METHANE EMISSION FROM RICE & WHEAT AGRICULTURAL PRACTICES IN HARYANA

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Geography

By

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2026

DECLARATION

I, hereby declared that the presented work in the thesis entitled "**Methane Emission from Rice & Wheat Agricultural practices in Haryana.**" in fulfillment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of **Dr. Tek Chand Saini**, working as Assistant Professor, in the Department of Geography of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph.D thesis entitled "**Methane Emission from Rice & Wheat Agricultural practices in Haryana.**" Submitted in fulfilment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the **Department of Geography**, is a research work carried out by **Manjit Singh,** Registration No 42000630, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

(Signature of Supervisor)

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Designation: Assistant Professor
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ABSTRACT

The present study entitled **"Methane Emission from Rice & Wheat Agricultural Practices in Haryana"** aptly reflects the core objective and scope of the thesis, which is to analyze, map, and evaluate methane emissions resulting from the cultivation of rice and wheat—two dominant crops in Haryana's agricultural landscape. Methane, a greenhouse gas with 28 times the global warming potential of carbon dioxide, is primarily emitted through anaerobic decomposition in flooded rice fields and to a lesser extent through soil microbial activity in wheat cultivation. This research utilizes advanced geospatial technologies, including Sentinel-2 satellite imagery for crop area detection and Sentinel-5P TROPOMI data for methane concentration analysis, to assess seasonal and spatial variations in emissions across Haryana.

Chapter 1 provides the conceptual framework and motivation for the study. It highlights how agriculture, especially rice and wheat cultivation, contributes significantly to methane (CH_4) emissions due to anaerobic soil conditions and traditional farming practices. India, as a major rice and wheat producer, faces significant environmental challenges from these emissions. The chapter sets the research context by addressing the growing global and local climate concerns. It introduces key concepts like Alternate Wetting and Drying (AWD) for emission reduction and emphasizes the research gaps in spatially detailed, crop-specific CH_4 emission mapping in Haryana. Objectives, scope, and hypotheses are clearly articulated to guide the study's direction.

Chapter 2 elaborates the methodological framework. Sentinel-2A/B satellite data, with high spatial and temporal resolution, was used for crop mapping and estimation. Methane mixing ratio data were acquired from Sentinel-5P and processed through Geostatistical methods like kriging for spatial interpolation. A combination of MODIS, EDGAR datasets, and phenology-based classification enhanced crop type identification. Ground-truthing using GPS data added accuracy. The integration of remote sensing and GIS allowed for multi-layered spatial analysis and methane estimation across the rice-wheat landscape of Haryana.

Chapter 3 applies Digital Image Processing (DIP) techniques for precise estimation of rice and wheat cultivation areas. Vegetation indices like NDVI were calculated from Sentinel-2 imagery, followed by supervised classification and pixel-based area estimation. Field validation enhanced accuracy. Block-wise and district-wise area statistics for rice and

wheat were compiled. Wheat was found to dominate Rabi season cultivation, with notable acreage in central and southern Haryana. The classification results revealed that Haryana cultivated approximately 21.14 lakh hectares of wheat during the Rabi season of 2021–2022**,** accounting for 47.85% of the state**'s** total area. Central Haryana districts such as Fatehabad, Jind, Kaithal, Karnal and Sirsa showed the highest concentration of wheat due to favorable conditions like fertile soils, adequate canal and groundwater irrigation, and suitable climatic patterns. In contrast, the southern and southwestern districts, including Bhiwani, Charkhi Dadri and Mahendergarh exhibited lower wheat density due to arid climates, sandy soils, and limited irrigation, with these regions favoring mustard and pulse cultivation.

while rice dominated the Kharif season in irrigated northern districts. ISODATA classification helped segment crop types effectively. Analysis reveals that during the 2021–2022 Kharif season, Haryana cultivated approximately 13.82 lakh hectares of rice, covering 31.3% of the state's total geographical area**.** The rice crop was found to be highly concentrated in northern and central districts such as Kaithal (73.4%)**,** Karnal (70.7%**)**, and Kurukshetra (65.5%), where favorable climatic conditions, extensive canal irrigation, and fertile alluvial soils promote intensive paddy farming. These districts alone account for a major share of the state’s rice acreage.

Chapter 4 provides detailed spatial and seasonal maps of methane emissions derived from satellite data. Methane emissions from wheat were mostly in the “Very Low” to “Moderate” category (1890–1910 ppb), with small areas exceeding 1920 ppb. Conversely, rice cultivation showed significantly higher emissions, particularly in flooded zones during monsoon months, reaching over 1968 ppb in some districts. Monthly emissions from October to December are visualized and classified, reflecting temporal emission trends and hotspot zones across Haryana.

Here, the methane emission levels from wheat and rice are compared both spatially and temporally. Rice, due to waterlogged conditions and anaerobic soil, is identified as the dominant emitter, especially during the monsoon. Wheat emissions remain consistently lower due to drier growing conditions. Emission intensity (per hectare) is significantly higher for rice. The findings establish rice fields as key contributors to regional methane emissions and provide seasonal insights into emission peaks. A comparative table clearly illustrates the emission-classified area under both crops. The analysis, based on methane mixing ratios in parts per billion (ppb), categorizes methane concentrations into five classes: very low, Low, Moderate, High, and Very High, with corresponding areas measured in hectares.

For wheat cultivation, the "Very Low" category exhibits the lowest methane concentration at 1890 ppb, covering 2,845,764.2 hectares, indicating minimal methane emissions across a large area. In contrast, the "Very High" category, with a methane concentration of 1968 ppb, covers the smallest area of 117,642.4 hectares, suggesting concentrated methane emissions in specific regions. The study highlights the spatial variation in methane emissions across Haryana’s wheat fields, emphasizing the need for targeted environmental policies to mitigate the impact of methane on climate change.

Similarly, methane emissions from rice cultivation show notable variation, with the "Moderate" category (1910 ppb) covering 430,622.9 hectares, while the "Very High" category (1968 ppb) spans 3,354,135.8 hectares, indicating significant methane emissions from rice fields. The findings underscore the large-scale contribution of rice cultivation to methane emissions in Haryana and suggest that areas with high to very high methane levels could be key targets for emission reduction strategies.

Chapter-5 results reveal that rice cultivation is a major source of methane emissions in Haryana, with the "Very High" methane concentration category (1968 ppb) covering a substantial area of 3,354,135.8 hectares. These emissions are most pronounced during the monsoon season when flooded rice fields create anaerobic conditions conducive to methane production. In contrast, wheat cultivation exhibits relatively low methane emissions, with the "Very Low" category (1890 ppb) dominating over 2,845,764.2 hectares. Methane emissions from wheat are stable throughout its growing season, primarily influenced by microbial activity and soil conditions.

Chapter-6 evaluates the farming practices responsible for methane emissions. Key sources include flooded paddy fields, residue burning, fertilizer use, and livestock management. Rice’s flooded conditions foster methanogenesis, while wheat emissions are driven by soil microbes and fertilizer-induced microbial activity. The chapter suggests mitigation strategies like AWD (Alternate Wetting and Drying), slow-release fertilizers, biogas

plants, crop diversification, and improved rice varieties to reduce emissions. These practices aim to balance productivity and environmental sustainability.

The study concludes that rice cultivation in Haryana contributes substantially to regional methane emissions, more than wheat. Satellite-based remote sensing is validated as a robust tool for mapping crop area and estimating associated emissions. Block-wise and district-wise data empower localized mitigation planning. Suggestions include promoting AWD, reducing residue burning, enhancing fertilizer management, and shifting toward lower-emission cropping systems. These strategies can assist Haryana in aligning with India’s broader climate goals while maintaining agricultural productivity.

ACKNOWLEDGEMENTS

A formal line of appreciation would hardly do justice in expressing my highest esteem and profound sense of deep gratitude to Dr. Tek Chand Saini, Assistant Professor, Department of Geography, Lovely Professional University, Jalandhar, Punjab, for his constant guidance, encouragement, support, and constructive criticism throughout this work. Without his enduring inspiration, keen interest, and deep involvement, this doctoral research would not have seen the light of day.

I express my gratitude to Dr. Reepu Daman, Dr. Anand Kumar, Dr. Rajesh Jolly, Dr. Surender Singh, and other teaching faculty members of the Department of Geography, Lovely Professional University, for their kind assistance and cooperation.

I would like to extend special thanks to Dr. Chander Shekhar, Director of Terra2Map and Geospatial Centre, Hisar for introducing me to research in a straightforward manner during my PhD coursework. His invaluable assistance with maps, GIS, and remote sensing was greatly appreciated. I also wish to commend the Institute for Remote Sensing and GIS for their exceptional support.

I would like to express my heartfelt gratitude to my best friend and well-wisher, Mr. Sonu Kumar, Project Fellow at HARSAC, CCS HAU Campus, Hisar, for his unwavering support and assistance throughout my PhD coursework.

With a profound sense of humility, I acknowledge the invaluable contribution made to my research by Dr. Sandeep Bidasra, Assistant Professor at F.G.M. Govt. P.G. College. I am deeply grateful for his moral, social, and academic support throughout my journey. I sincerely hope that his blessings will continue to guide and inspire me.

With utmost humility, I acknowledge the invaluable contribution to my research made by my revered teacher, my Guruji, Dr. Rajender Sewda, and Dr. Kuldeep Singh, Assistant Professor at Govt. P.G. College, Hisar. Their unwavering moral, social, and academic support has been indispensable throughout my journey. I sincerely hope that their blessings will continue to illuminate and inspire my path ahead.

I am sincerely grateful to my dear friend, Mr. Mukhtyar Singh, and Subham, who heads the Unique Geography Coaching Centre, for their steadfast support and invaluable assistance during my PhD studies.

I extend my heartfelt gratitude to my dear friends and roommates, Mr. Satyawan and Mr. Anil Kumar, for their exceptional social and moral support during my PhD journey. Their unwavering encouragement and understanding have been instrumental in overcoming challenges and staying focused. I am truly thankful for their presence and friendship.

I am extremely thankful to Dr. V. S. Arya, Director, HARSAC (Haryana Space Application Centre), Hisar, for extending all possible help and cooperation with academic and moral support during this work. They were kind enough to allow me to use the Centre's resources, without which I could not have completed this work.

I am deeply grateful to the dedicated staff members of HARSAC, including Pardeep Jangra, Chanan Mal, Basant Rai, Hemraj, and Sanjit Kumar, for their invaluable assistance during my PhD journey. Their guidance, support, and expertise have been instrumental in shaping my research and academic progress.

I am especially appreciative of the help rendered by my hometown friends Ranbir Singh, Jitender Singh, Sandeep Kumar and Narender Laseri for their direct or indirect assistance in completing this work. A big "Thank you!" also goes out to all the informants of both varieties for their willingness and cooperation throughout the course of my research work.

Thanks are due to many scientists and officials from different organizations such as CCS HAU, Hisar, and the Hisar District Administration for their stimulating discussions and constructive comments.

I would like to extend my deepest gratitude to my family for their unwavering support and encouragement throughout my PhD journey—my father, mother, brother, wife, and daughter, who showed fortitude in the face of my preoccupation with this work. I have devoted long hours, often working against the clock, and thus unwillingly neglected them on certain occasions. I would like to reassure them that I care for them no less than I care for my work.

Their constant belief in me, emotional support, and understanding have been invaluable. To my parents, for their unconditional love and sacrifices, and to my siblings, for their continuous motivation and patience, I am profoundly thankful. This accomplishment would not have been possible without their steadfast support.

I am grateful to the Almighty for His unseen help in the successful completion of this work. Last but not least, I dedicate this thesis to my father, Sh. Hawa Singh.

I thank the Chancellor of LPU, Mr. Ashok Mittal, for granting me admission to the PhD program and providing all the necessary facilities required for the research work.

(Manjit Singh)

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LIST OF ABBREVIATIONS

AWD	Alternate Wetting and Drying
ArcGIS	Arc Geographic Information System
CDM	Clean Development Mechanism
CCSHAU	Chaudhary Charan Singh Haryana Agricultural University
CH_4	Methane
CO_2	Carbon Dioxide
DEM	Digital Elevation Model
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
FFS	Farmer Field Schools
GHG	Greenhouse Gas
GIS	Geographic Information System
GWP	Global Warming Potential
HDRC	Hierarchical Decision Rule Classification
HFCs	Hydrofluorocarbons
HAA	Hydrologically Active Areas
ICAR	Indian Council of Agricultural Research
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing Satellite
ISODATA	Iterative Self-Organizing Data Analysis Technique
IoT	Internet of Things
KVA	Kilo Volt Ampere (if used in context)
KVK	Krishi Vigyan Kendra
LAI	Leaf Area Index
LISS	Linear Imaging Self-Scanning Sensor
LRI	Land Resource Inventory
LULC	Land Use / Land Cover
ML	Machine Learning

MLC	Maximum Likelihood Classifier
MODIS	Moderate Resolution Imaging Spectroradiometer
MSI	Multi Spectral Instrument
MSP	Minimum Support Price
NCR	National Capital Region
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NF_3	Nitrogen Trifluoride
N_2O	Nitrous Oxide
NOAA	National Oceanic and Atmospheric Administration
OBIA	Object Based Image Analysis
OH	Hydroxyl Radical
PAN	Panchromatic
PFCs	Perfluorocarbons
ppb	Parts per Billion
R^2	Coefficient of Determination
RMSE	Root Mean Square Error
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SRTM	Shuttle Radar Topography Mission
SF_6	Sulfur Hexafluoride
SPOT	Satellite Pour l’Observation de la Terre
TM	Thematic Mapper
TCT	Tasseled Cap Transformation
UTM	Universal Transverse Mercator
VI	Vegetation Index
WA+	Water Accounting Plus
WFS	Web Feature Server
WGS	World Geodetic System
WMS	Web Map Service

CHAPTER-1

INTRODUCTION

Agriculture refers to the cultivation and harvesting of plants and their products to fulfill the nutritional needs of humans and animals (Bhuvaneshwari et al., 2019, Kumar et al., 2019). Over the past 50 years, despite significant advancements in agriculture and the economy, humans have reshaped natural ecosystems to suit their own needs. This transformation is largely driven by the rising demand for food, which has led to the overuse of natural resources, rapid population growth, and the application of chemical agents to enhance crop yields and protect plants (Bergstrom and Randall, 2016).

It is widely accepted that the majority of climate changes observed over the past five decades are primarily the result of human activities, especially the rise in greenhouse gas (GHG) emissions (Hazell, 2001). The Intergovernmental Panel on Climate Change (IPCC) estimated that paddy fields worldwide release about 60 teragrams (Tg) of methane emissions annually, with the possible range varying between 20 and 100 Tg. Rice cultivation alone contributes approximately 8% of global agricultural greenhouse gas emissions, and methane, a greenhouse gas 28 times more potent than carbon dioxide, is a major concern (Regalado, 2024). Flooded rice paddies are responsible for about 12% of human-caused methane emissions worldwide, contributing to 1.5% of the total warming effect from all greenhouse gases.

As per Technical Assistance Report on Development and Dissemination of Climate-Resilient Rice Varieties for Water-Short Areas of South Asia and Southeast Asia the rice production, farmers typically keep fields flooded to prevent weed growth. However, methane is generated underwater when organic materials decompose in low-oxygen environments. An alternative practice known as the Alternate Wetting and Drying (AWD) method periodically dries out the fields rather than keeping them constantly flooded. Research shows that AWD can lower methane emissions by 30%–50% and reduce water usage by 10%–20%, all while maintaining rice yields during the growing season.

This method offers a sustainable solution to mitigate the environmental impact of rice cultivation without compromising productivity.

India is one of the largest producer of rice in the world, with paddy cultivation playing a crucial role in the country's agricultural economy. Rice is a staple food for millions of people in India, and the vast areas dedicated to paddy fields are essential for meeting both domestic and global demand. (V. Kumar et al., 2019).

But these approaches' environmental impact needs to be closely examined, particularly in light of methane emissions. Notwithstanding its importance, there is still a dearth of research on methane emissions from the farming of wheat and rice in Haryana.

In the ongoing centuries there is competition in a development in between different country. Because of both climate change and human activity; methane (CH4) sources become highly variable in countries going through a rapid era of development. As a result there is a pressing need to budget significant sources of CH4, such as wetlands (rice paddies and natural wetlands) and lakes (including reservoirs and ponds), which are particularly vulnerable to climate change.

Due to the anthropogenic activities and climate change in rice fields, wetlands and lakes which leads towards the release of the methane (CH4) in the atmosphere (Chen et al., 2013).Methane is produced in flooded soils mainly by bacteria that use carbon dioxide and hydrogen, and the process can vary based on soil type and conditions, affecting how quickly methane is made and released.

According to the IPCC 2022, this gas is responsible for between 30 and 50 percent of the temperature rise. Methane, as a greenhouse gas, has been projected to have contributed to an additional 0.5°C of global warming. These are chemically stable compound which remains in the surrounding atmosphere for a very long period of time up to era.

Methane is 28 times more effective compared to carbon dioxide at warming the globe over a 100-year period. The US National Oceanographic and Atmospheric Administration (NOAA) released a new preliminary estimate in 2021. The preliminary analysis revealed that the annual increase in atmospheric methane during 2021 was 17 parts per billion (ppb), the highest annual increase since systematic measurements started in 1983. In 2020, the rise was 15.3 ppb.With a potential to cause 25 times more global warming than carbon dioxide, methane is a powerful greenhouse gas scientists discovered that methane emissions increased by 50% between 2013 and 2018, compared to the preceding five years, in a research published in 2019.They had suggested that methane emissions would be a major impediment to meeting the Paris Agreement's temperature targets (Subramanian, n.d.)

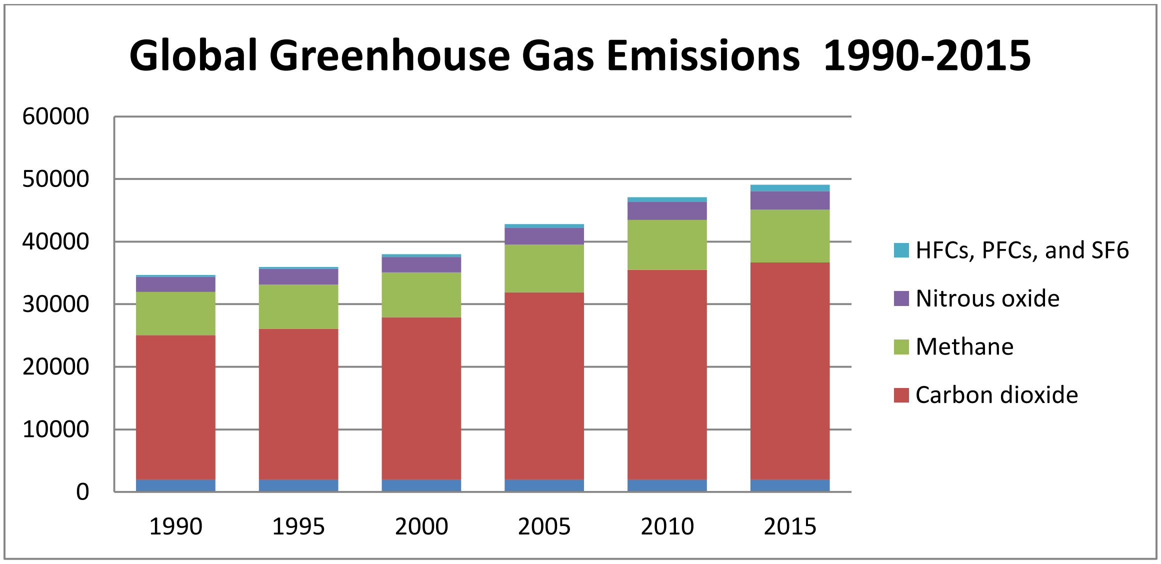


Figure 1.1: Emissions of Greenhouse Gases Worldwide by Gas, 1990–2015 (Data source: Climate Watch, 2023)

Table 1.1: Global Warming Potential (GWP) of Major Greenhouse Kyoto Gases.

Sr. No.	Greenhouse Gas	Global Warming Potential (GWP)
1	Carbon dioxide (CO2)	1
2	Methane (CH4)	25
3	Nitrous oxide (N2O)	298
4	Hydrofluorocarbons (HFCs)	124 – 14,800
5	Perfluorocarbons (PFCs)	7,390 – 12,200
6	Sulfur hexafluoride (SF6)	22,800
7	Nitrogen trifluoride (NF3)	17,200

(Data Source: Data source: IPCC 2007).

When methane is released into the atmosphere, Methane's interactions with oxygen, hydroxyl radicals, nitrogen oxides, and other atmospheric gases lead to various environmental effects. It plays a significant role in both warming the atmosphere and affecting air quality. For one thing, methane is predominantly removed from the atmosphere via oxidation, which results in the formation of water vapor and carbon dioxide. As a result, not only does methane directly contribute to global warming, but it also indirectly contributes to global warming through. Methane breaks down into carbon dioxide, which also traps heat and contributes to global warming over a longer period.(Hassan et al., 2016) Methane also combines with hydroxyl radicals (OH) during the oxidation process.. Methane also leads to the formation of ozone, which lowers air quality and causes a variety of health problems in animals, as well as premature human mortality and lower crop yields.. Methane has little direct effect on crop productivity or human health, while ozone causes about a million premature respiratory deaths annually on a global scale. An increase in greenhouse gases in the atmosphere, according to the Intergovernmental Panel on Climate Change (2021), will likely raise temperatures over most terrestrial surfaces, while the exact change may vary regionally.

The Intergovernmental Panel on Climate Change estimates that between 1901 and 2010, the worldwide average sea level increased by 19 cm (IPCC, 2014). By 2100, the sea level is anticipated to be 15 to 90 centimeters higher than it is currently, posing a threat to 92 million people.

Carbon dioxide, the most common greenhouse gas, is at the center of popular concern over global warming. Natural gas's primary component, methane (CH4), is the second most significant greenhouse gas. Developing countries, on the other hand, account for 70% of the potential for land use in agriculture to mitigate climate change, and 52% of these countries have targeted agriculture to reduce their climate change footprints.

