SPATIAL-TEMPORAL ANALYSIS OF STUBBLE BURNING IN PUNJAB USING ArcGIS AND ITS IMPACT ON GREEN HOUSE GAS AND PARTICULATES EMISSIONS

A PROJECT REPORT

SUBMITTED IN PARTIAL FULFILMENT OF THE

REQUIREMENTS FOR THE AWARD OF DEGREE

OF

MASTER OF TECHNOLOGY

IN

ENVIRONMENTAL ENGINEERING

Submitted by

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2K22/ENE/03

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CANDIDATE'S DECLARATION

I, Nishant Yadav, Roll No.2K22/ENE/03 of MTech Environmental Engineering, hereby declare that the project Dissertation titled "SPATIAL-TEMPORAL ANALYSIS OF STUBBLE BURNING IN PUNJAB USING Arc GIS AND ITS IMPACT ON GREEN HOUSE GAS AND PARTICULATES EMISSIONS" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology in Environmental Engineering is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of my Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

Place: D.T.U, Delhi, India NISHANT YADAV

JUNE 2024

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CERTIFICATE

I, hereby certify that the project Dissertation titled "SPATIAL-TEMPORAL ANALYSIS OF STUBBLE BURNING IN PUNJAB USING Arc GIS AND ITS IMPACT ON GREEN HOUSE GASAND PARTICULATES EMISSIONS" which is submitted by Nishant Yadav, Roll No. 2K22/ENE/03 (Department of Environmental Engineering), Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the Degree of Master of Technology is a record of the project carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

PLACE: DELHI

Dr. GEETA SINGH

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ACKNOWLEDGEMENT

I want to express my deepest gratitude to my supervisor Dr. Geeta Singh (Assistant Professor, Environmental Engineering Department, Delhi Technological University, Delhi) for her guidance, help, useful suggestions and supervision. Without her support which this report could not have been possible by showing a proper direction while carrying out the project. I also must acknowledge the unconditional freedom to think, plan, execute and express, that I was given in every step of my project work while keeping faith and confidence in my capabilities. I am also grateful to my friend Sanjeev Singh Sepavat and Ridhima Sharma, who have been a constant source of support throughout my work.

Above all, I owe it all to my Almighty God for granting me the wisdom health, and strength to undertake this research task and enabling me to completion.

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ABSTRACT

Burning crop residue is a significant worldwide environmental issue and one of the main contributors to the atmosphere's pollution and greenhouse gas emissions. Burning agricultural crop residue increases the emission of smoke, particulates matter, CO_2, N_2O, CH_4, CO, NH_3, NO_x, SO_2, NMHC, and volatile organic compounds, all of which are harmful to human health. Crop residue is produced in large amounts, with 71% of the net sown area planted in paddy during the kharif season and 84.6% under wheat during the rabi season. Of this, each year, 25% of the wheat straw and 95% of the paddy straw are burned. The dangerous practice has had a negative impact on soil, air, road safety, health, and other areas, resulting in significant financial and physical losses. This study calculated the greenhouse gas emissions related with analysing active stubble burning data data from the Moderate Resolution Imaging Spectroradiometer (MODIS) during a 5-year period (2019–2023). Using the MODIS-Terra+Aqua Direct Broadcast Burned Area Monthly L3 Global 500 SIN Grid V061) product, Arc GIS Pro 10.3 and the Punjab government GIS portal for crop burning data, fire hotspots were identified, indicating that the burning of crop residue in Punjab's agricultural fields may be the cause of the elevated pollutant levels. Analysis of active fire locations found in the MODIS and PRSC Crop Residue Burning (CRB) Information and Management System over a five-year period between the kharif and rabi seasons indicates that stubble burning is still being done. In Punjab, there were 358965 burning events total between 2019 and 2023, distributed as follows: 73684, 90943, 82178, 64135 and 48026. Monitoring conducted at the district level in Punjab's southwest and eastern regions during the research period revealed a notable increase in the number of fire incidents. For rice crops, the anticipated total greenhouse gas and particulates emissions between 2019 and 2023 varied from 19868 Gg/year to 21,921 Gg/year and for wheat crops, from 7961 Gg/year to 9852 Gg/year. The main causes of the practice's persistence were found to be a scarcity of buyers, a lack of time for the next harvest, a lack of support from the state government, and a workforce shortage. Farmers were advised to take steps to address the issue, such as using it as animal feed, providing subsidies for machines like the "Happy Seeder," which produce less straw during harvesting etc.

Keywords*: Stubble Burning, MODIS, ArcMap, Punjab, GHG Emissions,PM, Rabi, Kharif*

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LIST OF ABBREVIATIONS

MODIS	Moderate Resolution Imaging Spectroradiometer
PRSC	Punjab Remote Sensing Centre
CRB	Crop Residue Burning
GIS	Geographical Information System
GPS	Global Positioning System
CPCB	Central Pollution Control Board
DTU	Delhi Technological University
NCT	National Capital Territory
LULC	Land Use and Land Cover
CRBIMS	Crop Residue Burning Information and Management System
GHGs	Green House Gases
NASA	National Aeronautics and Space Administration
PAU	Punjab Agricultural University
PM	Particulate Matter
CO_2	Carbon Dioxide
CO	Carbon Monoxide
NO_x	Oxides of Nitrogen
N_2O	Nitrous Oxide
CH_4	Methane

Chapter 1

Introduction

Stubble burning is one of the major contributors to air pollution other than industrial and vehicle emissions [31]. It is that reported biomass burning as the largest source of primary fine carbonaceous particles, whereas it remains the second largest source of trace gases in the troposphere [32]. Biomass burning is a global phenomenon and can be an important contributor to poor air quality worldwide. Stubble burning includes forest fires, prescribed burning of savannas, and crop residue burning in fields. On a global basis, forest burning is the major source of the fire emissions due to its high carbon density and burning of agricultural waste is the second major source, representing nearly 2020 Tg (approx 25% of total biomass burned) [33]. In Asia, around 730 Tg of biomass is burned annually from both natural and anthropogenic sources which include forest fires, grassland fires, and crop residues burning in the field, of which 18% is contributed by India. It’s also estimated that around 18-30% of crop residue is burned in agricultural fields [3]. A study also found that ~15.9% residue is burned in agricultural fields in India [1]. In-situ crop residual burning is practiced not only in India but also worldwide despite having detrimental effects on air quality and human health.

Burning of crop residue in agricultural fields leads to the emissions of various air pollutants including Greenhouse gases (GHGs) and particulates like PM2.5, PM10, which can play an important role in changing the atmospheric chemistry locally, regionally and globally [3]. Many developed nations have banned the burning of agricultural residue. However, it is still a present practice in developing nations due to poor crop residue management. Preparation of fields for next season’s crop with just 10-15 days between harvesting the paddy crops and sowing the wheat crop, weeds removal, nutrient regeneration in croplands and to control agricultural diseases and pests are some of the major reasons mentioned to burn crop residues [34]. The amount of crop residue burned in fields has large regional disparity and mainly depends on the type of crop i.e. rabi and kharif crops.

1.1 Green House Emissions (GHGs) and Particulates Emissions

The uncontrolled burning of crop residue leads to atmospheric emissions of various pollutants such as Particulate matter (PM10, PM2.5), Carbon monoxide (CO), Carbon dioxide (CO_2), Sulphur dioxide (SO_2), Oxides of nitrogen (NOx), Ammonia (NH_3), Methane (CH_4), Elemental Carbon (EC), Organic Carbon (OC), Volatile Organic Compounds (VOCs), Polycyclic Aromatic Hydrocarbons (PAHs) as reported by [1]. Emissions of pollutants and their dispersion varies according to seasons, meteorology and type of agricultural. The declining air quality due to crop residue burning in the rural areas and its dispersion in surrounding areas are of great concern due to its adverse impacts on human health and the environment. However, to better understand the associated health risks, explicitly designed epidemiological studies are needed. Also, it is reported that not only long-term but also short-term exposure to crop residue burning causes respiratory disorders [3]. These studies also present that vulnerable populations, such as children, are at bigger risk. Hence, atmospheric emissions from crop residue burning pose a serious threat to human health and there is a need to minimize these emissions.

1.2 Indian Scenario

Technological development in the Agri-based sector and use of modern agricultural practices like combine harvester have enhanced the production of crop residue. It is estimated that 109 hectares of natural ecosystems will be converted to agriculture land by [14]. A report from the United Nations Department of Economic and Social Affairs evaluated that the world population will be 9.7 billion by 2050. This will exert pressure on the agriculture sector to meet their needs, particularly in South Asia (UN DESA, 2015). An increase in crop production will also eventually lead to the generation of more crop residue. India is an agriculture-based country with the highest net shown area in the world, and approximately 58% of the population derive their livelihoods from farming activities. Its major production is rice–wheat crops and generates a large quantity of agricultural wastes. This sum will rise in the future as rising productivity is required to keep up with the expanding population. The biomass that remains in the field after the economic components, such as grain, are harvested is referred to as agricultural residue. Every year, significant amounts of agricultural wastes are produced, including sugarcane leaves and tops, woody stalks, and cereal straws. Produce from farms that is milled creates a lot of residues as well. These leftovers are utilised as industrial fuel, personal cooking fuel, animal fodder, and thatching for rural dwellings. Nonetheless, a sizable amount of crop wastes is left in the fields unutilized. One of the biggest challenges is getting rid of so much agricultural wastes. To clear the field rapidly and cheaply and allow tilling practices to proceed unimpeded by residual crop material, the crop residues are burned in situ. Farmers opt for stubble burning because it is a faster and rather more easy way to manage the large quantities of crop residues and ready the field for the next crop well in time. Agricultural residues burning may emit significant quantity of air pollutants like CO_2, N_2O, CH_4, emission of air pollutants such as CO, NH_3, NOx, SO_2, NMHC, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) and particulate matter like PM10, PM2.5 at a rate far different from that observed in savanna/forest fire due to different chemical composition of the crop residues and burning conditions [13]. Hence, there is a need to identify sustainable crop residue management practices. Further, an accurate country-specific emission inventory is required for better air quality management.

There is a large variability in production of crop residue, and their use depends on the crops grown, cropping intensity, and productivity in different regions of India [35]. Cereal crops (rice, wheat, maize, and millets) accounts for 70% of the all-crop residue, with wheat crops accounting for 22% and rice for 34%. In India, the rice-wheat system is responsible for around 25% of all residue production. Traditionally, the excess agricultural waste—that is, the total residue generated less the quantity used for other purposes—is burned on the farm. Between 84 and 141 Mt of surplus agricultural waste are thought to be accessible annually in India, with cereal crops accounting for 58% of this total. Each year, about 70 Mt (four4.5 Mt of rice straws and 24.5 Mt of wheat straws) of the 82 Mt excess are burned.

Crop wastes in agricultural fields are becoming a major problem. Farmers burn wastes on the same agricultural field to save time and money, as it costs money and needs labor to remove [16–18]. In the previous two to three decades, this kind of burning of crop residue has been seen [19, 20]. In India, 347 Mt of agricultural residue were produced in 2000, with 90% of that amount coming from rice and wheat residue [21]. By 2018 [1], this amount had climbed to 585 Mt, indicating a very concerning scenario.

1.3 Punjab Scenario

Crop residue burning has been a common practice across the Indo-Gangetic plains during the past few decades, especially in Punjab and Haryana. With Only 15% and 50 percent of the paddy straw produced in Uttar Pradesh and Karnataka, respectively, was burnt in situ, compared to 80% in the states of Haryana, Punjab, and Himachal Pradesh [13]. Punjab is mainly an agrarian state and largest producer of food grains to the central pool. With 28 lakh hectares under wheat and paddy cultivation in the state, a total of around 47.2 lakh tones of straw is generated every year. 25 lakh tonnes of wheat straw and 22 lakh tonnes of paddy straw were included in this. Of this, each year, 25% of the wheat straw and 95% of the paddy straw are burned. The amount of residue has increased even more as a result of the crops' mechanized harvesting. To increase the soil's composition, the straw was manually harvested, cut into little pieces, and then ploughed back into the ground. Even though the state government outlawed stubble burning back in 2005, the practice persists because the law is not being followed. The National Aeronautics and Space Administration (NASA) of the United States and the Supreme Court of India have both brought attention to the issue, but to no result. Impacts include soil and air pollution, health risks, and road safety, among other things. air pollution brought on by burning residue, especially when paddy stubble grows annually. During that period, the quality of the air declines. As a result, respiratory and cardiovascular issues arise. The amount of carbon dioxide in the air increases by 70%, while the concentrations of carbon monoxide and nitrogen dioxide increase by 7% and 2.1%, respectively. The burning of a tonne of straw emits 3 kg of particulate matter, 60 kg of carbon monoxide, 1460 kg of carbon dioxide, 199 kg of ash, and 2 kilograms of sulphur oxide into the atmosphere, according to research done by the Centre for Sustainable Agriculture in Hyderabad. In addition, the technique severely depletes the soil of minerals as well as nutrients.

According to 2010 research by the Department of Soils at PAU, Ludhiana, burning stubble causes the soil to lose 6-7 kg of nitrogen per tonne, 1-1.7 kilograms of phosphorus, 14–25 kg of potassium, and 1.2–1.5 kg of sulphur. As a result, Rs. 150 crore more must be spent annually to replace the soil. Maintaining organic carbon is essential because it increases the soil's ability to store water. Burning soil results in the annual loss of around 38 lakh tonnes of organic carbon as well as 32 kgs of urea, 5.5 kgs of diammonium phosphate, and 51 kgs of potash per acre. If the farmer replows the paddy straw back into the fields, the fertility loss results in a loss of one quintal of additional wheat crop output. As a result, the projected monetary losses associated with this practice are around Rs. 500 crore year and include reduced fertility, extra nutrients, and yield loss as a result of stubble burning. Burning wheat or paddy straw causes the top three inches of soil to reach such a high temperature that it quickly alters the ratios of bacteria to fungus (9:1), carbon to nitrogen (11:1), and balance of carbon.

The highest frequency of burning paddy stubble is found in Punjab. During the Kharif session, 90% of farmers burnt crop leftovers [3]. Sally [4] claims that the Punjab government fined 23,000 farmers Rs. 6 crores for burning their stubble in 2019–20. There has been a recorded rise in stubble burning incidents in spite of different policies and agricultural residue management strategies.

In this work, we measured the air pollution emissions from farmland residue burning in Punjab for the last five years (2019–2023), along with the spatio-temporal patterns associated with month-wise and seasonal-wise patterns of cropland residue burning. Nitrous oxide (N_2O), carbon dioxide (CO_2), carbon monoxide (CO), PM2.5, PM10, methane (CH_4), and nitrogen oxides (NOx) are the principal air pollutants that are being targeted. The number of stubbles burnt events burned in the fields is a metric that has been mostly estimated based on assumptions in various research; this study calculates the number using secondary data. One of the first and most thorough studies of agricultural residue burning and related greenhouse gas emissions from Punjab will be this one. Keeping in viewpoint the above-mentioned facts, the present study was done to highlight the quantity of crop residue produced in two cropping seasons as well as problems related to its management in Punjab.

Therefore, this study used the methods of the Intergovernmental Panel on Climate Change (IPCC) to estimate the air emissions from burning agricultural residue. The paper suggests an integrated approach for sustainable agricultural residue management and evaluates the numerous methods already in use for using crop leftover.

Despite the valuable insights provided by previous studies, which have utilized remote sensing techniques to monitor stubble burning and its impacts on air quality, there is still a notable gap in research that specifically employs high-resolution MODIS imagery for this purpose in Punjab. For that, we use active fire counts information retrieved by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the polar-orbiting satellites Aqua and Terra of NASA Given the scale of the issue in this Punjab region, there is a urgent need for a focused investigation into this particular context.

1.4 GIS-Based burnt area Mapping

1.4.1 Arcmap 10.3

Arcmap is a state-of-the-art geospatial tool that helps create, edit, and visualize geospatial data. It helps users to visualize the data with the help of a table of content and data view. It can be used to build and manipulate data sets containing various data. North arrows, scale bars, titles, legends, tidy lines, and other elements are common on ArcMap maps.

Additionally, it can be used to submit various reference styles to use with any mapping function. Basic, Standard, or Advanced (previously ArcView, ArcEditor, or ArcInfo), and Pro are the four license levels offered for the ArcGIS package. Each step higher in the licensing gives the user more extensions, allowing them to run a broader range of queries on a data source. The Pro level of licensing allows the user to use extensions such as 3D Analyst, Spatial Analyst, and Geostatistics. Shape Files are used to run ArcMap, and Geodatabases can store bigger volumes of data in more current versions. These are the file types that are used to examine spatial data in the software. A new file extension is produced when a map (.tif) is saved. Only the relative path-names are saved with this file, not the layers or geographical data. This means that if the data in the map is not at the same location as it was the last time it was opened, an error will occur. This helps to keep the file compact and decreases the amount of data management redundancy.

1.5 Research Objectives

- To analyse the status of stubble burning in Punjab from 2019-2023
- This research also includes analysis stubble burning mapping using Arc GIS 10.3.
- To examine the impacts of crop residue burning on humans and environmental by calculating crop residue generation and using that calculating GHG emissions.

Chapter-2

Literature Review

Stubble burning in Punjab has emerged as a significant environmental challenge, contributing to severe air pollution and greenhouse gas emissions. This literature review examines existing research on the spatial and temporal patterns of stubble burning and its environmental impacts. Emphasis is placed on the utilization of ArcGIS technology for analyzing these patterns and quantifying emissions. The review aims to provide a comprehensive understanding of the current knowledge and identify gaps for future research:

Kaur et al. (2022) analyzed several kinds and root causes of Punjab's environmental degradation is investigated. It also showed that 41,090 premature fatalities occurred in Punjab in 2019 as a result of stubble burning's detrimental effects on the state's air quality. It emphasized the government's effort to reduce pollution by monitoring ambient air quality at 28 sites, including four rural Punjabi regions, to see how stubble burning affects the quality of the air [25].

