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Abstract

The Agricultural state of Punjab is dominated by paddy and wheat cropping patterns because of extensive agricultural land and fertile plains of rivers - Ravi, Sutlej and Beas. During the kharif season, paddy is the most sown crop by farmers of Punjab, which leads to stubble burning after crop harvesting. Existing literature shows that there has been a dearth of studies on patterns of stubble burning in Punjab during the kharif season. Therefore, the major objective of the present study is to analyse the pattern of stubble burning in Punjab during the kharif season and to highlight the factors responsible for stubble burning. The present investigation is mainly based on secondary data taken from the website of the Punjab Remote Sensing Center, Ludhiana, for the years 2016-2022, and the district has been taken as a unit of the study. Data has been analysed using DQ ([FHO VKHHW 7KH ¿QGLQJV RI WKH VWXG\ VKRZ WKDW overall, there has been a declining trend in the patterns of stubble burning in the state of Punjab.

Keywords: Spatial Patterns, Paddy, Kharif Season, Stubble Burning, Declining Trend

INTRODUCTION

Stubble burning is a typical agricultural practice that is carried out all throughout the world, including Punjab, India. Burning crop residue after the harvest, sometimes referred to as stubble burning, is typically done to clear the feld rapidly for the following crop since it is seen to be an afordable and efective practice. It is a serious environmental concern in India, especially in the northern areas where agriculture is the primary economic activity. Kumar et al. (2015) studied the socioeconomic and environmental repercussions of agricultural residue burning in Punjab, India, and discovered that the practice had negative efects on human health, soil quality, and climate change. It contributes heavily to the haze in the northern regions of India during the winter, though, making it one of the main sources of air pollution, posing serious health risks and degrading the ecosystem. Sarkar et al. (2018) examined the rising danger of agricultural residue burning in northern India using satellite data and discovered that crop residue burning in this region has become more frequent and severe, resulting in major repercussions on air quality, human health, and the ecosystem. The authors emphasized the critical importance of governmental actions to promote alternative crop management practices and reduce the negative consequences of agricultural residue burning.

The issue of stubble burning has received substantial attention at the national scale in the past few years due to its negative impact on air quality and human health. Punjab, which is renowned for its excellent agricultural

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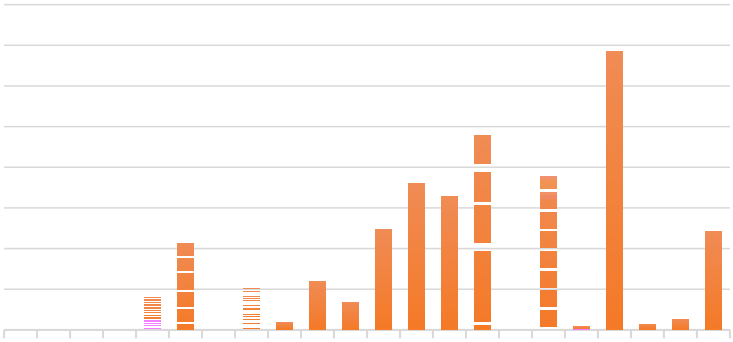
especially during the post-monsoon season. According to the authors, lowering the incidence of stubble burning by encouraging alternative crop management practices might enhance air quality and lower the health risks associated with air pollution exposure in northern India. Kumar et al. (2020) examined the spatial distribution of stubble burning in Punjab during the 2019 season using data from the Indian Space Research Organization's (ISRO) OceanSat-2 satellite and discovered that the districts of Sangrur, Barnala, and Mansa in the state's central region had the greatest density of stubble burning. According to the authors, this trend may be owing to the signi f cant proportion of small and marginal farmers in these regions, who may be more prone to engage in stubble burning due to economic limitations.