Haryana has made tremendous progress in agriculture over the past decades. Technological change with the introduction of short duration high yield variety of wheat, rice and mustard increased productivity of the crops manifold. The old and new alluviums are ideal for production of wheat and rice under the irrigation condition. The state has second largest contributor for the food grain to control Pool. Notable characteristics of the three previous decades' cropping patterns in Haryana and the notable shifts in the area planted to various crops. According to Sangwan (1985), the state's farming pattern changed mostly as a result of increased irrigation infrastructure. There is a lot of potential to develop a variety of crops due to the region's diverse soil, agro climatic conditions, availability of canal irrigation, and infrastructure services including roads and marketplaces.

With its vast rice-wheat cropping system, Haryana plays a significant role in India's agricultural sector. Rice and wheat is an important crop of kharif and rabi season in Haryana, respectively and Rice area has increased from 1,92,000 hectare to 13,54,000 hectare in last fifty years (Statistical Abstract, Haryana). In India, Haryana become second largest state in yield productivity after Punjab. Changes in cropping pattern and shifting in area under different crops has occurred in Haryana during last three decade.

Haryana is a key food-grain supplier to the Central Pool. Basmati rice exports account for more than 60% of the state's total exports in 2021-22, Haryana cultivated 1529.7 thousand hectares of rice, producing 5514.2 thousand tonnes at an average yield of 3605 kg/ha. Wheat, the largest Rabi crop, covered 2304.7 thousand hectares, yielding 4533 kg/ha and producing 10,447.2 thousand tonnes. Bajra and maize contributed 1119.7 thousand tonnes and 15.57 thousand tonnes, respectively. Sugarcane was the top commercial crop, with a yield of 81,918 kg/ha, producing 8822.6 thousand tonnes. The total combined food grain production (Kharif and Rabi) reached 17,225.77 thousand tonnes across 4474.47 thousand hectares.

In order to provide insight into the direction and magnitude of agricultural production in terms of crop acreage and yield and to accurately forecast the range of crop growth, it is widely acknowledged that accurate, up-to-date, and spatially explicit information on the cropping system is urgently needed at the global and regional scale. Pre-harvest crop production forecasts help decision-makers create the best possible plans for distribution, planning, setting prices, acquiring, moving, and storing necessary agricultural products. As a result, crop management and policy-making regarding price, circulation, and storage are significantly impacted by the nearly real-time agricultural information products from planting to harvesting. Accurate tools for decision-making are made possible by crop monitoring.

By offering up-to-date, verified, and accurate information in the form of maps, it lowers uncertainty. Remote sensing is the technology that makes this part of planning possible. In the end, this technology will assist in managing obstacles to attaining food security by offering transparent, real-time data on growth in emerging economies and developing nations in the form of precise, high-resolution maps.

Remote sensing is a great way to collect data across wide areas with a high revisit frequency at a regional to global scale, and it may greatly help provide a timely and accurate picture of the agriculture industry. Two aspects of crop production, yield and acreage, can be evaluated using the data captured by modern sensor satellites. Additionally, crop phonological information, stress conditions, and distribution can be identified. The information that is collected, among other things, enables decision makers to obtain an impartial and objective spatial view of wide area rick management and to better forecast the effects of occurrences.

GIS (Geographic information systems) have become an extremely useful tool for managing and analyzing vast amounts of geographical and temporal data and information. They can also be used to create information products, such as maps and textual and tabular reports for land use decisions. FAO has been creating GIS in recent years and using it in conjunction with its agro-ecological zoning and related models to address land-related challenges at the regional level. (Sarkar A, 2008). GIS-based tools and packages for land resources planning have advanced significantly in recent years, both at large (local) and small (regional/national) scales.

Land use planning in a region requires the automatic logical integration of terrain, soil resource, and bio-climate data; this is where GIS technology comes in very handy. One crucial aspect of GIS applications that supports integrated analysis is the creation of spatial databases from point databases using geo-statistical techniques. The system can hold all the information needed to address resource management issues. The main GIS inputs for land use planning are topographic maps, land resource maps, and contour maps including physiographic, geographic, and bio-climate data. For multi-layered database analysis, GIS is a crucial tool. Planning is made easier by its capacity to evaluate many kinds of data in the geographic domain. This study detects the shifting agriculture of rice crop in the state of Haryana and describes the use of remote sensing in paddy area calculation.

1.1 Geographical Background of Study Area:

1.1.1 About Haryana state

Geographically, Haryana is located between 74 degrees 28 and 77 degrees 36' longitude and between 27 degrees 37' and 30 degrees 35' latitude in the northern region of India. The National Capital Region (NCR) includes numerous state districts. Himachal Pradesh and North Punjab, U.P., about the state of Haryana. South-West Rajasthan and East Uttarakhand are also included.. It was created on 1 November 1966 with a very fertile state of India producing soil land and large cereals. Delhi, the national capital, is landlocked by Haryana State on three sides. The capital city of Chandigarh, Haryana, is also the state capital of Punjab. Bhiwani is Haryana's largest town in terms of area. The government has an area of 44,212 sq. Uh, km. It is possible to split Haryana into two natural areas, the Himalayan Terai and the Indo-Gangetic plain. This plain area is fertile and has north- south slopes. Haryana's south-west area is arid, dusty, desert land. Haryana doesn't have a seasonal river. The Ghaggar River flows through Haryana's Fatehabad district. Figure 1.2 represents the locational extent of the study area.

Rice, are associated with significant methane emissions due to the flooded conditions of paddy fields that create anaerobic environments. This study understanding the extent of the paddy-wheat cropping system and quantifying methane emissions is crucial for. In this study Sentinel series 2 and 5 satellite data used plays a pivotal role in providing accurate, large-scale, and continuous monitoring of these agricultural systems.

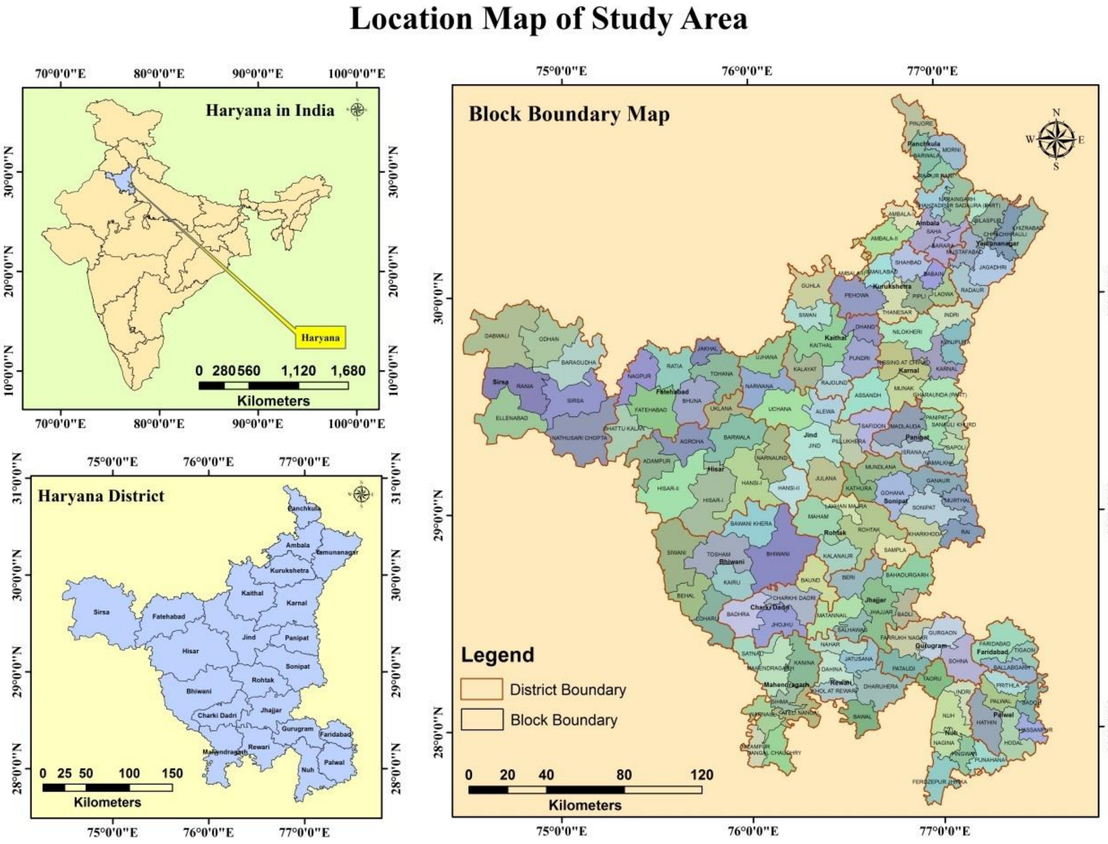


Figure 1.2: Location Map of Study Area. (Data Source**:** Administrative Boundary from Survey of India and map compose by QGis Software).

1.1.2 Road Network of Haryana:

Haryana has exhibited a notable surge in the development of road transportation, boasting an extensive network of over 23,000 kilometers of roads that serve as vital links connecting various villages and cities within the region. This infrastructure comprises a mix of National Highways, State Highways, and Major District Roads, all contributing to the overall connectivity and accessibility of the state. The proliferation of vehicles in the area is a direct consequence of the rapid pace of economic growth experienced by Haryana in recent years, a phenomenon that has unfortunately precipitated issues such as traffic congestion and road accidents, thereby culminating in both economic and human losses.

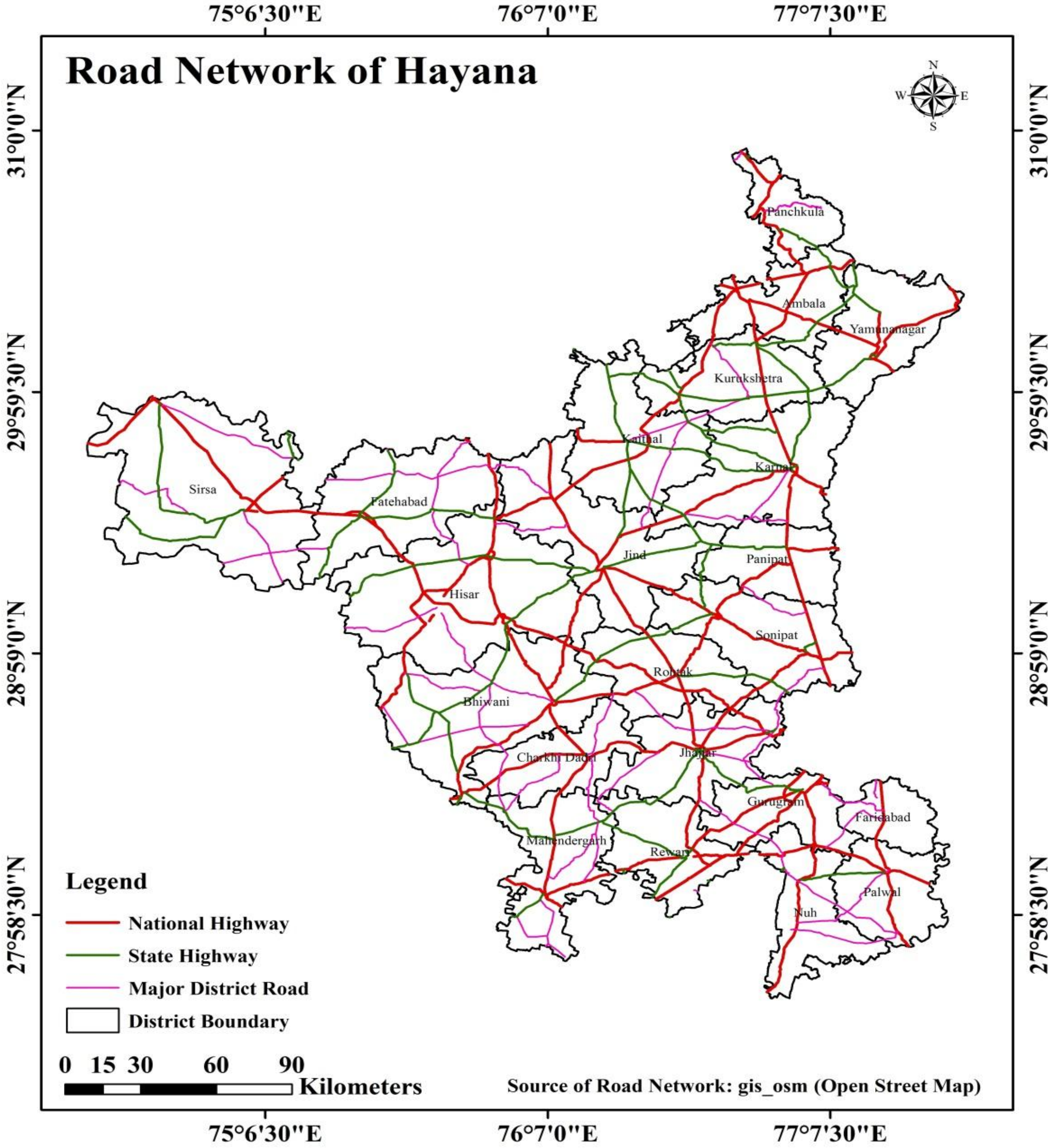


Figure 1.3: Road Network of Haryana (2022). (Data Source: Road Network from gis_osm (Open Street Map), Administrative Boundary from Survey of India and map compose by QGis Software).

Within the geographical confines of Haryana, one can observe a well-established road network that encompasses crucial National Highways including but not limited to NH-1, NH-2, NH-8, NH-10, NH-71, NH-71A, and NH-71B, each designed with varying lane configurations to cater to diverse transportation needs. The scope of this study extends across 9 districts situated in Haryana, collectively forming what is commonly referred to as the Haryana Sub-region of the National Capital Region (NCR), with these National Highways serving as pivotal links that connect the state to different parts of India, thereby facilitating both inter and intra-state movement of people and goods.

It is worth noting that the National Highways in Haryana exhibit a range of configurations, with some featuring expansive four-lane divided carriageways designed to optimize traffic flow, while others are either partially four-lane or restricted to two lanes, presenting a varied landscape of road infrastructure within the state. The primary aim underpinning these infrastructure developments is to bolster connectivity, ensure safety, and streamline the movement of passengers and goods, all the while mitigating delays that could impede the overall efficiency of the transportation system.

1.1.3 Physiographical Description of Haryana:

The northern Indian state of Haryana is bordered to the north by Punjab and Himachal Pradesh and to the west and south by Rajasthan. Its eastern boundary with Uttarakhand and Uttar Pradesh is delineated by the Yamuna River. Haryana forms Delhi's northern, western, and southern borders, encircling the city on all three sides. Northern India's Haryana state is landlocked. Haryana's elevation ranges from 200 to 1200 meters above sea level. Haryana's physiographic features include: With the exception of a few hills in the northern Shivalik system and the southern Aravalli system, Haryana is a plain state. Geographically speaking, the Haryana plain is a portion of the Indo-Gangetic plain, a vast plain created by the deposition of alluvium brought by the Himalaya and rivers. Three sub-divisions have been established in this area, which is the Haryana plain. The western Haryana plain has borders with the southern Haryana plain to the south, the eastern Haryana plain to the east, Punjab to the north, and Rajasthan to the west and southwest. It encompasses the districts of Sirsa, Fatehabad, Hisar and Bhiwani. The region differs from the eastern and southern Haryana plains because of the numerous sand dunes of various sizes and heights, the active wind erosion, and the deep water table. "The area is also referred to as "Bhiwani Bagar" geographically. The northern part of the city is only drained by the Ghaggar River and its flood plain bifurcates the Sirsa district. Cotton, Distribution of Elevation: The different altitudes and topographical characteristics found throughout the state of Haryana would be shown on an elevation map. An explanation of what such a map could show is provided below:

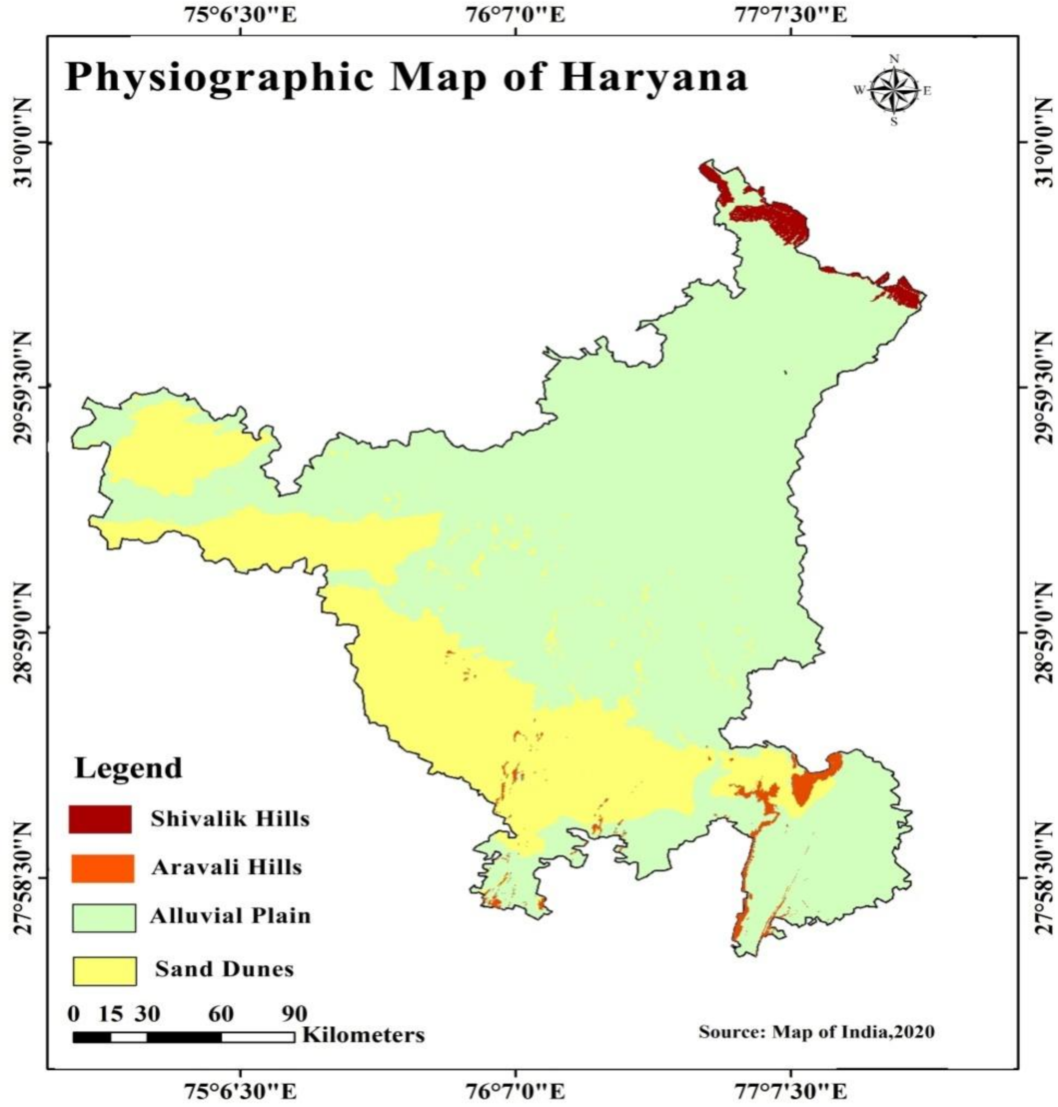
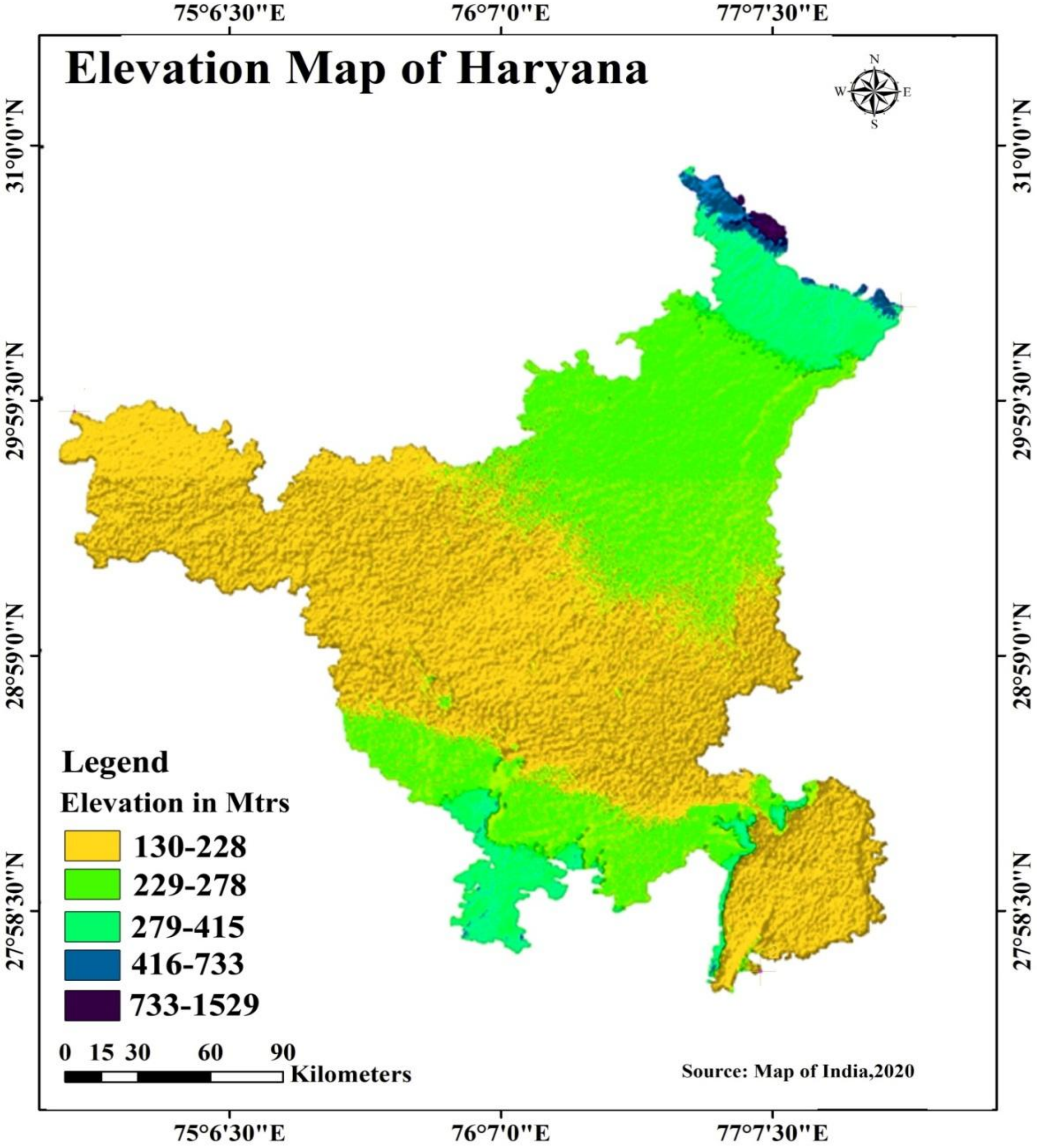


Figure 1.4: Physiographic Map of Haryana (2020). (Data Source: Data collect from Map of India).