Batra et al. (2017) examined the practice of stubble burning and its impact on public health in northwest India. Punjab is a state where stubble burning is more common than in other states. Burning paddy residue emits toxic gases that cause eye disorders, asthma, and severe respiratory infections. Some methods to reduce residual burning include the use of rotavators, choppers, happy speeders for in situ management approaches, and stubble in the production of power, biogas, and biofuel [20].

Yadav et al. (2018) emphasized in their study the detrimental effects that paddy burning has on both the environment and people. The quality of the air decreases as a result. Beneficial bacteria and fungi for the soil are destroyed by the heat produced by stubble burning. Serious health problems in humans, including as lung, heart, and respiratory disorders, can be caused by it. It explained government residue management rules, including the "Air Prevention and Control of Pollution Act, 1981" and "Section 144 of the Civil Procedure Code," which prohibit stubble burning [21].

Saini et al. (2019) analyzed in his research, burning stubble damages not just people and animals but also the environment. It causes a number of health problems that cause early mortality. In order to reduce pollution, it recommended actions including stubble breakdown, bio-composting, and unitization of stubble in bio-thermal power plants [22].

Prakash et al. (2021) In this study, according to their analysis, some of the causes of stubble burning include automated crop harvesting, a labour shortage, a lack of time to prepare fields for new crops, a lack of viable markets for residue, and a low degree of farmer awareness about crop residue management strategies. The practice of stubble burning is still commonplace despite several efforts for in situ and ex situ agricultural residue management as well as court decisions.[23]

Grover et al. (2015) In their study, they investigated the main causes of stubble burning, including high labour costs and shortages, farmers' lack of knowledge about alternative crop waste management techniques, a lack of funding, and insufficient time to prepare fields for the following crop. According to the study, burning paddy stubble degrades the quality of the air and soil, which has a negative effect on human health.[18]

Singh et al. (2015) In his study, carried out their investigation to track the impact of stubble burning on air quality. According to the study, Mandi-Gobindgarh's air quality declined as a result of spikes in PM10 and PM2.5 concentrations during stubble burning sessions, which had negative effects on both the environment and people [19].

Behera et al. (2023) his study was on the spatio-temporal analysis of stubble burning in Punjab using ArcGIS and its impact on greenhouse gas emissions highlights significant findings and methodologies. Stubble burning in Punjab and Haryana contributes substantially to air pollution, affecting regions such as Delhi and the NCR, especially during the onset of winter. The study employs satellite sensors like MODIS and TROPOMI to monitor fire incidents and measure concentrations of pollutants such as CO and NO2. Analysis on the Google Earth Engine platform reveals a threefold increase in stubble burning from October to November, with Punjab contributing the majority. This research underscores the effectiveness of remote sensing and GIS tools in assessing environmental impacts and aiding in the development of mitigation strategies.[5]

Das et al. (2022) demonstrated Using data from satellite observations, the study presents a thorough examination of stubble burning and its effects on air quality. It describes how to monitor changes in vegetation and burnt areas using a variety of spectral indices, including the Normalised Burnt Ratio (NBR) and the Normalised Difference Vegetation Index (NDVI). It also emphasises how successful satellite sensors like Sentinel-2 and Landsat are at identifying burned areas with high spatial resolution. The study highlights how burning stubble contributes significantly to air pollution, including the release of greenhouse gases and other pollutants like nitrogen dioxide and carbon monoxide. In order to lessen the negative effects of burning agricultural residue on the ecosystem, this research emphasises the necessity of precise monitoring and management techniques.

Ray et al. (2019) in his paper emphasises the negative effects of burning rice residue on the environment and air quality. The study monitors rice residue burning in Punjab and Haryana using multi-date satellite data, such as Sentinel-1A and AWiFS. The second and first fort weeks of October and November are identified as the peak burning seasons. The districts of Mansa and Bhatinda in Punjab and Fatehabad in Haryana exhibit the highest levels of burning. The study highlights how satellite remote sensing may be used to precisely map burned areas and stresses the importance of routine monitoring in order to put crop residue fire prevention strategies into place.

Chapter 3

Methodology

3.1. Study Area

The state of Punjab, which is located in northern India and is defined by the geographic coordinates 29.5-32.5°N latitude and 73.9-76.8°E longitude, is the subject of this research. Punjab, which covers an area of around 50,362 square kilometres, is home to 31,623,274 people. There are 23 districts in Punjab, which are divided physically into the areas of Majha, Malwa, Doaba, and Poadh. The five divisions that make up their official division are Patiala, Rupnagar, Jalandhar, Faridkot, and Firozepur. A District Collector is in charge of overseeing each district administratively. Forming part of the larger Punjab region of the Indian subcontinent, the state is bordered by the Indian states of Himachal Pradesh to the north and northeast, Haryana to the south and southeast, and Rajasthan to the southwest; by the Indian union territories of Chandigarh to the east and Jammu and Kashmir to the north..It is referred to as the "Granary of India" by many because of the country's abundant agricultural area, which makes a major contribution to food production. The geographical map of the study area is demonstrated in Figure 1. Punjab have a diverse topography, changing from the fertile alluvial plains of the Indus River system in the east to the Shivalik Hills' undulating terrains in the north.

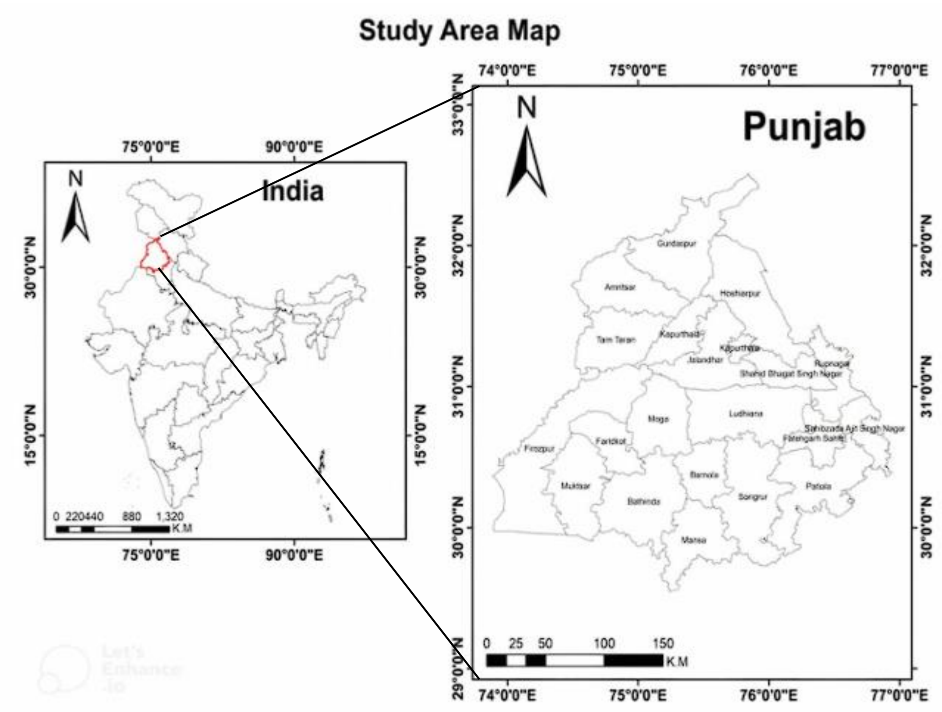


Figure 3.1: Study Area of Punjab

Three different seasons characterise Punjab's climate: the scorching summer (April - June), the rain-driven monsoon (July - September), and the chilly winter (October - March). October and November, the study's time range, correspond with the post-monsoon season, when temperatures start to drop and agricultural tasks like harvesting and managing crop residues get underway. Punjab’s economy is based mostly on agriculture, and the state prides itself on being a leading producer of staple grains including wheat, rice, and maize. Crop residue has significantly increased as a result of mechanised harvesting methods and intensive agricultural practices. Because of the frequent burning of this residual crop waste, Punjab has become a major hub for stubble burning occurrences. According to Pradhan et al. (2001), these occurrences have a negative impact on both human health and the environment by significantly adding to air pollution.

Punjab is a relevant research location because of the prevalence of stubble burning and the implications it has on air quality. This study aims to provide important insights by examining the time and geographical patterns of stubble burning episodes and evaluating any potential association with Punjab's ambient air quality. These observations may help shape effective mitigation and management plans to address this urgent environmental problem.

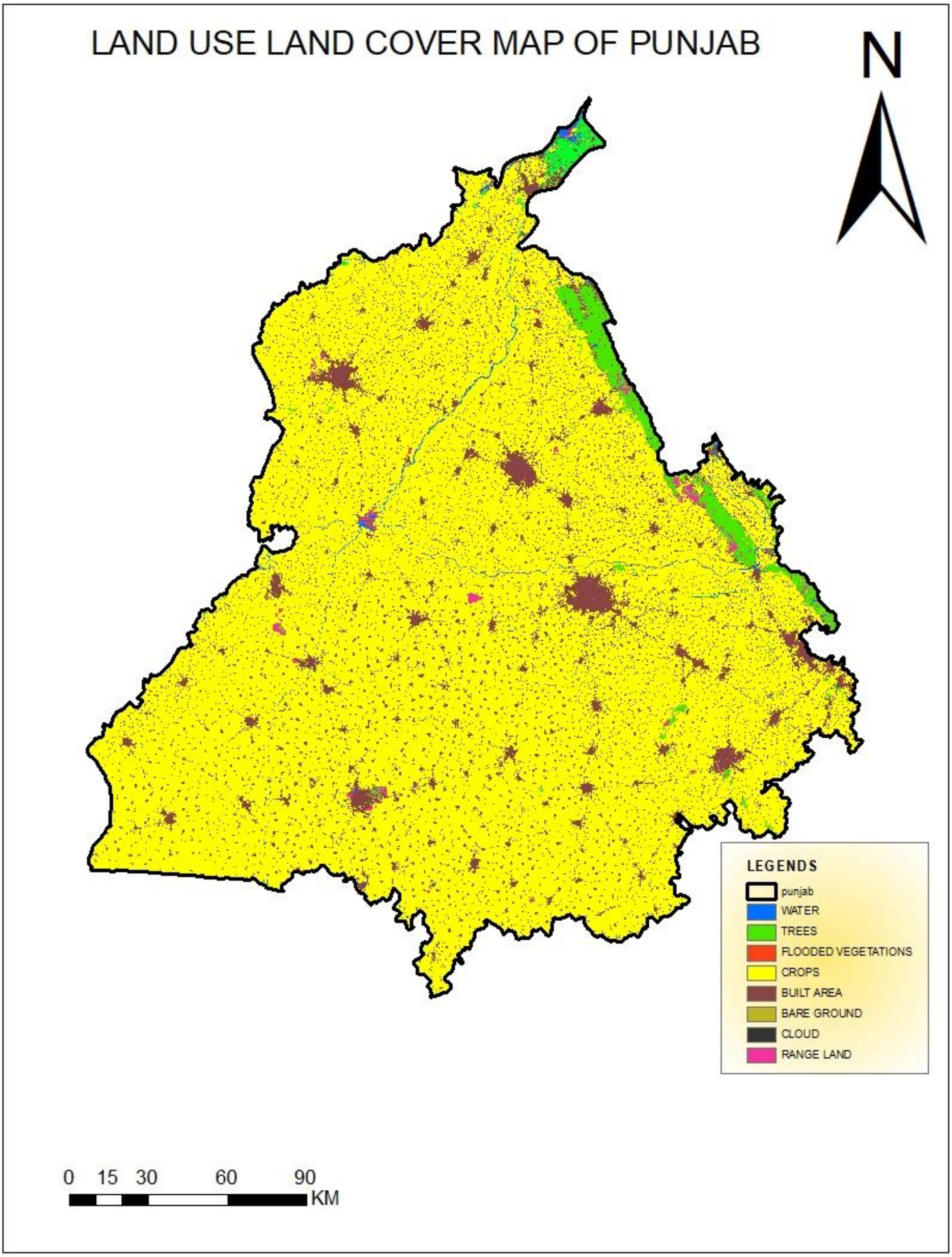


Figure 3.2 Land use Landcover Map of Punjab

3.2 Data Collection

This present study relies on various data sources to meticulously analyze stubble burning events and finds their subsequent greenhouse gas emissions in Punjab. The data sources used in this research are summarized in Table-1. To discern and analyze stubble burning incidents, we relied on analyzing active fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) during a 5-year period (2019–2023). Using the MODIS/Terra plus Aqua Direct Broadcast Burned Area Monthly L3 Global 500 SIN Grid V061) product, Arc GIS Pro 10.3 and the Punjab government GIS portal for crop burning data, fire hotspots were identified, indicating that the burning of crop residue in Punjab's agricultural fields may be the cause of the elevated pollutant levels. District wise analysis of active fire locations found in the MODIS and PRSC Crop Residue Burning (CRB) Information and Management System over a five-year period between the kharif and rabi seasons was done and on the basis of calculated fire events the amount of GHGs emitted were calculated using IPCC methodology. The pollutants calculated were PM2.5, PM10, CO_2, CO, CH_4, N_2O, NO_X and their concentrations were calculated in Gg/year. Furthermore, we integrated the Land Use Land Cover (ESA CCI LULC) map using 10m resolution ESA SENTINEL-2 images. We were able to isolate agricultural areas with the use of this data, which also allowed us to concentrate our study on the spatial distribution of stubble burning incidents within these 23 distinct districts. An extensive investigation of the temporal and geographical patterns of stubble burning incidents and their possible impact on Punjab's ambient air quality was made possible by the variety of data sources available.

Table 3.1 Data Used in the Study

Data Source	**Description**	**Spatial Resolution**	**Year(s)**
MODIS (MCD64A1)	High-resolution satellite imaging for stubble burning detection and its monitoring	500m	2019-2023
SENTINEL-2	LULC Map	10m	2019-2023
PRSC Crop Residue Burning (CRB) Information and Management System	Active fire points	NA	2019-2023
Ministry of Agriculture and Farmers Welfare, Government of India	Crop Production data	NA	2019-2023

3.2.1 Land Use and Land Cover Data

Data on land use and land cover were gathered at a spatial resolution of 10 m from ESRI SENTINEL-2 for the years 2019–2023. Arc GIS 10.3 was used to construct the ESRI SENTINEL-2 land use land cover (LULC) map. The ESRI SENTINEL-2 data, which was gathered between 2019 and 2023, is offered in tile format at the equator using an HDf4 file format with a sinusoidal grid. Using the border map, the land use and land cover map for the state of Punjab was derived. To locate farmland fires throughout Punjab, the extracted map was superimposed with MODIS active fire data for the months of Rabi (April 1–30 May) and Kharif (September 10–30 November) from 2019 to 2023.Step-wise LULC Map making is shown below:

(1) SENTINEL-2: The European Space Agency (ESA) launched Sentinel-2, a wide-swath, high-resolution, multispectral imaging mission. Popular, open-access, and free satellite photography. This 290 km^2 earth observation dataset is divided into 13 spectral bands (443-2190 nm). The Sentinel-2 satellite has a spatial resolution of 10 m for its four visible and near-infrared bands, 20 m for its six red edge and shortwave infrared channels, and 60 m for its three atmospheric correction bands. Sentinel-2 returns after 10 days; however, the cycle lasts for just five days since it is a constellation of two satellites that are phased out at 180 degrees. The. hdf extension data of 2019 to 2023 for Rabi (1st April -30th May) and Kharif (10th September – 30th November) were retrieved from the Arc GISonline library for data processing and analysis. The algorithm generates LULC predictions for 10 classes.[26]

Table 3.2 Specifications of SENTINEL-2

Variable mapped	Land use/land cover in 2017, 2018, 2019, 2020, 2021,2022,2023
Data Projection	Universal Transverse Mercator (UTM)
Mosaic Projection	WGS84
Extent	Global
Source imagery	Sentinel-2
Cell Size	10m (0.00008983152098239751 degrees)
Type	Thematic
Source	Esri Inc.
Publication date	January 2024

(2) LULC Map Data Processing: Data for LULC mapping is downloaded from ESRI Sentinel-2 Land Cover Explorer portal. Data that is available on this is from 2017- present year. For this study purpose data is downloaded from 2019-2023. The whole world in this is separated in different tiles. Based upon the study area which is Punjab in this case tiles are figured out on explorer page. Then by clicking on tile data can be downloaded based on year required or overall, for all years from 2017 to till date. Now for this study purpose we are downloading data for Punjab as shown in figure 3.3. on clicking data automatically starts downloading. The format of file will be .tiff.

