minimize crop residue burning. There are few crops in India that have guaranteed minimum sale price and are also subsidized. These provisions encourage farmers to grow those particular crops, resulting in the generation of large amounts of crop residue from these specific crops. There have been several efforts by the Indian government, including based on recent court intervention. Still, there is no respite from burning activities and the occurrence of Delhi winter smog every year. Hence, the study emphasizes a need to adopt integrated approaches having in situ eco-friendly solutions, which enhances the farmer's income and focuses on employability, capacity building, awareness generation, and in situ economically viable solutions.

Keywords Crop residue burning · IGP · COVID-19 · Air pollution · Agriculture policy · Fire counts

Introduction

The State of Global Air (2020) report highlighted that air pollution has become the 4th leading risk factor for premature deaths globally and is responsible for around 6.75 million premature deaths and 213 million years of healthy life lost (Health Effects Institute, 2020). Low- and middle-income countries like India, which are already facing the challenge of poor air quality, are ruthlessly hit by the COVID-19 pandemic. Pozzer et al. (2020) reported that air pollution is a significant cofactor for increasing COVID-19 mortality risk. The recent Emissions Gap Report (2020) also highlighted that although there was a dip in carbon dioxide emissions during the COVID-19 pandemic. However, with the carbon dioxide current emissions rate, we are far behind in meeting the Paris Agreement goals to limit global warming well below 2°C, preferably to 1.5 °C (EGR, 2020), as highlighted in the recent Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) that we need to massively cut the greenhouse gas (GHGs) emissions to achieve our goal. The primary sources of increasing

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Highlights

1. Studied sudden rise in crop residue burning (CRB) in IGP during COVID-19 pandemic
2. Kharif CRB increased significantly (60%) in the year 2020 as compared to 2019
3. Lack of human resources, low income of farmers, and poor regulatory compliance led to a massive increase in the CRB.
4. Community-based solutions should be promoted for sustainable crop residue management.

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atmospheric emissions are increasing industrial and vehicular sources, including biomass burning (Gurjar et al., 2016; Ravindra et al., 2016; Ullah et al., 2018; Singh et al., 2020a; Mor et al., 2021).

In India, crop residue burning leads to emissions of 824 Gg of PM_{2.5} and around 211 Tg of CO₂ equivalent GHGs to the atmosphere (Ravindra et al., 2018). In post-monsoon seasons, the air quality, especially in Indo-Gangetic Plains (IGP), degrades to extreme levels, having a significant linkage to crop residue burning (Singh et al., 2020a, b, c a,b; Mor et al., 2021; Singh et al., 2021). The Ministry of Agriculture, Government of India, initiated the National Policy for Management of Crop Residues (NPMCR, 2014) to curb crop residue burning and avert environmental deterioration. The NPMCR policies focus on promoting in situ crop residue management, technological intervention, diversification use of the crop, capacity building, and awareness of farmers and formulation and implementation of applicable laws. After the National Green Tribunal (NGT), India ordered to implement NPMCR strictly and ban the open burning of crop residue in agricultural fields.

However, despite having a policy and legal framework, the highest crop residue burning events were recorded in 2016. Crop residue burning also affects local and regional air quality resulting in massive haze events during the crop residue burning in winters (Lui et al., 2021; Grover and Chaudhry 2019; Irfan et al., 2015; Ravindra et al., 2020; 2021a, b). Due to NGT and public concern about air pollution, government provided subsidies for sustainable crop residue management practices such as purchase/hire of farming machinery and strict compliance of ban on crop residue burning activities through active surveillance (penalty) on violators. These initiatives (carrot and stick approach) partially helped in declining crop residue burning activities in the subsequent years compared to 2016.