Plain Areas: A large portion of Haryana is made up of gently rolling or level plains, particularly in the eastern and southeast areas that border Uttar Pradesh and Delhi. These regions would seem to be rather homogeneous, with contour lines placed further apart to ow only slight variations in height. grains & oil seeds are significant in the region.



Source: Map of India,2020

Figure 1.5: Elevation Map of Haryana (2020). (Data Source: Derived from SRTM DEM USGS, 2020, processed in ArcGIS).

River Valleys: The Yamuna, Ghaggar, and Markanda are just a few of the rivers that run through the state. On an elevation map, river valleys might be shown as low-lying regions with closely spaced contour lines to show the riverbanks' steady elevation decline.

Aravalli Range: The Aravalli Range, a collection of low hills and ridges that stretches into Rajasthan, is a prominent feature of southwest Haryana. These hills would be seen as closely spaced contour lines on the elevation map, signifying steeper slopes and higher heights in relation to the nearby plains.

Shivalik Hills: The foothills of the Shivalik Range are located in the northern portion of the state, close to the Himachal Pradesh border. The contour lines that depict these hills' progressive height changes as they move from the plains to higher terrain would be used to depict them on the elevation map.

Delhi Ridge: The Delhi Ridge is a collection of low hills and ridges that runs along the northern border of Haryana, close to the state's capital, Delhi. The height of these landmarks in relation to the nearby plains would be shown on the elevation map by contour lines.

Urban Areas: On the elevation map, Haryana's towns and cities, including Chandigarh, Faridabad, and Gurugram, would appear as comparatively flat areas, with contour lines showing the slight elevation fluctuations inside urban landscapes.

1.1.4 Geology of Haryana

The study of earth's rocks and minerals in relation to its origin, composition, and manner of occurrence is known as geology. The rocks found in Haryana are diverse and come from the following three geological domains: The Aravali Mountains' pre-cambrian rocks, the Himalayas' tertiary rocks, and the Indo-Gangetic Plains' Quaternary deposits. The sub-region is dominated by the Pre-Cambrian rocks of the Aravali Mountains and the Quaternary sediments of the Indo-Gangetic plains.

The semi-arid region of western India includes the area surrounding Khodana in the Bhiwani district of Haryana. Photointerpretation technology was successfully used to highlight the broad geology and structural pattern of the mature Precambrian terrain, which were ground-checked and correlated with the findings of comprehensive integrated surveys conducted for base metal sulphide mineralization in the region. This was done because the vegetation is sparse and primarily xerophytic. Aerial photos and on-ground inspection revealed several shear/fault zones that were highly limonitized and sub-parallel to the regional fold axes and formational contacts.

It has been explored if the pyrite-pyrthotite that is found while drilling through shear zones can be directly used to landuse planning. Other uses of Haryana State's limited land resources include the use of ochreous material as pigments, clay-rich pockets in pasture lands or micro-depressions in the surrounding terrain for locally built brick kilns, and the discrete use of quartzites as road ballasts, building stone, and bund material.

1.1.5 Climate of Haryana

The state has a subtropical, semi-arid to sub humid, continental climate with a monsoon pattern. The state is divided into three separate climate zones: hot semi-arid, hot desert, and hot sub humid. Haryana experiences extreme summer heat and extreme winter cold. In the months of May and June, the high temperature reaches 46 degrees Celsius. The monsoon season, which lasts from the middle of June to September, and the winter rains, which last from December to February, are the two clearly defined seasons of rainfall in the state.

Haryana's climate is distinguished by its aridity, extreme temperatures, and rarity of rainfall. Four seasons can be used to categorize the year. The summer season, which lasts through the end of June, comes after the winter season, which falls in the month of November and lasts until the south west monsoon season lasts from July until roughly the middle of September, while the post-monsoon season lasts from the middle of September to October

Rainfall of Haryana:

The Haryana rainfall records are adequate for lengthy periods of time. The state receives 400 mm of rain on average per year. In the state, the amount of rainfall rises mainly from west to east. The state receives almost 72% of its average annual rainfall during the brief south-east monsoon season, which runs from July to September, with July and August being the wettest months. June experiences a sizable amount of rainfall, primarily in the form of thunderstorms. There is virtually no rainfall the rest of the year.

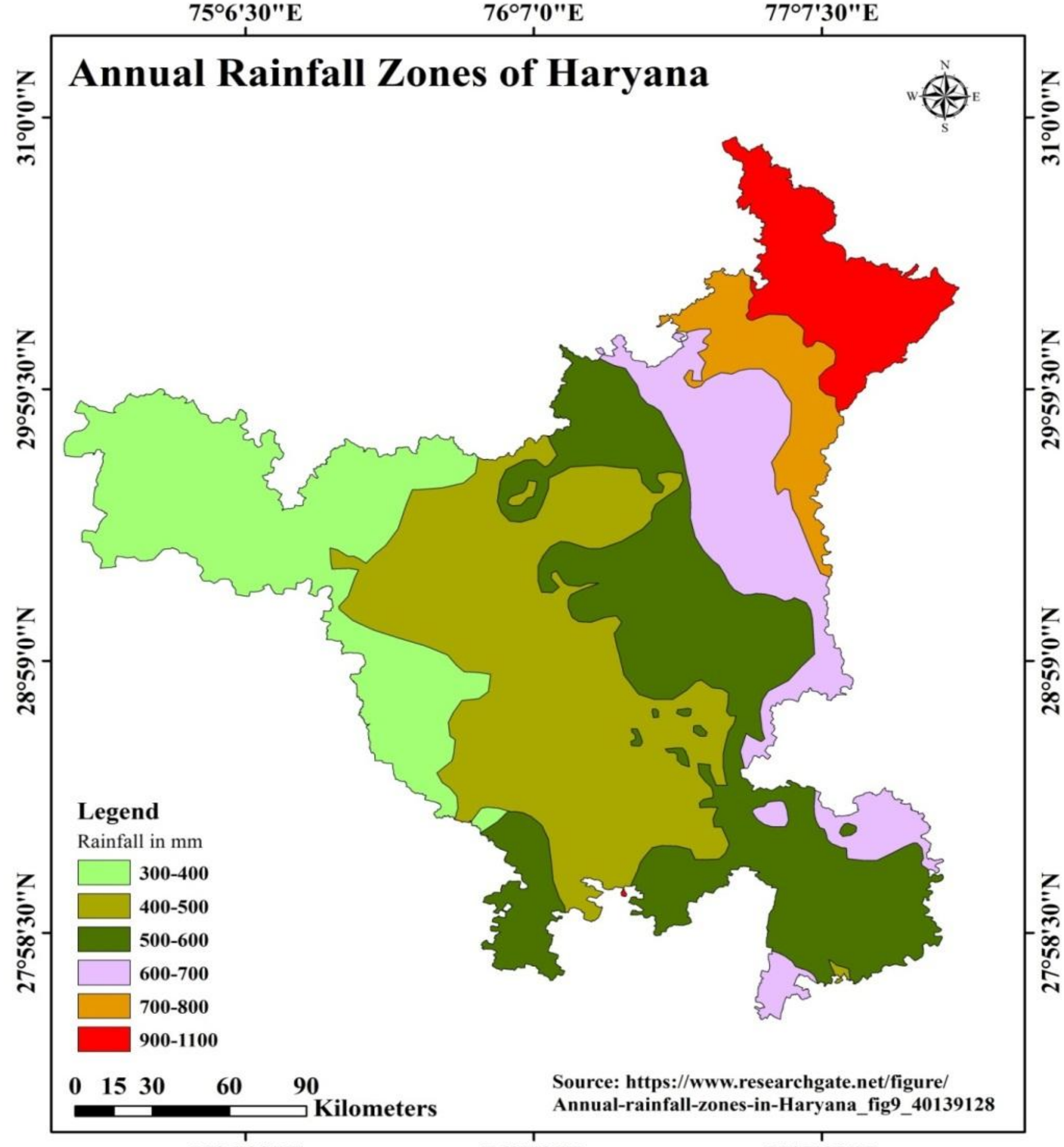


Figure 1.6: Annual Rainfall Zones of Haryana (2022). (Data Source: Derived from Annual Rainfall zones in Haryana (IMD), processed in ArcGIS).

Humidity:

In Haryana, during the monsoon season, the relative morning humidity is typically high. In the months of December through February, the humidity is typically 70% or higher. The summer months are the driest of the year, with relative humidity averaging around 30% in the afternoons. The humidity is generally lower during the rest of the year.

Winds:

In the state, winds are typically calm, with occasional intensification during the late summer and monsoon seasons. While winds from the south-west or west are more frequent during the south-west monsoon season, easterlies and South-Easter also blow on occasion. While south-westerly or westerly winds are more frequent in the mornings during the post-monsoon and winter seasons, northerly and north-westerly winds are more common in the afternoons. In the summer, morning winds occur more frequently from the west or south-west. They generally come from west to north-west directions in the afternoons.

1.1.6 Soil of Haryana:

Inceptisols: These soils cover approximately 58.0% of the total area and are found across all districts of Haryana. Inceptisols are characterized by their moderate weathering and development, making them suitable for a variety of agricultural activities.

Entisols: Encompassing about 29.0% of the state's area, Entisols are prevalent in all districts of Haryana. These soils are typically young and show minimal development, often found in areas with recent geological processes such as floodplains and terraces.

Aridisols: Covering 9.0% of Haryana's land area, Aridisols are prominent in districts like Sirsa, Fatehabad, Hisar, and Bhiwani. These soils are characterized by their arid climate and high evaporation rates, posing challenges for agriculture due to limited moisture availability.

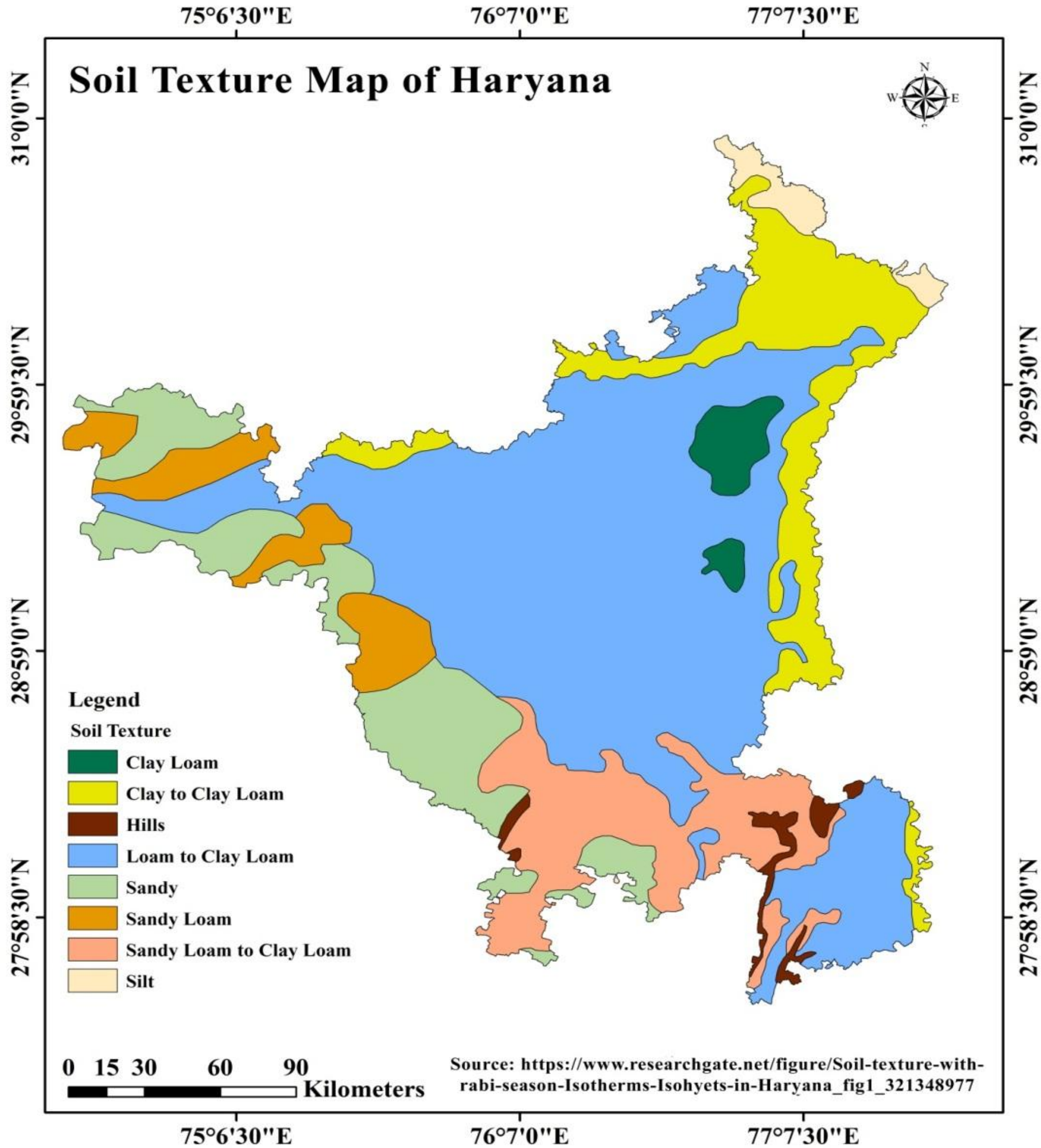


Figure 1.7: Soil Texture Map of Haryana. (Data Source: https://www.researchgate.net/figure/Soil-texture-with-rabi-season-Isotherms-Isohyets-in-Haryana_fig1_321348977)

Alfisols: Representing 2.0% of Haryana's territory, Alfisols are mainly found in districts like Karnal and Kurukshetra. These soils are relatively well-developed with a clay-rich subsoil horizon, making them suitable for cultivation of crops like wheat and rice.

Hills and Rock Outcrops: Occupying 2.0% of the state's area, these areas are primarily located in districts such as Mahendergarh, Rewari, Gurgaon, and Panchkula. Characterized by rocky terrain and shallow soils, these regions are often unsuitable for intensive agriculture but may support limited grazing or horticultural activities.

Table-1.2: Soil order in Haryana

Sr. No.	Order	Area (%)	Districts
1.	Inceptisols	58.0	All districts
2.	Entisols	29.0	All districts
3.	Aridisols	9.0	Sirsa, Fatehabad, Hisar, Bhiwani
4.	Alfisols	2.0	Karnal, Kurukshetra
5.	Hills and Rock outcrops	2.0	Mahendergarh, Rewari, Gurgaon, Panchkula

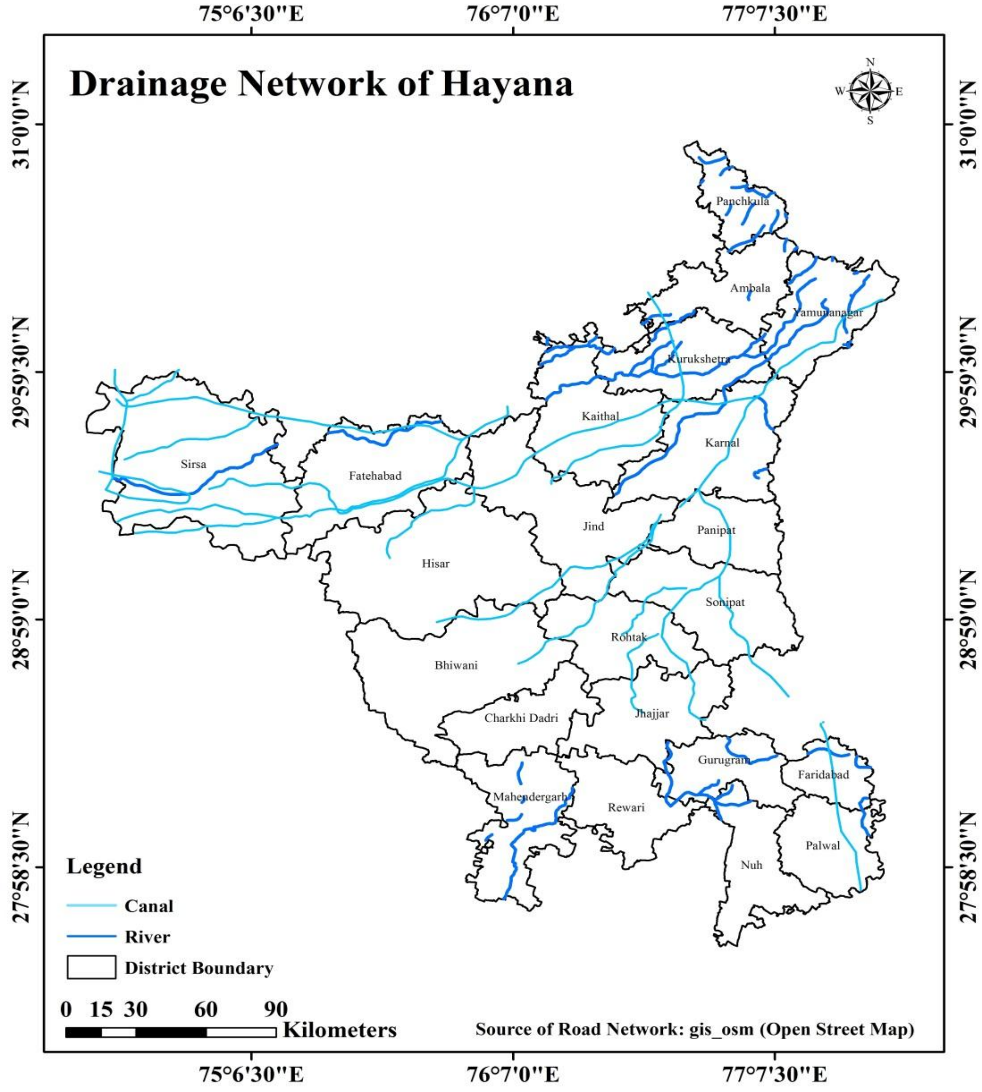
(Data Source: https://hau.ac.in/page/soil-types-in-haryana)

1.1.7 Drainage System of Haryana:

Haryana's rivers are mostly found in the Ganga and Indus basins. The Yamuna and its tributaries in the east comprise the Ganga basin, while the Ghaggar sub-basin and its tributaries in the west of the state serve the Indus basin.

Beginning from the Yamunotri Glacier in Uttarakhand and joining the Ganga at Triveni Sangam in Prayagraj, the Yamuna is the longest tributary river in India. Along the route, it encounters its tributaries, which include Tons, Chambal, Sindh, Betwa, and Ken, and passes through multiple states. With about 57 million people relying on its waters and the Yamuna providing more than 70% of Delhi's water supply, it is crucial for both agricultural and water supply. The Yamuna is revered as the goddess Yamuna in Hinduism, and taking a bath in her holy waters is thought to release one from the agony of death.

The drainage system of Haryana is an essential aspect of its geographical and agricultural landscape, playing a crucial role in water management, irrigation, and flood control. Situated in the northern part of India, Haryana is predominantly an agrarian state with a rich network of rivers, canals, and water bodies that contribute to its drainage system. In this comprehensive overview, we will delve into the various components of the drainage system in Haryana, including its rivers, canals, reservoirs, and water management practices.



Source of Road Network: gis_osm (Open Street Map)

Figure 1.8: Drainage Network of Haryana (2022). (Data Source: Create by scholar use sentinel-2 (satellite) image in ArcGIS).

Rivers:

Haryana is traversed by several major rivers, which form the backbone of its drainage system. The prominent rivers in Haryana include the Ghaggar-Hakra River, Yamuna River, and the Markanda River. The Ghaggar-Hakra River, also known as the Ghaggar River, is one of the most significant rivers in the region. Originating from the Shivalik Hills in Himachal Pradesh, it flows through the northern and western parts of Haryana before ultimately disappearing into the Thar Desert in Rajasthan. The Yamuna River, originating from the Yamunotri Glacier in Uttarakhand, forms the eastern boundary of Haryana, serving as a vital water source for irrigation and drinking purposes. Additionally, the Markanda River, a tributary of the Ghaggar River, flows through the northern part of Haryana, contributing to the state's drainage system.

In India and Pakistan, the Ghaggar-Hakra River is a seasonal river that only flows during the monsoon season. Before the Ottu barrage, it was known as Ghaggar, and after the barrage, it was known as the Hakra. Although the river is linked to the Nara River, the downstream Hakra River completely dried up with the installation of the Otu Barrage. Originally supplied by the Himalayan Sutlej River, the Ghaggar-Hakra paleochannel began to veer off course around 15,000 years ago. The basin is separated into two sections, Khadir and Bangar. During the rainy season, Khadar is the lower flood-prone area and Bangar is the higher portion that doesn't flood.

Canals:

Canals play a crucial role in the irrigation infrastructure of Haryana, facilitating the distribution of water for agricultural purposes. The state is served by an extensive network of canals, including the Bhakra Canal, Western Yamuna Canal and the Sirsa Branch Canal. The Western Yamuna Canal, originating from the Tajewala Barrage on the Yamuna River, is one of the major irrigation canals in Haryana, supplying water to various districts in the state. The Bhakra Canal, originating from the Bhakra Dam in Himachal Pradesh, serves the southern parts of Haryana, providing water for irrigation and drinking purposes. Additionally, the Sirsa Branch Canal, a distributary of the Bhakra Canal, plays a crucial role in irrigating agricultural lands in the Sirsa district of Haryana.

