Journal of Natural Resource Conservation and Management
Vol. 6, No. 2, pp 123-131, 2025
doi: 10.51396/ANRCM.6.2.2025.123-131

Spatio-temporal variability of crop residue burning in Indian Punjab

Satyam Kakkar[1], Arun Kaushal[1], Raj Setia[2], and Preeti[1,*]

[1]*Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana, Punjab, India*
[2]*Punjab Remote Sensing Centre, Ludhiana, Punjab, India*
**Corresponding author email: sheoranpreeti749@gmail.com*

Received : July 06, 2025
Revised : September 04, 2025
Accepted : September 07, 2025
Published : December 31, 2025

ABSTRACT

Crop residue burning, particularly paddy stubble burning is a common practice among farmers in Indian Punjab, which causes a major environmental and public health concern. It results in emissions of carbon monoxide, methane and other gases that intensify air pollution and climate change. This study analysed the spatio-temporal dynamics of crop residue burning in Punjab using remote sensing and GIS from 2019-23. Satellite-derived sensor data from Moderate-Resolution Imaging Spectro-Radiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) were obtained from NASA's Fire Information for Resource Management System (FIRMS), for the period September-November from 2019-23. Due to its finer spatial resolution (375 m²), VIIRS detected more fire events than MODIS (1 km²). Both datasets showed increasing crop residue burning from 2019 to 2021, followed by a clear decline in 2022 and 2023. MODIS data recorded increases of 66.4% (2019-20) and 5.68% (2020-21), with reductions of 39.2% (2021-22) and 21.1% (2022-23). Similarly, VIIRS data showed increase of 62% (2019-20) and 4.77% (2020-21), followed by decrease of 39% (2021-22) and 26% (2022-23). Spatial patterns were consistent, with Bathinda, Sangrur, Moga, Firozpur and Mansa showing high fire activity, while Pathankot, Hoshiarpur, Nawanshahr, Rupnagar and S.A.S Nagar recorded low activity.

Keywords: Crop residue burning, MODIS, Remote sensing, Spatio-temporal, VIIRS

INTRODUCTION

Crop residue burning (CRB), particularly paddy stubble burning, has emerged as a critical environmental, public health and agricultural sustainability issue in Punjab, India. The state's intensive rice-wheat cropping system generates large quantities of crop residues and open-field burning, remains a widely practiced method for rapid field clearance to facilitate timely wheat sowing. However, this practice leads to substantial emissions of particulate matter, carbon monoxide, methane, volatile organic compounds and greenhouse gases, severely degrading air quality and contributing to regional climate forcing (Singh *et al.,* 2020; Maurya *et al.,* 2022). Despite regulatory interventions and promotion of alternative residue management practices, CRB persists, indicating the need for improved monitoring and targeted mitigation strategies.

Satellite remote sensing has proven to be an effective tool for detecting, monitoring and analysing agricultural fires at regional to global scales. Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) active fire products have been extensively used to characterize spatio-temporal patterns of agricultural burning across diverse agro-climatic regions (McCarty *et al.,* 2006; Korontzi *et al.,* 2012; Qin *et al.,* 2013; Thumaty *et al.,* 2015; Zhang *et al.,* 2020). Studies have consistently shown that CRB exhibits strong spatial dependence on crop type and land use, and temporal dependence on harvesting practices and seasonal cycles (Rios and Raga, 2017; Zhuang *et al.,* 2018). In India, particularly in Punjab and Haryana, remote sensing analyses have revealed intense post-monsoon burning associated with paddy residue, with VIIRS demonstrating higher sensitivity than MODIS due

to its finer spatial resolution (Vadrevu and Lasko, 2018; Chhabra *et al.,* 2019).

Recent investigations highlight both increasing long-term trends and recent declines in fire occurrences, influenced by policy measures, technological interventions and socio-economic factors (Yin, 2020; Vadrevu *et al.,* 2022). However, the spatial concentration of fire hotspots remains persistent, necessitating detailed district-level assessments using spatial statistics to identify clustering, hotspots and temporal shifts (Wei *et al.,* 2020; Shaik *et al.,* 2023). Although several studies have examined CRB in India, comprehensive spatio-temporal analyses integrating MODIS and VIIRS data for recent years remain limited for Punjab. The present study aims to analyse the spatio-temporal variation and hotspot patterns of crop residue burning in Punjab from 2019 to 2023 using MODIS and VIIRS satellite data within a GIS framework. The study seeks to enhance understanding of burning dynamics to support effective residue-burning mitigation and sustainable agricultural management.

MATERIALS AND METHODS

Study Area

The study area comprises the state of Punjab in northern India, covering a total geographical area of 50362 km², of which a substantial proportion is cultivable land under assured irrigation. The state has an average elevation of 300 m above mean sea level, Punjab lies between latitudes 29.30°N to 32.32°N and longitudes 73.55°E to 76.50°E. Punjab has a tropical to semi-arid, subtropical monsoon climate, characterized by hot summers and cold winters. The average annual rainfall varies spatially, ranging from about 580 mm in the plains to nearly 960 mm in the sub-mountain regions, with a general decreasing trend from north to south. Of the five rivers historically associated with Punjab, the Sutlej, Beas and Ravi flow through the present state of Indian, Punjab. The combination of fertile alluvial soils, abundant rainfall and extensive irrigation infrastructure makes Punjab one of the most agriculturally productive states in India. Administratively, Punjab is divided into 23 districts (Anonymous, 2026).