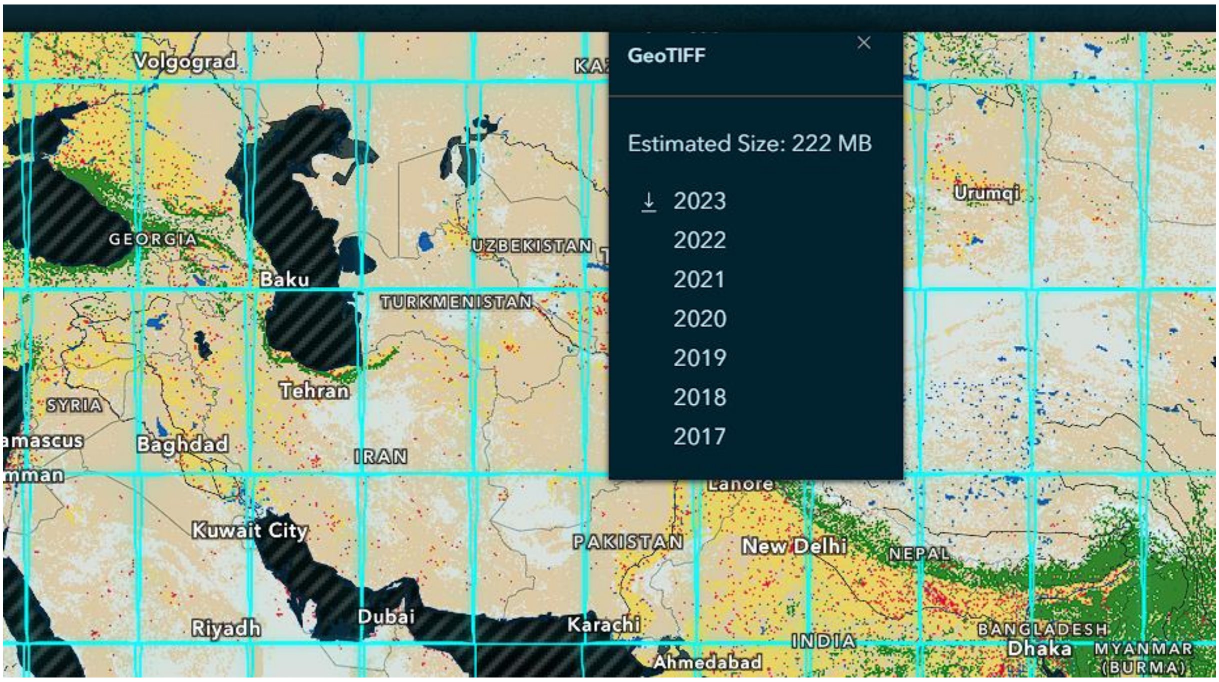


Figure 3.3 Downloading Tile for year 2023

(3) LULC Map processing: now on Arc GIS 10.3 software by clicking on new map we can start making our LULC map for that new folder is made in desktop storage and downloaded file is saved in it. Now on Arc GIS software add data is clicked and file is added that is downloaded. After successfully importing tile to Arc map, shape file of Punjab is added. The extension of shape file will be .shp. Now by searching extract by mask in search toolbar, we can extract the boundary of map as shown in figure 3.4. now by clicking extract mask a dialogue box will be open. There in that box in the input raster, click on the current tif file, now in feature mask data column we need to select the shape file of Punjab and then OK is clicked. Now after click on Geoprocessing Tab on the Arc map page, click on results to see whether is operation is carrying out or not. Now we have three layers on the screen i.e. Punjab shape file, tile and extract my mask layer. Now click on the extract my mask layer and click properties and in the general tab rename it as PUNJAB LULC, as shown in figure 3.5. Now in symbology tab, label for all 12 class of LULC is given as shown in Table 3.3. After giving all the details click ok. Now after deleting tile, we get the extracted layer of the map.

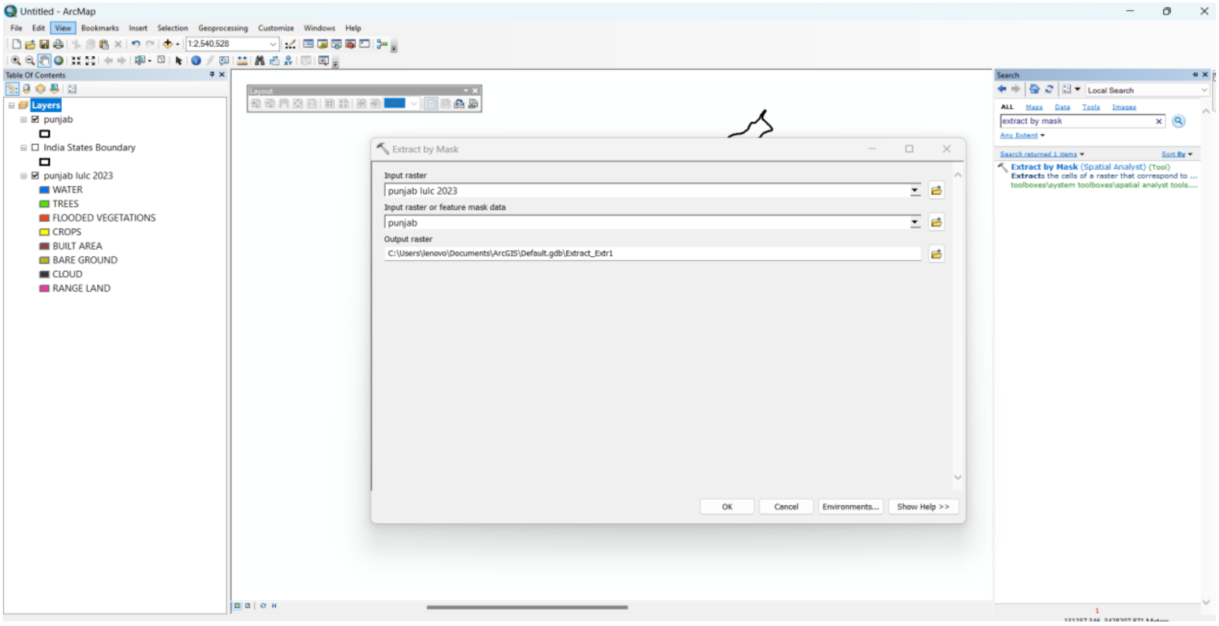


Figure 3.4 Extracting by Mask

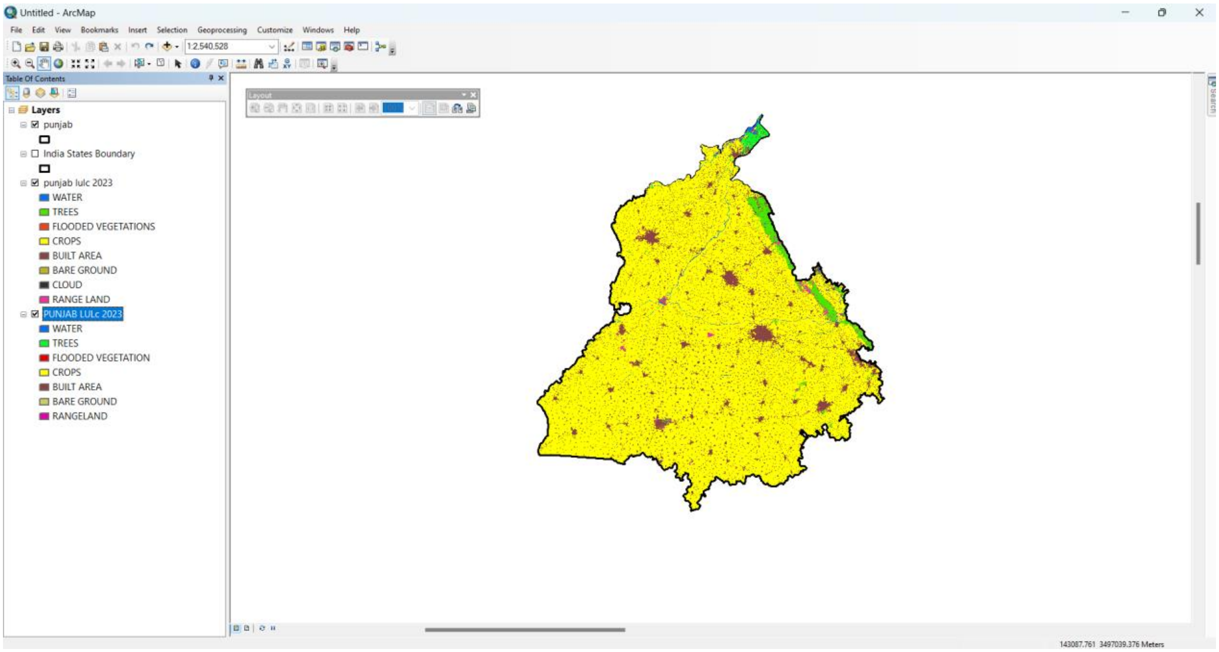


Figure 3.5 Extracted Layer of Map

Table 3.3 Different LULC Class Definitions

Water	Areas where water was predominantly present throughout the year; may not cover areas with sporadic or ephemeral water
Trees	Any significant clustering of tall (~15 feet or higher) dense vegetation, typically with a closed or dense canopy
Flooded vegetation	Areas of any type of vegetation with obvious intermixing of water throughout a majority of the year
Crops	Human planted/plotted cereals, grasses, and crops not at tree height.
Built Area	Human made structures; major road and rail networks; large homogenous impervious surfaces including parking structures, office buildings and residential housing.
Bare ground	Areas of rock or soil with very sparse to no vegetation for the entire year;
Snow/Ice	Large homogenous areas of permanent snow or ice, typically only in mountain areas or highest latitudes; examples
Clouds	No land cover information due to persistent cloud cover

(4) Standard LULC Map Processing: click on layout and then by clicking on insert section we need to insert north arrow, legend, scale bar, title of the map. As shown in Figure 3.6.

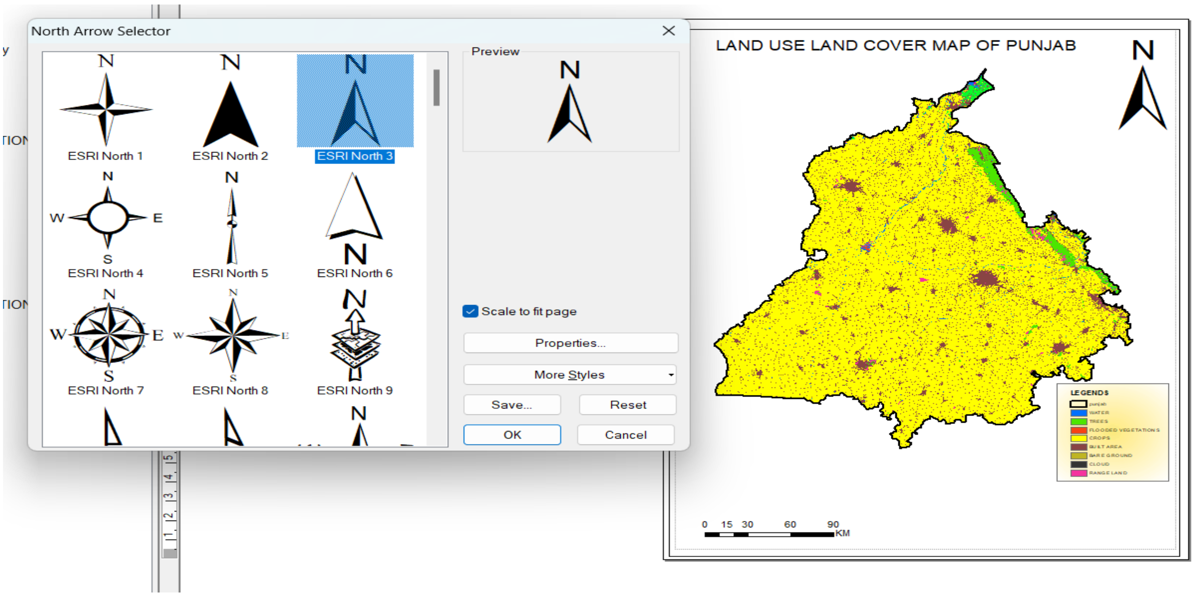


Figure 3.6 Legend and Scale Bar Insertion

3.2.2. Stubble Burning MODIS Data Mapping

This study uses fire burnt data derived from the High-resolution satellite imagery for stubble burning detection and monitoring that is (MODIS) satellite product. We used data at 100 km resolution generated through MODIS/Terra plus Aqua Direct Broadcast Burned Area Monthly L3 Global 500 SIN Grid V061)-MCD64A1 product of MODIS. The MODIS fire product (MCD64A1) was downloaded from 2019 to 2023 for Rabi crops (1st April -30th May) and Kharif crops (10th September – 30th November) to identify cropland fires across Punjab. Step wise stubble burning data processing and mapping process is discussed below:

(1) MODIS MCD64A1 Fire Product: Per-pixel burned-area and quality information are included in the monthly global gridded 500-meter (m) product known as the Terra and Aqua combined MCD64A1 Version 6 Burned Area data product. The 500 m Moderate Resolution Imaging Spectroradiometer (MODIS) Surface Reflectance imagery combined with 1 kilometre (km) of MODIS active fire data is used in the MCD64A1 burned-area mapping technique. The system generates dynamic thresholds that are applied to the composite data using a fire sensitive Vegetation Index (VI). With a measure of temporal texture, the VI is generated from MODIS shortwave infrared atmospherically adjusted surface reflectance bands 5 and 7. For every MODIS tile, the system determines the date of fire for each of the 500 m grid cells. With values allocated to unburned land pixels and extra special values set aside for missing data and water grid cells; the date is recorded in a single data layer as the ordinal day of the calendar year on which the burn happened [27].

(2) Stubble Burnt Map Data Processing: Data for stubble burning mapping is downloaded from Earthdata search portal of NASA. Data that is available on this is from 2001- present year. For this study purpose data is downloaded from 2019-2023.After creating account at the portal we can search the relevant data Now in the search box MCD64A1 is searched and we get MODIS/Terra+Aqua Direct Broadcast Burned Area Monthly L3 Global 500 SIN Grid V061)-MCD64A1 product of MODIS. Now temporal range of the data is selected i.e. start and end date of the data required which is 2019 to 2023 for Rabi crops (1st April -30th May) and Kharif crops (10th September – 30th November) in this case as shown in figure 3.7. The temporal range is selected one by one. Then we need to search the desired area which is Punjab in our case. The location is selected using region of interest tool. The data granules are loaded on monthly basis. We get 4 granules for Rabi crops and 6 granules for kharif crops, as shown in figure 3.8. The layers are present in tile form and format of file is hdf, As shown in figure 3.9.