Reservoirs:

Haryana is home to several reservoirs and barrages, which serve as storage facilities for water and help regulate its distribution for various purposes. The state's reservoirs are primarily fed by rivers and canals, ensuring a reliable supply of water for irrigation, drinking, and industrial use. One of the notable reservoirs in Haryana is the Bhakra Dam, located on the border with Himachal Pradesh. Built on the Sutlej River, the Bhakra Dam is one of the largest multipurpose dams in India, serving as a vital source of water for irrigation and hydroelectric power generation. Additionally, the Tajewala Barrage on the Yamuna River and the Ottu Barrage on the Ghaggar-Hakra River are essential structures that regulate the flow of water and facilitate irrigation in Haryana.

Water Management Practices:

Water management practices in Haryana are aimed at optimizing the utilization of available water resources while mitigating the risks associated with floods and water scarcity. The state government has implemented various water management initiatives, including the construction of check dams, water harvesting structures, and canal lining projects. Check dams are built across small streams and rivulets to conserve rainwater and recharge groundwater aquifers. Water harvesting structures such as ponds and reservoirs are constructed to capture rainwater and store it for agricultural and domestic use during the dry season. Additionally, canal lining projects are undertaken to reduce water seepage and evaporation losses, thereby maximizing the efficiency of water distribution for irrigation.

Challenges and Future Outlook:

Despite the significant progress made in water management and irrigation infrastructure, Haryana faces several challenges in its drainage system. Rapid urbanization, industrialization, and agricultural expansion have led to increased water pollution and degradation of water bodies in the state. Additionally, climate change-induced factors such as erratic rainfall patterns and rising temperatures pose risks to water availability and agricultural productivity. Addressing these challenges requires concerted efforts from the government, stakeholders, and the community to implement sustainable water management practices, enhance water conservation measures, and promote efficient use of water resources.

1.1.8 Demography of Haryana

The population of Haryana increased by 42,06,898 persons during the last decade, registering a decadal growth of 19.9%. Haryana's urban population grew from 28.9% in 2001 to 34.9% in 2011, while the national average climbed by 31.2%.

Population Density

The given map represents the Population Density of 2011 (Census 2011) in the study area, expressed as number of persons per square kilometre. The density is classified into six categories ranging from very low (0–249 persons per sq. km) to extremely high (above 10,000 persons per sq. km). Different colour shades indicate varying concentration levels, where light blue represents sparsely populated areas and dark red denotes highly congested urban zones.

The spatial pattern clearly shows an uneven distribution of population. The western and south-western parts of the region are predominantly covered with low to moderate density classes (0–249 and 250–499 persons per sq. km). These areas are largely rural in character, dominated by agricultural land use, scattered settlements, and relatively lower urban development. The presence of sandy tracts and comparatively less infrastructural concentration may also contribute to lower population density in these zones.

In contrast, the eastern and south-eastern parts exhibit significantly higher population densities. The red and dark orange patches indicate major urban centres where density exceeds 1,000 persons per sq. km, and in some pockets even crosses 10,000 persons per sq. km. These high-density clusters correspond to towns and city cores, where administrative, commercial, industrial, and service activities are concentrated. Better road connectivity, availability of employment opportunities, educational institutions, and healthcare facilities have attracted higher population concentration in these areas.

The central region shows mixed density patterns, reflecting semi-urban growth and transitional rural-urban characteristics.

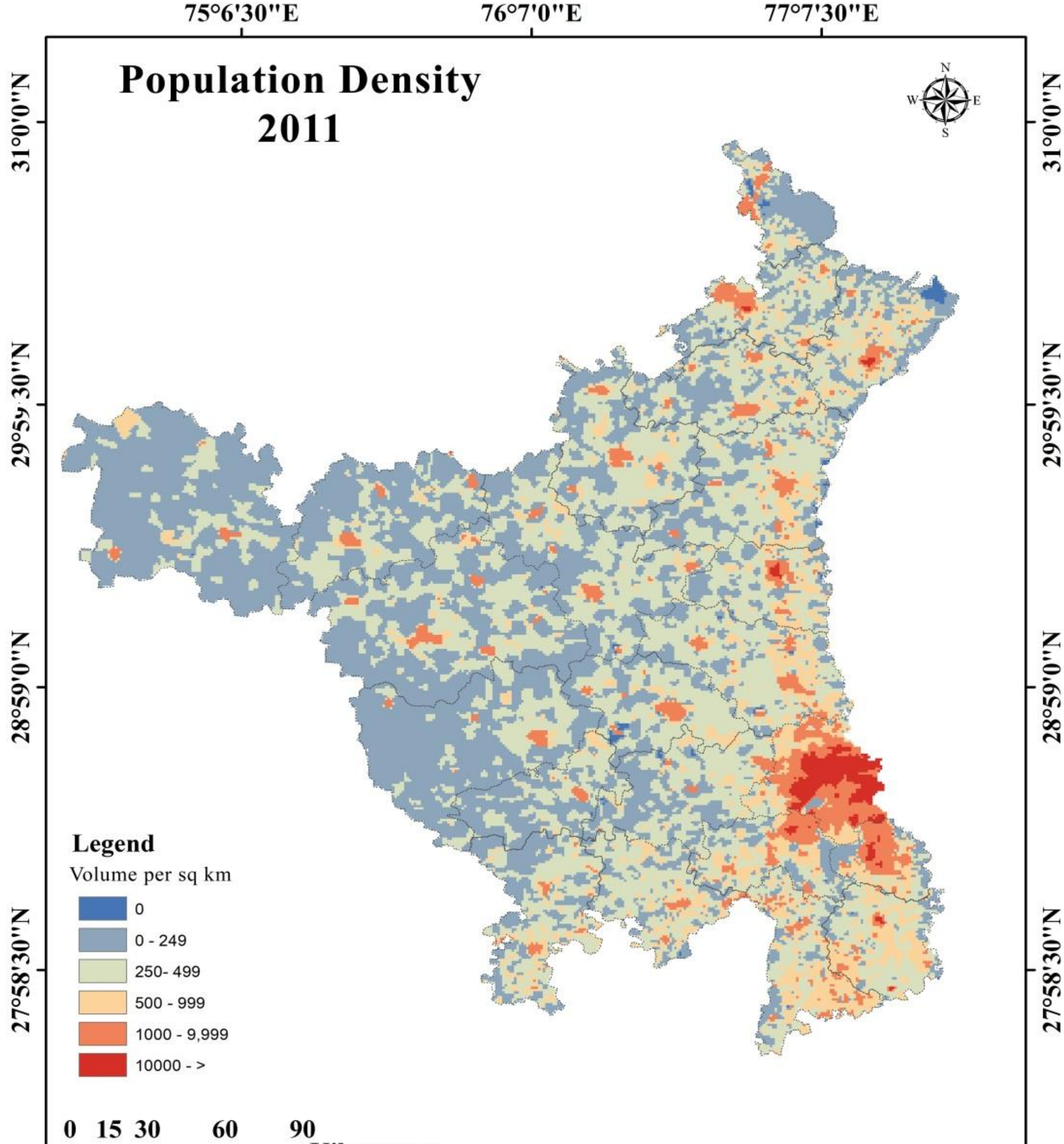


Figure 1.9: Population Density 2011. Source: Census of India (2011), Primary Census Abstract; Haryana Administrative Boundaries from Census GIS Database; Map prepared by the author.

The literacy rate

With Gurgaon district having the highest literacy rate and Mewat district having the lowest, Haryana has risen from 67.9% in 2001 to 75.6% in 2011. Female literacy has also increased from 55.7% to 65.9% in 2011.

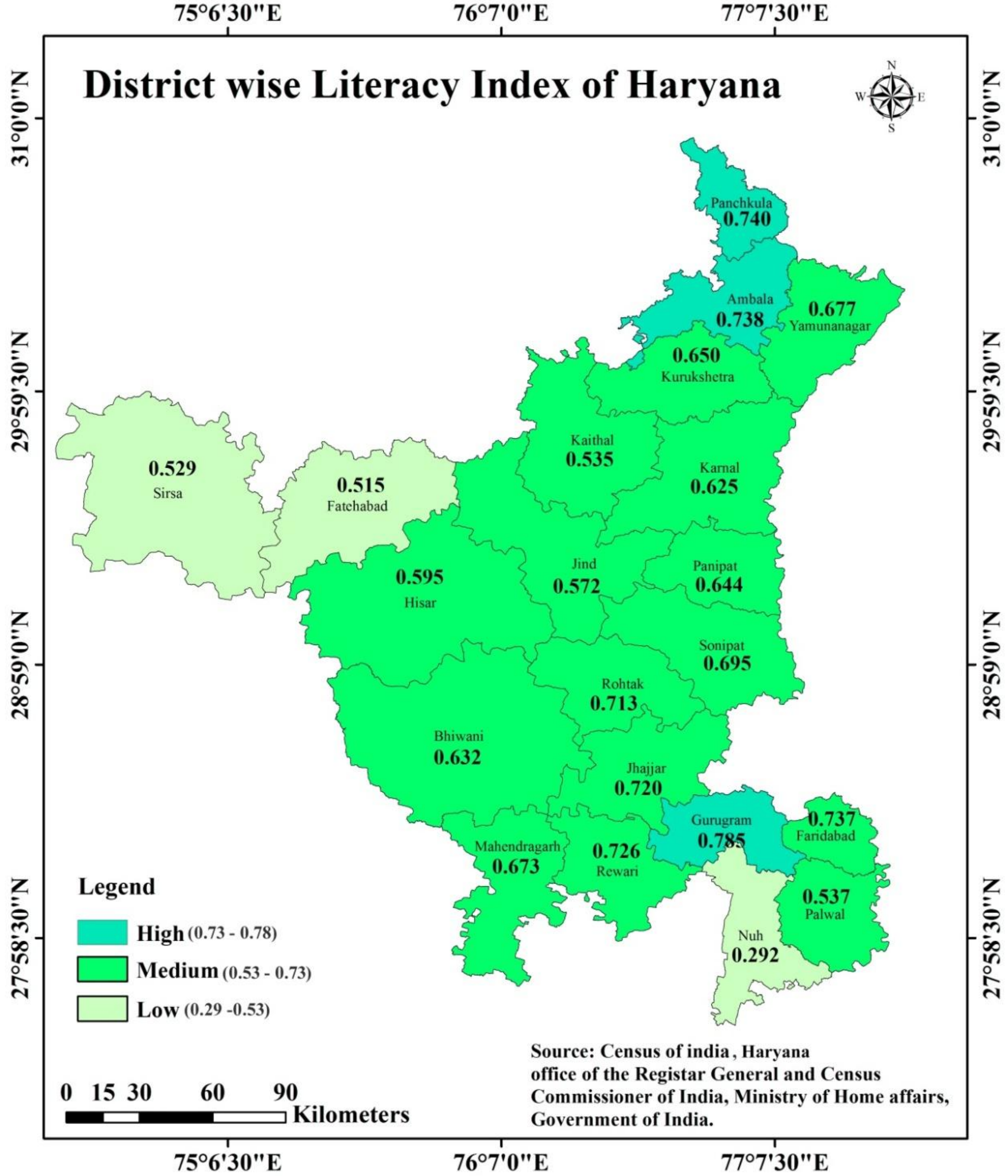


Figure 1.10: District wise Literacy Index of Haryana (2011). (Data Source: Census of India, Haryana 2011, office of the Registrar General and Census commissioner of India, Ministry of Home affairs, GoI)

The map titled “District wise Literacy Index of Haryana” depicts the spatial distribution of literacy levels across districts based on Census data, classified into High (0.73–0.78), Medium (0.53–0.73), and Low (0.29–0.53) categories. The literacy index ranges from a minimum of 0.292 in Nuh to a maximum of 0.785 in Gurugram, indicating significant regional disparities. High literacy districts such as Gurugram (0.785), Panchkula (0.740), Ambala (0.738), and Faridabad (0.737) are largely urbanized and economically developed, benefiting from better educational infrastructure and proximity to the National Capital Region. The majority of districts, including Rohtak, Jhajjar, Rewari, Sonipat, Panipat, Karnal, Kurukshetra, Yamunanagar, Hisar, Jind, Kaithal, Bhiwani, Mahendragarh, and Palwal, fall under the medium literacy category, reflecting moderate educational progress with a mix of rural and urban characteristics. In contrast, Nuh shows an exceptionally low literacy index (0.292), highlighting socio-economic backwardness and limited access to educational facilities, while Sirsa (0.529) and Fatehabad (0.515) lie near the lower threshold. Overall, the map reveals a clear pattern where higher literacy is concentrated in the northern and southern urban-industrial belts, whereas relatively lower literacy levels are observed in the western and south-western rural districts, emphasizing the need to address regional educational imbalances in Haryana.

Sex Ratio-

In 2011, Haryana's sex ratio rose from 861 to 879, with Gurgaon having the lowest ratio (854) and Mewat having the highest ratio (907).In 2011, the percentage of children in the 0–6 age group fell from 15.8% to 13.3%, with Mahendergarh experiencing the most decline (-43 points) and Kurukshetra district experiencing the largest improvement (47 points).In 2011, the sex ratio of children in the 0–6 age group increased from 819 to 834, with Mahendergarh experiencing the most decline (-24 points) and urban areas experiencing the largest gain (24 points).

1.2 Statement of Problem:

India is the world's second-largest producer of rice and wheat, producing approximately 95 million metric tons of rice and 109.52 million tons of wheat annually. However, agriculture is a significant source of methane emissions, particularly from rice fields, which are flooded and create anaerobic conditions conducive to methane production. Methane emissions from rice and wheat cultivation are an increasing environmental concern due to their contribution to climate change.

At the global level, challenges in quantifying methane emissions arise from varying agricultural practices, soil types, and environmental conditions across regions. In Southeast Asia, continuous flooding of rice paddies leads to high methane emissions, while other regions like the U.S. adopt water management techniques that reduce emissions. These differences highlight the difficulty in creating standardized global models for methane emissions. Moreover, the lack of observational data and inconsistent definitions of wetlands further complicates emission estimates.

Nationally, states like Punjab contribute significantly to methane emissions, yet research and high-resolution mapping in India remain limited. These gaps in data and research hinder the development of precise strategies to curb emissions.

Focusing on Haryana, a major rice-producing state, the problem is even more pronounced. Limited observational data, a lack of comprehensive studies, and the absence of high-resolution maps create significant challenges in assessing methane emissions. Understanding methane emission dynamics from wetlands and rice paddies in Haryana is crucial for developing mitigation strategies to meet sustainability goals.

1.3 Scope of the Present Study

The scope of the this study on Methane Emission from Rice & Wheat Agricultural practices in Haryana is briefly given below: -

a. Estimation of wheat and paddy crop acreage in Haryana within a short time using high-accuracy satellite data.
b. Assessment of methane emissions from rice and wheat cultivation practices.
c. Analysis of temporal variation (rise and fall) in methane emissions.

d. Understanding the greenhouse effect and climatic impact of methane gas.
e. Providing awareness to farmers about methane emissions and promoting alternative, sustainable cultivation practices.
f. Contribution towards environmental protection by supporting measures that help reduce ozone layer depletion.

1.4 Literature Review:

Remote Sensing and Geospatial Techniques in Agriculture

Mariye, Jianhua, Maryo, Tsegaye and Aletaye (2024) research about the Legabora watershed, Ethiopia, utilizes remote sensing and GIS to analyze land use/cover dynamics from 1976 to 2022. The study identifies changes in cropland, settlement, forest and degraded lands offering insights into driving factors and implications for evidence-based land use policies. The research contributes to understanding the complex dynamics of land use in the region.

Wang et al. (2023) explained the spatial-temporal patterns of urban expansion in China from 1995 to 2020. Using spatial measures, the research analyzes the relationship between urban built-up areas and various land use/cover classes. The findings reveal substantial urban growth and its impact on different land cover types, providing valuable information for land management decisions and urban planning in China.

Mhanna, Halloran, Zwahlen, Asaad and Brunner (2023) focused on using machine learning and remote sensing to understand LULC changes in the Syrian portion of the Orontes River Basin from 2004 to 2022. The study addresses challenges in conflict zones and reveals changes in cropland, settlements, providing insights into the complex dynamics of LULC changes in conflict-affected regions. The methodology developed in this research Combination of remote sensing products, machine learning techniques, and statistical analysis and normalization of 21 bands in every pixel using a specific formula. Suggestion for further research on the impacts of armed conflict on water resource.

Patle et al. (2023) discussed the Mahi Basin, India, applies the WA+ framework and satellite remote sensing data from 2003 to 2020 to estimate green and blue water consumptions. The study evaluates the productivity of land and water, highlighting hotspots and areas of strength for district-level sustainable management of water resources. The results provide policymakers with useful information for creating plans for the efficient management of agricultural water resources.

Ullah et al. (2022) investigated the impact of the Chashma Right Bank Canal on land-use and land-cover (LULC) changes in Dera Ismail Khan, Pakistan, utilizing Landsat satellite imagery from 1990 to 2018. The study quantifies transformations in agricultural areas, built-up regions, and cropping patterns, highlighting the significant alterations in LULC driven by irrigation projects. The findings emphasize the importance of considering canal-induced changes in understanding regional land-cover dynamics.

Mishra, Roy, Pandey, Khalkho & Singh (2014). Using night time land surface temperature imaging, the study examines the dynamics of coal fires in the Jharia Coalfield in India between 2006 and 2015. The study highlights how mining activities and structural flaws affect the spread of coal fires by determining their spatiotemporal variance and direction of propagation. The findings contribute to understanding the challenges associated with coal fires in mining regions.

Kumar, Shwetank & Jain (2020) studied employs Landsat satellite imagery from 1996 to 2017 for the Haridwar region, show casing the utility of remote sensing in assessing land-use/land-cover (LU/LC) changes. Their search, validated through ground surveys, GPS, and literature review, reveals significant decline in orchards converted to urban and agricultural land due to urbanization. The study emphasizes the vital role of remote sensing in monitoring temporal changes in LU/LC, providing valuable insights for regional development.

Ahlawat, Sheoran, Roohi, Dahiya, & Sihag (2020) studied offers a significant contribution to understanding cropping systems in Hisar District, Haryana, India, utilizing satellite data and RS techniques. The identification of major crops and the application of advanced classification methods showcase the study's methodological strengths. The claimed 90% accuracy in mapping cropping patterns underscores the potential of RS technology for agricultural monitoring. The practical implications for land use and water management in the region highlight the study's relevance. However, a more detailed discussion on validation processes and a comparative analysis of classification methods would enhance the study's scientific robustness. Overall, the research provides valuable insights for policymakers and land managers but could benefit from further methodological elucidation.

Mishra, Rai & Rai (2020) identified the study in Sikkim Himalaya employs geospatial techniques, utilizing Landsat-5 TM and Sentinel 2A MSI data for land use and land cover (LULC) change detection in the Rani Khola watershed from 1988 to 2017. The research applies supervised classification with Maximum Likelihood Classifier (MLC) and assesses accuracy using High Resolution Planet scope imagery and ground verification. Results indicate a substantial increase in dense forest, built-up area, and water bodies, while open forest, agriculture, and barren land have decreased. According to the study, forestry dominates land use in the watershed, and it highlights significant policy implications for the sustainable management of land use and land cover in the area.

Bhandari, Joshi, Thapa, Sharma & Rauniyar (2022) studied in Tanahun, Nepal, assesses land cover changes over two decades, migration effects, and the impact of Rhesus macaque on crop yield. Using Landsat imagery and household surveys, it reveals an increase in forest cover and a substantial decrease in agricultural land. The accuracy assessment validates the methodology with an overall classification accuracy of 86.11%. Migration effects show a positive correlation with changes in land cover. Crop production analysis indicates significant reductions in paddy, maize, and millet, correlating with increased forest cover. The econometric model identifies key factors influencing crop damage, emphasizing the importance of distance from forest, water bodies, settlements, and owner's home. The study recommends active forest management, remittance investment in agriculture, and provision of damage relief for sustainable land use.

Jain et al. (2019) carried out by harnessing the power of Synthetic Aperture Radar (SAR) data obtained from a variety of satellites and integrating it with sophisticated yield models. The utilization of multi-temporal SAR data, encompassing both HH and VV polarizations, emerged as particularly valuable in the accurate estimation of paddy acreage, particularly during the crucial monsoon season. To achieve this, the study meticulously adopted a Hierarchical Decision Rule based classification (HDRC) methodology, which played a pivotal role in identifying rice cultivation areas within selected sample segments. The estimation of rice yields was executed through the amalgamation of weather-based models and remote sensing-based models, with the accuracy of the results rigorously evaluated using established statistical measures such as Coefficient of Determination (R2) and Root Mean Square Error (RMSE). The study leveraged the temporal datasets from RISAT-1, Radarsat-2, and Sentinel 1A in the C band to estimate the extent of rice cultivation in the primary kharif rice growing states. It was observed that SAR C band VV polarization data exhibited promising capabilities in mapping rice fields, even in scenarios where HH polarization data was not available. The integration of SAR-based monitoring holds significant promise in facilitating efficient management strategies for food crops, thereby lending invaluable support to overarching food security initiatives. It is worth noting that the consistent availability of Sentinel 1A data stands poised to substantially enhance the accuracy levels and overall outcomes of such endeavors.

Somvanshi, Kunwar & Singh (2018) used remote sensing and GIS Techniques for Sustainable land resources planning and management. They discussed that digital imagery provide the impending for computerized map invention, a process that is extensively enlarge the amount and temporal correctness of information available to land. Remote sensing and GIS address issues standing up to the turn of events and mix of geographic data frameworks into arranging, quality evaluation and order of computerized pictures. Automated methods for consolidating quantitative and subjective information data extricating measures with the similarity of decision information taking care of modes.

Kar, Obi Reddy, Kumar & Singh (2018) investigated the dynamics of Nagpur's urban and peri-urban landscape from 1936 to 2010 using historical maps and Landsat data. Utilizing Object-Based Image Analysis (OBIA), the research reveals significant urban expansion and changes in land cover classes, providing valuable insights for sustainable urban development. The study show cases the potential of satellite data and GIS techniques in monitoring and managing urban landscapes.