Collection and Analysis of Data

Active fire points data from the MODIS and VIIRS products were collected from NASA's Fire Information for Resource Management System (FIRMS) for the period 15th September to 30th November over five consecutive years (2019-23) across India. MODIS is widely applied in environmental monitoring and fire management studies (Korontzi *et al.,* 2012; Hall *et al.,* 2016; Coskuner, 2022). VIIRS is extensively used for night-time fire detection, climate and environmental assessments and applications related to public health and safety (Vadrevu and Lasko, 2018; Zhang *et al.,*2020). Fig. 1 to 4 illustrate the spatial distribution of fire points detected by MODIS and VIIRS across India for the years 2019 and 2023 and the data was analyzed in GIS environment.

Data Processing

The shape file of Punjab state boundary was obtained. All the original Indian shape files downloaded from FIRMS were overlapped with the shape file of Punjab state boundary. Ten shape files for fire points of Punjab (five from MODIS and five from VIIRS) were generated.

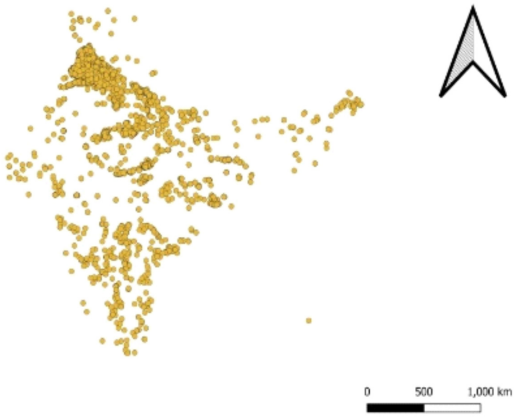

Fig. 1. 2019 MODIS Fire Points across India

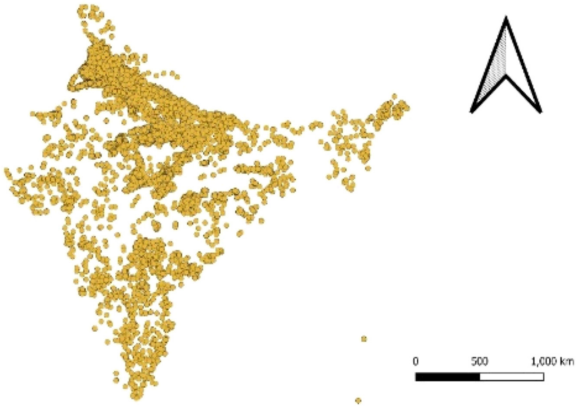

Fig. 2. 2019 VIIRS Fire Points across India

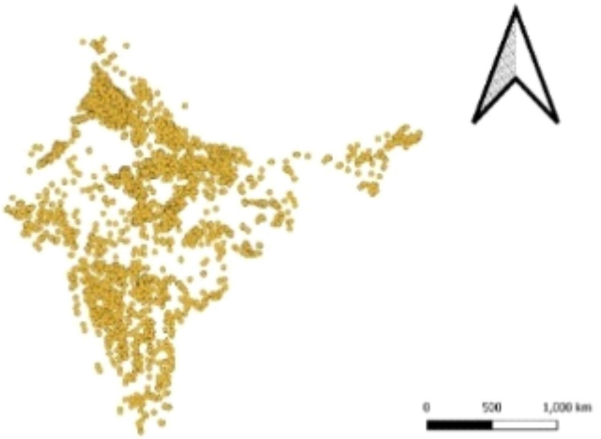

Fig. 3. 2023 MODIS Fire Points across India

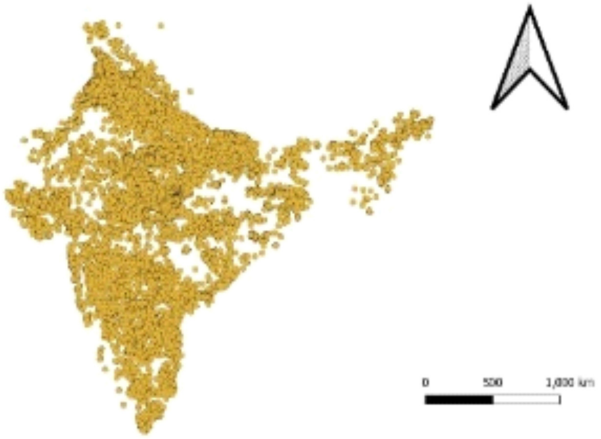

Fig. 4. 2023 VIIRS Fire Points across India

Confidence level filtering

Fire points include a confidence level which is an indicator of how certain a sensor is, that a detected fire is actually a fire (Higher confidence levels suggest greater certainty). MODIS provides confidence levels in percentages, while VIIRS classifies them as low, nominal or high. Only fire points with a confidence level above 30% for MODIS and nominal or high for VIIRS were considered (Qin *et al.,* 2013; Hall *et al.,* 2016; Verma *et al.,* 2019; Fu *et al.,* 2021).