Moreover, in early 2020, the COVID-19 pandemic adversely affected the globe, including India, leading to unprecedented lockdown (Ravindra et al., 2021a, b; Biswal et al., 2021). In 2020, the global spread of the SARS-CoV-2 virus, which primarily causes respiratory illness and is also known as COVID-19 disease, led to the shutdown of all major anthropogenic activities to control its transmissions (Ravindra et al., 2021c, d). The COVID-19 lockdown helped to reduce the concentration of major pollutants (PM_{2.5}, NO₂, etc.) significantly across the world and in India (Liu et al., 2020; Singh et al., 2020a, b, c; Kumari and Toshniwal, 2020; Mor et al., 2020). But as the restrictions were lifted, the air quality started to decline in counties like India. Further, the crop residue (paddy) burning in agrarian states of India (i.e., Punjab and Haryana) recorded a steep rise (> 60%) resulted in a high pollution load in Indo-Gangetic Plain. The emissions from these crop residue burning activities during the COVID-19 pandemic significantly impact air quality. Zhu

et al. (2020) and Travaglio et al. (2021) reported that poor air quality strongly correlates with COVID-19 infection spread.

Hence, this study tries to explore the factors that lead to an abrupt increase in crop residue burning in the wake of the COVID-19 pandemic and highlights the issues and prospects for sustainable crop residue management so that suitable recommendations can be made to minimize crop residue burning, which negatively affects the health and environment.

Methodology

The data earth observation satellites are now widely used to monitor agriculture activities. In the current study, the data of active fire count was acquired from NASA/NOAA Suomi-National Polar-orbiting (Suomi NPP) satellite having Visible Infrared Imaging Radiometer Suite (VIIRS) sensor onboard for current and historic fire counts. VIIRS 375 m FIRMS standard active fire product which passes through 1:30 p.m. and 1:30 a.m. local time was used to study the fire counts (<https://firms.modaps.eosdis.nasa.gov/>). Due to higher spatial resolution, this VIIRS sensor data is highly used for fire management purposes as it helps to detect fires even of small intensity (NASA Earthdata, 2020; Singh et al., 2020a). The acquired data in the form of a shapefile was further processed using QGIS software to determine the number of fire counts over Punjab and Haryana states and their spatial distribution (Singh et al., 2021). Various policy documents and scientific literature policy opinions were critically examined to understand the chronology of policies and implementation strategies introduced to restrict crop residue burning in India. The data of paddy production was acquired from the Department of Agriculture, Cooperation, and Farmers Welfare, India (<http://agricoop.nic.in/>).

Crop residue burning trends

In India, Punjab and Haryana are the major agricultural states located in the IGP region, where major crop residue burning activities occur every year (Singh et al., 2020a, b, c), as shown in Fig. 1. From 2012, since when the fire counts data of the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor of NASA's Suomi NPP satellite is available, the highest fire counts were recorded in 2016 as 100029. The trend fluctuated before the year 2016, but later it started declining, and in subsequent years, the fire counts were reduced by 32.0 %, 34.2%, and 49.5% during the years 2017, 2018, and 2019, respectively.

However, an unexpected increase in paddy residue burning activities was noted in the year 2020, having around 80889 fire counts observed over the two major agricultural states (Punjab and Haryana), as shown in Fig. 2. The paddy

Fig. 1 Crop residue burning activities over northern states of India (red dots) and a thick blanket of smoke over the Indo-Gangetic Plain (IGP) region. (Source: NASA worldview dated 6 November 2020).

residue burning in 2020 increased by 18.9%, 23.0%, and 60.2% from 2017, 2018, and 2019, respectively. Amid the COVID-19 pandemic, the sudden increase in crop residue burning activities and related increases raises a human health concern as air pollution is a major risk factor for COVID-19 and may increase the related mortality in neighboring cities and megacity New Delhi. These locations are also reported to be the most polluted cities globally (Singh et al., 2020a, b, c).

Factors leading to an abrupt increase in crop residue burning activities.