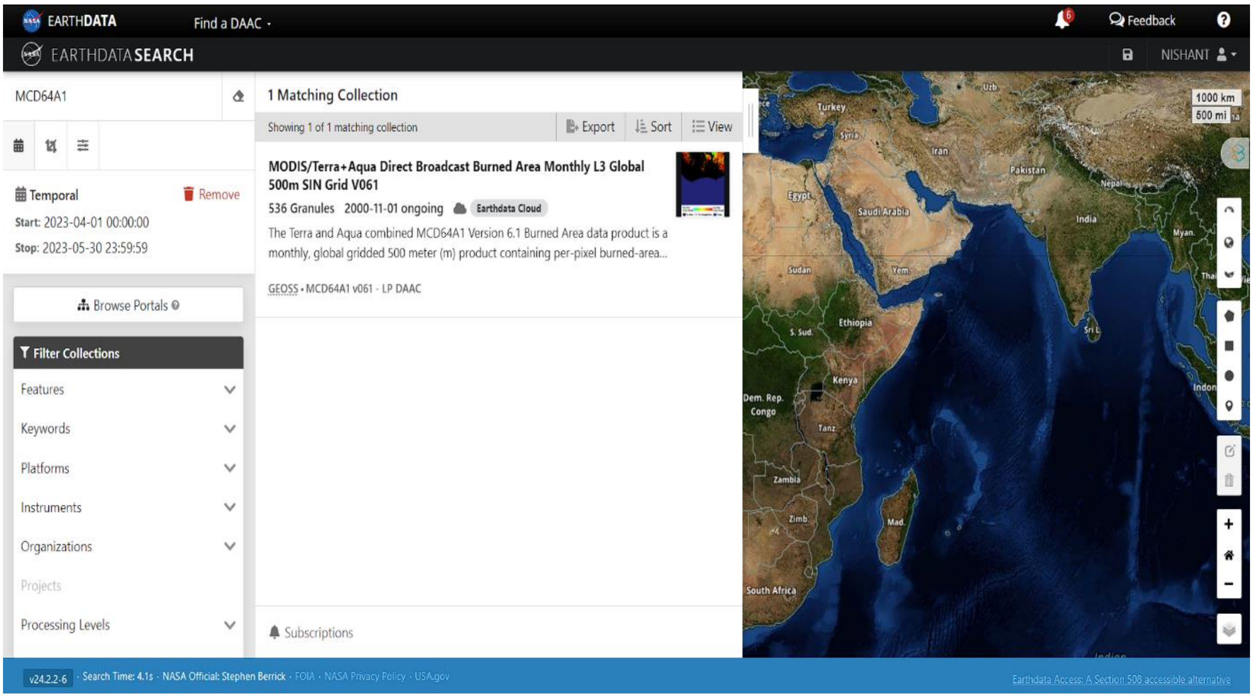


Figure 3.7 Temporal Range Selection

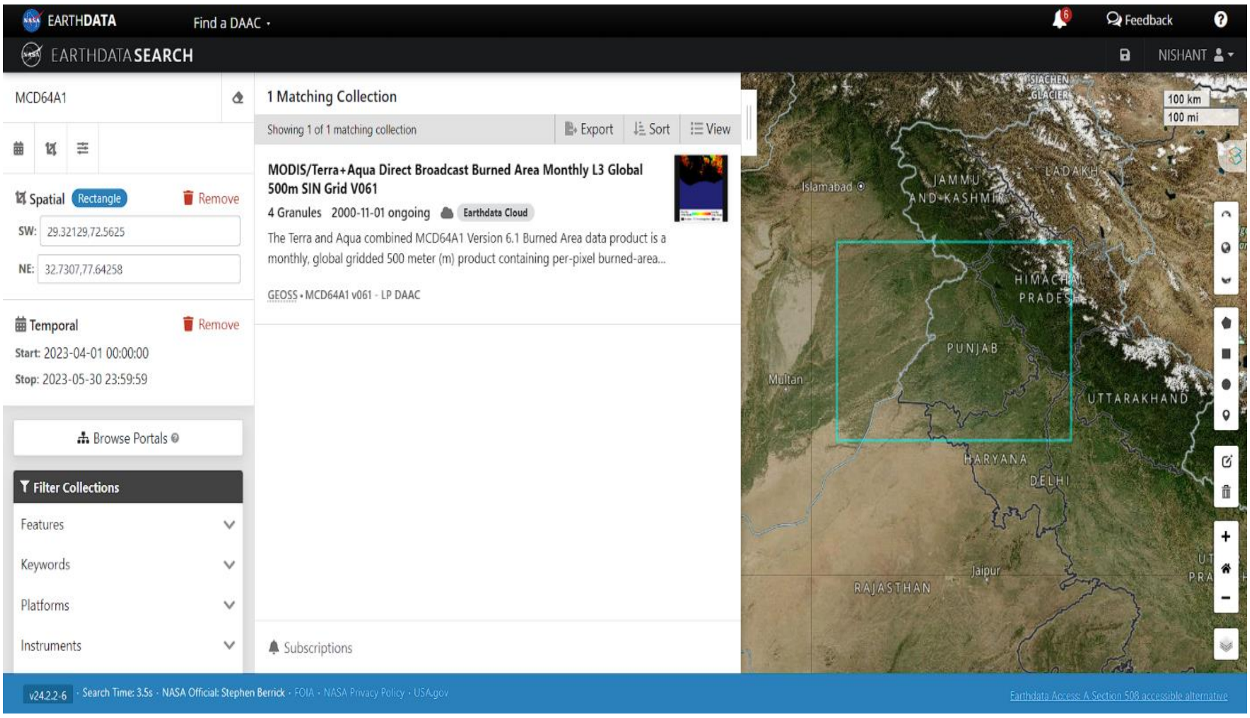


Figure 3.8 selection of location i.e. Punjab

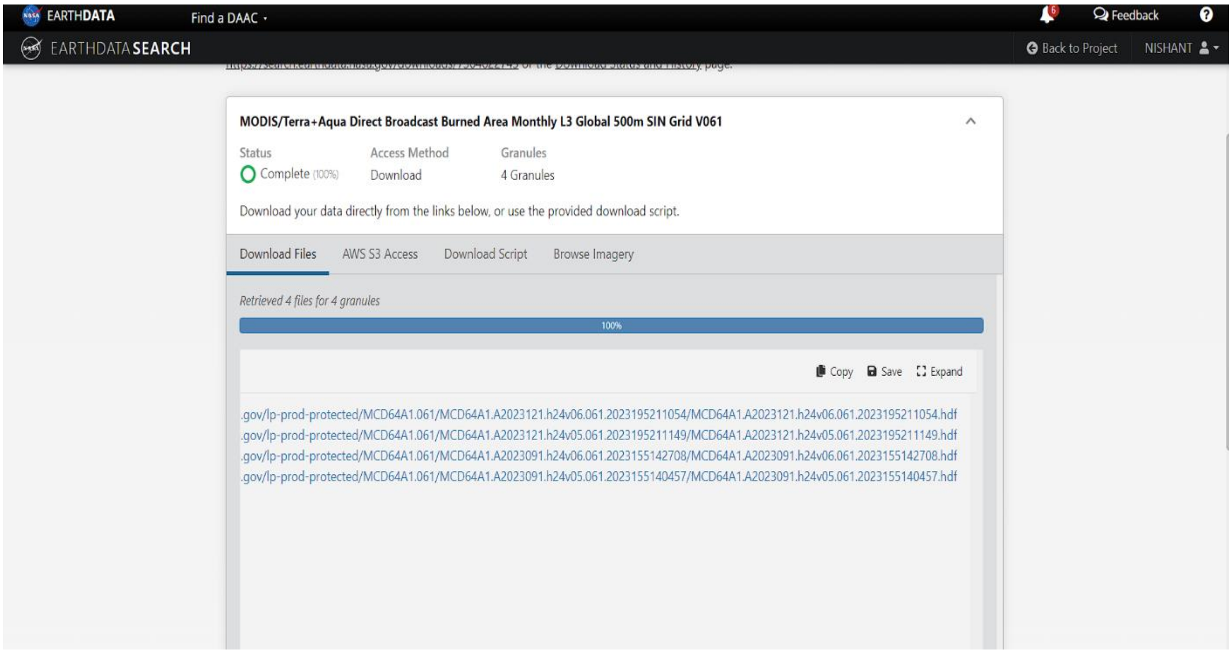


Figure 3.9 File Downloading in HDF format

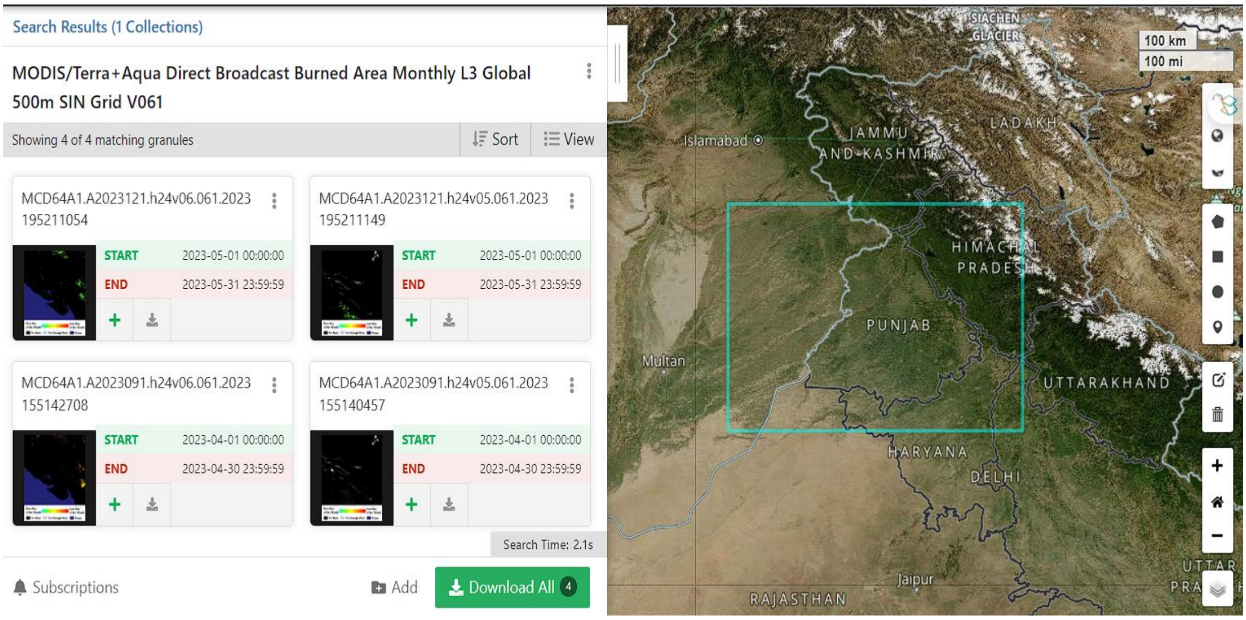


Figure 3.10 Granule Selection

(3) Stubble Burnt Map Processing: Now on Arc GIS 10.3 software by clicking on new map we can start making our Burnt area map, for that new folder is made in desktop storage and downloaded file is saved in it. Now on Arc GIS software add data is clicked and file is added that is downloaded. After successfully importing tile to Arc map, shape file of Punjab is added as it's our study area. The extension of shape file will be .shp. The process is same for Rabi and Kharif. Now for rabi in search toolbar, search Extract Subdataset. In Extract Subdataset dialogue box in input raster box chose the .hdf file, in Subdataset ID box select 0 since it is burnt area product. After that select the output folder and then click ok as shown in figure 3.11. This step is repeated 4 times for Rabi crop mapping and 6 times for Kharif crop mapping because of different granules. So now data will be extracted as it is in sinusoidal projection. White color represents the burnt area and black color represents unburned area. Now again click the search toolbox and search Project Raster since the data is in sinusoidal projection. Now click on Project Raster dialogue box. In this input the Subdataset one by one. Again, create a folder for Project Raster and save the layer in it one by one with .tif data format. Now in output coordinate system, select WGS_1984_UTM_Zone_43N, as Punjab falls in this zone. As shown in figure 3.12. After clicking ok Projected Raster gets processed. Reminder that This step is repeated 4 times for Rabi crop mapping and 6 times for Kharif crop mapping because of different granules. Now go to the layer and change the layer properties. Select UTM zone WGS_1984_UTM_Zone_43N. Again, go to the search toolbar and search Clip and select the Clip (Data Management). In this in the Input Raster dialogue box, input the Projected Raster file previously saved and select Punjab shape file in output Extent dialogue box. After that create folder for Clip raster and click save. So now data will be clipped and we get Punjab burnt area for that particular period. As shown in figure 3.13. Now go to layer properties and classify the data in 2 categories i.e. Burned Area and Unburned Area. As shown in figure 3.14.