Kumar et al., (2018) highlighted the significance of precise information on rice cultivation, crucial for national decision-makers. Their study, conducted in Haryana, India, utilizes Landsat and MODIS imagery for the Kharif seasons of 2015 and 2016, employing unsupervised ISODATA classification. Validation with ground truth data shows a commendable overall accuracy of 90%.The research emphasizes the annual 5% increase in rice cultivation in Haryana, corroborated by state statistical records. Additionally, he study explores the spatial distribution of rice crops with in different climatic zones, revealing cultivation in areas deemed marginally suitable or unsuitable, providing valuable insights for sustainable planning.

(Anurag & Kumar, 2016) Remote sensing and Geographic Information System (GIS) applications have been extensively utilized in the field of crop mapping, a critical aspect of agricultural monitoring and management. One particular method that has gained prominence in this domain is the Tasseled Cap Transformation (TCT), which was specifically designed for the purpose of mapping crops and vegetation by harnessing satellite-derived data. The state of Haryana has been a focal point for crop mapping endeavors employing remote sensing technologies, leveraging datasets such as LISS-III and Landsat for regions like Fatehabad, Hisar, Kurukshetra and Bhiwani. Among the plethora of crops that have been successfully mapped in these districts, notable ones include paddy, cotton, wheat, bajra, maize, mustard, jowar and sugarcane. In the execution of these mapping initiatives, sophisticated techniques like ISODATA clustering and hierarchical classification have been deployed. Furthermore, to ensure the precision and reliability of the mapping outputs, meticulous attention was given to incorporating ground truth information and implementing atmospheric correction methodologies on the remote sensing datasets. The outcomes of these mapping exercises exhibited varying degrees of accuracy, as evidenced by the range of Kappa values obtained, which spanned from 0.52 to 0.81.

Singh & Batta (2020) LRI is being executed by ICAR-NBSS&LUP in a consortia mode including State Governments/State Departments of Agriculture, State Agricultural Universities, National Remote Sensing Center, Hyderabad, India, State Remote Sensing Applications Centers and Soil and Land Use Survey of India. The need and importance of undertaking Land Resource Inventory of the nation on 1:10000 scale to create resource base data needed for circumstance explicit agrarian landuse planning and management of land resources is examined. A theoretical model for LRI including readiness of base guide utilizing far off detecting and GIS, age of soil map (on 1:10000 scale) and speculation expected to be made in that are talked about. Utility of geo-entryway in combining database and mining the data from the database for their utilization towards extreme objective of practical horticultural creation is additionally featured. Contextual investigations managing the utilization of LRI-produced database for land use planning are introduced. LRI imagines to create NBSS-Geoportal, an electronic stage towards Web Map Server (WMS) and web Future Server (WFS). On nation level the speculation is reached out to be Rs. 1,20,000M which comes out to be Rs. 120/ha. A need program of the ICAR-NBSS&LUP and speculations subsequently are relied upon to produce rich profits for land use planning program in the nation.

Hassan et al. (2016) identified the land use and land cover change in Islamabad, Pakistan, utilizing geospatial techniques demonstrates a comprehensive approach to mapping and analyzing the evolving urban landscape. Employing remote sensing and GIS, the research spans the period from 1992 to 2012, revealing notable increases in agricultural, built-up, and water body areas, while forests and barren lands exhibit a decline. The study attributes these changes to economic development, climate shifts, and population growth, showcasing an awareness of underlying driving forces. However, a more nuanced discussion of environmental impacts and socio-economic implications would enhance the study's depth. Overall, the research contributes valuable insights into the dynamic interplay between human development and environmental changes in Islamabad.

Rao, Hathiram, Tukaram, Kumar (2015) discussed about land is the main characteristic resources on which all exercises are based. The expansion in populace and human exercises are expanding the interest on the restricted land and soil resources for agribusiness, woods, field, metropolitan and mechanical land employments. Data on the rate and sort of changes in the utilization of land resources is basic for appropriate planning, management and to regularize the utilization of such resources. Advances in satellite sensor and their investigation methods are making distant detecting frameworks reasonable and appealing for use in examination and management of common resources. Land use maps are significant devices for farming and regular resources considers. The different classifications of land use in the zone perceived are woodland, agribusiness, Settlement, Fallow Land, Salt influenced land, water bodies and reeds. Agribusiness is the significant land use classifications in the examination zone because of the one of prolific soil of the world. The target of this paper is land use land cover investigation of Khammam area of Telangana State.

Singh, Kumar,. Kumar (2015) Land-use/land-cover (LU/LC) change is a significant component of global environmental change research, essential for understanding ecosystem dynamics and modeling environmental impacts. Remote sensing has emerged as a valuable tool for efficiently extracting LU/LC change information. In a study conducted in the Nathusari Chopta block of Sirsa district, IRS-P6 AWiFS satellite data from the Kharif, Rabi, and Zaid seasons of 2007 and 2009–10 were used to interpret LU/LC changes using the WGS-84 datum and UTM projection system. On-screen visual interpretation at a 1:50,000 scale enabled detailed mapping of LU/LC patterns. A common vector layer was generated from both years' data to identify and quantify category-wise changes. This approach provided insights into the temporal dynamics of land use and emphasized the effectiveness of multi-seasonal satellite data in monitoring and managing land resources.

Rawat & Kumar (2015) exploration of the spatio-temporal dynamics of land use/cover in the Hawalbagh block, Uttarakhand, India, through Landsat imagery from 1990 to 2010 presents a comprehensive understanding of landscape changes over two decades. The study's strength lies in its dual emphasis on spatial and temporal dimensions, providing a holistic assessment of alterations in vegetation, agriculture, built-up areas, and water bodies. The use of supervised classification and recognition of the significance of digital change detection techniques enhance the study's credibility. However, the research could benefit from a more thorough discussion of methodological limitations, including potential errors in supervised classification, and the absence of ground truthing, which may impact the precision of identified land-use changes. A deeper explanation of the specific digital change detection techniques employed would further enhance the study's replicability and comparability with similar research efforts. Despite these considerations, Rawat & Kumar's work stands as a valuable contribution to the field, offering insights that are pertinent for environmental management and policy formulation. By shedding light on the evolving landscape in the Hawalbagh block, the study aids in fostering a nuanced understanding of the intricate dynamics between human activities and the environment.

Muslim, Romshoo, & Rather (2015) investigation was primarily centered on the cartography of paddy rice within the geographical expanse of the Kashmir Himalayan region by employing a plethora of multi-temporal data derived from the MODIS satellite. An assessment was conducted by the study to measure the effectiveness of utilizing spectral reflectance measurements obtained from satellite imagery and the application of two distinctive indices, namely the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI), in the process of delineating and overseeing paddy rice fields within the specified region. The findings brought to light the superiority of NDWI as an index, showcasing an exceptional overall accuracy rate of 95% in contrast to NDVI, which exhibited an overall accuracy rate of 93% in the task of outlining the extent of land dedicated to paddy cultivation within the region. As a recommendation stemming from the study, it was proposed that the employment of indices-based methodologies coupled with the utilization of multi-temporal data procured from the MODIS satellite holds immense promise for the purpose of mapping paddy rice on a regional scale within the confines of the Kashmir region. Furthermore, due recognition was extended by the study towards the National Aeronautics and Space Administration (NASA) for their generosity in furnishing complimentary and easily accessible MODIS data products that are invaluable for conducting research in the realms of environmental and agricultural.

Noureldin et al. (2013)study is primarily concerned with the utilization of satellite remote sensing techniques and vegetation indices (VI) in the creation of empirical models for predicting rice yield before harvesting. These models were formulated by utilizing spectral information obtained from SPOT satellite images, which encompassed red and near-infrared bands, alongside vegetation indices derived from the aforementioned bands. Moreover, the incorporation of Leaf Area Index (LAI) in conjunction with the spectral data played a pivotal role in the development of precise models for estimating rice yield. The process of validating these models entailed the application of statistical assessments such as the standard error of estimate and the correlation coefficient to gauge the relationship between the anticipated yield and the modeled yield. Subsequent observations revealed that these models remained valid up to 90 days post-planting under comparable environmental conditions and agricultural methodologies practiced in Egypt. the paper underscores the pivotal role played by satellite remote sensing technologies, vegetation indices, and LAI in the formulation of precise prediction models for rice yield in Egypt.

Tomar & Singh, (2012) observed the quick changes and increase of land use surrounding Shivpuri, India, it is crucial to establish land use plans that take land resource monitoring into consideration. This satellite imagery and remote sensing techniques are being used to conduct exploratory, semi-detailed, and tidy gritty surveys in order to gather useful and diverse data at the same scale and support the monitoring of crucial data. The goal of this research is to improve understanding of land utilization parameters and development monitoring by introducing concentrated ashore resource mapping through directed characterization. A controlled order image generated from controlled mark classes on a 1:15,000 scale varies from pixel to pixel (test focuses using an irregular point create or for each land cover class) land uses on satellite images and accuracy evaluation scheduled and executed.

Maurya, A. K. (2011) evaluated the discussion pertains to the application of remote sensing and GIS methodologies in estimating the acreage and production levels of soybean cultivation in the region of Madhya Pradesh, located in India. The research makes use of data obtained from MODIS satellites and a Geographic Information System (GIS) database to delineate and map out the specific areas designated for soybean cultivation, thereby enabling the projection of yield production levels. It is documented that the accuracy achieved in estimating both the acreage area and production of soybean stands at a noteworthy 80.72%, signifying a notable 7% enhancement in performance when compared to data from the previous year. Furthermore, the study proffers insights into the leading nations in terms of soybean production, shedding light on the substantial contribution made by Madhya Pradesh towards the overall soybean production output of India. Moreover, the paper delves into the utilization of Normalized Difference Vegetation Index (NDVI) values alongside sophisticated statistical analyses to forecast the prospective yield of soybean crops across various districts within the confines of Madhya Pradesh. The procedural framework introduced within this scholarly investigation has notably bolstered the precision levels observed in the estimation of soybean crop acreage and production figures within select regions of Madhya Pradesh, courtesy of leveraging MODIS-based image classification techniques in tandem with GIS resources. The amalgamation of GIS functionalities with MODIS-derived image processing mechanisms has demonstrably resulted in a marked improvement in the precision levels associated with the classification of soybean fields, further attesting to the feasibility, reproducibility, and speediness of this innovative approach. Undoubtedly, the amalgamation of remote sensing technologies and GIS applications emerges as a pivotal asset in the comprehensive analysis of soybean cultivation endeavors, facilitating a meticulous and reliable appraisal of acreage extents, yield potential, and overall production yields.

Majumder (2011) studied about impacts of vegetation health during the periods of abandoned and restored forests were investigated using multi-temporal satellite datasets. The three multi-temporal Landsat 5 and 7 satellite datasets were subjected to NDVI mapping in order to examine the vegetation and forest health. The NDVI map results verified that the natural forests are regaining their vegetative health by identifying the newly restored woods.

Chitade (2010) studied utilizing remote sensing and GIS techniques in Chandrapur district reveals a substantial 67% increase in open-cast coal mine areas between 1990 and 2010. The use of multi-temporal satellite data enhances the study's ability to capture dynamic land use changes. The findings underscore the significant environmental impact of coal mining activities in the region. The study contributes valuable insights for assessing the expanding footprint of mining and guiding sustainable land management practices. However, a more detailed examination of specific land cover changes and inclusion of ground truthing would strengthen the study's robustness. Overall, the research serves as a crucial resource for understanding and addressing the environmental consequences of open-cast coal mining in Chandrapur district.

Ololade, Annegarn, Limpitlaw & Kneen.(2008) studied on land-use changes in the Rustenburg Mining Region presents a comprehensive analysis using Landsat images and remote sensing techniques. The research effectively identifies a concerning rise in open cast mines, tailing dams, and cultivation at the expense of decreasing vegetation cover.

The expansion of built-up areas is attributed to increased transport networks and immigration of mine workers. While the methodology is robust with the use of standard image enhancements and supervised classification, a more detailed discussion on classification accuracy and socio-economic implications could enhance the study's depth. Overall, the research sheds light on the profound environmental disturbances caused by mining and agricultural activities, emphasizing the need for sustainable practices in the region.

Saxena & Prasad (2008) carried out the integrated land and water conservation and resource creation plan for Chevella sub watershed in Andhra Pradesh has been studied with remote control and GIS. In order to plan land use/land cover, hydro geomorphology and soil charts, IRS LISS III and IRS PAN Imaginary were used for the analysis. In the sense of water's significance in the ecological equilibrium for livelihoods. The preparation and maintenance of this resource and their most favorable, economic and equal usage have become a question of the utmost urgency in view of its increasing insufficiency, a whole action plan has been formulated for land and water resource growth. It has been found that the Chevella watershed is drained by abundant streams with undulating topography and moderate slopes to the south and elevations of 575 to 670 meters above MSL(median sea level). Thus it is obligatory for the analysis to show the significance of water storage to prevent rain water wastage.

De Alwis, Easton, Dahlke, Philpot & Steenhuis (2007**)** investigated the delineates a procedural framework for assessing the spatial heterogeneity of saturated regions by analyzing a chronological succession of satellite images, specifically focusing on the application of the Normalized Difference Water Index (NDWI) computed from Landsat 7 ETM+ remote sensing data. The resultant depiction of hydrologically active zones (HAA) exhibited a notable concurrence with both directly observed and computationally simulated saturated territories dispersed across the landscape, thereby underscoring the considerable potential inherent in leveraging remote sensing technologies to demarcate saturated locales within the environment. The dataset acquired through remote sensing operations effectively represented the spatial dispersion of saturated sectors across a diverse array of land types present within the hydrological basin, hence establishing itself as a promising methodology with broad-ranging utility across multiple domains such as hydrological assessment, urban planning, land zoning, and the formulation of sustainable land management strategies aimed at mitigating environmental contamination.

Wardlow, Egbert, & Kastens (2007). investigated the centered around scrutinizing the suitability and effectiveness of time-series MODIS 250 m Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) datasets for the purpose of classifying land use/land cover (LULC) pertaining to crops within the geographical expanse of the U.S. Central Great Plains. The scholarly inquiry involved the employment of both graphical and statistical methodologies in the analysis of a comprehensive 12-month time-series encompassing MODIS EVI and NDVI datasets derived from a vast array of over 2000 cultivated field sites situated in the state of Kansas. The multi-temporal patterns identified within the VI datasets for each crop type consistently correlated with their inherent phenological attributes, and a majority of crop categories displayed discernible spectral differences at certain stages throughout the growth cycle. Furthermore, disparities in the multi-temporal VI patterns of crops across different regions of Kansas were noted, indicative of variances in climate conditions and planting schedules.

Shalaby & Tateishi, (2007) used three different sets of data. The first were the Enhanced Thematic Mapper Plus (ETM+) and Thematic Mapper (TM) images from 1987 and 2001, respectively. The digital topographic maps, which were derived from the hardcopy topographic maps, came in second. The third was the ground data that was gathered from 1999 to 2002. The study took four steps: geometric correction, where the authors geocoded the 2001 image using the ground control points from the 1983 topographic maps, and then used the image to register the 1983 image; image enhancement and visual interpretation, where the two images and two false color composites were subjected to contrast stretching; image classification, where the maximum likelihood classifier was used for the land cover classes and the supervised classification was used for the ground checkpoints and digital topographic maps; and land cover and land use change detection, where the authors processed the image data using the post-classification change detection technique and cross-tabulation analysis.

Xiao et al. (2006) conducted a study focus on paddy rice agriculture across 13 countries situated in South and Southeast Asia through the utilization of MODIS images. This study a specialized paddy rice mapping algorithm is employed, leveraging MODIS-derived vegetation indices to pinpoint the initial phase of flooding and transplanting activities within paddy rice fields. Subsequently, the resulting paddy rice map derived from MODIS data is meticulously juxtaposed against national agricultural statistical information at both national and subnational scales. Through this comprehensive analysis, the research showcases the immense potential of the MODIS-based algorithm in producing up-to-date datasets pertaining to paddy rice agriculture, which can offer valuable insights for applications such as irrigation management, ensuring food security, and estimating trace gas emissions within the regions under scrutiny. Furthermore, an in-depth accuracy assessment of the MODIS-derived rice estimates is meticulously executed by cross-referencing them with national agricultural statistical datasets sourced from a myriad of reputable outlets. It is imperative to note that the study conscientiously acknowledges the inherent constraints associated with the MODIS-based algorithm, such as its inherent limitations in detecting minute patches of paddy rice fields and susceptibility to interference from cloud cover disturbances.

Prasad, Chai, Singh & Kafatos (2006) discussed regarding the creation and implementation of a sophisticated crop yield prediction model specifically tailored for the state of Iowa. This model heavily relies on leveraging remote sensing data, including but not limited to NDVI (Normalized Difference Vegetation Index), soil moisture levels, surface temperature readings, and rainfall metrics. Through the utilization of a non-linear Quasi-Newton multi-variate optimization technique, the model aims to effectively minimize any inconsistencies and errors that may arise during the process of yield prediction. Furthermore, the foundation of the model rests upon a meticulously crafted piecewise linear regression methodology, incorporating a crucial breakpoint, with the coefficients of the empirical equation being meticulously derived through the aforementioned approach. These variables are identified as key indicators that wield substantial influence over the normal growth patterns of crops. Noteworthy is the model's commendable performance in aligning with the observed crop yield values for both corn and soybean crops, as evidenced by the high R-squared (R2) values of 0.78 and 0.86, respectively. However, it is duly noted that the model remains cognizant of the fact that various external factors such as pest infestations, diseases, and human interventions can potentially introduce localized discrepancies in the predicted crop yield outcomes.

Sarma & Kushwaha (2005) used remote sensing and GIS techniques to study the effects of coal mining on land use and land cover in the Jaintia Hills District of Meghalaya, India. They used LANDSAT data from 1975, 1987, 1999, and 2007 and came to the conclusion that, between 1975 and 2007, the mining area increased fourfold while the forest area decreased threefold. For the mapping of land use and land cover for the various four-year data, a visual interpretation technique was employed. Rice cultivation plays a significant role in global agriculture, providing sustenance for millions while also contributing to greenhouse gas emissions, notably methane (CH4). Understanding and mitigating methane emissions from rice ecosystems are critical for sustainable agricultural practices and environmental stewardship. This literature review synthesizes recent research findings and strategies aimed at comprehending and reducing methane emissions from rice fields.

Manjunath & Panigrahy (2003) investigated the utilization of satellite remote sensing and Geographic Information System (GIS) for the purpose of mapping the rice-growing pattern within the agricultural landscape of India, aiming to produce a comprehensive seasonal rice cropping pattern along with a detailed crop calendar. Within the study, a combination of multidate SPOT VGT 10-day composite normalized difference vegetation index (NDVI) data, RADARSAT SAR data, and IRS WiFS data was employed to accurately delineate the extent of rice cultivation areas and to extrapolate the spatial configurations characterizing the rice crop calendar. The findings of the investigation revealed the presence of two predominant rice cropping patterns prevalent in India, namely the wet season and dry season cropping patterns. The significance of high temporal resolution datasets such as SPOT VGT data emerged as a pivotal factor in capturing the intricate dynamics characterizing rice planting activities during both wet and dry seasons, enabling a detailed exploration of crop dynamics at the state and regional levels, including aspects related to cropping patterns and crop rotation practices. The strategic acquisition of multidate data spanning the growth stages of the crop has demonstrated significant utility in deriving the crop calendar, thereby enabling the effective tracking of sowing and harvesting progressions throughout the agricultural cycle.

Verma et al. (2003**)** focused on the effect of temperature on wheat yield. Meteorological data like temperature and rainfall were collected from different stations form IMD and remote sensing satellite data using IRS LISS-I, LISS-II, and LISS-III sensors was for spectral indices and acreage estimation. A supervised pattern recognition algorithm was used for crop discrimination. The study show cases the potential of satellite data and GIS techniques in monitoring and managing cropping pattern.

Bozzini & Maselli (2002**)** conducted of multi temporal NDVI data spanning several years, precisely from 1986 to 1991, which have been meticulously pre-processed utilizing a well-established and reliable methodology. The pre-processing methodology that was adopted for this investigation encompassed various crucial steps such as geo-referencing, spatial degradation, the generation of NDVI images, cloud masking, maximum value compositing, image normalization, temporal interpolation, as well as the computation of NDVI values. Furthermore, the standardized NDVI values were meticulously computed through a process that involved subtracting the average sub-district values over the multiple years and subsequently dividing them by the standard deviation observed across those same years. Additionally, a detailed stratification of the data based on the standardized NDVI levels that were observed at the conclusion of June was meticulously carried out, further enhancing the depth and accuracy of the analysis. The subsequent phase of the research involved the application of regression analysis techniques specifically to the four distinct data groups, each of which was categorized based on the NDVI values that were observed specifically in the month of June.

Xiao et al., (2002) investigated the creation of quantitative correlations between vegetation-derived vegetation indices and field-measured leaf area index (LAI) for paddy rice fields. During the 1999 rice growing season, this study was conducted in Jiangning County, Jiangsu Province, China. Utilizing a LI-COR LAI-2000 plant canopy analyzer, the scholars gauged LAI at five sampling locations and obtained 27 vegetation synthesis products for the corresponding period. Their analysis revealed statistically notable linear correlations between the normalized difference vegetation index (NDVI) and LAI data during the paddy rice growing season in 1999. Additionally, the research emphasized the feasibility of utilizing VGT-derived NDVI to predict LAI in paddy rice fields across various landscapes over time. Extensive field sampling was carried out at five sites in Jiangning County, a region predominantly characterized by double cropping systems of winter wheat and paddy rice or rapeseed and paddy rice. The researchers also executed surveys and interviews with farmers to amass data on rice crop varieties, seeding and transplanting dates, and fertilization methodologies.

Ji-hua & Bing-fang (1999) studied examines various approaches for assessing the status of crops through the utilization of remote sensing data. The primary source of data for monitoring large-scale crop conditions is satellite imagery. Monitoring models directly utilize remote sensing indices like NDVI, LAI, RVI, PVI, and crop reflectance across different spectral bands. A method known as same-period comparison involves comparing remote sensing data (e.g., NDVI) from a specific period with historical data from the same timeframe. By analyzing time series of NDVI throughout the crop season, crop growth profiles are established, along with NDVI statistics at a specific scale like a province. Models for crop growth, also referred to as crop growing modes, are employed to simulate crop growth status and evaluate crop conditions. This evolution includes a transition from qualitative to quantitative monitoring, the incorporation of additional indices for enhanced monitoring precision, the utilization of crop growth models for monitoring crop conditions, and the amalgamation of GPS, GIS, and RS data for superior monitoring outcomes.