In 2020, when the country was already fighting with the COVID-19 pandemic, a sudden increase in paddy residue-burning activities was noted. During the COVID-19 pandemic, the labor, which majorly was from other states of India, migrated back to their home states. During harvesting season, there was a scarcity of workforce to manage the crop residue, possibly leading to increased

paddy residue burning activities. Further, there could be other factors such as the dissent of farmers against new agricultural laws, i.e., which are a combination of three agricultural laws: (a) Farmers' Produce Trade and Commerce (Promotion and Facilitation) Act, 2020, (b) Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Act, 2020, and (c) Essential Commodities (Amendment) Act, 2020. The farmer in state Punjab and Haryana has some reservations over these bills, and they protest for a long time against them.

Also, the Government of India has introduced a new law called the "Commission for Air Quality Management in National Capital Region and Adjoining Areas Act, 2021" in which violation of air pollution laws will result in heavy penalties and punishments. The farmers also had reservations against this law when it was introduced in 2020 and manifest that the government is unable to provide farmers sustainable crop residue management solutions. Instead, they are trying to punish them with heavy fines. This act also has provisions to provide a practical framework and platform to curb crop

Fig. 2 Trend of daily fire counts over Punjab and Haryana (green line, average 2012–2019; and red line, 2020 from 1 September–30 November) (a), total fire counts from 2012 to 2020 during 1 September–30 November for the year 2012–2020 (b).

residue burning by research development, awareness, and capacity building of farmers.

Do we need to change agricultural practices for cleaner emissions?

In Punjab and Haryana, a dual cropping system is practiced having wheat and paddy as major crops. The wheat straw is generally utilized and used as fodder for cattle, but paddy straw contains high silica not suitable for cattle feed and is burned openly in agricultural fields (Ravindra et al., 2020). This led to the emission of harmful air pollutants into the atmosphere, which has significant implications on the environment and public health.

In the year 2017, as per the recommendation of the Department of Agricultural Research and Education for the adoption of mechanized crop residue management practices, the Ministry of Agriculture & Farmers Welfare pronounced the arrangement in the 2018–2019 budget of India. As a result, the scheme “Promotion of Agricultural Mechanization for in-Situ Management of Crop Residue in the State of Punjab, Haryana, Uttar Pradesh and National Capital Territory (NCT) of Delhi” was launched with a fund of 11.51 billion INR for the year 2018–2020 to curb the air pollution by providing subsidize machinery for in situ crop residue management in the states of Punjab, Haryana, Uttar Pradesh, and NCT of Delhi. This fund has provisions for establishing Custom Hiring Centers for agriculture machinery, distribution of machinery, Information Education Communication (IEC) activities, etc. Around 29,488 machines were acquired

under this scheme, of which 19109 machines were given under Custom Hiring Centers and 10379 machines were directly assigned to farmers (PIB, 2019).

Apart from it, to manage the paddy straw and curb the air pollution from its open burning, we also need to rethink current agriculture policies and subsidies on particular crops like paddy, especially in the northern states of India. The policies like free electricity, subsidized fertilizers, and increasing minimum support prices (MSP) every year are needed to be evaluated compared with other crops in terms of cultivation and production cost, water requirements, fertilizer and pesticide use, GHGs emissions, income and consumption patterns, etc. The state of Punjab and Haryana respectively produces only 11.01% and 3.88% of rice of the entire country’s rice production but accounted for 141.65 Gg of $PM_{2.5}$ in two months of Kharif harvesting (Beig et al., 2020).

Besides, cultivating paddy is a large source of methane emissions and a threat to global warming, whereas leaching of pesticides and chemicals is a public health threat. Moreover, paddy cultivation is also becoming a threat to groundwater as these regions are already dealing with water scarcity due to over-pumping of groundwater. Though in Punjab state, the “Preservation of Subsoil Water Act 2009” improved the average annual rate of decline in the water table from 0.9 (2000–2008) to 0.7m (2008–2012) (NIPFP, 2020) by delaying the sowing of paddy by 1 month and subsequently its harvesting.