Agricultural Land Masking

As provided on the website of FIRMS, the fire points not only contain data that are from crop residue burning, it also detects wildfires, household fires, smoke sometimes and other forms of fire. But according to the present study, the requirement was only for those fires that occurred on the agricultural lands. To obtain crop residue fire points the shape

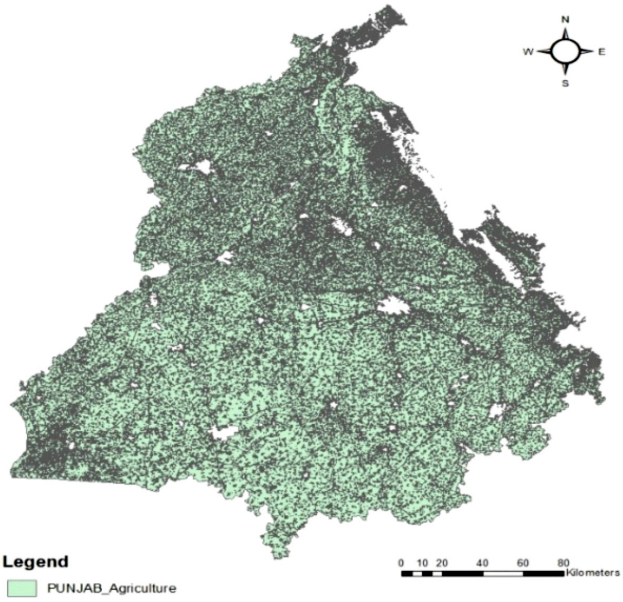

Fig. 5. Punjab's Agricultural Land

file of agricultural layer of Punjab (Fig. 5) was masked with all the shape files for fire points of Punjab map. This way ten shape files of crop residue burning points of Punjab were generated from 2019 to 2023.

District-Level Analysis

District boundary shape file map of Punjab state was overlapped with the crop residue burning fire point data shape file maps. Excel files containing yearly fire counts for each district were extracted by GIS platform and district-wise fire points for each year were calculated. Separate tables were generated for MODIS and VIIRS fire points.

Zonal Analysis

Punjab was divided into three zones: North East, Central and South West. South West Punjab consists of Bathinda, Faridkot, Fazilka, Firozpur, Mansa and Muktsar districts. North East Punjab consists of Gurdaspur, Hoshiarpur, Pathankot, Rupnagar, Mohali and S.B.S Nagar districts. Central Punjab consists of Amritsar, Barnala, Fatehgarh Sahib, Jalandhar, Ludhiana, Kapurthala, Malerkotla, Moga, Patiala, Sangrur and Tarn Taran districts. Crop residue burning fire points from MODIS and VIIRS were combined and analyzed zone-wise. This zonal data was used to plot graphs to visualize fire trends over the years.

Hotspot Analysis

The hotspot analysis of CRB was conducted using ArcGIS at the block level. The final refined crop residue burning fire point data was overlapped with the block boundary shape file of Punjab. Spatial statistics were applied to identify hotspots and cold spots for every year. The main outputs, GiZScore, which is a statistical measure indicating the intensity of clustering for a feature relative to its neighbors and GiPValue, which is a measure indicating the statistical significance of the clustering pattern were used to indicate the spatial clustering of fire points. Positive GiZScores denote hotspots, while negative values denote cold spots. The analysis was validated by comparing hotspots across the five years to identify consistent patterns. In this study, the crop residue burning fire points detected by MODIS and VIIRS are summed to enhance the accuracy and completeness of the hotspot analysis. Now to authenticate the data or to check that the hotspots as well as cold spots are common in these 5 years (2019-23), the data for all these 5 years was combined in a single excel file and the locations with common hot and common cold spots were extracted. This excel was transported back into ArcGIS to get the map of hot and cold spots of crop residue burning on block basis from the year 2019-23 for the state of Punjab (Singh *et al.,* 2020; Majumdar, 2023; Shaik *et al.,* 2023; Lv *et al.,* 2024).

RESULTS AND DISCUSSION

Crop Residue Burning Locations in Punjab

Spatial maps generated for Punjab during 2019-23 using MODIS and VIIRS reveals a clear concentration of crop residue burning fire points after applying confidence filtering, agricultural masking and district-level overlapping. Fig. 6-9 indicate a higher density and wider spatial spread of fire events in 2019 compared to 2023, with VIIRS consistently capturing more fire points than MODIS due to its finer spatial resolution (Thumaty *et al.,* 2015; Vadrevu and Lasko, 2018; Yin, 2020).

District Wise Analysis

From the CRB location maps of Punjab from 2019-23, excel files containing yearly crop residue burning fire counts for each district were extracted by using GIS, MODIS and VIIRS data as presented in Table 1. Using MODIS data (Table 1), crop