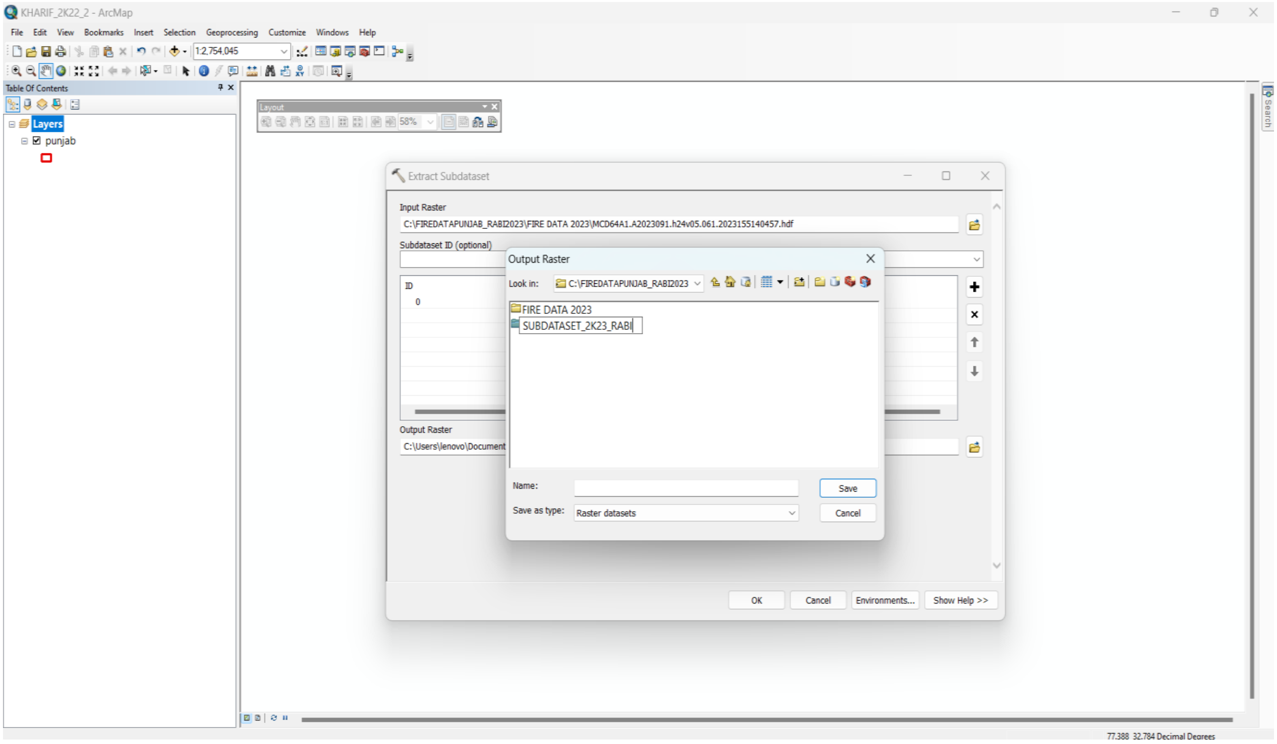


Figure 3.11 Creating Subdataset Folder

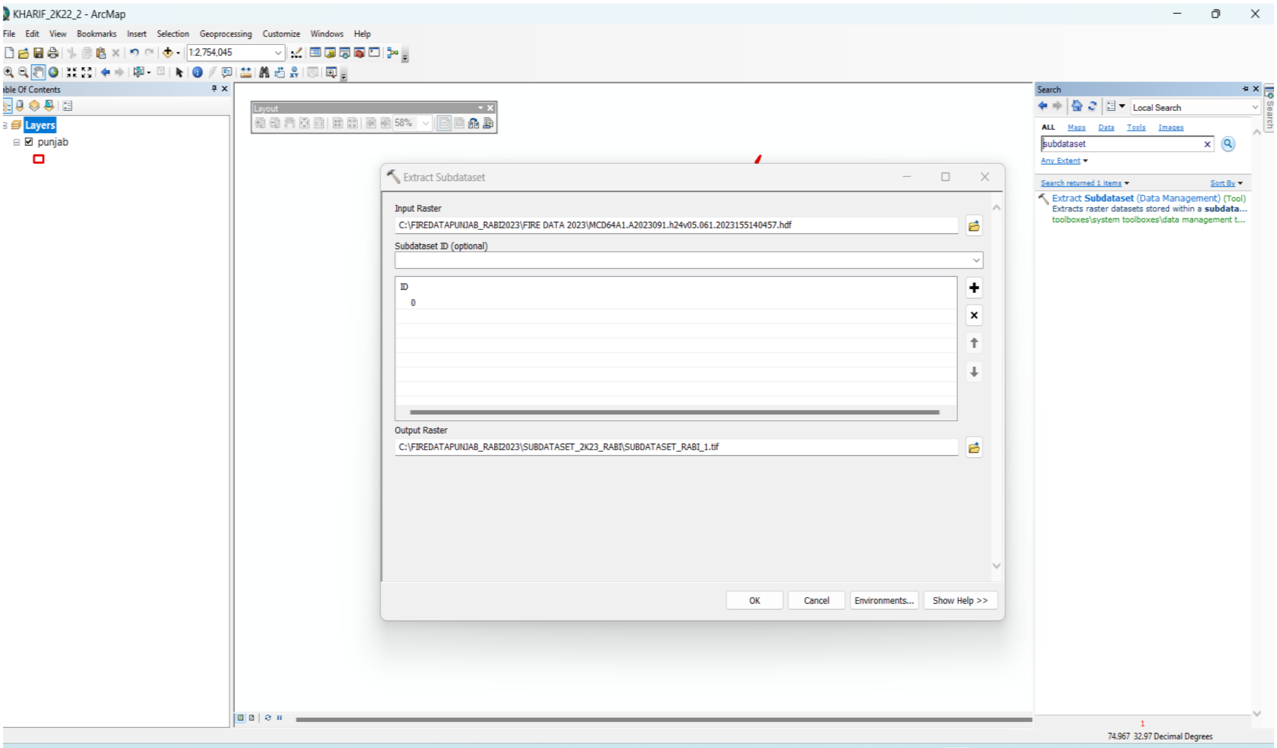


Figure 3.12 Subdataset Value Input

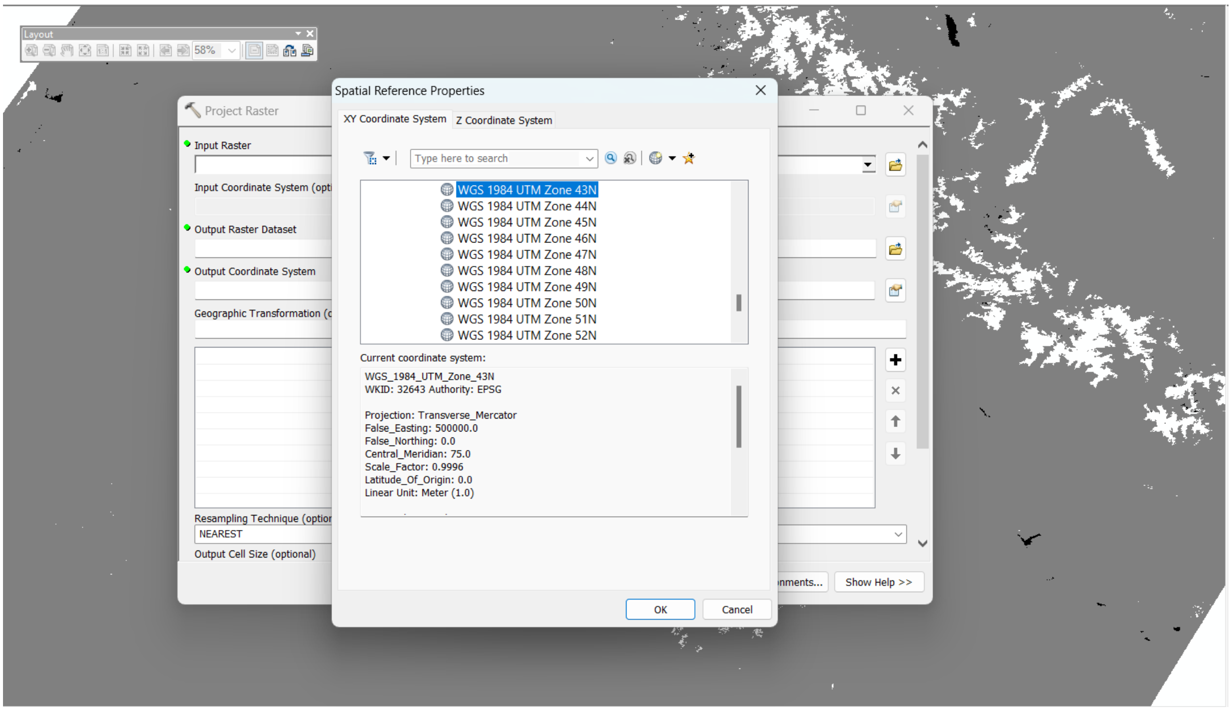


Figure 3.13 Output Coordinate System Input

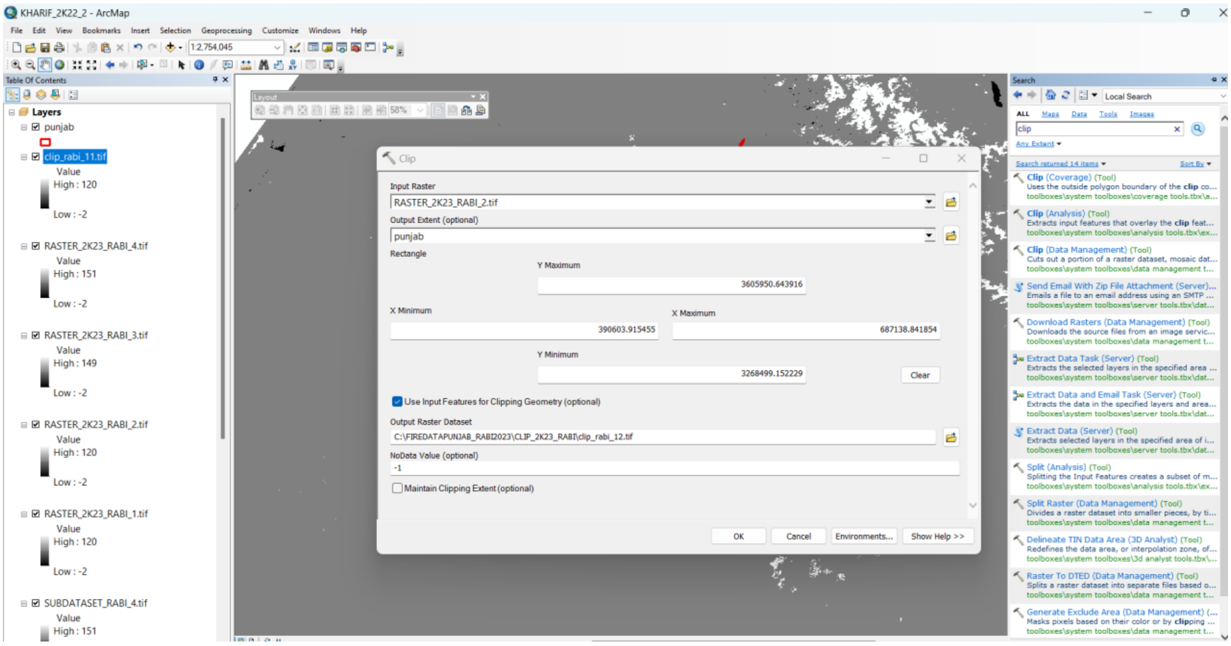


Figure 3.14 Clipping Raster

(4) Standard Burned Map Processing: click on layout and then by clicking on insert section we need to insert north arrow, legend, scale bar, title of the map. As shown in Figure 3.15.

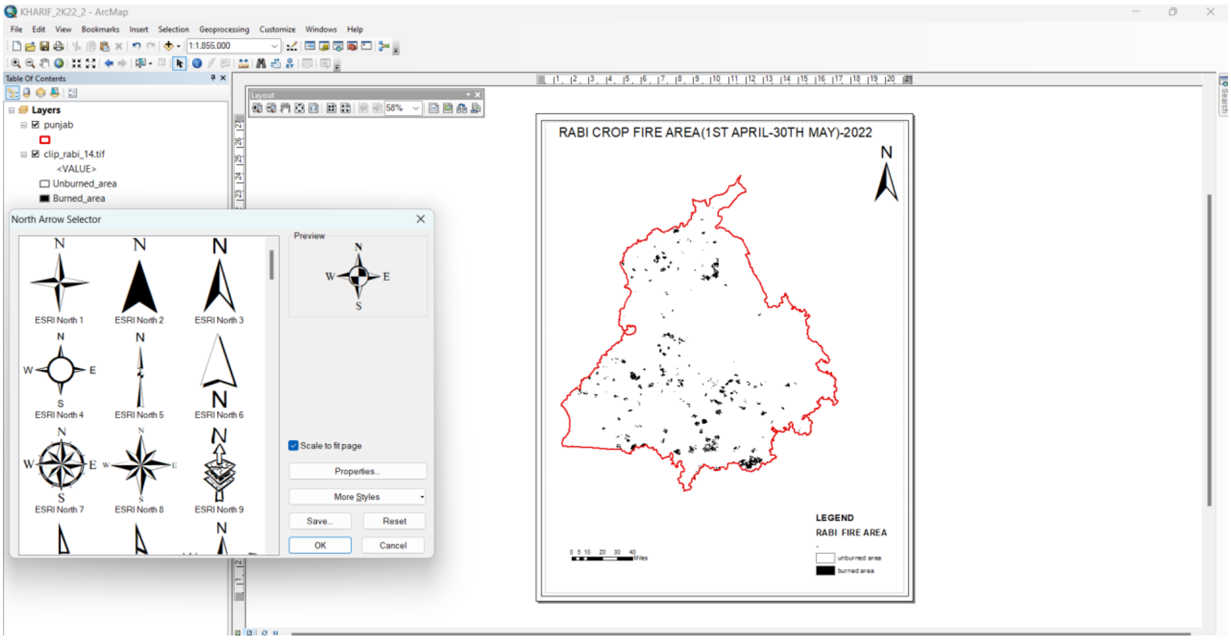


Figure 3.15 Inserting North Arrow and Legend

3.2.3 District wise Fire Event Data

The daily active fire events due to crop residue burning in Punjab were captured from BHUVAN-Punjab which is ISRO Geo platform and Punjab Crop Residue Burning Information and Management System (CRBIMS) data from 2019 to 2023 for Rabi (1st April -30th May) and Kharif (10th September – 30th November). These points were geo-tagged with district and state boundary of Punjab. District-wise daily fire events were extracted and cumulated to the state for computing total fire events. LULC mask are used to remove non-agricultural area. This work is already shown in figures above. Fire events were calculated both district wise and yearly wise. As shown in figure 3.16. From CRBIMS we got daily active fire events data in the format of .xls and we converted it into .xlsx format as shown in figure 3.17. After that excel sheet was prepared where every year (2019-2023), fire events were calculated for rabi and kharif season. As shown in table 3.5 and District wise calculations in shown in Table 3.6.

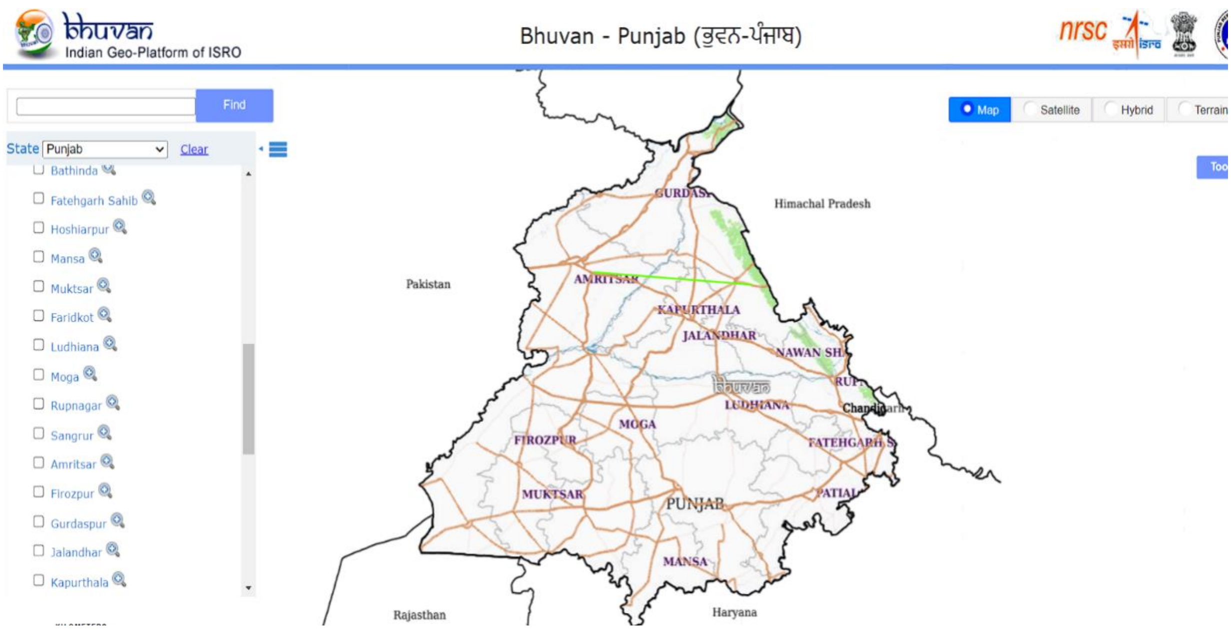
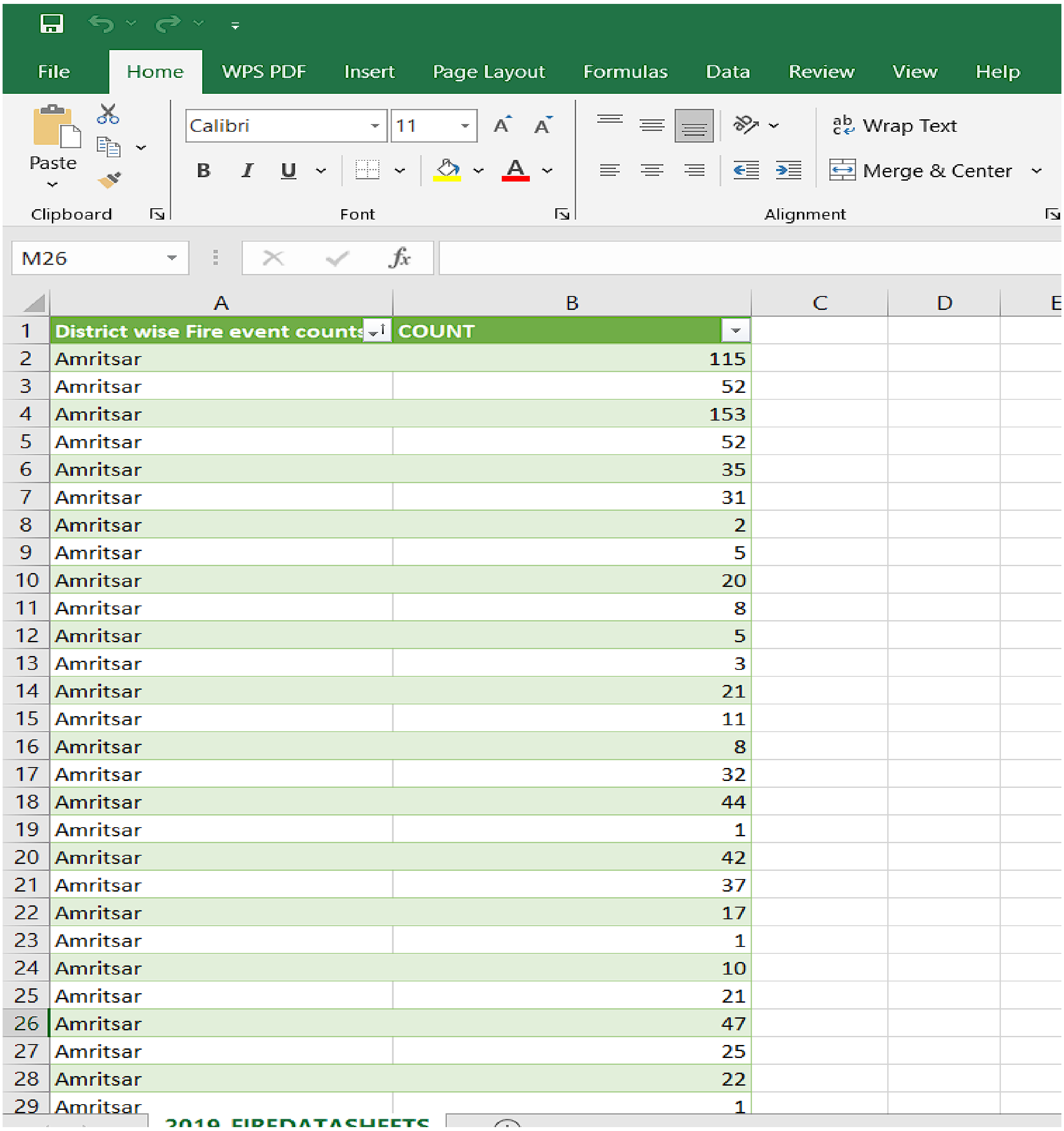


Figure 3.16 Bhuvan District Wise Land Cover Portal



	District wise Fire event counts	COUNT
2	Amritsar	115
3	Amritsar	52
4	Amritsar	153
5	Amritsar	52
6	Amritsar	35
7	Amritsar	31
8	Amritsar	2
9	Amritsar	5
10	Amritsar	20
11	Amritsar	8
12	Amritsar	5
13	Amritsar	3
14	Amritsar	21
15	Amritsar	11
16	Amritsar	8
17	Amritsar	32
18	Amritsar	44
19	Amritsar	1
20	Amritsar	42
21	Amritsar	37
22	Amritsar	17
23	Amritsar	1
24	Amritsar	10
25	Amritsar	21
26	Amritsar	47
27	Amritsar	25
28	Amritsar	22
29	Amritsar	1

Figure 3.17 Daily Active Fire Data Sheet as captured from CRBIMS

Table 3.4 Active Fire Events for Rabi and Kharif Season (2019-2023)

	2019		2020		2021		2022		2023	
District wise Fire event counts	**RABI**	**KHARIF**	**RABI**	**KHARIF**	**RABI**	**KHARIF**	**RABI**	**KHARIF**	**RABI**	**KHARIF**
AMRITSAR	1022	1510	1147	2313	789	2175	1245	1542	871	1573
BARNALA	479	3257	408	4519	437	4326	472	2910	542	2316
BATHINDA	797	6036	1065	7806	597	4481	830	4592	586	2972
FARIDKOT	373	2545	508	3845	448	3953	527	2693	464	2022
FATEHGARG SAHIB	216	896	140	1362	123	1724	72	1149	138	888
FAZILKA	532	3135	560	3125	406	2388	527	2856	437	1854
FEROZPUR	794	5313	1059	6967	946	6288	1429	4295	847	3398
GURDASPUR	673	1497	963	1938	663	1396	1127	854	954	389
HOSHIARPUR	263	316	434	407	377	331	483	259	410	118
JALANDHAR	571	1563	616	1794	555	2548	835	1388	622	1196
KAPURTHALA	441	1422	36	1631	504	1803	730	1108	504	1048
LUDHIANA	1035	2532	1019	4330	517	5817	950	2682	889	1801
MALERKOTLA	1608	3877	832	2454	461	1383	227	677	179	413
MANSA	360	3924	341	4961	294	3217	372	2815	333	2268
MOGA	724	3267	1192	5843	579	6515	1099	3609	1010	2795
PATHANKOT	111	14	150	11	150	16	168	11	92	14
PATIALA	518	4212	407	5324	414	5368	455	3336	419	1878
RUPNAGAR	89	131	66	209	84	307	75	146	41	46
SAS NAGAR	93	201	26	262	43	206	33	162	20	133
SANGRUR	1000	6991	607	8076	676	8082	785	5239	637	5618
SHAHID BHAGAT SINGH NAGAR	172	279	193	192	186	355	231	270	185	238
SRI MUKTSAR SAHIB	686	3961	1049	5458	721	4602	729	3884	587	1669
TARN TARAN	875	3373	770	4528	810	4117	1072	3184	586	2026

Table 3.5 District Wise Fire Events (2019-2023)

District wise Fire event counts	COUNT-2019	COUNT - 2020	COUNT-2021	COUNT-2022	COUNT-2023
AMRITSAR	2532	3460	2964	2787	2444
BARNALA	3736	4927	4763	3382	2858
BATHINDA	6833	8871	5078	5422	3558
FARIDKOT	2918	4353	4401	3220	2486
FATEHGARG SAHIB	1112	1502	1847	1221	1026
FAZILKA	3667	3685	2794	3383	2291
FEROZPUR	6107	8026	7234	5724	4245
GURDASPUR	2170	2901	2059	1981	1343
HOSHIARPUR	579	841	708	742	528
JALANDHAR	2134	2410	3103	2223	1818
KAPURTHALA	1863	1667	2307	1838	1552
LUDHIANA	3567	5349	6334	3632	2690
MALERKOTLA	5485	3286	1844	904	592
MANSA	4284	5302	3511	3187	2601
MOGA	3991	7035	7094	4708	3805
PATHANKOT	125	161	166	179	106
PATIALA	4730	5731	5782	3791	2297
RUPNAGAR	220	275	391	221	87
SAS NAGAR	294	288	249	195	153
SANGRUR	7991	8683	8758	6024	6255
SHAHID BHAGAT SINGH NAGAR	451	385	541	501	423
SRI MUKTSAR SAHIB	4647	6507	5323	4613	2256
TARN TARAN	4248	5298	4927	4256	2612

3.2.4 Estimation of GHG and Particulates Emissions

A version of equation (1) is designed to estimate burning of agricultural residue [3, 28]. The following formula is used to get the overall emissions from crop residue.

E_{cr} (Gg per year) = crops (P x R x D x E x B x EF) ………………………………………… (1)

here R is the residue to crop production ratio, D is the dry matter fraction, E is the burning efficiency or fraction actually oxidised, B is the percentage of dry matter burned in fields (%), and EF is the emission factor, or grammes of gas emitted per kg of dry matter residue burned in fields (g kg-1). The crop yearly crop production data is taken from Ministry of Agriculture and Farmers Welfare, Government of India. As there is no comprehensive study available for the valuers of these parameters, the values are taken from Ravindra et al. [3] and IPCC Inventories [28]. The are shown in Table 3.6 & 3.7.