In India, stubble burning is practised mostly in Punjab, Haryana and UP, which contributes solely to the grave winter pollution in the National Capital, Delhi. The state of Punjab is known for being India's BREADBASKET. Though relatively small, Punjab grows about 30.2% of the rice (Statistical Abstract of Punjab, 2022), and 90-95% area is under intensive paddy farming. In November, farmers typically harvest rice and sow wheat. After harvest, they set f re to leftover plant debris to clear the f elds for the next plantings. Stubble burning became a rampant practice during the green revolution period when mass production of paddy was enabled in the plains of Punjab and Haryana. Historically, farmers harvested and ploughed f elds manually, tilling plant debris back into the soil. But after the introduction of COMBINES in the year 1980s, burning of stubble became common because the machines leave stalks that are about one foot tall. Burning the stalks was the quickest and cheapest way to clear them. Earlier, due to a lack of adequate knowledge and correct information about how e f ectively utilise the stubble, they have no choice but to burn the stubble to clear the f eld for the next crop. Das et al. (2021) investigated the geographical patterns of stubble burning in Punjab during the 2020 crop season. They discovered that agricultural waste burning was predominant in Punjab's central and western regions. According to the study, the overall number of burning events in 2020 will be fewer than in past years, potentially as a result of increasing knowledge and adoption of alternative crop management practices. Gulati et al. (2023) discovered signi f cant year-to-year f uctuations in stubble-burning areas and pollution concentrations in Punjab between 2019-2022 and found that November consistently had more burned areas and higher pollutant levels than October, highlighting the need for focused actions to o f set the negative e f ects of stubble burning on air quality. The government has also established a network of biomass power plants to convert crop leftovers into electricity and has provided farmers with incentives to encourage them to use alternative agricultural waste management practices. Despite these measures, stubble burning remains a major environmental and health concern in Punjab during the Kharif season. This study report aims to make a contribution to a better understanding of the regional patterns of stubble burning and to suggest viable strategies to mitigate the practice's negative repercussions.

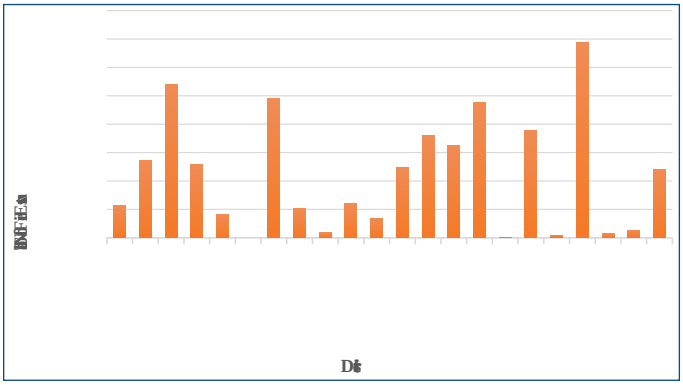
STUDY AREA

Punjab is an agricultural state that is known for its rice-wheat cropping system. Punjab is a landlocked state in northern India that shares borders with Pakistan, Jammu and Kashmir, Himachal Pradesh, Rajasthan, Haryana, and other states. The three principal geographical areas of Punjab are Majha, Doaba, and Malwa, each with its distinct topography, climatic conditions, and agricultural practices. The region is located between 29 degrees 30 minutes north and 32 degrees 32 minutes north latitude and 73 degrees 55 minutes east and 76 degrees 50 minutes east longitude, with a population density of 550 persons per square kilometre. It has a land size of 50,362 square kilometres (1.53 per cent of India's total geographical area) and a population of 2,77,04,236 people (2.29 per cent of the total population) (Census of India, 2011). Until 2021, Punjab had 22 districts. Nonetheless, on June 2, 2021, the Punjab government formally recognized Malerkotla as the province's 23rd district. As a result, the total number of districts will increase to 23 by 2023.

Punjab is known for its vibrant culture and has a long history that covers many di f erent eras. Punjab, sometimes known as the "Granary of India," is a state with a mainly agricultural economy. Many industries, including those manufacturing textiles, sporting goods, and pharmaceuticals, are also located there. Despite recent signi f cant economic growth, the state is still dealing with di f culties such as unemployment, poverty, and income inequality.



SAS Nagar (144), and SBS Nagar (256). According to the fndings, stubble burning was not uniformly dispersed throughout all districts in Punjab. In 2018, Sangrur appeared as a possible hotspot for stubble burning, with the most fre occurrences. Districts such as Rupnagar, Pathankot, SAS Nagar, and SBS Nagar experienced fewer fres, implying that stubble burning was not as popular or prevalent in those regions. Fig. 4 shows the total fre events in the year 2018.



Source: Punjab Remote Sensing Center, Ludhiana, Punjab.