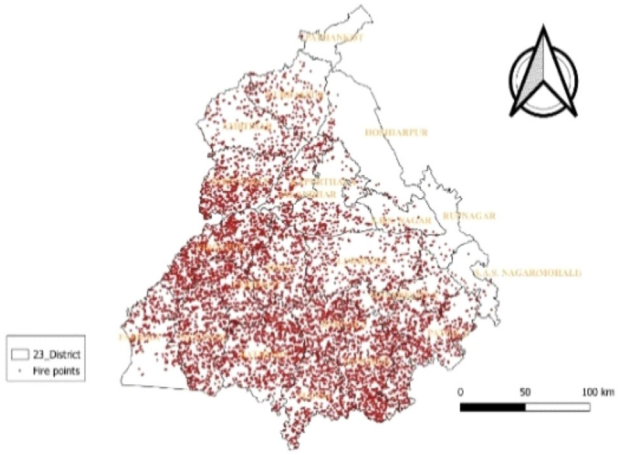

Fig. 6. Crop residue burning locations in Punjab by MODIS in 2019

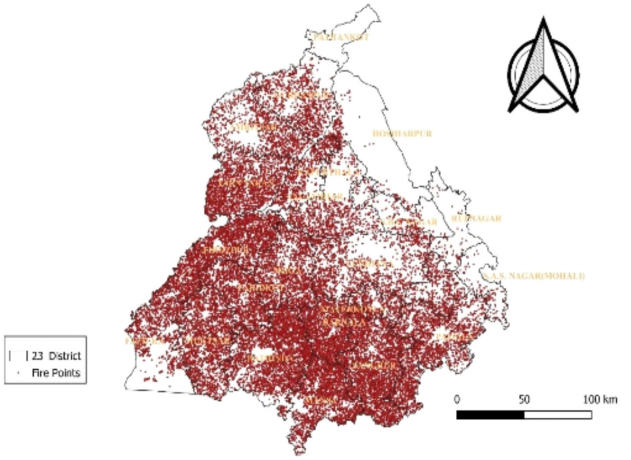

Fig. 7. Crop residue burning locations in Punjab by VIIRS in 2019

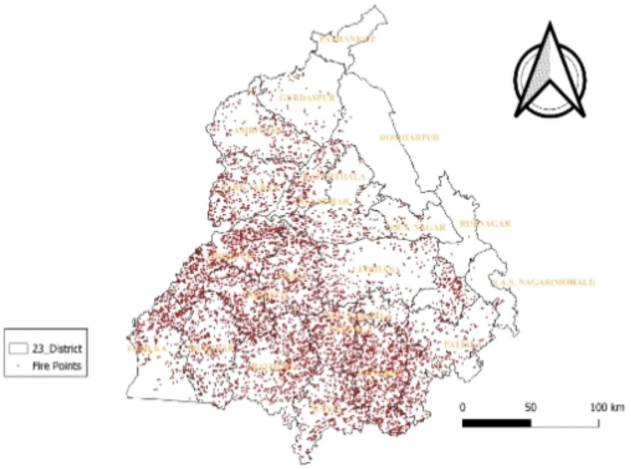

Fig. 8. Crop residue burning locations in Punjab by MODIS in 2023

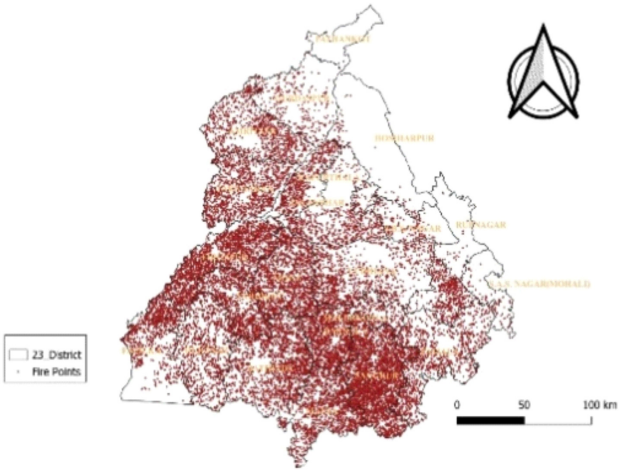

Fig. 9. Crop residue burning locations in Punjab by VIIRS in 2023

residue burning fire counts in Punjab increased from 9290 in 2019 to 16339 in 2021, indicating a clear rising trend, followed by a sharp decline to 7830 by 2023. VIIRS-based analysis shows a comparable pattern, with fire detections rising from 41431 in 2019 to 70422 in 2021 and subsequently decreasing to 29282 in 2023, while consistently identifying Sangrur and Bathinda as high-incidence districts and Pathankot as a low-incidence district. The higher absolute counts from VIIRS reflect its improved sensitivity to small agricultural fires, a feature also highlighted in comparative sensor evaluations (VIIRS detected substantially more small fires than MODIS) (Coskuner, 2022). The synchronized post-2021 decline across both sensors aligns with broader regional analyses reporting reduced agricultural fire activity following intensified policy enforcement and management interventions (significant reduction in fire counts after peak years) (Wei *et al.,* 2020; Fan *et al.,* 2023), supporting the effectiveness of recent mitigation measures in Punjab.

Creation of maps indicating crop residue burning fire points (District Wise)

District-wise fire count map derived separately from MODIS and VIIRS for the period 2019-23 illustrate clear spatial and temporal variability in crop residue burning across Punjab. CRB in the year 2023 is depicted in Fig. 10 using graduated green shades, where darker tones indicate higher densities. These spatial patterns are in strong agreement with

Table 1. Crop residue burning points in Punjab using MODIS and VIIRS (2019-23)