As the planetary boundary height was low during the Kharif harvesting period in North India, crop residue burning emissions get trapped all over the IGP region, leading

to haze-like conditions (Ravindra et al., 2020). To mitigate these threats, we need to investigate and revisit our agricultural practices for cleaner emissions. As also suggested in the NPMCR, we need to shift our ongoing cropping system to mixed cropping. The withdrawn of subsidies on paddy and provides incentives on other crops like pulses and oil-seeds. This could also improve the farmer's income and soil health.

Perspective of carrot (subsidy) vs. stick (law)

To encourage in situ management of paddy straw, the Punjab Pollution Control Board has made it mandatory for all the combine harvesters to have a Super Straw Management System (Super SMS) attached with a machine (PPCB 2019). The violators of the NGT order will have to pay environmental compensation. The fine is based on landholding, i.e., ~33 USD per fire incidence having landholding less than 2 acres, ~65 USD per fire incidence who have landholding between 2 acres but less than 5 acres, and ~203 USD per incidence which have landholding more than 5 acres.

In 2018, 3997 cases, 510 cases, and 6193 cases of crop residue burning were registered against farmers in Haryana, Uttar Pradesh, and Punjab, and environmental compensation of 3.2 million, 2.6 million, and 1.9 million INR were recovered, respectively (NGT document, 2019). In 2019, a penalty of around 0.8 million USD was imposed on 23,000 farmers in Punjab. In contrast, in 2020, around 34,000 USD plenty was imposed on farmers from Punjab and Haryana states, where more than 700 fire cases were registered against farmers (Economic times, 2020).

Even though having so many laws for curbing air pollution in India (Fig. 3), the failure of their compliance resulted in air pollution adversities in many parts of India, especially in the IGP region. However, related law like “Preservation of Subsoil Water Act 2009” has been implemented strictly and efficiently in Punjab as the government cuts off the free power supply and makes the seeds unable during a specific period to ensure compliance.

As crop residue burning activities in the Northern states of India already result in a burden of 30 million USD per year in terms of health burden, increasing due to the upsurge in these activities (Chakrabarti et al., 2019). Hence, there is a need to rethink the current agriculture policies and subsidies for particular crops like paddy. The government cannot spend money on a produce that adversely affects the environment and human health.

Conclusion and way forward

As the seasonal crop residue burning in the IGP region causes severe air pollution and poses a threat to human health problem. Hence, 60% increase in the fire counts in 2020 especially in the post-monsoon season, has brought an alarming situation. Especially in the COVID-19 pandemic, increasing air pollution and its health impact is at the center stage. This massive increase in crop residue burning activities during COVID-19 seems to be linked to various factors like lack of human resources, low income of farmers, and poor regulatory compliance. The study stressed that for sustainable crop residue management, there is a need to take farmers in confidence to

Fig. 3 Timeline of critical policy interventions to curb air pollution and stubble burning in India

adopt cleaner agricultural practices and adopt integrated approaches having in situ eco-friendly solutions, which not only enhances the farmer's income but also focuses on employability, capacity building, awareness generation, and in situ economically viable solutions. With the current agriculture policy, we need to focus on the point highlighted below to have a way forward.

- a. The benefits to farmers should be holistic and given on crop production rather than to manufacturers of machines and/or on machines as machines work for a few weeks and the huge investments locked in it.
- b. In water deficit states like Punjab and Haryana, the indigenous "Happy Seeder" can help in effective crop residue management and save up to 1.45 million liters of water per hectare through less evaporation of water and sidestepping pre-sowing irrigation (The Nature Conservancy, 2017).
- c. As small-scale farmers and individuals do not have the capacity to create a long-lasting solution, community-based solutions are needed for sustainable crop residue management. The linking of the Mahatma Gandhi National Rural Employment Guarantee Act (MGN-REGA) to community agriculture in villages can help in providing a community-based solution.
- d. Empowering stakeholders with technical as well as socio-economic support is needed. The government needs to design policy interventions based on local problems and indigenous knowledge.
- e. Government should form policies and give incentives on the crops based on cost-benefit analysis from farm to market and keeping environmental and public health concerns as a mainstay of policy.
- f. Government agencies should adopt a comprehensive and holistic approach to curb crop burning across all cropping seasons rather than choosy approach.