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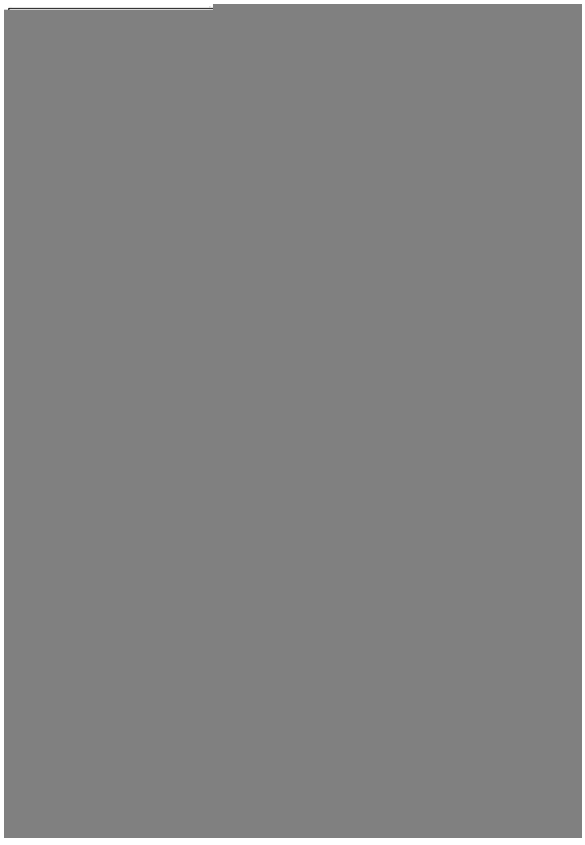
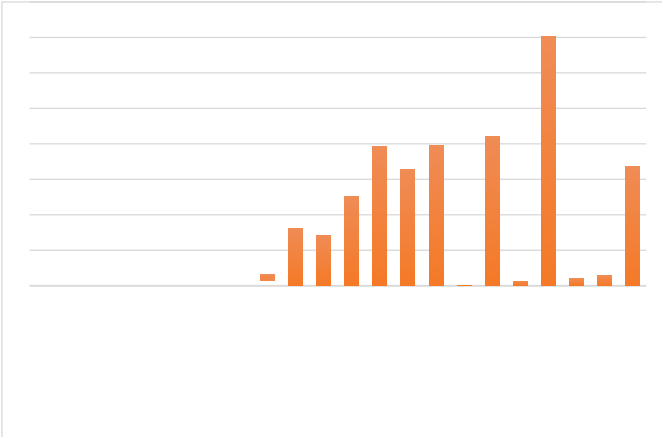
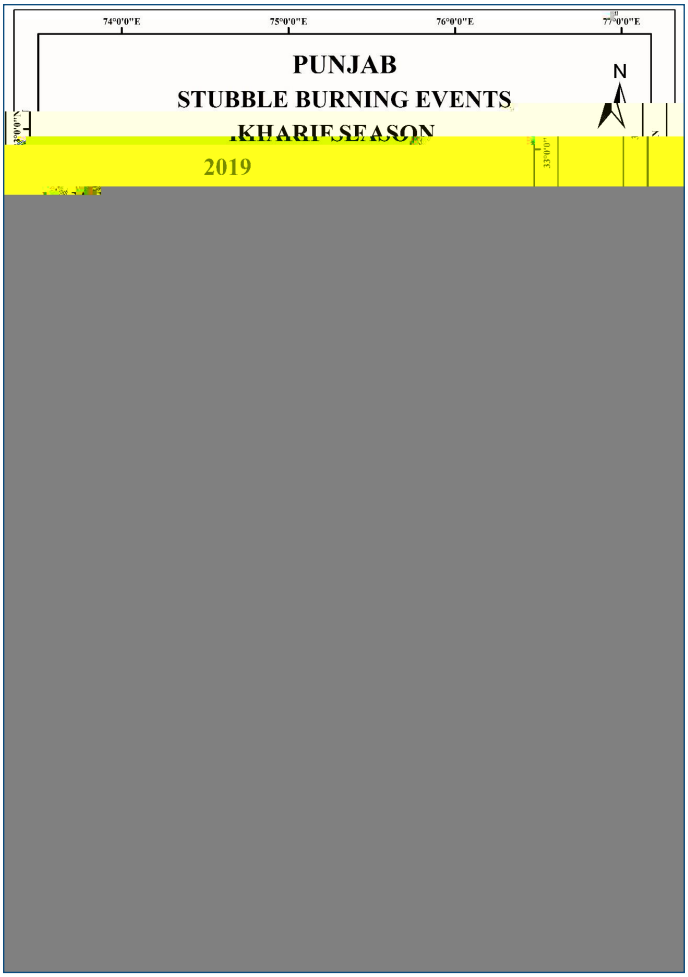
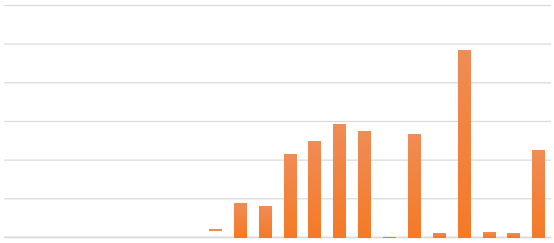