District	Crop residue burning points (Nos.)									
	Years									
	MODIS					VIIRS				
	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023
Amritsar	246	444	409	271	258	1421	2342	2010	1344	1315
Barnala	456	788	782	508	424	2408	3929	3849	2412	1877
Bathinda	961	1537	1651	970	74	4450	6821	7291	4201	2504
Faridkot	466	953	954	580	484	1839	3197	3353	2120	1485
Fatehgarh Sahib	152	288	377	177	181	652	1136	1504	1013	648
Fazilka	337	661	828	480	404	1589	2960	3152	2288	1280
Firozpur	939	1625	1518	1033	886	3864	6023	5432	3939	2934
Gurdaspur	218	291	199	124	55	1248	1799	1349	797	330
Hoshiarpur	51	77	66	48	19	250	383	372	248	107
Jalandhar	291	348	523	256	248	1164	1564	2442	1168	881
Kapurthala	233	320	394	265	233	1061	1421	1623	1043	785
Ludhiana	478	828	1181	602	333	1845	3745	5238	2170	1452
Malerkotla	137	227	278	133	86	599	1110	1217	570	328
Mansa	568	910	918	495	416	3001	4522	4490	2615	1933
Moga	524	1137	1270	664	603	2384	5213	5527	2970	2210
Muktsar	742	1309	1424	802	490	2963	4695	5248	3316	1262
Pathankot	3	2	0	0	3	4	12	10	4	4
Patiala	756	1183	1087	743	414	3051	4527	4796	2888	1535
Rupnagar	22	36	54	51	5	98	187	361	239	44
S.A.S. Nagar	23	26	35	20	11	141	185	233	116	96
S.B.S. Nagar	44	40	110	58	43	232	157	447	233	204
Sangrur	987	1494	1379	1021	1043	4431	7354	7013	4465	4541
Tarn Taran	656	936	902	627	448	2736	3932	3465	2771	1527
Total	9290	15460	16339	9928	7830	41431	67214	70422	42930	29282

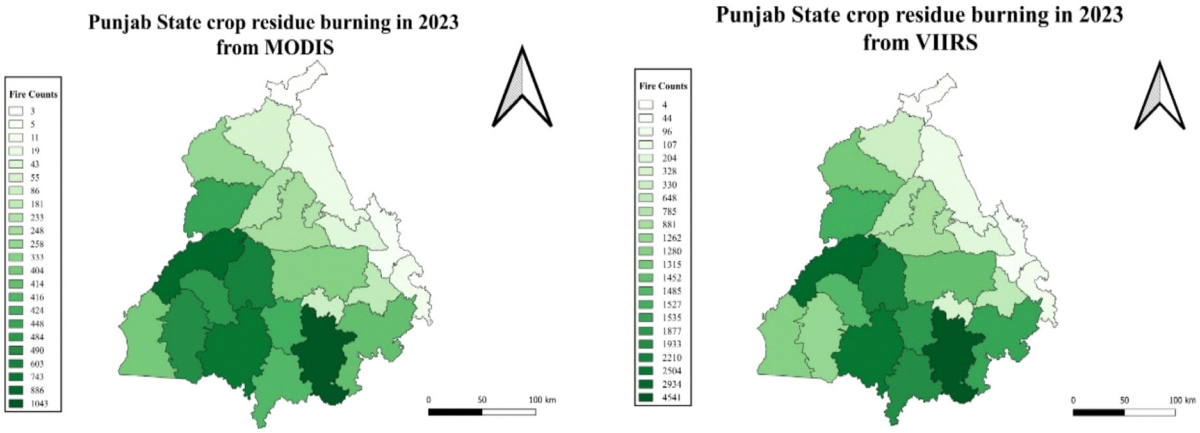

Fig. 10. Crop residue burning counts of Punjab (district-wise) in 2023 from MODIS and VIIRS sensors

earlier regional and national-scale studies, which reported that agricultural fire activity is concentrated in intensively farmed plains and significantly lower in hilly or sub-mountainous regions (Azhar *et al.,* 2019; Verma *et al.,* 2019; Maurya *et al.,* 2022).

Zonal Analysis

Zone-wise analysis based on the combined MODIS-VIIRS fire datasets indicates that crop residue burning was consistently highest in the Central zone and lowest in the North-East zone of Punjab throughout 2019-23 (Fig. 11-13). The sharp rise during 2019-21 and subsequent decline aligns with earlier findings that identified central and south-western Punjab as dominant residue-burning regions (Korontzi *et al.,* 2012; Chhabra *et al.,* 2019; Zhang *et al.,* 2022; Majumdar, 2023). Similar zone-level contrasts, with minimal burning in topographically

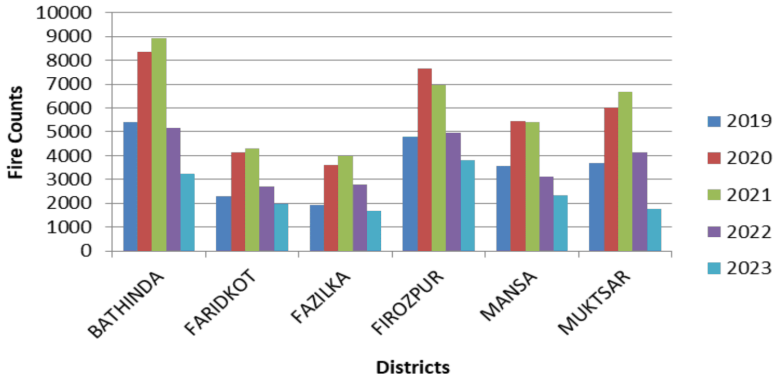

Fig. 11. Number of crop residue burning cases across South West Punjab (2019-23)