Table 3.6 Emissions Factor used in the Study

S.No	POLLUTANT	EMISSION FACTOR(g/Kg)-RICE	EMISSION FACTOR(g/Kg)-WHEAT
1	PM2.5	8.3	7.6
2	PM10	9.1	8.36
3	CO_2	1460	1787
4	CO	93	60
5	CH_4	9.59	3.55
6	N_20	0.07	0.07
7	No_x	3.1	3.3

Table 3.7 Types of crops and coefficients used for crop residue Burning Emission Estimation.

S.No.	Land Use Land Cover Class	Wheat	Rice
1	Residue to Crop Ratio(R)	1.75	1.76
2	Dry Matter Fraction(D)	0.83	0.85
3	Dry Matter Burned in Fields%(B)	0.23	0.8
4	Burn Efficiency(E)	0.86	0.89

3.2.5 Crop Residue Generation: Crop residue generation is also important parameter in stubble burning and is calculated based on following formula [1]:

Crop Residue Generation (Mt/year) = (P x R x D) ………………………………………… (2)

where R is the residue to crop production ratio, P is production per year (Mt/year), D is the dry matter fraction.

Chapter-4

Results & Discussion

In this section we will deal will the results and the results will include yearly fire events from 2019-2023, district wise fire events, Arc GIS 10.3 generated maps, crop residue generation, greenhouse gas (GHG) estimation. On the basis of this conclusion will be generated.

4.1 Seasonal Variability of Fire Events

Since the start of the green revolution, Punjab has experienced significant cropping intensity due to the advent of the rice-wheat system. With 84.6% of the net sown area planted in wheat during the rabi season and 70% in paddy during the kharif season [29], this cropping strategy generates a large amount of crop residue. In this study yearly wise rabi and kharif burning events are calculated for 5 years. District wise calculations are also done. Seasonal Variability of crop residue Fire, in which total of 358965 fire events were recorded in all 23 districts of Punjab, using CRBIMS active burning data for last 5 years (2019 to 2023). The highest number of fires were recorded in 2020 with 90943 events and lowest being in 2023 which was 48026 events in my study. As shown in table 3.8.

Table 4.1: Yearly Wise Rabi and Kharif Burning Events (2019-2023)

YEARS	2019		2020		2021		2022		2023	
CROP SEASON TYPE	RABI	KHARIF	RABI	KHARIF	RABI	KHARIF	RABI	KHARIF	RABI	KHARIF
TOTAL	13432	60252	13588	77355	10780	71398	14473	49661	11353	36673
TOTAL(RABI +KHARIF)	73684		90943		82178		64134		48026	
TOTAL(2019-2023)	358965									

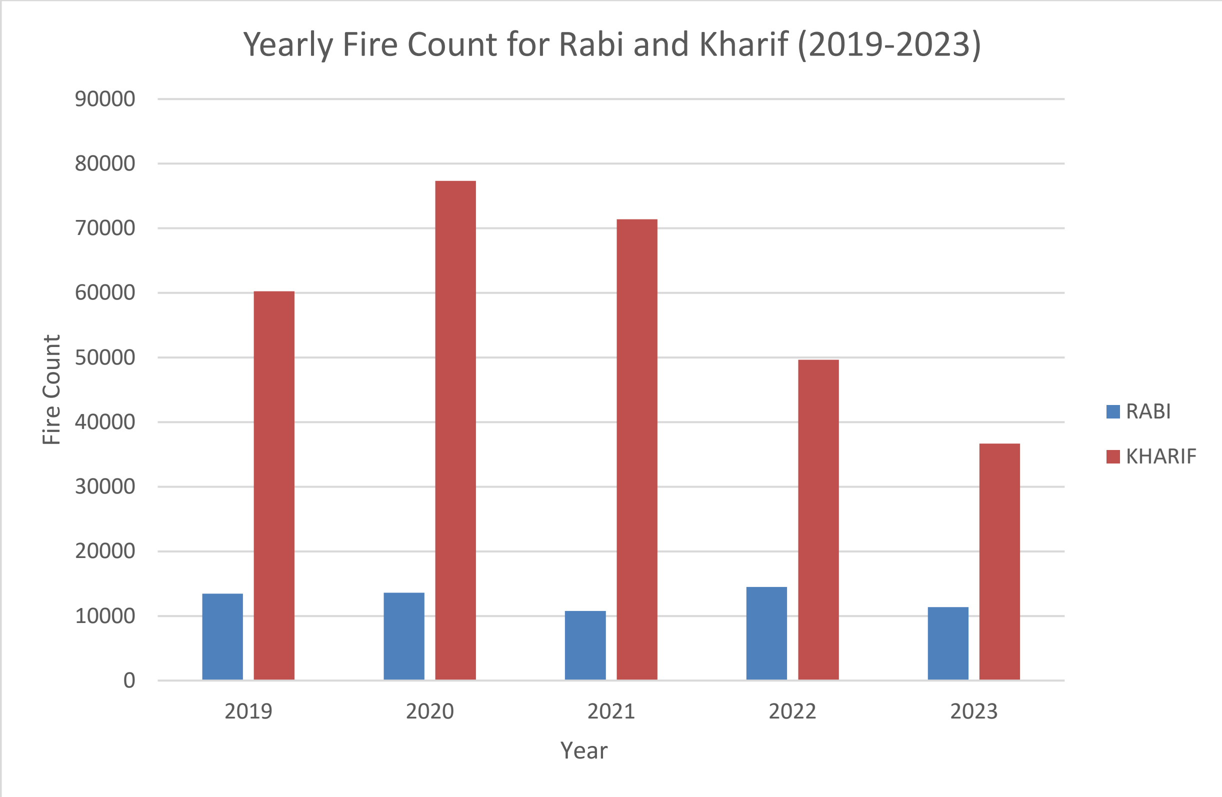


Figure 4.1 Yearly Fire Count for Rabi and Kharif (2019-2023)

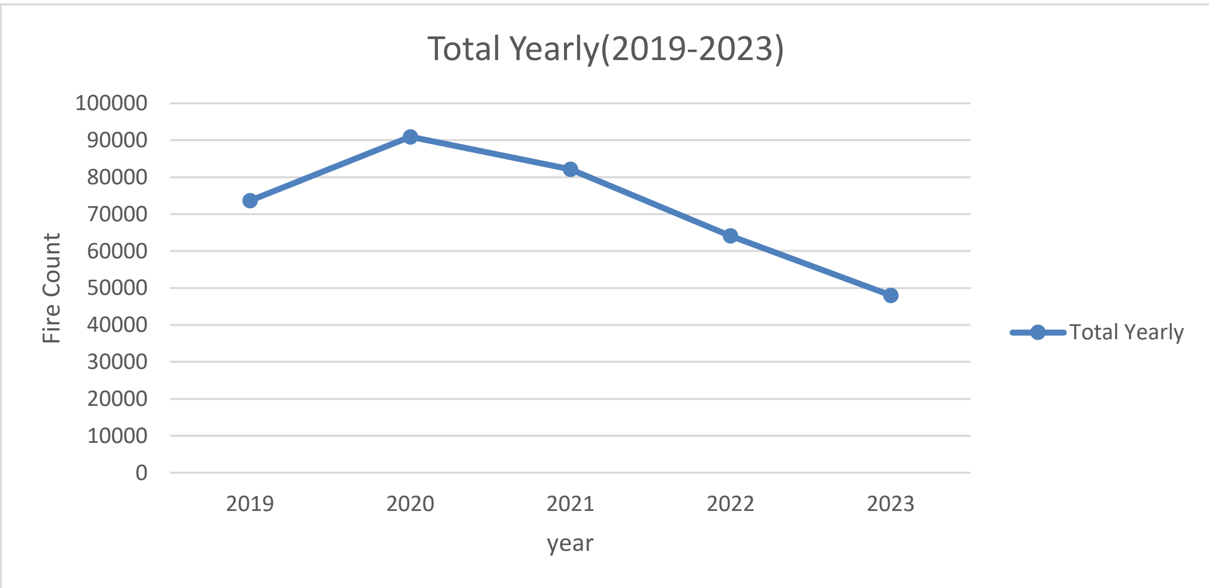


Figure 4.2 Yearly Fire Count (2019-2023)

4.2 District-wise Variability of Fire Events

tabulates all the fire events district wise and with the help of MODIS/Terra+Aqua Direct Broadcast Burned Area Monthly L3 Global 500 SIN Grid V061)-MCD64A1 product of MODIS burned area Product, GIS mapping of burned area was done. Table 4.2 depicts the district wise variability of fire events. It can be seen that maximum fire event is recorded in Sangrur which is in southern side of Punjab and least was in Pathankot district, which is in northern side of Punjab during (2019-2023) period. As shown in figure 4.3 and figure 4.4. So, from the table it is evident that most of the fire events happened in Malwa region of Punjab i.e. Bathinda, Sri Muktsar Sahib, Mansa, Barnala, Ludhiana etc. It is also evident that the fire events are more during kharif season as compared to rabi season since kharif season is paddy season and it generates more crop residue. The reason for more fires in Malwa region according to reports being Persistent use of high-yield paddy, lack of government support for crop diversification, and unseasonal rains have contributed to farm fires. Farmers' choice for the long-duration PUSA 44 paddy type is the reason for the higher fire counts in this area. PUSA 44 is a high-yielding rice variety with a large straw load that boosts crop residue. It matures in around 160 days after sowing, leaving less time for CRM [30].

Table 4.2 District Wise fire Events (2019-2023)

District wise Fire event counts	COUNT-2019	COUNT -2020	COUNT-2021	COUNT-2022	COUNT-2023	TOTAL
AMRITSAR	2532	3460	2964	2787	2444	14187
BARNALA	3736	4927	4763	3382	2858	19666
BATHINDA	6833	8871	5078	5422	3558	29762
FARIDKOT	2918	4353	4401	3220	2486	17378
FATEHGARG SAHIB	1112	1502	1847	1221	1026	6708
FAZILKA	3667	3685	2794	3383	2291	15820
FEROZPUR	6107	8026	7234	5724	4245	31336
GURDASPUR	2170	2901	2059	1981	1343	10454
HOSHIARPUR	579	841	708	742	528	3398
JALANDHAR	2134	2410	3103	2223	1818	11688
KAPURTHALA	1863	1667	2307	1838	1552	9227
LUDHIANA	3567	5349	6334	3632	2690	21572
MALERKOTLA	5485	3286	1844	904	592	12111
MANSA	4284	5302	3511	3187	2601	18885
MOGA	3991	7035	7094	4708	3805	26633
PATHANKOT	125	161	166	179	106	737
PATIALA	4730	5731	5782	3791	2297	22331
RUPNAGAR	220	275	391	221	87	1194
SAS NAGAR	294	288	249	195	153	1179
SANGRUR	7991	8683	8758	6024	6255	37711
SHAHID BHAGAT SINGH NAGAR	451	385	541	501	423	2301
SRI MUKTSAR SAHIB	4647	6507	5323	4613	2256	23346
TARN TARAN	4248	5298	4927	4256	2612	21341

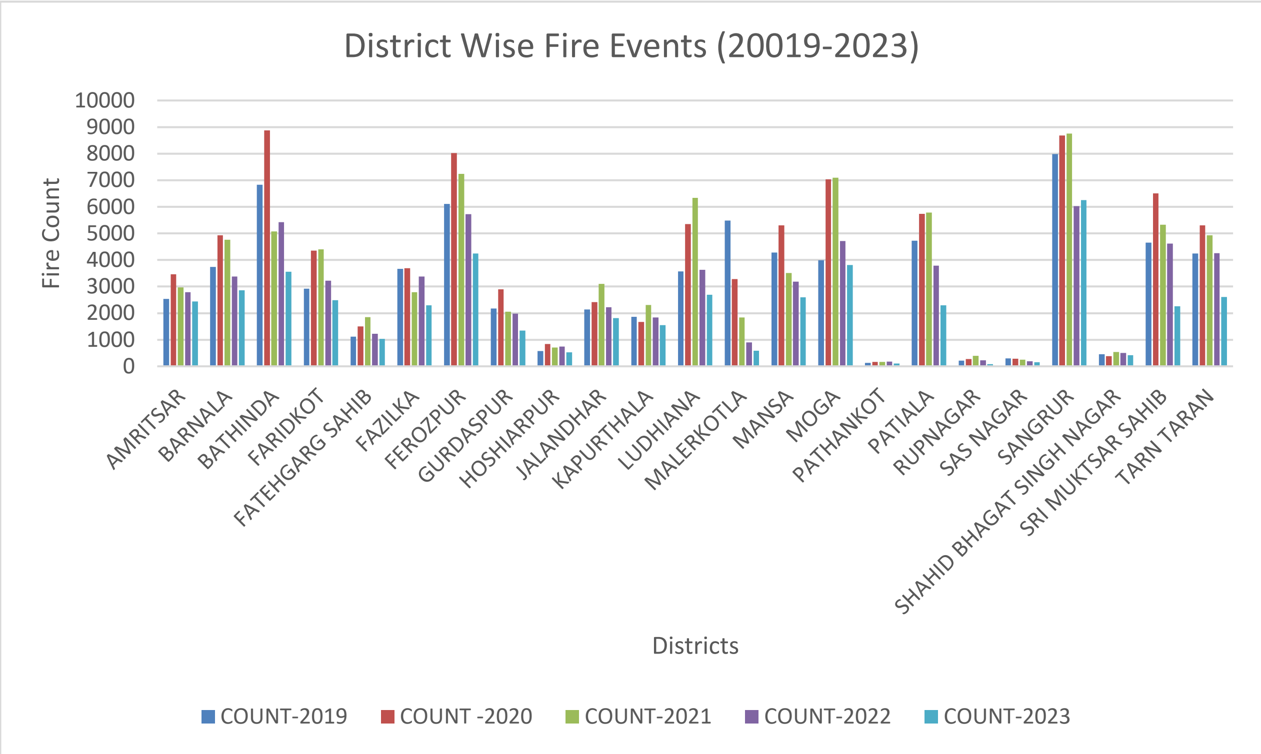


Figure 4.3 District Wise Fire Count (2019-2023)

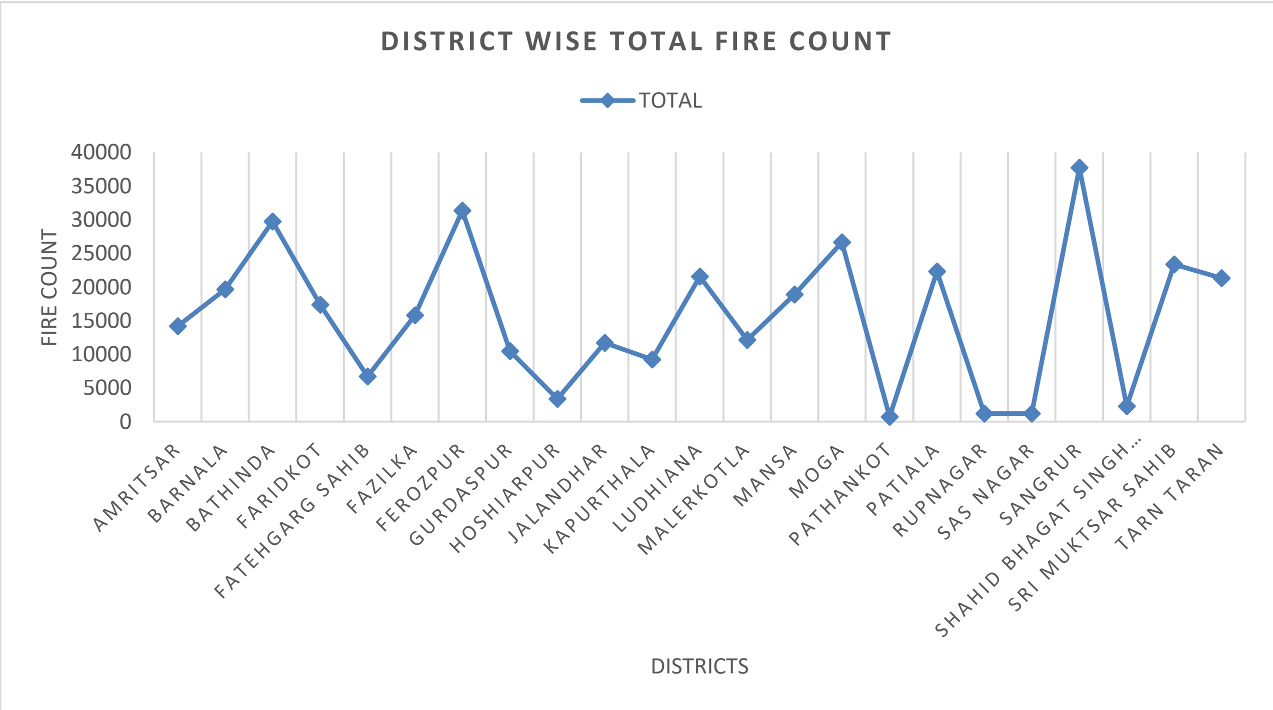


Figure 4.4 Total District Wise Fire Count

4.3 Terra+Aqua -MCD64A1 MODIS GIS Mapping

In this study with the help of MODIS/Terra+Aqua Direct Broadcast Burned Area Monthly L3 Global 500 SIN Grid V061)-MCD64A1 product of MODIS burned area Product, GIS mapping of burned area was done. It was done separately for rabi and kharif for 2019-2023 period. Data was taken for Rabi (1st April -30th May) and Kharif (10th September – 30th November). With the help of Arc GIS 10.3 maps were made. As shown from figure 4.5 to figure 4.15. With these maps its quite evident that mostly fire events were recorded in Malwa region of Punjab and during kharif season which is paddy growing season and compared to rabi it is less due to PUSA44 paddy variety usage. Also, another reason is that rabi period is small as compared kharif period. Also, it is visible that during 2020 season more fire events were recorded as compared to other years. The reason being During Kharif 2020, over 27 per cent of the area across the Malwa districts was under PUSA 44 [30].