Spatal Pa tern of Stubble Burning during Kharif Season-2019

From the Fig. 5, it is clear that in 2019, a total of 55,210 fres caused by stubble burning were reported in Punjab. After the analysis of the given data, the results show that stubble burning was frequent in all districts of Punjab, albeit to various degrees of intensity. Sangrur, Bathinda, and Firozpur had the largest number of fre occurrences, with 7,021, 6,036, and 5,313 fres, respectively. These districts feature a large concentration of agricultural activities, including crop production such as rice and wheat, as well as a lack of awareness that contributes to stubble burning. Mansa (3,924), Muktsar (3,961), and Moga (3,267) are three more districts with a high number of fres. These areas were likewise heavily agriculturally based.







Spatal Pattern of Stubble Burning during Kharif Season-2020

In 2020, 76,590 fres caused by stubble burning were reported in Punjab (Fig. 6). Sangrur had the largest number of fres among the districts, with a staggering 9,705 instances due to the district's high agricultural activity and intensive farming practices. The districts of Firozpur and Moga also saw a high number of fres, with 6,947 and 5,843 instances, respectively. Due to the great concentration of agricultural land in these regions, large-scale stubble burning occurs.

Bathinda, another important district, had 7,806 fres because of its vast agricultural practices, especially paddy agriculture, which produces a signifcant amount of crop waste. Mansa (4,961), Muktsar (5,458), and Tarn Taran (4,528) are three more districts with a high number of fres. It is disturbing that even regions with lesser populations, such as Barnala (4,519) and Fazilka (3,125), saw a signifcant number of fres. This suggests that stubble burning is a common practice throughout Punjab's agricultural regions. However, it is important to note that certain districts saw fewer fres than others, such as Rupnagar (209) and SAS Nagar (262). This shows that these areas may have put in place efective measures to avoid stubble burning or adopted alternate agricultural residue management strategies.

Spatal Patern of Stubble Burning during Kharif Season-2021

The data given in Fig. 7 shows the number of fres caused by stubble burning in various districts of Punjab in 2021. In 2021, 71,304 fres were reported in Punjab as a result of stubble burning. Sangrur had the maximum number of

Other districts with a high number of fres were Bathinda (4,592), Firozpur (4,295), Moga (3,609), and Muktsar (3,884). In these districts, there were also a high number of stubble burning occurrences, showing a repeating tendency.

SAS Nagar	162	240	-78	-32.50 %
Firozpur		6036	-1741	-28.84 %
Muktsar		5250	-1366	-26.0 %
Faridkot		3550	-857	-24.14 %
Amritsar		1788	-246	-13.76 %
Tarn Taran		3619	-435	-12.0 %
Fazilka		3063	-207	-6.76 %
Total	49922	81042	-31120	-38.39 %

Source: Punjab Remote Sensing Center, Ludhiana, Punjab.

Total Percentage Change in Fire Events from 2016-2022 during Kharif Season

From Table 2, it is very clear that the district of Pathankot had the most substantial drop, with a 96.4286% decrease in fre occurrences throughout the Kharif season. This demonstrates a signi f cant decrease in the number of fres in this district throughout the investigated period. Fire incidents decreased signi f cantly in Ludhiana, Hoshiarpur, Jalandhar, and SBS Nagar, with percentage decreases of -65.1553%, -63.4697%, -62.2724%, and -75.4545%, respectively.

Several additional districts, including Gurdaspur, Rupnagar, and Kapurthala, had cJETderable reductions in fre occurrences, with reductio ranging fro -51.7-41% to -55.5957%. Ho ever, few $ istricts saw co iderably modest decreases in fre inbs à U Ď˙

soil requires additional labour, time, and resources. The financial burden associated with these alternatives often leads farmers to choose stubble burning as a cost-saving measure.

- Area under paddy continues to dominate the Kharif crop mix, leading to enormous paddy residue generation.
- Some argue that the provision of subsidies for farm equipment like happy seeders (machines that sow wheat without the need for prior clearing of residue) and financial incentives for adopting alternative residue management practices have not been adequate or accessible to all farmers, which discourages them from adopting non-burning methods.
- Many farmers may not be aware of the detrimental effects of stubble burning on air quality, human health, and the environment. Lack of knowledge about alternative techniques for managing crop residue contributes to the continued practice of burning.
- The socio-economic conditions of farmers, including small landholdings, lack of credit, and economic pressure, can influence their decision-making process. Immediate financial gains from stubble burning may outweigh the long-term benefits of adopting sustainable practices.