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References

- Beig G, Sahu SK, Singh V, Tikle S, Sobhana SB, Gargeva P, Ramakrishna K, Rathod A, Murthy BS (2020) Objective evaluation of stubble emission of North India and quantifying its impact on air quality of Delhi. *Science of The Total Environment* 709:136126
- Biswal A, Singh V, Singh S, Kesarkar AP, Ravindra K, Sokhi RS, Chipperfield MP, Dhomse SS, Pope RJ, Singh T, Mor S (2021) COVID-19 lockdown-induced changes in NO₂ levels across India observed by multi-satellite and surface observations. *Atmos Chem Phys* 21(6):5235–5251
- Chakrabarti S, Khan MT, Kishore A, Roy D, Scott SP (2019) Risk of acute respiratory infection from crop burning in India: estimating disease burden and economic welfare from satellite and national health survey data for 250 000 persons. *Int J Epidemiol* 48(4):1113–1124
- Economic times (2020) https://economictimes.indiatimes.com/news/politics-andnation/punjab-haryana-begins-penalising-farmers-for-stubbleburning/articleshow/78684425.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cpst. Accessed 4 November 2021
- EGR (2020) <https://www.unep.org/emissions-gap-report-2020>. Accessed 4 November 2021
- Grover D, Chaudhry S (2019) Ambient air quality changes after stubble burning in rice–wheat system in an agricultural state of India. *Environ Sci Pollut Res* 26(20):20550–20559
- Gurjar BR, Ravindra K, Nagpure AS (2016) Air pollution trends over Indian megacities and their local-to-global implications. *Atmos Environ* 142:475–495
- Health Effects Institute (2020) State of Global Air 2020. Special Report. Boston, MA: Health Effects Institute. https://www.stateofglobalair.org/sites/default/files/documents/2020-10/soga-2020-report-10-26_0.pdf. Accessed 4 November 2021
- Irfan M, Riaz M, Arif MS, Shahzad SM, Hussain S, Akhtar MJ, van den Berg L, Abbas F (2015) Spatial distribution of pollutant emissions from crop residue burning in the Punjab and Sindh provinces of Pakistan: uncertainties and challenges. *Environ Sci Pollut Res* 22(21):16475–16491
- Kumari P, Toshniwal D (2020) Impact of lockdown on air quality over major cities across the globe during COVID-19 pandemic. *Urban Climate* 34:100719
- Liu F, Wang M, Zheng M (2020) Effects of COVID-19 lockdown on global air quality and health. *Science of The Total Environment* 755:142533
- Liu, Y., Zhang, J. and Zhuang, M., 2021. Bottom-up re-estimations of greenhouse gas and atmospheric pollutants derived from straw burning of three cereal crops production in China based on a national questionnaire. *Environmental Science and Pollution Research*, pp.1-6.