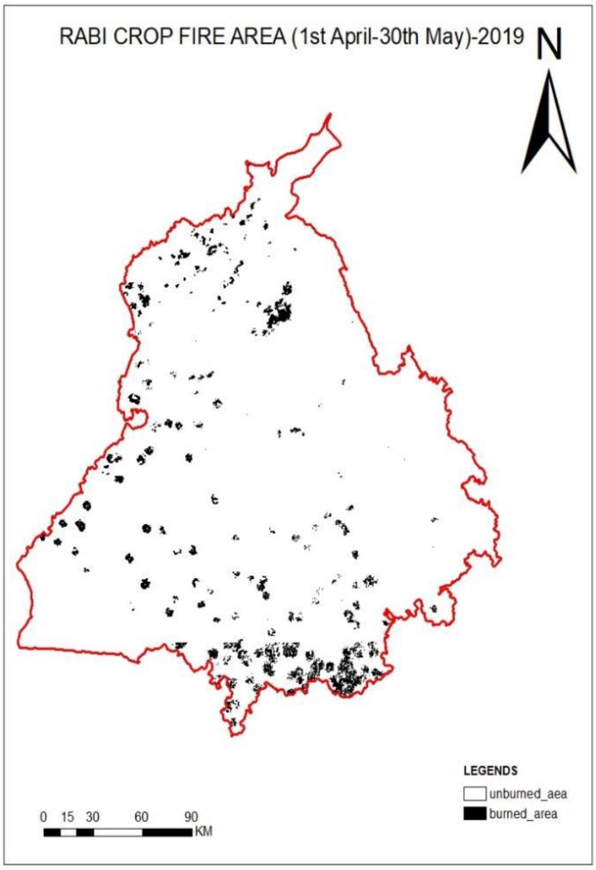


Figure 4.5 Rabi 2019

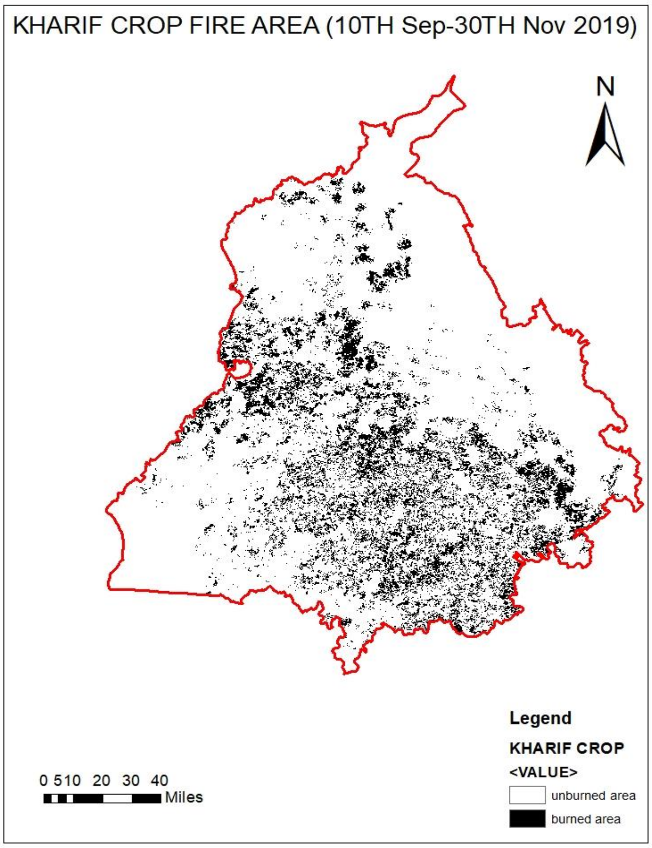


Figure 4.6 Kharif 2019

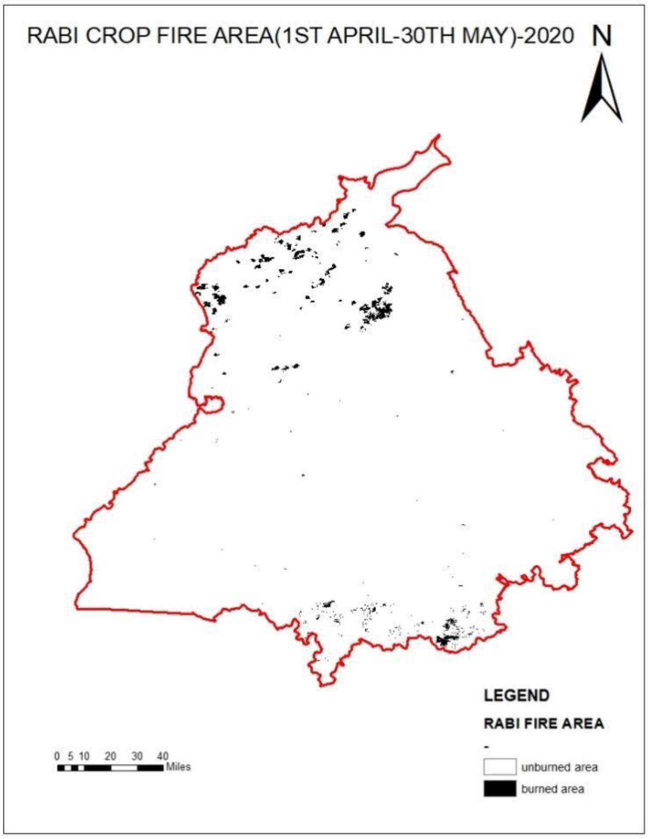


Figure 4.7 Rabi 2020

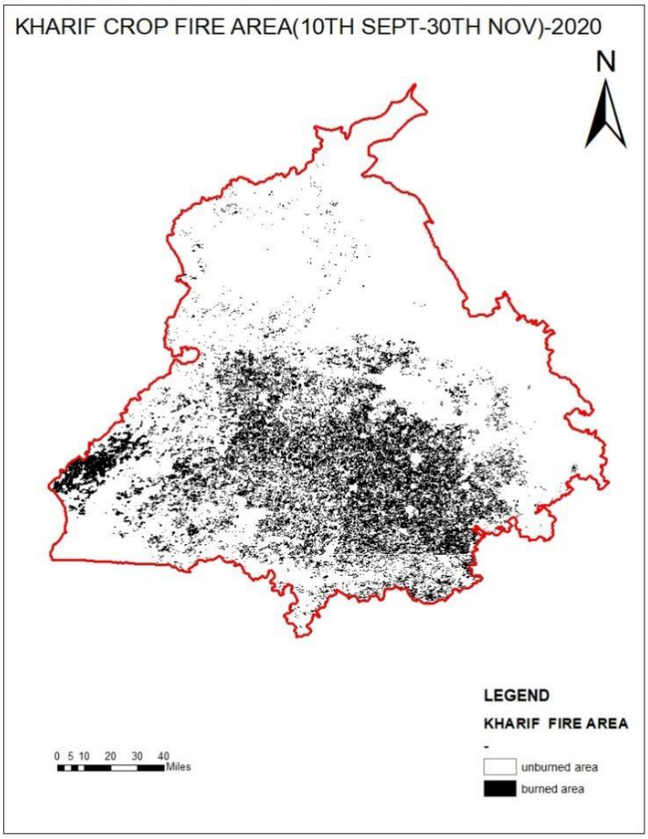


Figure 4.8 kharif 2020

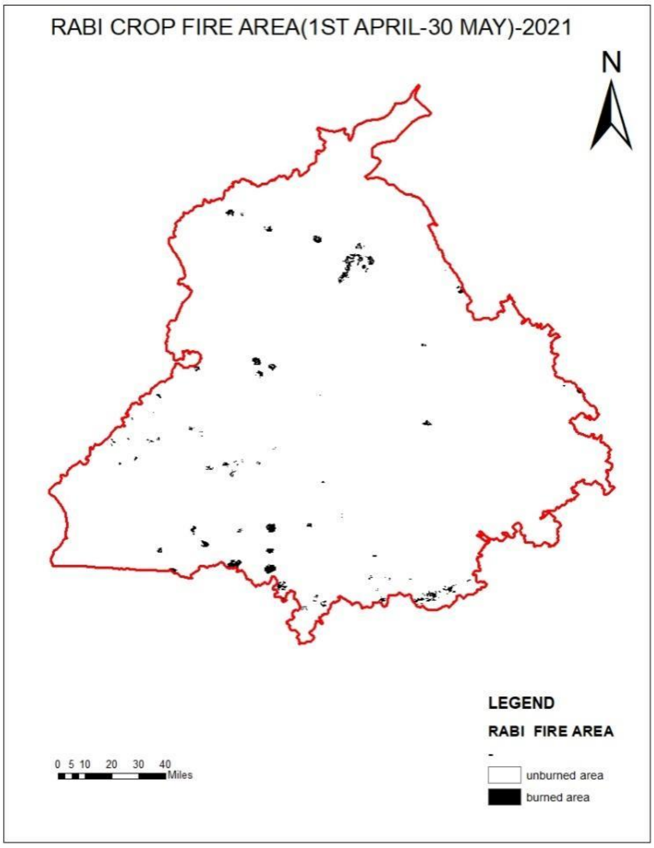


Figure 4.9 Rabi 2021

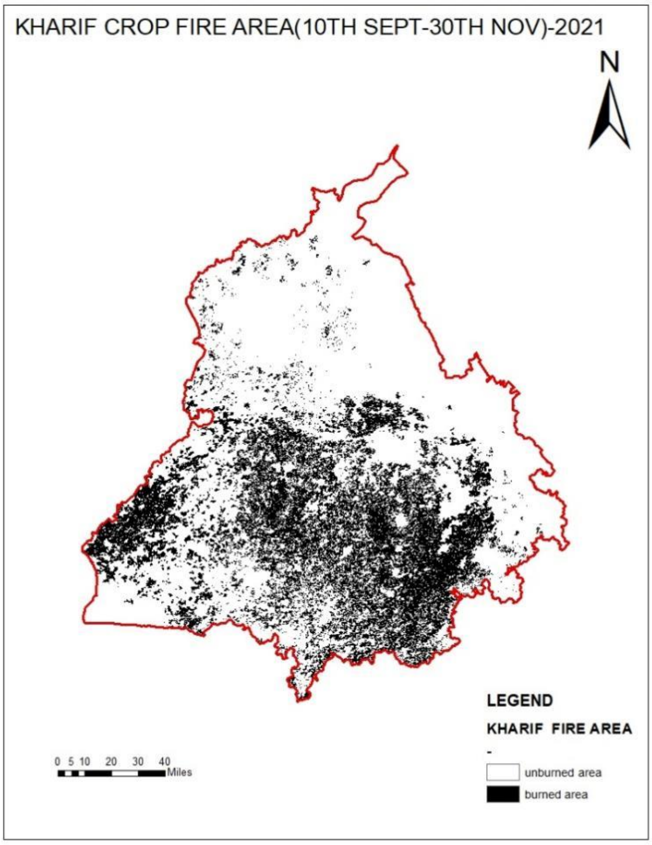


Figure 4.10 kharif 2021

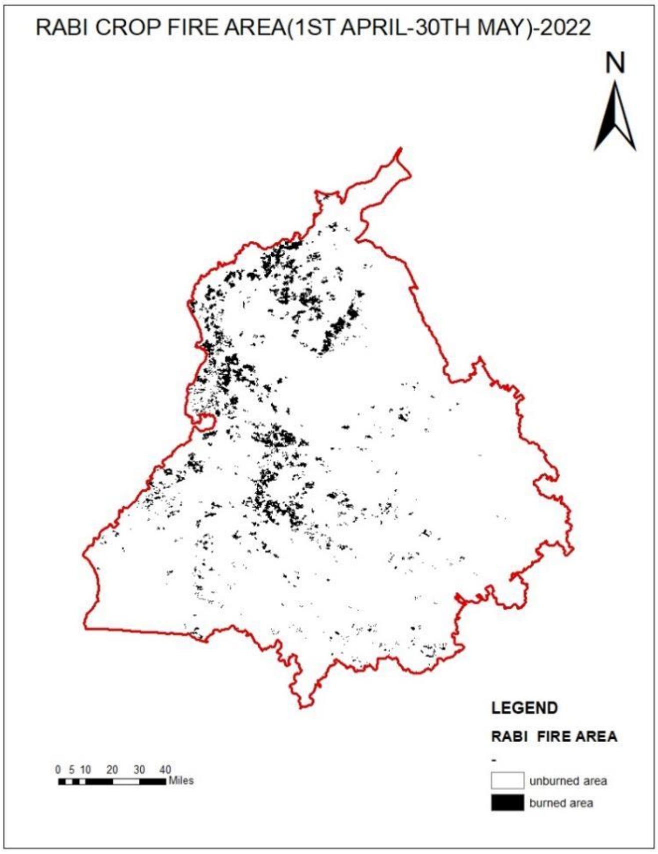


Figure 4.11 Rabi 2022

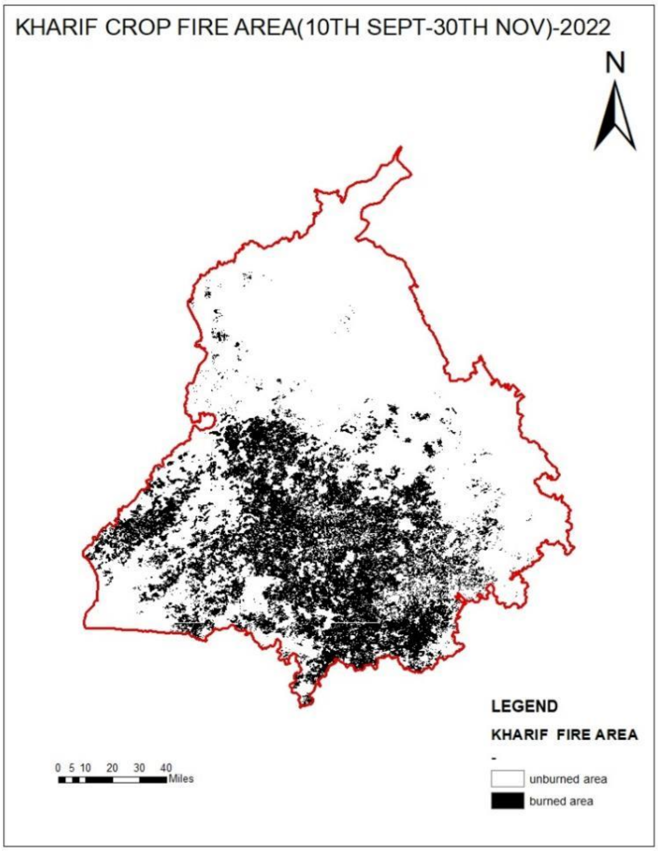


Figure 4.12 kharif 2022

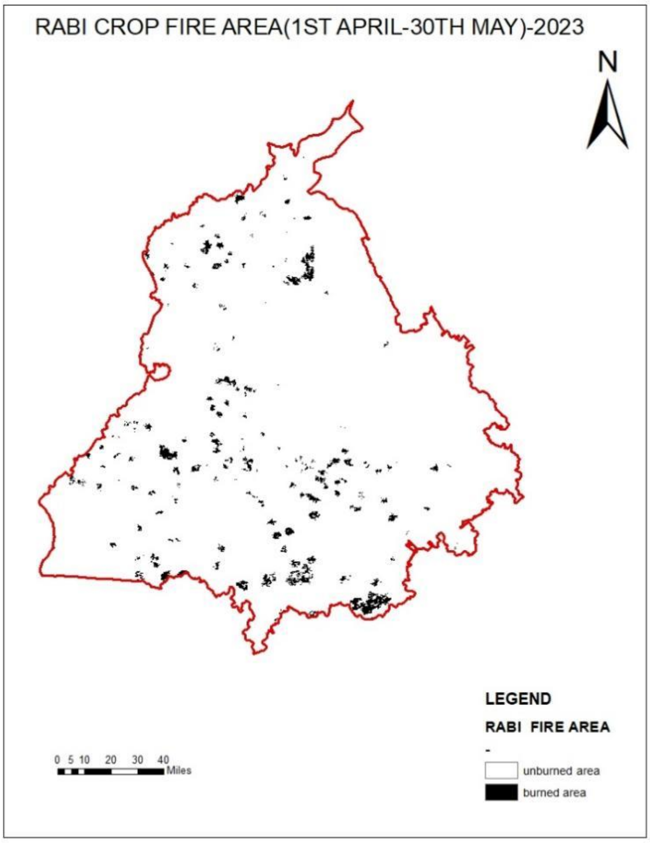


Figure 4.13 Rabi 2023

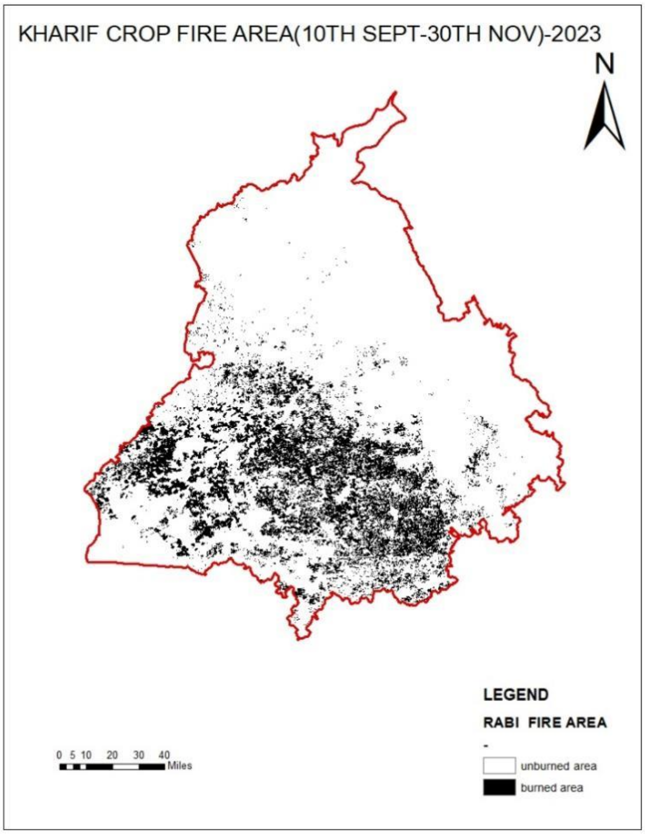


Figure 4.14 kharif 2023

4.4 Crop Residue Generation

crop residue generation is one of the important factors in emissions estimation and is calculated based on Product of Crop Production (Mt/year), Residue to Crop Ratio(R) and Dry Matter Fraction(D). It can be summarized that crop residue generated was more for wheat than rice. It was 122.26 Mt for wheat and 93.73Mt for rice for 5-year period. As listed in table 4.3. The reason may be because of higher crop to grain ratio of wheat as compared to rice (Figure 4.14) Still crop residue burning is more during kharif season because of small turnaround time. Also, wheat straw is used as fodder and mulch thus reducing the necessity to burn