Punjab's Malwa region accounts for a higher number of fires because farmers favour the long-lasting PUSA 44 paddy type. PUSA 44 is a high-yielding rice variety with a short CRM period of roughly 160 days after sowing and a high straw load that enhances crop residue. Despite efforts by the Punjab Agricultural University and the state government to discourage its adoption due to its lengthy and input-intensive cultivation, farmers continue to favour this rice variety due to its better yield when compared to shorter-duration alternatives. Over 27% of the Malwa districts' land was governed by PUSA 44 in Kharif 2020.

Addressing stubble burning requires a multi-faceted approach that involves providing accessible and affordable alternatives for crop residue management, raising awareness among farmers about the environmental and health impacts of burning, improving infrastructure for residue handling, and implementing effective policies and incentives to encourage the adoption of sustainable agricultural practices. Collaborative efforts involving the government, agricultural experts, researchers, and farmers' organisations are crucial for finding viable solutions and mitigating the issue of stubble burning in Punjab.

Alternative to Avoid Stubble Burning

To avoid stubble burning in Punjab, several alternate solutions have been proposed and implemented. These solutions aim to provide farmers with economically viable and environmentally friendly alternatives for managing crop residue. Crop residue can be managed in two ways. The residue left after the crop harvest can either be incorporated back into the soil or collected and supplied for other applications as boiler fuel in industries and power plants and in packaging materials, among others. These management practices are referred to respectively as in-situ and ex-situ. Over the last few years, both the central and the state governments have been recommending the in-situ method as the ideal solution for residue management. Here are some of the alternate solutions:

- Encouraging the use of specialised farm machinery like happy seeders, mulchers, and zero tillage machines can help manage crop residue effectively. Happy seeders, in particular, allow farmers to sow wheat without clearing the previous crop residue, reducing the need for burning.
- *Crop Diversification:* Promoting crop diversification by encouraging farmers to cultivate crops with shorter harvest residues, such as maize, pulses, or vegetables, can reduce the problem of stubble burning. These crops have lower residue volume and can be managed more easily.
- Adopting in-situ crop residue management techniques involves incorporating crop residue back into the soil through ploughing, mulching, or using specific machinery. This practice helps improve soil health, retains moisture, and reduces the need for burning.
- Encouraging the use of crop residues for bioenergy production, such as biomass power plants or biogas generation, provides farmers with an additional income source while reducing the

need for burning. This approach promotes the sustainable utilization of crop residue.

- Providing financial incentives and subsidies to farmers for adopting non-burning practices and investing in machinery for residue management can alleviate the financial burden associated with alternative methods.
- Conducting awareness campaigns and educational programs to highlight the environmental and health hazards of stubble burning can help change farmers' perceptions and promote the adoption of sustainable practices. Sharing success stories and best practices from farmers who have successfully shifted away from burning can also inspire others to follow suit.
- Continued research and development efforts can focus on developing cost-effective and efficient technologies for residue management. This includes exploring innovative techniques, improving existing machinery, and finding new uses for crop residues.
- Encouraging collaboration between government agencies, agricultural institutions, research organisations, and farmers' associations is essential for effective planning, implementation, and monitoring of stubble-burning alternatives. This collaboration ensures that solutions are practical, tailored to local needs, and supported by relevant stakeholders.

Therefore, it's important to note that the successful implementation of these alternate solutions requires sustained support from the government, adequate infrastructure, financial resources, and the active participation of farmers. A comprehensive approach that addresses technical, economic, and social aspects is crucial for long-term solutions to stubble burning in Punjab.

CONCLUSION

So, in conclusion, it can be said that overall, there has been a declining trend in the patterns of stubble burning, but paddy straw waste or Paraali has been identified as a major Environmental and Health Hazard. Therefore, it is extremely important to understand the underlying cause and existing situation as to why the farmers burn stubble and then deal with the basic problem. The effects of stubble burning have expanded beyond the borders of Punjab, affecting other states as well. Within Punjab, certain hotspots and clusters have arisen, and government measures have attempted to address the issue. Alternative efforts were made through Kisan camps, training and workshops, apart from campaigns through various print media, televised shows and radio jingles, informing farmers about the alternative usage of crop residue. Stronger monitoring and enforcement mechanism through the use of remote sensing technology - use of real-time satellite imagery, along with the village-level enforcement teams with the aim of zero incidence rate of crop residue burning through prevention and penalization. To establish long-term solutions and alleviate the environmental and health dangers connected with stubble burning, however, continued efforts and a multi-faceted approach combining farmers, legislators, and technical improvements are required.

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