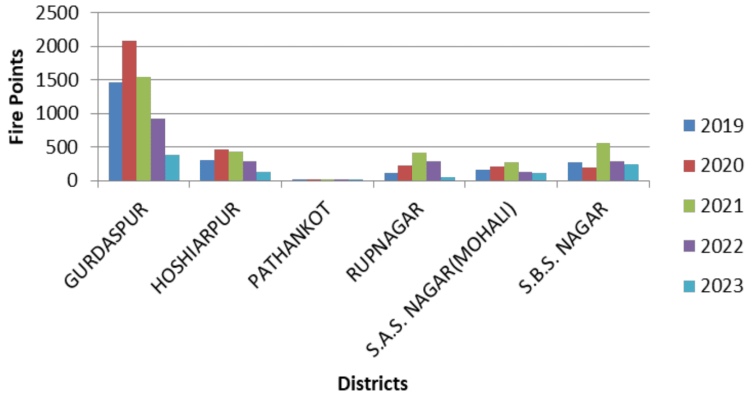

Fig. 12. Number of crop residue burning cases across North East Punjab (2019-23)

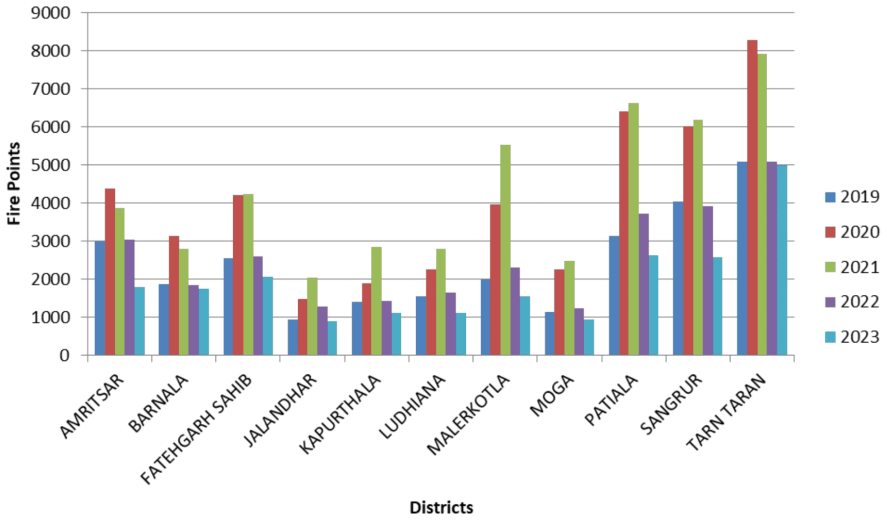

Fig. 13. Number of crop residue burning cases across Central Punjab (2019-23)

complex or less intensively farmed regions, have also been reported in broader spatio-temporal assessments of agricultural fires. Moreover, the relatively lower CRB incidence and steeper decline in the north-east zone align with findings that attribute reduced burning to diversified land use, lower cropping intensity and terrain constraints compared to central and south-west agricultural belts (Rios and Raga, 2017; Lv *et al.,* 2024).

Hotspot Analysis

The hotspot analysis of common hotspots and cold spots of crop residue burning at the block level across Punjab is presented in Fig. 14. In this figure, red colour represents persistent hotspots of crop residue burning observed during 2019-23, while pink colour denotes persistent cold spots over the same period. The identified hotspot blocks include Guru Har Sahai and Ghall Khurd blocks of Firozpur district; Faridkot and Kot Kapura blocks of Faridkot district; Moga, Bagha Purana, and Nihal Singh Wala blocks of Moga district; Sherpur block of Ludhiana district; Sangrur, Sunam, Dirba, and Lehra Gaga blocks of Sangrur district; Budhlada block of Mansa district; Phul, Bhagta Bhai Ka, and Nathana blocks of Bathinda district; Sehna block of Barnala district; and Kot Bhai at Giddarbaha block of Muktsar district. All the identified hotspot blocks, except Sherpur block, belong to the South-West zone of Punjab. The cold spot blocks of crop residue burning include Nawa Shahr, Saroya, Balachaur, and Banga blocks of S.B.S. Nagar district; Nurpur Bedi block of Rupnagar district; Adampur West block of Jalandhar district; Garh Shankar, Bhunga, Hoshiarpur, Dasuya, Talwara, Mukerian, and Hajipur blocks of Hoshiarpur district; Dorangala and Dina Nagar blocks of Gurdaspur district; and Pathankot, Sujanpur, Bamial, Gharota, and Narot Jaimal Singh blocks of Pathankot district. All these cold spot blocks, except Adampur West block, fall within the North-East zone of Punjab, indicating consistently low crop residue burning activity in this region during 2019-23. The spatial clustering pattern aligns well with earlier hotspot-based assessments that reported persistent agricultural fire hotspots in intensively irrigated, mechanized farming regions, while sub-mountainous and diversified land-use areas consistently emerge as cold spots (stable hotspot clusters in intensively cultivated plains; minimal fire clustering in hilly regions) (Hall *et al.,* 2016; Rios and Raga, 2017). Similar block and sub-regional clustering of crop residue burning has also been observed in geospatial studies emphasizing the role of cropping intensity and residue load in driving persistent fire hotspots (recurrent hotspots linked to intensive residue generation) (Sehgal *et al.,* 2021).