Table 4.3 Crop Residue Generation (Mt/year)

	Crop Residue Generation for different Financial Year (Mt/year)					
Type of Crop	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	TOTAL(Mt/year)
RICE	19.17	17.62	18.22	19.28	19.44	93.73
WHEAT	26.63	25.52	24.89	21.52	24.4	122.96

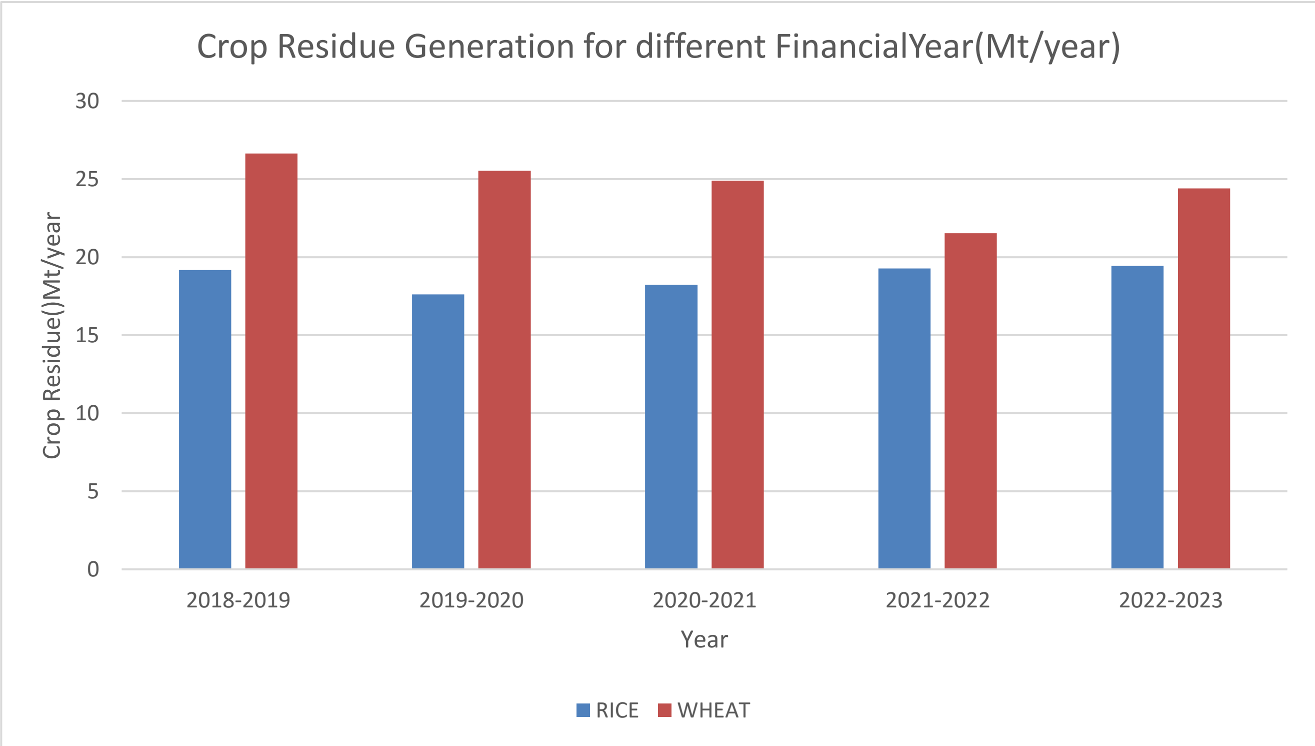


Figure 4.15 Crop Residue Generation for Different Financial Year (Mt/year)

4.5 Green House Gases and Particulates Estimation

The yearly variability in GHG production and emissions from Punjab's two main crops—rice and wheat—during the previous 5 financial year years is compiled in Tables 4.4 and 4.5. The findings show that output for GHG emission has grown for rice from 21618.41 Gg/year and for wheat, it gone down from 9151.61 Gg/year to 9024.47 Gg/year.one of the reason is due to decrease in production (Figure 4.16) due to poor rainfall, heat stress during this period. Out of all GHGs highest amongst them is CO_2 because of its greater emission factor (refer table 3.6). For rise crop CO2 emissions rose from 19936.66Gg/year to 20216.58 Gg/year for Rice crops and from 9415.99 Gg/year to 8625.34 Gg/year for wheat crops.CO_2 accounted for 92.21% of total rice crop emissions and 95.55% for wheat crop emissions. For PM2.5 the emissions percentage was 0.5% for rice crop emissions and 0.4% for wheat crop. For other GHGs refer table 4.6. So, over all major emissions are CO_2, CO, PM2.5 AND PM10.

Table 4.4 Year Wise GHG Emissions and Particulates for Rice (2019-2023)

YEAR	Crop Production(Mt)-Rice	PM2.5	PM10	CO_2	CO	CH_4	N_2O	NO_x	TOTAL(Gg/year)
2018-2019	12.82	113.33	124.26	19936.66	1269.93	130.95	0.95	42.33	21618.41
2019-2020	11.78	104.14	114.18	18319.33	1166.91	120.33	0.87	42.33	19868.09
2020-2021	12.18	107.68	118.05	18941.38	1206.54	124.41	0.91	40.21	20539.18
2021-2022	12.89	113.95	124.94	20045.52	1276.87	131.66	0.96	42.56	21736.46
2022-2023	13	114.92	126	20216.58	1287.76	132.79	0.96	42.92	21921.93

Table 4.5 Year Wise GHG Emissions and Particulates for Wheat (2019-2023)

YEAR	Crop Production(Mt)-Wheat	PM2.5	PM10	CO_2	CO	CH_4	N_2O	NO_x	TOTAL(Gg/year)
2018-2019	18.34	40.04	44.05	9415.99	316.14	18.7	0.36	16.33	9851.61
2019-2020	17.57	38.36	42.2	9020.66	302.87	17.9	0.35	15.64	9438
2020-2021	17.14	37.42	41.16	8799.9	295.46	17.5	0.34	15.26	9207.02
2021-2022	14.82	32.35	35.59	7608.78	255.47	15.1	0.29	13.19	7960.78
2022-2023	16.8	36.68	40.35	8625.34	289.6	17.2	0.33	14.96	9024.47

Table 4.6 Emission % for Different GHGs and Particulates (2019-2023)

POLLUTANTS	EMISSION % (RICE)	EMISSION%(WHEAT)
PM2.5	0.56	0.4
PM10	0.57	0.44
CO_2	92.21	95.57
CO	5.8	3.2
CH_4	0.6	0.18
N_2O	0.004	0.003
NOX	0.19	0.16

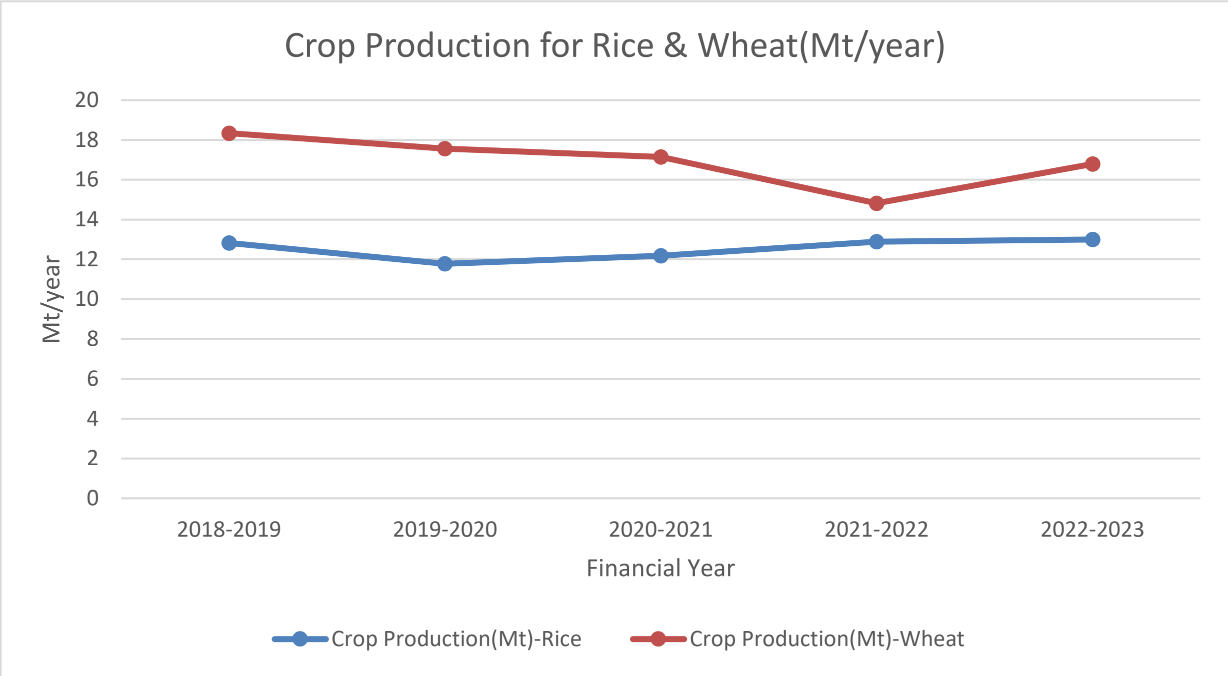


Figure 4.16 Crop Production for Rice & Wheat (Mt/year)

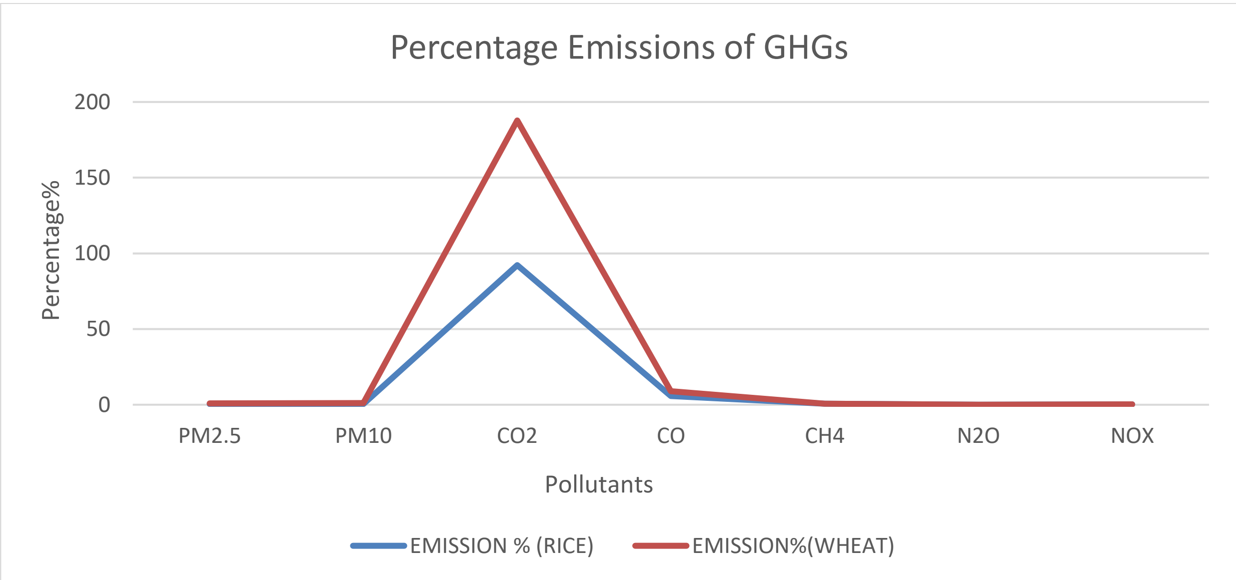


Figure 4.17 Percentage Emissions of GHGs and Particulates

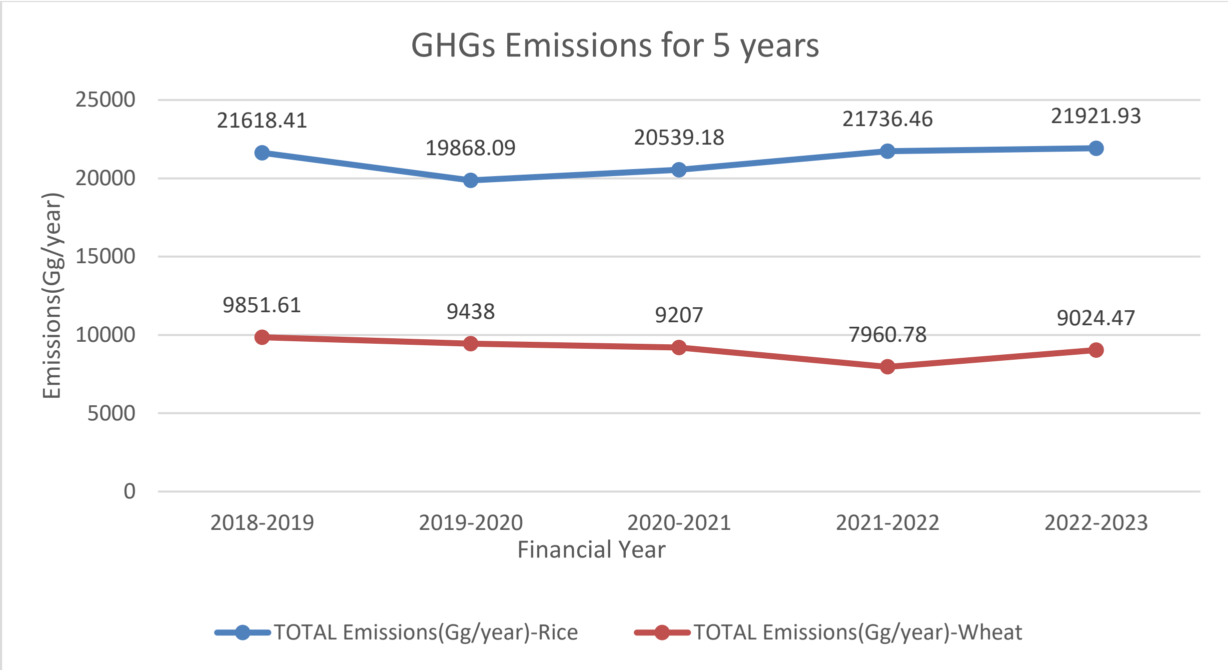


Figure 4.18 Emissions of GHGs and particulates (Gg/year)

Chapter 5

Conclusion

The study highlights the significant environmental and health impact of stubble burning in Punjab, mainly focused on the spatial -temporal analysis of fire events using GIS and satellite data. There were some key findings. From 2019 to 2023, a total of 358965 fire events were recorded across Punjab with the highest number in 2020(90943 events) and the lowest in 2023(48026 events) which means that’s government initiative to combat stubble burning is working satisfactorily with problem still persistent. For this cause government is taking various initiatives and have prepared action plan under the governance of MOEFCC under Air Quality Act of NCT and Adjoining Areas 2021 like in-situ, ex-situ crop Residue Management (CRM), imposing of environmental compensation by pollution control board of Punjab, ban of stubble burning under section 144 under NGT compliance, effective monitoring and promoting alternative use of stubble burning. Another key finding was that majority of fire events occurred during the kharif season which attributes for larger volume of crop residue generated from paddy compared to wheat. Districts in the Malwa region, such as Sangrur and Bathinda exhibited highest number of fire incidents due to widespread cultivation of high residue crops like PUSA44 variety of paddy. The study also estimated significant greenhouse gas emissions from stubble burning with rice crop emissions ranging from 19868Gg/year to 21921Gg/year and wheat crop emissions were from 7961Gg/year to 9862Gg/year. These emissions contributed to regional air pollution and have broader implications on climate change. Stubble burning have shown significant deterioration of air quality leading to elevated levels of pollutants like CO2, PM2.5, CO, PM10 etc. These pollutants have serious health impact causing respiratory and cardiovascular diseases among the population. With all the research happening in this field main problem that is arising is short time span between kharif harvesting and wheat sowing period, also less variable rainfall patterns and heat waves are also impacting the crop growth. To mitigate this, the study proposes some mitigation measures like use of happy seeder to cut residue without burning, residue can be used as compost for mushroom cultivation, rice and wheat straws can be used for paper cultivation, can be used for biofuel production because of high lignocellulose value. Also educating farmers, enhancing farmer awareness, improving policy and Enforcement, subsidies for farmers will also be helpful.

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