Foody & Arora (1997) identified results are obtained from each classification approach depending on the type of satellite data and the classification subject, among other considerations. The study area's characteristics, auxiliary data, and the spectrum bands chosen all have an impact on the categorization results. Many algorithms for classifying land cover have been examined and compared in a plethora of research studies, with a particular emphasis on particular scenarios. Guidelines for choosing the best and most accurate data and a matching classification system have also become essential as the use of satellite data grows in popularity due to its increasing availability. Although sophisticated remote sensing and GIS technologies have been developed to classify crop land, it is anticipated that simple processes will be developed and adopted in order to achieve the desired result with the least amount of data sources available. This is done in an effort to reduce time while also achieving a productive outcome. The goal of the current study is to create a straightforward approach for defining the State of Haryana's Kharif rice area.

Loveland et al. (1995) introduced a novel classification system for land cover in the United States utilizing AVHRR data, which involves the detailed delineation and cartography of 159 distinct seasonal land-cover zones based on factors such as vegetative composition, phenology, relative productivity, and various other landscape parameters. This classification method involves a sophisticated approach to land-cover regionalization, where the delineation of uniform regions is established based on the seasonal attributes of land cover, which are further enriched by incorporating additional descriptive attributes to enhance the specificity and accuracy of the classification. The manuscript references earlier studies on regionalization techniques, such as the monothetic or univariate regionalization methodology put forth by Kochler and Anderson.

Methane Emission Mechanisms and Factors

Ouyang et al.(2023) estimated the global methane emissions from rice agriculture using the machine learning with random-forest model in conjunction with paddy-rice methane-flux data from 23 global eddy covariance locations and MODIS remote sensing data. He Evaluated of data-driven model performance and variable importance. The analysis conducted by the author demonstrated that temperature-related predictors were found to have the highest importance score. This finding emphasizes the crucial role of climatic factors in influencing methane flux from paddy-rice fields. Moreover, these results not only enhance our existing understanding of methane flux dynamics but also provide valuable insights for policymakers and researchers in this field.

Nikolaisen et al.(2023) conducted a study comparing existing empirical models to better understand methane emissions from rice ecosystems. Their research sheds light on the complexities of methane dynamics in rice paddies and highlights the importance of accurate modeling for predicting emissions. Such modeling efforts are crucial for informing mitigation strategies and policy decisions.

Saha et al., (2021) identified significant differences in CH4 emission rates among different types of rice cultivation and growing seasons. Hybrid varieties exhibited the highest CH4 emissions per hectare, while local land races showed the lowest emissions. However, when normalized against yield, local land races displayed the highest emission rates. Notably, the Aman season accounted for the largest proportion (61%) of total annual CH4 emissions across all rice types. , the estimated CH4 emission in 2020 was 2348 Gg CH4 yr−1, with a slight increase to 2376 Gg CH4 yr−1 projected for the year 2060, considering a 0.5% migration of cultivable rice land to non-agricultural activities. the findings of this study provide valuable insights into CH4 emissions from rice cultivation systems in Bangladesh. By considering different rice types and cultivation practices, the study contributes to a better understanding of the factors influencing CH4 emissions in this important agricultural sector. The model-based approach used in this study offers a robust method for estimating CH4 emissions and could be further refined and applied in other rice-producing regions to support mitigation efforts and sustainable rice cultivation practices.

Kozicka, Gozdowski, & Wójcik-Gront (2021) evaluated the spatial-temporal changes in CH4 content in the atmosphere for selected countries and regions with major CH4 emissions from rice farming in 2019–2021 using TROPOMI satellite sensor methane content at a global scale. In this study author found the clear association between the methane content and the emissions of greenhouse gases from croplands is evident, demonstrating seasonal fluctuations, particularly peaking in the third quarter. In addition, a significant long-term pattern reveals an annual rise of approximately 15 ppb in the methane content, highlighting the enduring influence of agricultural activities. The dependability of the data obtained from the Sentinel-5P satellite further enhances our capability to conduct robust temporal analyses at various scales, offering invaluable insights into the dynamics of methane emissions over time.

Luiz, Villela, de Lima, Vieira & Frighetto (2019) evaluated the seasonal methane emissions during the 2008/2009 harvest from an irrigated rice plantation in the municipality of Tremembé, State of São Paulo, Brazil. Specifically, the study aimed to quantify methane emissions using the static chamber technique and gas chromatography. Luiz employed the static chamber technique coupled with gas chromatography to measure methane emissions. The study focused on a rice plantation under a pre-germinated system, which involves flooding the field prior to planting. The research was conducted over the 2008/2009 harvest season, and measurements were taken to estimate methane emission factors and global warming potentials. The study revealed high seasonal methane emissions from the flooded rice field, attributed primarily to the extended flooding period typical of rice cultivation. The estimated methane emission factor was determined to be 6.51 kg CH4 ha-1 dia-1, highlighting the substantial methane release associated with this agricultural practice. Additionally, the partial global warming potential (pGWP) was calculated at 27.2 Mg CO2 eq growing season-1 ha-1, emphasizing the significant contribution of methane emissions to overall greenhouse gas dynamics. Furthermore, the yield-scaled pGWP (YpGWP) was determined to be 3.9 kg CO2 eq kg-1 grain, providing insights into the emissions intensity concerning rice.

Ge et al. (2018) The new open-path methane analyser (LI-7700) was utilized for measurements, the semi-empirical multiplicative model was also employed to estimate CH4 fluxes, and the eddy covariance approach was used to measure the methane flux from an irrigated rice farm in East China. In this research seasonal variation in methane flux was observed, with a peak during the late vegetative stage And Diurnal patterns of methane flux were observed during vegetative stages. He found strong positive correlations between CH4 flux and Tsoil and VWC Soil temperature and volumetric water content were important factors controlling methane emissions. Model has potential for estimating CH4 emissions over larger areas. Good agreement between measured and modeled methane fluxes was obtained method’s in Yancheng, Jiangsu Province, China.

Yodkhum, Gheewala & Sampattagul (2017) focused on Khao Dawk Mali 105 (KDML 105), a widely exported Thai rice variety cultivated through organic practices. Using Life Cycle Assessment (LCA) and the 2006 IPCC Guideline for National Greenhouse Gas Inventories, the research evaluates the cradle-to-farm GHG emissions, revealing a total of 0.58 kg CO2-eq per kg of paddy rice. Field emissions emerged as the primary source, constituting 83% of total emissions, followed by land preparation, harvesting, and other stages. The comparative analysis underscores the environmental benefits of organic farming, indicating significantly lower GHG emissions compared to conventional rice production, primarily attributed to the use of organic fertilizers. This research provides valuable insights for enhancing the environmental sustainability of Thai rice production in a competitive global market.

B. Zhang et al. (2016) looks into the amount of methane (CH4) emissions from rice fields around the world, as well as their spatiotemporal patterns and environmental restrictions. It emphasizes how crucial it is to precisely estimate these emissions because they could have a positive feedback loop with climate change. The study uses satellite-derived inundation area data and a coupled biogeochemical model to estimate CH4

emissions and identify environmental restrictions from 1901 to 2010. The findings reveal substantial variability in CH4 emissions from global rice fields, ranging from 18.3 ± 0.1 Tg CH4/yr under intermittent irrigation to 38.8 ± 1.0 Tg CH4/yr under continuous flooding in the 2000s. This underscores the significant influence of water management schemes on CH4 emissions, with continuous flooding resulting in higher emissions compared to intermittent irrigation. Over the past century, the study indicates an 85% increase in global CH4 emissions from rice cultivation. The primary drivers of this increase include the expansion of rice fields, elevated CO2 concentration, and nitrogen fertilizer use. However, climate variability has had a mitigating effect on cumulative CH4 emissions for most of the study period. The research suggests that optimizing irrigation practices could contribute to reducing CH4 emissions from global rice fields. This implies that future trends in CH4 emissions will be shaped by both human demand for rice production and the adoption of optimized water management practices.
Smartt et al. (2015) examined the impact of chamber size on rice production methane emissions. While not directly addressing mitigation strategies, this study contributes to methodological advancements in methane measurement techniques, which are essential for accurate quantification of emissions and evaluating mitigation efforts.

Ke, Lu & Conrad (2014) investigated the behavior of methane in rice field microcosms to understand their roles in methane production and soil nitrogen cycling. The study likely observed distinct behaviors of response to environmental factors such as water management and fertilization. It may have identified their contributions to methane emissions and nitrification processes in rice field ecosystems. Provides insights into the microbial dynamics of methane production and nitrogen cycling in rice field ecosystems, advancing understanding of the factors influencing methane emissions and soil nutrient dynamics.

Butcher et al. (1992) determine the amount and the spatiotemporal patterns of greenhouse gas emissions from rice fields worldwide in order to have a deeper understanding of the underlying factors controlling the emissions. Methane emissions from rice fields were measured using a linked biogeochemical model. Methane emissions were estimated using the current inundation area, which was obtained from satellite data. Additionally, the model incorporated global crop geographic distribution and regional agricultural census data to enhance its accuracy. The performance of the model in predicting methane emissions at observation sites was evaluated. The data sets used in the study had a spatial resolution of 0.5 degrees in both longitude and latitude. The author found the amount of CH4 emitted from rice fields worldwide ranged from 18.3 ± 0.1 Tg CH4/yr to 38.8 ± 1.0 Tg CH4/yr, contingent upon irrigation plans.

Mitigation Strategies for Methane Emissions:

Senthilraja et al. (2023) conducted to examine the impacts of organic amendments on methane emissions in the rice ecosystem. The results reveal that the combination of blue-green algae and Azolla leads to a reduction in methane emissions by 37.9%. Moreover, it has been observed that there is a positive correlation between methane emissions and both soil and water temperature. Furthermore, the application of BGA, Azolla, FYM, and GLM has been found to increase crop yield by 26.5%. The bio-fertilization technique, involving the use of BGA and Azolla, has proven to be effective in the reduction of methane emissions. It is crucial to address the issue of rice production, as it contributes significantly to the global climate crisis and necessitates emission reduction. Notably, rice production in countries such as India, China, and Southeast Asia dominates the global markets. Unfortunately, methane emissions from rice farming are on the rise, exacerbating the issue of global warming.

Vo et al. (2020) studied to determine methane emission factors from Vietnamese rice production through meta-analysis, synthesizing data from multiple field sites. The research likely calculated average methane emission factors for different rice cultivation practices and environmental conditions in Vietnam. It may have identified factors influencing methane emissions variability and assessed the effectiveness of mitigation measures. By pooling data from multiple field sites, this study provides robust methane emission estimates for Vietnamese rice production, informing policy development and emission reduction strategies tailored to the Vietnamese context.

Romasanta et al. (2017) carried out the employs both experimental approaches and field observations to assess emissions. Experiment A involves a combustion chamber setup to collect smoke for chemical analysis, while Experiment B examines soil-borne emissions under different straw management practices. These practices include straw retention and incorporation, partial straw removal with stubble incorporation, complete straw removal, and straw burning followed by incorporation of ash and unburned residues. Results show that at a constant straw moisture of 10%, the mass-scaled emission factors for CH4 and N2O are 4.51 g and 0.069 g per kg dry weight of straw, respectively. Field trials conducted over two seasons reveal variations in greenhouse gas emissions among different management practices. The total global warming potential (GWP) is calculated for each practice over the cropping seasons. The results indicate that straw retention with incorporation (SRt) exhibits the highest GWP, while complete straw removal (CSRm) shows the lowest. Straw burning (SB) and partial straw removal (PSRm) practices have similar intermediate GWPs. The study highlights the importance of considering both direct emissions from straw management and subsequent off-field emissions when assessing the overall greenhouse gas impact. While the research provides valuable insights for emission inventories and carbon footprint analyses related to rice cultivation, it acknowledges the need for further investigation into the utilization of removed straw and its associated emissions beyond the scope of this study.

Epule, Peng, & Mafany (2011) evaluated to propose strategies for achieving a balance between rice production and methane emission reduction in paddy rice fields, emphasizing the importance of win-win sustainability scenarios. The report likely discusses various agricultural practices, technologies, and policy interventions that can help mitigate methane emissions without compromising rice yields. It may highlight successful case studies or pilot projects demonstrating the feasibility of sustainable rice production practices. This research offers a comprehensive approach to tackling the dual concerns of food security and environmental sustainability in rice agriculture by promoting win-win sustainability scenarios. It offers practical solutions for policymakers, farmers, and other stakeholders to promote sustainable rice production while reducing methane emissions.

Kongchum, Bollich, Hudnall, DeLaune & Lindau (2006) carried out study to find out how rice production and methane emissions in a Crowley silt loam paddy soil are affected by water management strategies and the addition of rice straw. The study used a split-plot design with five rates of rice straw incorporation as subplot treatments and two water management strategies (continuously inundated, alternately flooded and drained). The results provided numerous significant insights on rice farming and the mitigation of methane emissions. First off, compared to the continuously flooded treatment, the rice production from the alternately flooded and drained treatment was noticeably higher. This shows that improving rice growth and output can be achieved by periodically draining the crop during the growing season. Second, in both water management treatments, the application of rice straw at high rates (12 and 24 t ha-1) resulted in a decrease in rice yield. This suggests that incorporating too much straw could be detrimental to rice productivity. Furthermore, methane emission increased with higher rates of rice straw application. However, emissions were observed to be lower in plots subjected to alternately flooded and drained treatment. Overall, the results of this study highlight the importance of adopting appropriate water management techniques and optimizing rice straw incorporation rates to enhance rice production while minimizing methane emission. By draining the field for short periods during the growing season, farmers may be able to achieve a dual benefit of increased rice yield and reduced greenhouse gas emissions.

Pathak et al.(2003) underscores the significance of agricultural practices in influencing methane emissions from rice-wheat cropping systems in the Indo-Gangetic plains. The research highlights the potential of intermittent wetting and drying of soil during rice cultivation as a strategy to mitigate methane emissions, while also considering the impact on crop yields. Additionally, the study demonstrates the effectiveness of dicyandiamide (DCD) application alongside urea in reducing methane emissions, offering promising avenues for sustainable agricultural management. However, findings also reveal complexities, such as the adverse effect of intermittent wetting and drying on yields and the varying impact of nitrogen sources on methane emissions. Overall, the study provides valuable insights into the intricate relationship between agricultural practices and greenhouse gas emissions in the context of rice-wheat cropping systems, contributing to efforts towards environmental sustainability in agricultural landscapes.

Impact of Agricultural Practices on Methane Emissions:

Oda & Chiem (2018) investigated the effect of rice cultivation practices on methane emissions in high-emitting paddies. The objective is likely to assess the impact of agricultural management practices on methane dynamics and emission rates. The research likely demonstrates that certain rice cultivation practices, such as water management and fertilizer application, can reduce methane emissions from high-emitting paddies. It may identify specific management strategies that effectively mitigate methane emissions while maintaining or enhancing rice productivity. By highlighting the potential for rice cultivation practices to reduce methane emissions in high-emitting paddies, this study provides actionable insights for sustainable rice production. It underscores the importance of adopting environmentally friendly agricultural practices to mitigate the climate impact of rice cultivation.

Balakrishnan et al. (2018) investigated the effect of floodwater management practices on methane emissions from rice fields. The report likely examined the influence of different flooding regimes, such as intermittent flooding or mid-season drainage, on methane emissions. It may have identified floodwater management strategies that can mitigate methane emissions while maintaining rice productivity. Contributes to understanding the relationship between floodwater management practices and methane emissions from rice fields, offering insights into sustainable water management strategies for reducing greenhouse gas emissions from agriculture.

Arai et al. (2015) investigated the greenhouse gas emissions in the Mekong Delta from burning rice straw and growing straw mushrooms. Their findings emphasize the need for alternate crop residue management strategies to reduce methane emissions and the negative environmental effects of traditional farming practices.

Horwath (2011) evaluated methane and nitrous oxide emissions from a Chinese wheat-rice farming system under different tillage practices, focusing on the wheat-growing season. The author found variations in nitrous oxide and methane emissions between different tillage practices, with implications for greenhouse gas mitigation strategies in agricultural systems. The study may have identified tillage practices that minimize methane emissions while maintaining crop productivity. By examining greenhouse gas emissions from a specific cropping system and tillage practices, this research enhances understanding of the environmental impacts of agricultural management practices and provides insights into strategies for mitigating greenhouse gas emissions from wheat-rice cropping systems in China.

G. Zhang et al. (2020) investigated distribution of rice paddies and the concentrations of atmospheric methane (XCH4). To achieve precise measurements of atmospheric CH4, IMAP 7.1 and OCPR7.0 products were employed. By incorporating MODIS data and a phenology-based algorithm, the accurate identification and mapping of rice paddies were made possible. These findings were then cross-validated with existing products and statistical data. Additionally, the paddy rice maps were aggregated to match the resolutions of XCH4 data, allowing for a comprehensive analysis to determine the relative contribution of rice agriculture to CH4 emissions. This analysis drew upon insights from EDGAR data. The rice paddy region in monsoon Asia experienced a decline in size from 2007 to 2015, while also observing a correlation between the spatial distribution of rice paddies and the concentration of atmospheric methane. It was noted that areas with dense rice paddy cultivation exhibited elevated levels of methane concentration.

In many scientific domains, remote sensing and GIS have become one of the most economical and efficient tools. With the development of computer technologies, it has become increasingly valuable for the survey, monitoring, and management of natural resources. It is being used, particularly in agriculture, to pinpoint location-specific characteristics for additional interventions. The identification of different crop covering is one of the most important methods for figuring out the kind and quantity of crop planted in a particular location. Both the creation of new agricultural operations and efficient land use planning might benefit greatly from this data. Many studies have been carried out to develop the land cover classification in this respect.

1.5 Research Gap:

Haryana, India. Existing research often lacks integration of high-resolution spatial data and fails to address the specific challenges related to accurately mapping the rice-wheat cropping system in this area. Moreover, the use of advanced GIS tools for validating and refining acreage estimates remains underexplored, leading to potential inaccuracies in crop area assessments. This gap limits effective agricultural planning and resource management.

Even if the use of GIS and remote sensing technologies for environmental monitoring and crop acreage estimation has advanced significantly, there remain critical gaps in understanding methane emissions at the district level, particularly in agriculturally intensive regions like Haryana, India.

While previous studies have focused on general methane emissions in paddy fields, there is a lack of comprehensive, spatially detailed assessments that integrate rice and wheat cultivation data with methane emission estimates using GIS overlay techniques.

Furthermore, little attention has been given to systematically comparing methane emissions from wheat and paddy, even though both are major crops in the region. The absence of district-level, crop-specific methane emission inventories leaves a gap in effectively identifying high-emission zones, which is crucial for targeted mitigation strategies.

Additionally, the current literature is limited in providing specific, locally-tailored mitigation techniques for methane reduction, particularly in the context of wheat, a crop less studied for its methane emissions compared to paddy. Reducing greenhouse gas emissions in rice-wheat cropping systems and creating sustainable agriculture practices depend on filling these gaps.

1.6 Research Hypothesis

Methane emission from rice crop filed is significantly influenced by water management practices with intermittent wetting and drying cycles leading to reduced emissions compared to continuous flooding, while increased fertilizer application, particularly nitrogen, may lead to higher methane emissions. This hypothesis incorporates key factors like water management, fertilizer use and their impact on methane production and release. Following hypothesis were observed for the present study.

H_1: Rice-growing areas emit more methane compared to wheat-growing areas in Haryana.

H_2: Continuously flooded rice fields release higher methane than intermittently irrigated rice fields**.**

H_3: Higher application of nitrogen-based fertilizers increases methane emissions in both rice and wheat areas.

1.7 Objectives:

This study is based on the following objectives:

1. To identify the area under rice and wheat cultivation in Haryana.
2. To assess the methane emission across Haryana.
3. To comparative analysis of the methane emission under rice and wheat crop.
4. To evaluate the role of agricultural practices responsible for methane emission in Haryana.

1.8 Summary

Chapter 1 introduces the intricate connection between agriculture, climate change, and environmental sustainability, focusing on methane emissions from rice and wheat cultivation in Haryana, India. Agriculture, vital for food security, has significantly altered natural ecosystems, with methane being a key greenhouse gas, especially from flooded rice fields. Methane accounts for 12% of global anthropogenic emissions, and alternative farming practices like Alternate Wetting and Drying (AWD) offer potential to mitigate these emissions without compromising crop yields.

India, as a major rice producer, faces the challenge of balancing agricultural productivity with environmental concerns. Haryana, a key agricultural state, has seen significant changes in cropping patterns driven by irrigation and technological advancements. However, limited research exists on the spatial and temporal analysis of methane emissions in this region, especially from rice and wheat farming.

Remote sensing and GIS technologies are introduced as essential tools for mapping, monitoring, and managing agricultural practices. These technologies provide accurate and timely data, facilitating sustainable land use planning, crop forecasting, and environmental impact assessments.

The chapter further discusses Haryana’s geographical, infrastructural, and physiographic features, setting the stage for the study of methane emissions in the region. It highlights Haryana's diverse geology, subtropical climate, and the challenges of water management in an area dependent on irrigation systems like canals and reservoirs. The state also faces growing urbanization, pollution, and climate change impacts, necessitating sustainable water management practices.

The chapter also examines the increasing role of remote sensing in global agricultural monitoring, citing numerous studies from regions like Ethiopia, China, and Pakistan. These studies demonstrate the effectiveness of satellite data in monitoring land use and cover changes, crop patterns, and environmental transformations. Particularly in India, the integration of RS-GIS technologies has advanced crop-specific studies, contributing to sustainable agricultural planning.

In terms of methane emissions, the chapter highlights various studies (Show in Literature review) examining the influence of agricultural practices on emissions in rice-wheat cropping systems. It emphasizes strategies such as intermittent flooding and mid-season drainage to reduce methane emissions from rice fields while maintaining productivity. Additionally, alternative crop residue management practices, like avoiding rice straw burning, have been shown to reduce emissions. Advanced remote sensing and GIS technologies have been employed to assess methane concentrations in rice paddies, linking agricultural practices to increased methane levels.