CONCLUSION

This study assessed the spatio-temporal dynamics of crop residue burning in Punjab during 2019-23 using MODIS and VIIRS active fire data. VIIRS detected a higher number of fire events due to its finer spatial resolution, while both sensors showed similar temporal trends. Crop residue burning increased from 2019-21 and subsequently declined during 2021-23. Spatial patterns revealed that the

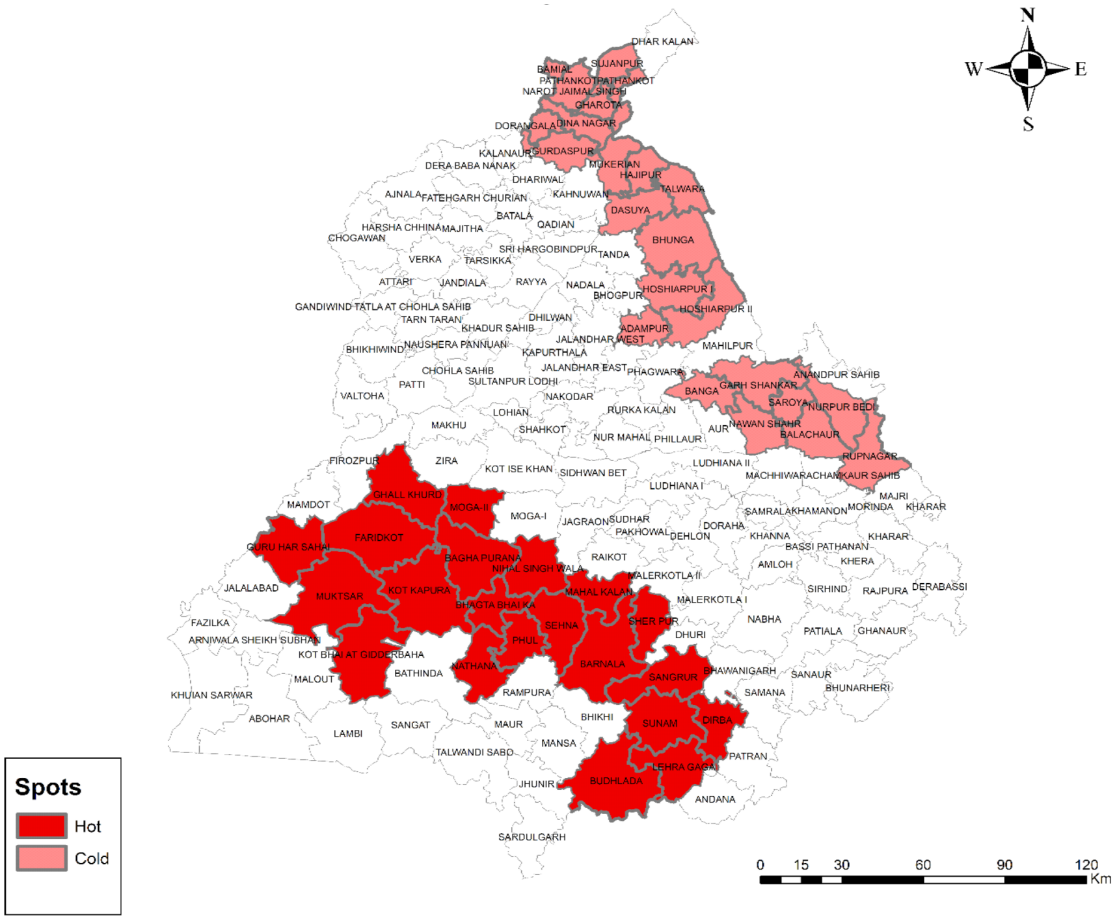

Fig. 14. Hot and cold spots of Crop residue burning in Punjab (block-wise) from 2019-23

central and south-west zone of Punjab consistently experienced higher CRB incidences, whereas the North-East zone recorded minimal activity. Persistent hotspots were concentrated in few blocks of the south-western and central zone, while cold spots dominated the north-east zone. The decline in CRB occurrences after 2021 indicates the effectiveness of policy measures, technological interventions, and awareness initiatives undertaken by State and Central Government agencies. The study demonstrates the utility of multi-sensor satellite data for monitoring crop residue burning and supporting targeted mitigation strategies in Punjab.

ACKNOWLEDGEMENTS

Authors sincerely acknowledge the Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana, Punjab, for providing the required facilities, institutional support and a supportive research environment for this study. They also express their gratitude to the Punjab Remote Sensing Centre, Ludhiana, for providing essential geospatial data and technical assistance that facilitated the successful completion of the research. The authors further thank all persons who directly or indirectly contributed through their valuable guidance and support.

REFERENCES

Anonymous (2026). Punjab state profile. *Punjab Data Portal*. Retrieved January 24, 2026, from https://punjab.data.gov.in/

Azhar, R., Zeeshan, M. and Fatima, K. (2019). Crop residue open field burning in Pakistan: Multi-year high spatial resolution emission inventory for 2000–2014. *Atmospheric Environment*, *208*, 20–33.

Chhabra, A., Sehgal, V.K., Dhakar, R., Jain, N. and Verma, R. (2019). Monitoring of active fire events due to paddy residue burning in Indo-Gangetic Plains using thermal remote sensing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*, 649–657.

Coskuner, K.A. (2022). Assessing the performance of MODIS and VIIRS active fire products in the monitoring of wildfires: A case study in Turkey. *iForest*, *15*, 85–94.