- Mor S, Kumar S, Singh T, Dogra S, Pandey V, Ravindra K (2020) Impact of COVID-19 lockdown on air quality in Chandigarh, India: understanding the emission sources during controlled anthropogenic activities. *Chemosphere* 263:127978
- Mor, S., Singh, T., Bishnoi, N.R., Bhukal, S. and Ravindra, K., 2021. Understanding seasonal variation in ambient air quality and its relationship with crop residue burning activities in an agrarian state of India. *Environmental Science and Pollution Research*, pp.1-14.
- NGT document (2019). https://greentribunal.gov.in/sites/default/files/all_documents/Affidavit-NGT_25-9-19.pdf. Accessed 4 November 2021
- NIPFP (2020). https://www.nipfp.org.in/media/medialibrary/2020/06/WP_308_2020.pdf. Accessed 4 November 2021
- NPMCR (2014). http://agricoop.nic.in/sites/default/files/NPMCR_1.pdf. Accessed 4 November 2021
- PIB (2019). <https://pib.gov.in/PressReleaseDetailm.aspx?PRID=1590402>. Accessed 4 November 2021
- Pozzer, A., Dominici, F., Haines, A., Witt, C., Münzel, T. and Lelieveld, J., 2020. Regional and global contributions of air pollution to risk of death from COVID-19. *Cardiovascular Research*.
- PPCB (2019). <http://www.ppcb.gov.in/Attachments/Reports%20and%20Documents/ActionPlanstubble.pdf>. Accessed 4 November 2021
- Ravindra K, Goyal A, Mor S (2021a) Influence of meteorological parameters and air pollutants on the airborne pollen of city Chandigarh, India. *Sci Total Environ* 151829. <https://doi.org/10.1016/j.scitotenv.2021.151829>
- Ravindra K, Goyal A, Mor S (2021d) Does airborne pollen influence COVID-19 outbreak? *Sustainable Cities and Society* 70:102887
- Ravindra K, Sidhu MK, Mor S, John S, Pyne S (2016) Air pollution in India: bridging the gap between science and policy. *Journal of Hazardous, Toxic, and Radioactive Waste* 20(4):A4015003
- Ravindra K, Singh T, Biswal A, Singh V, Mor S (2021c) Impact of COVID-19 lockdown on ambient air quality in megacities of India and implication for air pollution control strategies. *Environ Sci Pollut Res* 28(17):21621–21632
- Ravindra K, Singh T, Mandal TK, Sharma SK, Mor S (2021b) Seasonal variations in carbonaceous species of PM aerosols at an urban location situated in Indo-Gangetic Plain and its relationship with transport pathways, including the potential sources. *J Environ Manag.* <https://doi.org/10.1016/j.jenvman.2021.114049>
- Ravindra K, Singh T, Mor S (2019) Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. *J Clean Prod* 208:261–273
- Ravindra, K., Singh, T., Sinha, V., Sinha, B., Paul, S., Attri, S.D. and Mor, S., 2020. Appraisal of regional haze event and its relationship with PM_{2.5} concentration, crop residue burning and meteorology in Chandigarh, India. *Chemosphere*, p.128562.
- Singh V, Singh S, Biswal A, Kesarkar AP, Mor S, Ravindra K (2020) Diurnal and temporal changes in air pollution during COVID-19 strict lockdown over different regions of India. *Environmental Pollution* 266:115368
- Singh T, Biswal A, Mor S, Ravindra K, Singh V, Mor S (2020) A high-resolution emission inventory of air pollutants from primary crop residue burning over Northern India based on VIIRS thermal anomalies. *Environmental Pollution* 266:115132
- Singh T, Ravindra K, Sreekanth V, Gupta P, Sembhi H, Tripathi SN, Mor S (2020) Climatological trends in satellite-derived aerosol optical depth over North India and its relationship with crop residue burning: rural-urban contrast. *Science of The Total Environment* 748:140963
- Singh T, Ravindra K, Beig G, Mor S (2021) Influence of agricultural activities on atmospheric pollution during post-monsoon harvesting seasons at a rural location of Indo-Gangetic Plain. *Science of The Total Environment* 796:148903
- The Nature Conservancy (2017). <https://www.tncindia.in/about-us/news/no-burn-agriculture-possible-by-2022/>. Accessed 4 November 2021
- Travaglio M, Yu Y, Popovic R, Selley L, Leal NS, Martins LM (2021) Links between air pollution and COVID-19 in England. *Environmental Pollution* 268:115859
- Ullah A, Khan D, Khan I, Zheng S (2018) Does agricultural ecosystem cause environmental pollution in Pakistan? Promise and menace. *Environ Sci Pollut Res* 25(14):13938–13955
- Zhu Y, Xie J, Huang F, Cao L (2020) Association between short-term exposure to air pollution and COVID-19 infection: evidence from China. *Science of the Total Environment* 727:138704

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