Finally, the chapter identifies significant research gaps in Haryana, particularly the lack of high-resolution spatial data and GIS tools for accurately mapping rice-wheat systems and assessing methane emissions at the district level. This gap limits effective resource management and sustainable agricultural planning. Addressing these gaps through comprehensive, district-specific methane emission inventories and mitigation strategies is crucial for promoting sustainable agriculture in the region.

CHAPTER-2

DATA AND METHODOLOGY

Introduction: Data and Methodology

Accurate crop mapping and agricultural monitoring require the integration of high-resolution satellite imagery, systematic ground verification, and advanced digital image processing techniques. In the present study, multi-temporal satellite datasets were utilized to identify and classify major crops within the study area. Remote sensing provides synoptic, repetitive, and cost-effective coverage of large geographical regions, making it an efficient tool for agricultural land-use assessment and crop discrimination.

For this purpose, multispectral data from the European Space Agency's Sentinel-2A and Sentinel-2B satellites were employed. Sentinel-2 is part of the Copernicus Programme and carries a Multispectral Instrument (MSI) with 13 spectral bands ranging from the visible to shortwave infrared (SWIR) regions of the electromagnetic spectrum. These bands provide detailed information on vegetation characteristics, moisture conditions, and crop health. The satellite offers spatial resolutions of 10 m, 20 m, and 60 m, a swath width of 290 km, and a revisit frequency of approximately five days, enabling continuous monitoring of agricultural fields during different crop growth stages.

The spectral bands used in this study include the Green (B3), Red (B4), and Near-Infrared (B8) bands with 10 m spatial resolution, which are particularly effective for vegetation analysis and crop differentiation. The 16-bit radiometric resolution enhances the sensitivity of the sensor to subtle variations in reflectance values, improving classification accuracy.

In addition to satellite data, ground truth information was collected through field surveys using handheld GPS devices. Ground verification is a crucial component of remote sensing analysis, as it links spectral signatures recorded by the sensor with actual land surface features. Field visits were conducted during the crop season to record crop types, geographic coordinates, and photographic evidence. These reference datasets were later used for supervised classification and accuracy assessment.

The digital data loading and preprocessing were carried out using ERDAS Imagine software. Preprocessing steps included geo-referencing, radiometric calibration, atmospheric correction, and geometric correction to ensure spatial and spectral accuracy. Following preprocessing, complete pixel-based classification techniques were applied to categorize land cover classes, particularly wheat and rice crops. Accuracy assessment was performed using ground truth data through standard validation techniques.

2.1 Satellite Data: For the crop mapping in the study area, Sentinel-2A/B satellite data is utilized. Sentinel-2A/B is part of the European Space Agency's Copernicus program, providing high-resolution multispectral imagery. The spectral bands and spatial resolution of Sentinel-2A/B data used in this study are outlined below:

Analysis was conducted using the Sentinel 2 A/B data scene (free source) obtained from the Landsat location. A multispectral imaging device with 13 spectral bands, spanning from visible to shortwave infrared (SWIR), is carried by Sentinel-2A/B (Table 2.1). They provide three distinct spatial resolutions: ten, twenty, and sixty meters. For the Sentinel-2 constellation, the revisit period is two to three days when both Sentinel-2A and Sentinel-2B are operational, and five days at the equator with a single satellite. The scene spans about 290 km from east to west.

Table: 2.1-Specifications of European Space Agency Sentinel 2A/B sensor.

Parameter	**Specifications**
Spectral Band (nm)	B3: 543-578 (Green); B4: 650-680 (Red); B8: 785-900 (NIR)
Spatial Resolution	10 m
Radiometric Resolution	16 bit
Temporal Resolution	5 days
Swath-width	290 km

(Data Source: https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/sentinel-2a/)

Table 2.1 provides details on the Sentinel 2 scene. Sentinel captures information across many bandwidths. The visible, near-infrared, and short-wavelength infrared sections of the electromagnetic spectrum are separated into these bandwidths. A lot of data regarding the land cover can be shown and examined from these different bandwidths.

Table 2.2 Specifications of Landsat-2 Sensor.

S. No	Bands	Wavelength (micrometers)	Resolution (meters)
1	Band 1 - Coastal aerosol	0.433 - 0.453	60
2	Band 2 - Blue	0.458 - 0.523	10
3	Band 3 - Green	0.543 - 0.578	10
4	Band 4 - Red	0.650 - 0.680	10
5	Band 5 - Vegetation Red Edge	0.698 - 0.713	20
6	Band 6 - Vegetation Red Edge	0.733 - 0.748	20
7	Band 7 - Vegetation Red Edge	0.773 - 0.793	20
8	Band 8 - Near Infrared (NIR)	0.785 - 0.900	10
9	Band 8A - Narrow NIR	0.855 - 0.875	20
10	Band 9 - Water vapor	0.935 - 0.955	60
11	Band 10 - Short Wave Infrared (SWIR) - Cirrus	1.365 - 1.385	60
12	Band 11 - Short Wave Infrared (SWIR) 1	1.565 - 1.655	20
13	Band 12 - Short Wave Infrared (SWIR) 2	2.100 - 2.280	20

(Source: https://sentinels.copernicus.eu/documents/247904/685211/Sentinel-2_User_Handbook).

In geo-informatics, gathering ground truth data is crucial. As you are aware, every surface feature—water, soil, vegetation, etc.—has a unique spectral signature. Therefore, in a perfect world for remote sensing, the spectral signatures would fully specify the nature of the Earth's surface characteristics. In practice, however, the indistinctness of spectral signatures, atmospheric effects, and the complexity of Earth surface characteristics serve as barriers to distant sensing in the absence of ground truth data. By helping to connect the picture data to the context of Earth surface features that are present on the ground, ground truth data collecting complements the synoptic overview that satellites give. Therefore, ground truth is crucial for interpreting images.

The mobile GPS was used to get ground truth during the season. In the second two weeks of January 2020, ground truth data for wheat rice was gathered. On the 1:100000 maps, large areas of land features related to rice and wheat were indicated, and the location data was captured using a handheld GPS. Additionally, field photos were gathered. In order to identify the burnt stubble of wheat, related crops, and land features during the digital categorization of satellite data, these ground truth sites and field photos were utilized.

2.2 Digital Data Loading and Preparation

The process of digital data loading and preparation is a fundamental step in remote sensing analysis, essential for extracting meaningful insights from satellite imagery. In this study, Sentinel digital data covering the temporal period from March 2022 to sept.2022 was utilized. This data, acquired in JPEG format from the European Space Agency (ESA) website (https://scihub.copernicus.eu/), represents a crucial resource for monitoring changes in land cover and land use over time. To begin the analysis, the temporal JPEG data was imported into ERDAS Imagine software, a widely-used platform for processing and analyzing remote sensing data.

The choice of Sentinel satellite data for this study is significant due to its high spatial resolution and frequent revisits, enabling the capture of detailed information about land surface dynamics. Sentinel satellites, part of the Copernicus program, offer multispectral and radar imagery with a wide range of applications, including agriculture, environmental monitoring, urban planning, and disaster management.

Upon importing the .JPEG data into ERDAS Imagine, the first step in the preparation phase is to ensure the data is correctly dereferenced and formatted for further analysis. Geo-referencing involves aligning the satellite imagery with geographic coordinate systems, allowing for accurate spatial referencing and integration with other geospatial datasets. This process is crucial for maintaining the spatial accuracy of the imagery and facilitating meaningful spatial analysis. Next, the temporal dataset is organized and managed within Erdas Imagine, where various preprocessing steps may be applied to enhance the quality and usability of the imagery. Common preprocessing techniques include radiometric calibration, atmospheric correction, and geometric correction, aimed at reducing sensor artifacts, atmospheric interference, and geometric distortions.

Radiometric calibration adjusts the pixel values of the imagery to account for variations in sensor sensitivity and environmental conditions, ensuring consistency and accuracy in the data. Atmospheric correction removes atmospheric effects such as haze, clouds, and aerosols, which can distort the spectral signatures of land surface features. Geometric correction rectifies geometric distortions caused by sensor viewing geometry, Earth's curvature, and terrain relief, aligning the imagery with the true ground coordinates. Once the preprocessing steps are completed, the temporal dataset is ready for digital analysis using a complete enumeration approach. In complete enumeration, every pixel within the image is analyzed and classified based on its spectral characteristics, without the need for sampling or statistical inference. This approach is well-suited for capturing detailed information about land cover and land use patterns across large geographic areas.

Digital analysis encompasses a range of techniques, including classification, change detection, and feature extraction, aimed at extracting meaningful information from the satellite imagery. Classification involves categorizing pixels into distinct land cover classes or thematic categories based on their spectral signatures. Common classification methods include supervised, unsupervised, and object-based techniques, each with its strengths and limitations.

Change detection identifies and quantifies changes in land cover and land use over time by comparing multiple images acquired at different temporal intervals. This process enables the detection of land cover changes such as urban expansion, deforestation, agricultural land conversion, and natural disasters. Change detection techniques may involve image differencing, vegetation indices, and machine learning algorithms to identify and analyze significant changes in the landscape.

Feature extraction aims to delineate and characterize specific land surface features such as roads, buildings, water bodies, and vegetation using automated algorithms or manual digitization techniques. These extracted features serve as valuable input for spatial analysis, modeling, and decision-making in various applications.

In summary, the digital data loading and preparation phase involves importing, organizing, and preprocessing satellite imagery to facilitate subsequent analysis and interpretation. By leveraging advanced remote sensing techniques and software tools such as ERDAS Imagine, researchers can extract valuable information about land cover dynamics, environmental changes, and human activities from Sentinel digital data, contributing to informed decision-making and sustainable resource management.

2.3 Ground truth:

Establishing reliable reference data is a crucial step in the ground truth process for image classification of wheat and rice crops in Haryana, or anywhere else for that matter. This data is used to validate the classification findings obtained from remote sensing photos. This is a general method for producing ground truth data for crop classification of wheat and rice:

Field Surveys: Gather ground truth data by conducting field surveys during the growth season. These studies ought to be place in different parts of Haryana where crops like rice and wheat are grown.

Method of Sampling: To guarantee that the ground truth data is representative of the whole study region, develop a sampling technique.

Data Collection: Gather ground truth data through a variety of techniques, including: Field Measurements.

Take pictures: To visually record the crop kinds and conditions, take pictures of the tested sites.

Annotation: List the crop varieties that are present in each sampled area by annotating the gathered data. Experts might complete this manually, or crowdsourcing could be used with appropriate quality control procedures.

Data Validation: Use cross-validation and consistency checks to confirm that the annotated ground truth data is accurate.

Temporal Variability: In order to account for seasonal variations, gather ground truth data at several phases of crop growth.

In order to account for geographic variation in crop distribution, make sure that ground truth samples are distributed appropriately throughout the study area.

Data management: For categorization purposes, arrange and manage the ground truth data in an organized format that is easily integrated with remote sensing pictures.

Accuracy Assessment: Evaluate the categorization outcomes derived from remote sensing photography using the ground truth data.

Major Road and Ground Control Point map for Kharif crop 2022:

The map entitled "Major Road and Ground Control Points of Haryana – Kharif 2022" presents an integrated geospatial depiction of Haryana's transportation network and the spatial distribution of Ground Control Points (GCPs) used for field verification and satellite image correction during the Kharif season of 2022. The base layer is derived from Sentinel-2 satellite imagery acquired between 4 September and 11 September 2022, overlaid with district boundaries and categorized road networks. The transportation system is classified into three hierarchical categories: National Highways (shown in yellow), State Highways (green), and District Roads (cyan). Together, these networks reveal a dense and well-connected infrastructural framework across the state, facilitating mobility, trade, and agricultural activities. The National Highways form the principal arterial routes, linking major economic and administrative centers such as Gurugram, Faridabad, Rohtak, Hisar, Ambala, Panchkula, and Karnal, thereby reflecting the strategic importance of Haryana within the National Capital Region (NCR) and northern India. State Highways function as secondary connectors between district headquarters and major towns, while District Roads provide last-mile connectivity to rural settlements and agricultural fields.

The spatial distribution of GCPs, represented by green star symbols, is extensive and systematically dispersed across different districts to ensure geometric accuracy and positional reliability of satellite imagery used for crop mapping and land use analysis. A noticeable concentration of GCPs is observed in agriculturally intensive districts such as Karnal, Kurukshetra, Kaithal, Jind, Hisar, Fatehabad, and Sirsa, which are prominent for Kharif crops like rice and cotton.

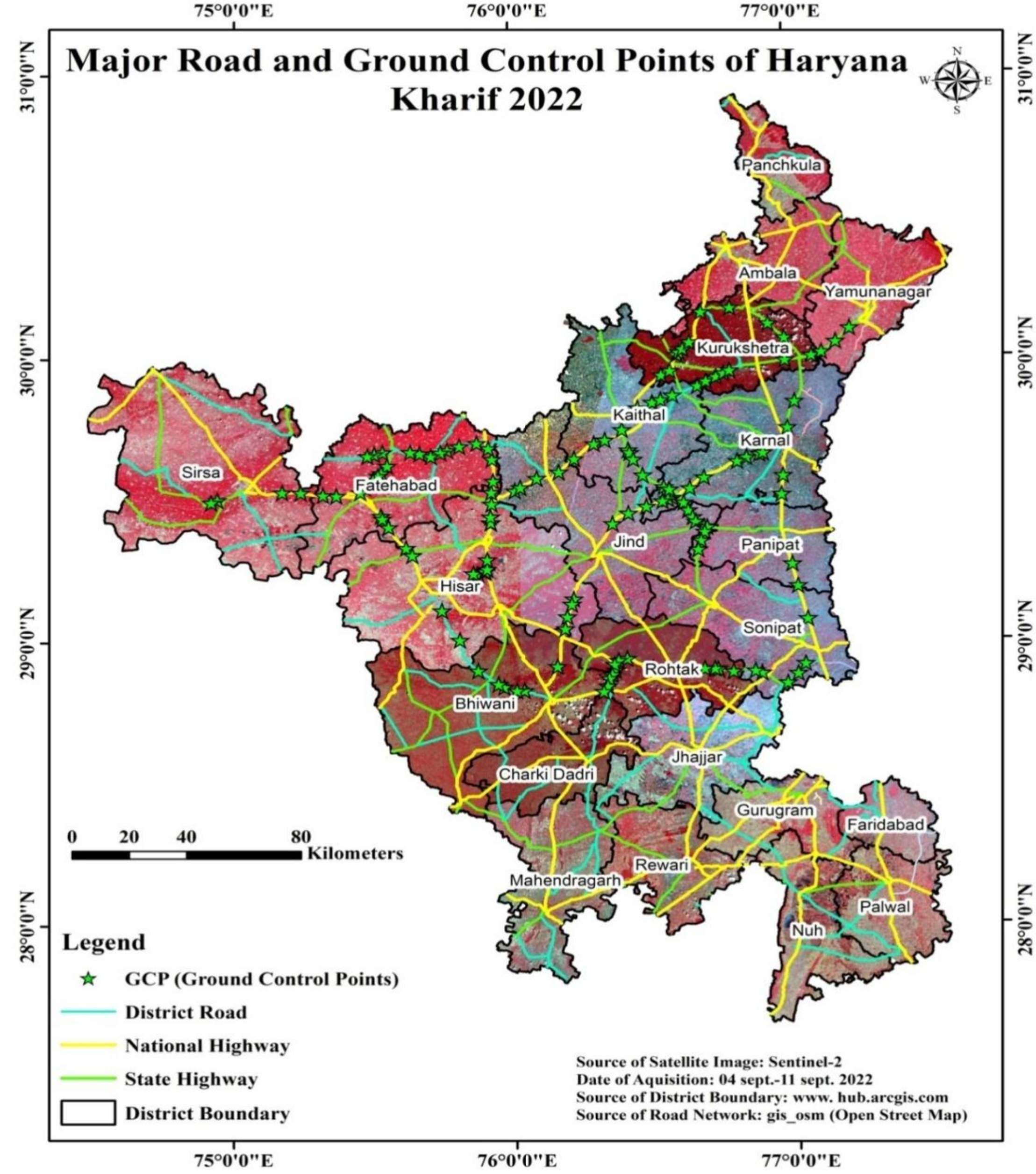


Figure 2.1: Major Road and Ground Control Points of Haryana Kharif 2022. (Data source: Primary Ground Control Points collection by Scholar).

Their alignment along major transportation corridors indicates the practical consideration of accessibility during field surveys, as road connectivity plays a critical role in efficient ground truth data collection. Comparatively fewer GCPs are observed in relatively less accessible or sparsely populated tracts, though spatial coverage remains adequate to maintain overall mapping precision. The Figure (2.1) highlights the strong interrelationship between infrastructure development and geospatial data acquisition. Efficient road networks not only enhance regional economic growth but also significantly support remote sensing validation processes by enabling systematic field visits. Furthermore, the integration of satellite imagery with ground-based reference points demonstrates a robust methodological framework for agricultural monitoring, ensuring higher classification accuracy and reliable spatial outputs. Overall, the map effectively illustrates Haryana’s transportation hierarchy and its role in supporting geospatial surveys and Kharif crop assessment, emphasizing the importance of infrastructure in facilitating scientific research and spatial planning at the district and state levels.

Major Road and Ground Control Point map for Rabi crop 2022:

The map titled “Major Road and Ground Control Points of Haryana – Rabi 2022” presents the spatial distribution of transportation networks and Ground Control Points (GCPs) across Haryana during the Rabi season of 2022. The base layer is derived from Sentinel-2 satellite imagery acquired on 15 March 2022, overlaid with district boundaries and categorized road networks. The transportation infrastructure is classified into National Highways (yellow), State Highways (green), and District Roads (cyan), illustrating a dense and hierarchical road system that connects major urban, agricultural, and administrative centers throughout the state. National Highways serve as primary corridors linking key cities such as Gurugram, Faridabad, Rohtak, Hisar, Ambala, Panchkula, Karnal, and Panipat, while State Highways and District Roads provide regional and local connectivity, particularly supporting rural settlements and agricultural fields during the Rabi cropping season.

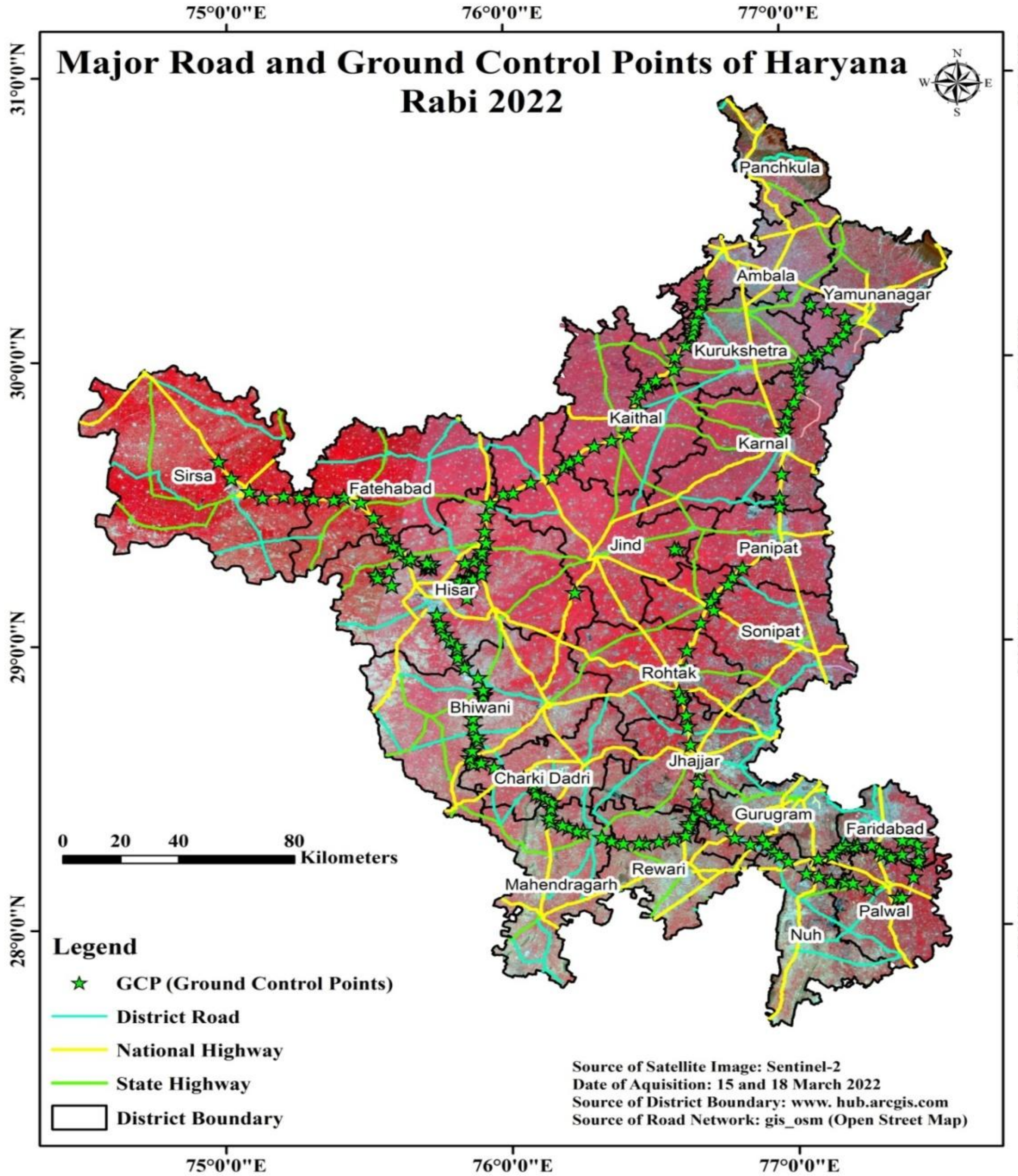


Figure 2.2: Major Road and Ground Control Points of Haryana Rabi 2022. (Data source: Primary Ground Control Points collection by Scholar).

The green star symbols represent Ground Control Points, which are systematically distributed across the state to ensure geometric correction, positional accuracy, and validation of satellite-based crop mapping. A significant concentration of GCPs can be observed in agriculturally productive districts such as Karnal, Kurukshetra, Kaithal, Jind, Hisar, Fatehabad, and Sirsa, where Rabi crops like wheat and mustard dominate. The clustering of GCPs along major transportation routes highlights the importance of road accessibility in facilitating efficient field surveys and ground truth data collection. Compared to sparsely connected regions, areas with better infrastructure exhibit higher density of control points, reflecting logistical considerations in survey design.