Fan, H., Yang, X., Zhao, C., Yang, Y. and Shen, Z. (2023). Spatiotemporal variation characteristics of global fires and their emissions. *Atmospheric Chemistry and Physics*, *23*, 7781–7798.

Fu, Y., Gao, H., Liao, H. and Tian, X. (2021). Spatiotemporal variations and uncertainty in crop residue burning emissions over North China Plain: Implication for atmospheric CO, simulation. *Remote Sensing*, *13*, 1–21.

Hall, J. V., Loboda, T. V., Giglio, L. and McCarty, G. W. (2016). A MODIS-based burned area assessment for Russian croplands: Mapping requirements and challenges. *Remote Sensing of Environment*, *184*, 506–521.

Korontzi, S., McCarty, J. and Justice, C. (2012). Monitoring agricultural burning in the Mississippi River Valley region from the Moderate Resolution Imaging Spectroradiometer (MODIS). *Journal of the Air & Waste Management Association*, *58*, 1235–1239.

Lv, Q., Yang, Z., Chen, Z., Li, M., Gao, B., Yang, J., Chen, X. and Xu, B. (2024). Crop residue burning in China (2019–2021): Spatiotemporal patterns, environmental impact and emission dynamics. *Environmental Science and Ecotechnology*, *21*, 1–10.

Majumdar, D. (2023). Spatial distribution and temporal variation of biomass burning and surface black carbon concentrations during summer (2015–2021) in India. *Air Quality, Atmosphere & Health*, *16*, 459–476.

Maurya, N.K., Pandey, P.C., Sarkar, S., Kumar, R. and Srivastava, P.K. (2022). Spatio-temporal monitoring of atmospheric pollutants using Sentinel-5P TROPOMI data: Impact of stubble burning — A case study. *ISPRS International Journal of Geo-Information*, *11*, 1–31.

McCarty, J.L., Justice, C.O. and Korontzi, S. (2006). Agricultural burning in the southeastern United States detected by MODIS. *Remote Sensing of Environment*, *108*, 151–162.

Qin, X., Yan, H., Zhan, Z. and Liao, Z. (2013). Characterising vegetative biomass burning in China using MODIS data. *International Journal of Wildland Fire*, *23*, 69–77.

Rios, B. and Raga, G.B. (2017). Spatio-temporal distribution of burned areas by ecoregions in Mexico and Central America. *International Journal of Remote Sensing*, *39*, 949–970.

Sehgal, V.K., Dhakar, R., Chhabra, A., Jain, N., Sahoo, R. N. and Mukherjee, J. (2021). Geospatial approach for monitoring of crop residue burning for its management including conservation agriculture. *Journal of Agricultural Physics*, *21*, 274–284.

Shaik, S., Kant, Y., Sateesh, M., Sharma, V., Rawat, D.S. and Chandola, H.C. (2023). Spatio-temporal variation of biomass burning fires over the Indian region using satellite data. *Atmospheric Remote Sensing*, *2023*, 121–138.

Singh, T., Biswal, A., Mor, S., Ravindra, K., Singh, V. and 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*, 1–12.

Thumaty, K.C., Rodda, S.R., Singhal, J., Gopalakrishnan, R., Jha, C.S., Parsi, G.D. and Dadhwal, V.K. (2015). Spatio-temporal characterization of agricultural residue burning in Punjab and Haryana, India, using MODIS and Suomi NPP VIIRS data. *Current Science*, *109*, 1850–1855.

Vadrevu, K. and Lasko, K. (2018). Intercomparison of MODIS Aqua and VIIRS I-Band fires and emissions in an agricultural landscape — Implications for air pollution research. *Remote Sensing*, *10*, 1–17.

Vadrevu, K., Eaturu, A., Cassadaban, E., Lasko, K., Schroeder, W., Biswas, S., Giglio, L. and Justice, C. (2022). Spatial variations in vegetation fires and emissions in South and Southeast Asia during COVID-19 and pre-pandemic periods. *Scientific Reports*, *12*, 1–21.

Verma, S., Dara, J.A., Malaysia, D., Khare, P.K., Dayanandan, S. and Khan, M.L. (2019). A MODIS-based spatio-temporal assessment of agricultural residue burning in Madhya Pradesh, India. *Ecological Indicators*, *105*, 496–504.

Wei, Z., Wang, G., Chen, T., Hagan, D.F.T. and Ullah, W. (2020). A spatio-temporal analysis of active fires over China during 2003–2016. *Remote Sensing*, *12*, 1–19.

Yin, S. (2020). Biomass burning spatiotemporal variations over South and Southeast Asia. *Environment International*, *145*, 1–12.

Zhang, S., Zhao, H., Wu, Z. and Tan, L. (2022). Comparing the ability of burned area products to detect crop residue burning in China. *Remote Sensing*, *14*, 1–16.

Zhang, T., Jong, M.C., Wooster, M.J., Xu, W. and Wang, L. (2020). Trends in eastern China agricultural fire emissions derived from a combination of geostationary (Himawari) and polar (VIIRS) orbiter fire radiative power products. *Atmospheric Chemistry and Physics*, *20*, 10687–10705.

Zhuang, Y., Li, R., Yang, H., Chen, D., Chen, Z., Gao, B. and He, B. (2018). Understanding temporal and spatial distribution of crop residue burning in China from 2003 to 2017 using MODIS data. *Remote Sensing*, *10*, 1–17.