Ground-based methane concentration measurements:

Ground truthing was conducted through extensive field surveys across the major crop-growing regions of Haryana to ensure accurate classification of rice and wheat crops as well as to validate methane concentration estimates. GPS-enabled mobile devices were used to record the geographic coordinates of sampled fields, while crop type information and photographs were collected for training and validation purposes. Field surveys were carried out during January 2020 (Rabi season) and October 2020 (Kharif season)**,** ensuring that seasonal variability in cropping patterns was adequately captured. Representative samples were selected across different districts to reflect spatial and agro-climatic diversity.

In addition to crop identification, ground-based methane concentration measurements were collected at selected field sites. Portable methane analyzers were employed to capture methane levels at the surface during critical periods, including:

- **Peak growth stage of rice fields** (when anaerobic decomposition in flooded soils leads to elevated methane emissions).
- **Wheat post-harvest phase** (particularly in areas prone to stubble burning, which significantly increases methane release).

Methane measurements were recorded at multiple locations within each field to minimize local variability and averaged for site-level estimation. These ground methane readings were subsequently compiled into a spatial dataset and compared with satellite-derived methane mixing ratios from Sentinel-5P TROPOMI.

The correlation between ground methane concentrations and tropospheric methane retrievals served as an essential validation step, ensuring the reliability of satellite-based estimates. This dual ground truthing approach—crop classification accuracy and methane validation—strengthened both the agricultural mapping and environmental monitoring aspects of the study.

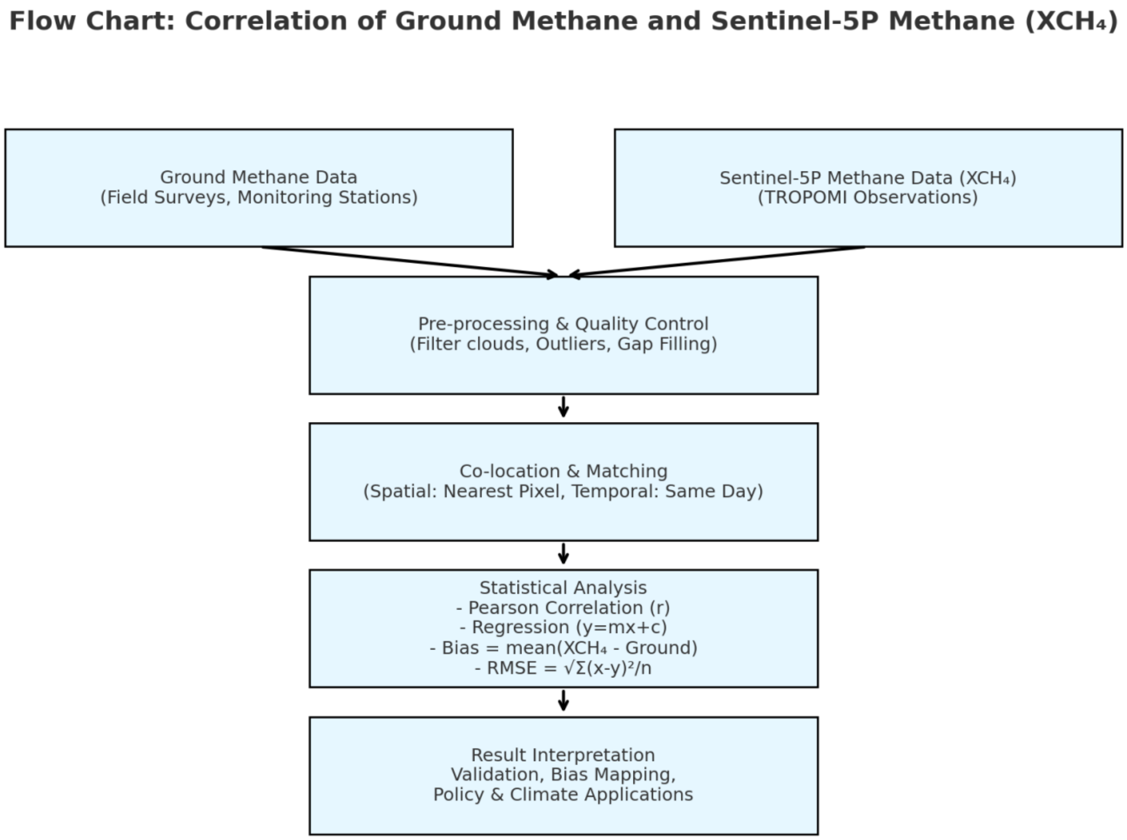


Figure:2.3 Methodology Flow chart of Correlation of Ground and sentinel-5P Methane (XCH_4). (Data Source: Methodology adapted from established satellite validation frameworks (Hu et al., 2018; Dils et al., 2020).

2.4 Supervised Classification

The reflectance of a pixel in each of the spectral bands determines its spectral signature in a multispectral image. After analyzing the spectral signatures, pixels are categorized into groups according to comparable signatures in a technique known as multispectral classification (Sabins, 2007). For instance, on a TM image, every pixel that depicts a region of wooded land should have a spectral signature that is similar. The goal of classification processes is to put these comparable pixels together.

This allows for the generation of a layer where each type of land cover is represented by a distinct class. The imaging system's spectral and spatial resolution properties determine how detailed the classes are. Generally speaking, Landsat imagery works well for making a map that classifies land cover. The computer looks for clusters—natural groups of related pixels—in an unsupervised classification technique (Jensen, 2009).

The Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm is used in ERDAS to carry out unsupervised categorization. The analyst enters a confidence threshold and the desired number of clusters using this technique. Clusters are then constructed iteratively by the computer or software, which means that they get increasingly better with each subsequent iteration. When the user-specified maximum number of iterations or the confidence level is reached, the iterations cease (Jensen, 2009). The computer will iteratively construct the clusters until it is 95% certain that it has achieved the optimal distribution of pixels into 30 clusters, for instance, if the user requests 30 clusters with 95% confidence.

The methane emission data of study area downloaded from the Sentinel-5 Precursor and the methane emission will be estimate by using the interpolation technique.

This methodology outlines the steps required to generate methane mixing ratio data for Haryana using Sentinel 5P imagery, making it valuable for environmental monitoring and policy formulation related to methane emissions in the region as represented in the figure 2.4.

Acquire Sentinel 5P satellite imagery containing methane mixing ratio data. Perform radiometric calibration and atmospheric correction on the raw satellite data to reduce atmospheric interference and noise. Re-project the satellite imagery to a common geographic coordinate system, such as WGS 84, to ensure compatibility with other spatial datasets and analysis. Isolate the specific band or channel in the satellite data that contains methane mixing ratio information.

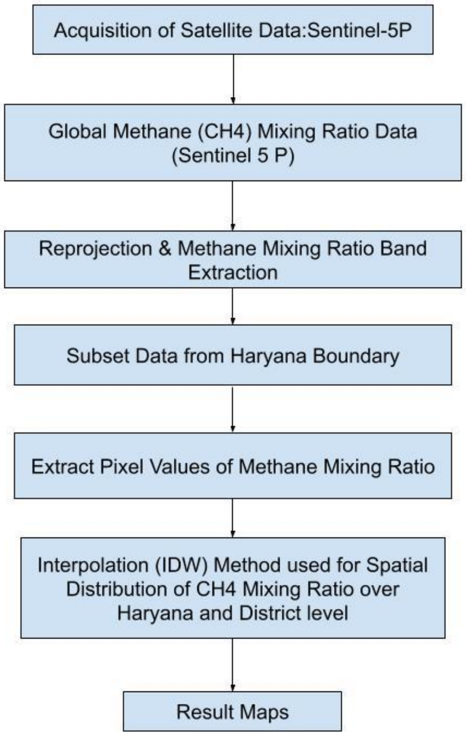


Figure 2.4: Represent the methodology flow chart.

Source: ESA (2019), Hu et al. (2018), and Burrough & McDonnell (1998).

This is typically a narrow spectral band sensitive to methane absorption. Define the spatial boundary of Haryana and uses this boundary to subset the methane mixing ratio data. This step ensures that only data relevant to Haryana are used for further analysis. Extract methane mixing ratio values for each pixel within the Haryana boundary. This will result in a dataset with methane concentration values for different locations within Haryana.

Use the Simple Kriging interpolation method to estimate methane mixing ratio values at locations where data were not directly measured. Simple kriging assumes that data values in space are not randomly distributed but exhibit spatial continuity. This means that values at nearby locations are more similar to each other than to values at distant locations. Aggregate the interpolated methane mixing ratio data to the district level within Haryana. This will provide estimates of methane concentrations for each district within the state. Calculate the overall methane estimation for Haryana by aggregating the methane mixing ratio values for the entire state. Generate result maps displaying the spatial distribution of methane mixing ratios over Haryana. These maps can visually represent the variation in methane concentrations across the state and its districts. Visualize the result maps and prepare a comprehensive report summarizing the findings. Include key statistics, trends, and insights related to methane levels in Haryana.

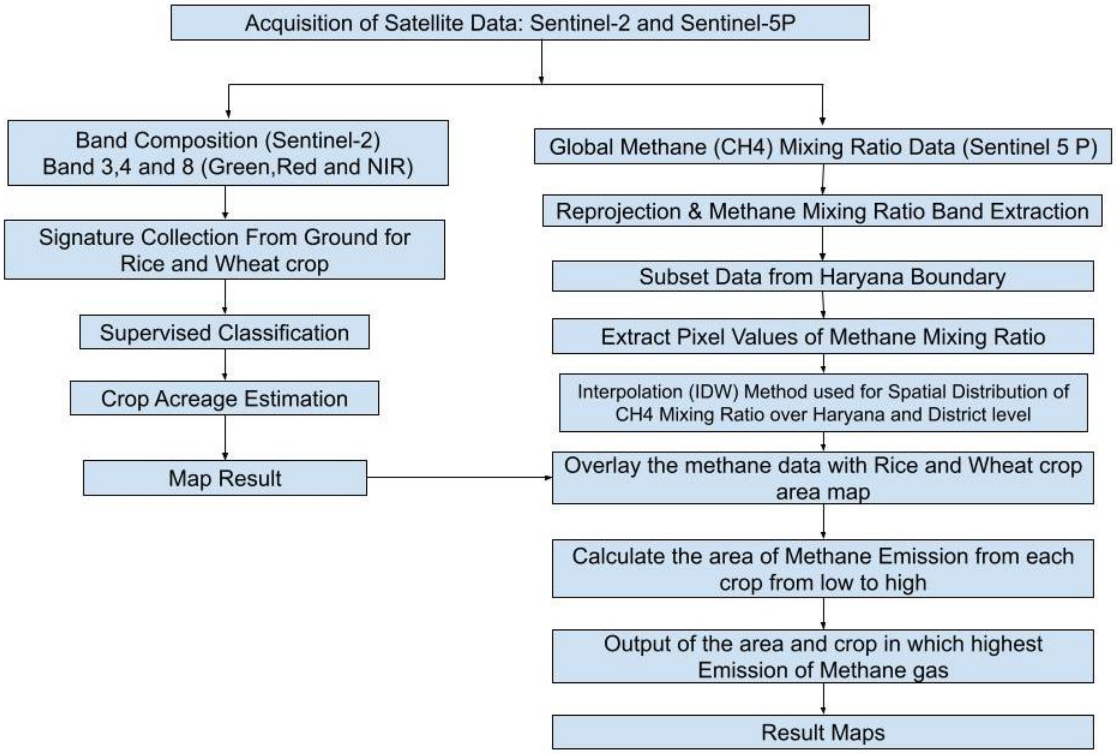


Figure 2.5: Flow chart of Methodology

(Data Source: ESA 2019, Jensen 2016, Hu et al. 2018 and Burrough & McDonnell 1998).

2.5. Interpolation Method: Geo-statistical techniques permit us to decide the ward variable anytime in the considered field, just as the vulnerability of the measurable assessment as a device to think about the most appropriate alternative (an itemized assessment of geo-statistical techniques embraced in the paper is given in the valuable data). The kriging technique is one of the geo-statistical interjection strategies that are utilized for displaying of spatial information. Kriging is a broadly utilized geo-statistical strategy that gives the “probably esteem” of the variable at a non-exploratory point. This assessor is straight, impartial and ideal (least mistake), and can be utilized from numerous points of view, as per the circumstance emerging in the spatial assessment issue within reach. The term kriging incorporates an assortment of introduction strategies whose point is to locate an ideal straight forecast. From the measurable perspective, kriging gives the best direct fair assessors.

2.6 Summary

Chapter 2 outlines the data sources and methodology used for assessing methane emissions from rice and wheat cultivation in Haryana. Sentinel-2A/B satellite data, offering high-resolution multispectral imagery, was employed for crop mapping, while Sentinel-5P data was utilized to estimate methane emissions through interpolation techniques like Simple Kriging. Ground truth data was collected via field surveys using mobile GPS devices to validate satellite-derived classifications. The data was processed in ERDAS Imagine software, where preprocessing steps like radiometric calibration and atmospheric correction were applied. The study employed supervised and unsupervised classification methods, including the ISODATA algorithm, to categorize land cover types and track changes over time. Geo-statistical techniques, particularly Kriging, were used to predict methane concentrations at unmeasured locations, resulting in spatial distribution maps of methane emissions for Haryana, contributing to environmental monitoring and sustainable management efforts.

CHAPTER-3

AREA ESTIMATION OF WHEAT AND RICE CROP USING DIP (DIGITAL IMAGE PROCESSING)

Introduction: Area Estimation of Wheat and Rice Crop Using Dip (Digital Image Processing)

Digital Image Processing (DIP) is used to estimate wheat and rice crop areas by analyzing sentinel 2 A/B satellite. The process involves preprocessing the images to enhance quality, calculating vegetation indices like NDVI to distinguish crops from non-vegetation areas, and then segmenting and classifying the image into different crop types using methods like thresholding or machine learning. Post-processing techniques help refine the classification and the area is estimated by counting pixels or converting pixel data into polygons. The accuracy is then assessed by comparing the results with actual field data or statistical measures. This approach allows for efficient, large-scale crop monitoring and area estimation.

3.1 Wheat Area Estimation:

The state of Haryana produces wheat as a cereal crop. The fourth-largest wheat-growing state is Haryana. In Haryana, wheat is the primary crop grown during the Rabi season. According to satellite data, Haryana's total wheat crop area in 2021–2022 was 21.14 lakh hectares, or 47.85% of the total area.

The districts in the central region of Haryana, which are dominated by wheat, have good soils and an extensive irrigation infrastructure. This region grows wheat in over 65% of Haryana's total land area. The eleven districts (Fatehabad, Jind, Kaithal, Karnal, Kurukshetra, Panipat, Rohtak, Sirsa, Sonipat and Palwal) listed above are fevering to all ideal circumstances for the wheat crop (Table 3.1). The physical and climatic circumstances, plan area, irrigation system, ground water availability, and riverine soil all contribute to this region of Haryana. Table 3.1 about 7.54 percent of Haryana is used for wheat cultivation.

Haryana's south is an extremely impoverished region that is prone to wheat. There are fewer favourable conditions for mustard crops, which predominate in this area.

Table 3.1: District wise Wheat area Estimation.

Sr. No.	District	Area in hac (district)	Area in hac (Wheat mask)	% between district area & wheat mask	Acreage between District Wheat Mask &State Wheat Mask (%)	Total acreage (%)
1	Fatehabad	252512.38	161365.71	63.90	7.63	65.37
2	Jind	275091.45	190188.6	69.14	9.00	
3	Kaithal	227414.15	168879.03	74.26	7.99	
4	Karnal	247051.69	163111.07	66.02	7.72	
5	Kurukshetra	168420.28	92918.02	55.17	4.40	
6	Panipat	130273.18	86159.4	66.14	4.08	
7	Rohtak	166906.98	84878.27	50.85	4.02	
8	Sirsa	426992.74	224233.27	52.51	10.61	
9	Sonipat	215722.32	127454.13	59.08	6.03	
10	Palwal	135954.82	82782.9	60.89	3.92	
11	Ambala	151202.99	71589.23	47.35	3.39	7.54
12	Panchkula	88292.59	11918.03	13.50	0.56	
13	Yamunanagar	171777.26	75971.52	44.23	3.59	
14	Bhiwani	329686.83	103480.17	31.39	4.90	27.08
15	CharkhiDadri	137349.63	35531.42	25.87	1.68	
16	Faridabad	74264.41	27690.08	37.29	1.31	
17	Gurugram	125953.44	29424.86	23.36	1.39	
18	Hisar	407523.72	191809.31	47.07	9.07	
19	Jhajhar	190215.07	61612.21	32.39	2.91	
20	Mahendergarh	194082.76	33837.99	17.43	1.60	
21	Nuh	150076.58	48332.39	32.21	2.29	
22	Rewari	150886.60	40778.98	27.03	1.93	
Total	**Haryana**	**4417652.0**	**2113946.6**	**47.9**	**100**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

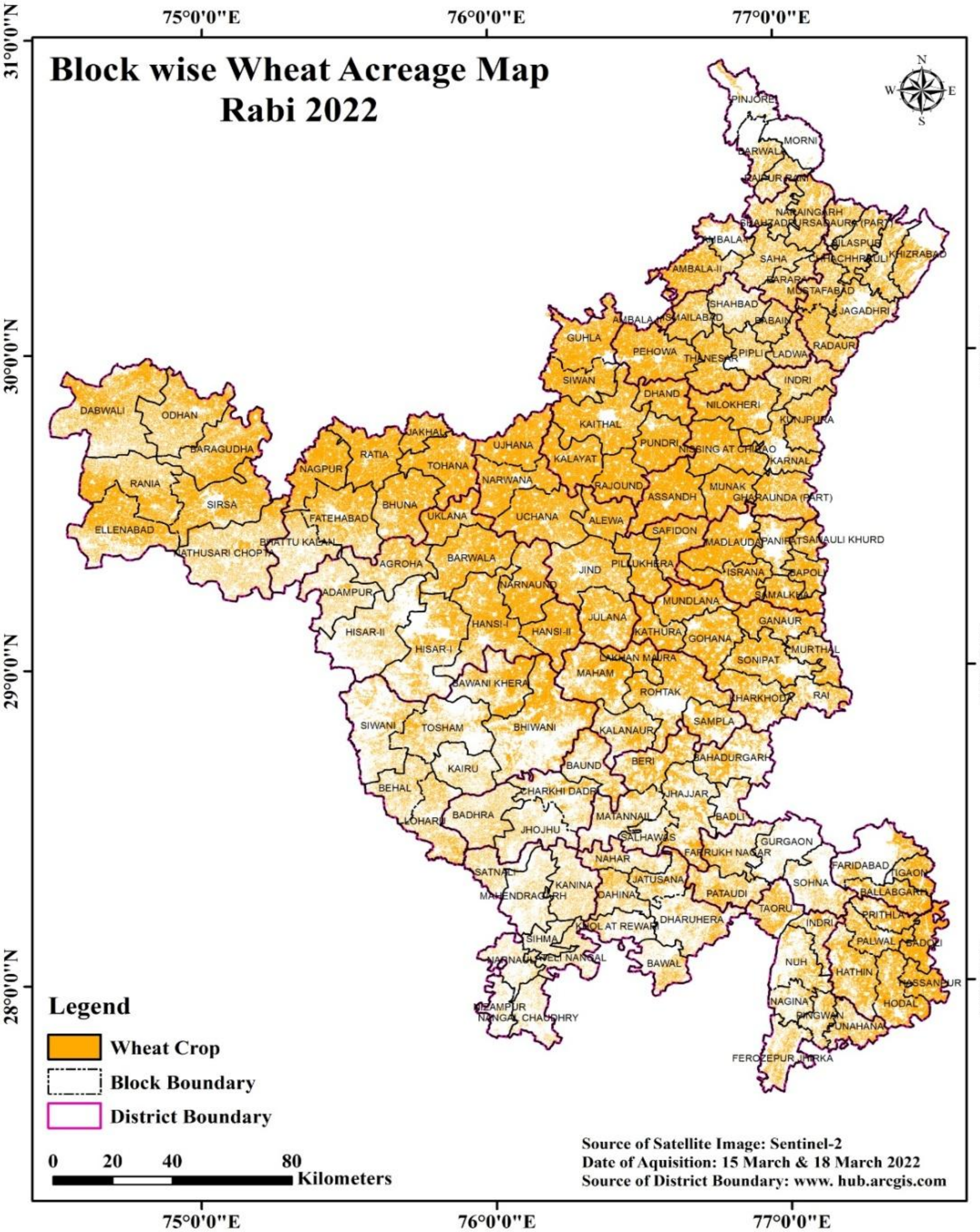


Figure 3.1: Block Wise Wheat Acreage Map Rabi 2022, (Data Source: Sentinel 2 Satellite Data 2022)

Arid weather, minimal irrigation, and sandy soil. Nine districts, including Bhiwani, Charkhi Dadri, Faridabad, Gurugram, Hisar, Jhajhar, Mahendergarh, Nuh and Rewari districts, are located in this area, which is mostly used for the cultivation of mustard, gram, and pulse crops (Table 3.1).

Approximately 27.08 percent of Haryana is planted with wheat. Supervised (ISODATA) pictures for the wheat fields under research for the months of March 2022 were observed using satellite data to calculate the acreage of wheat planted, wheat field acreages were calculated in ERDAS Imagine. The results of these calculations were contrasted with the area that the farmers reported during their field visits. The location area and attribute data gathered for the wheat fields are displayed in Supplementary Table 3.1.

Crop area estimation data has always been obtained via remote sensing. Geographic resolution. High resolution, which is necessary to record the growth patterns of crops. Crop yields have historically been correlated with vegetation indicators that include two or more spectral bands with predetermined weights. Recent developments in technology have made it possible to obtain high spatial resolution (3 m, commercial Planet) and high temporal resolution satellite data at moderate (10-30 m, combination of free Landsat 8 and Sentinel-2). This explains why Haryana's crop area estimation has produced positive outcomes. The most effective technique for estimating the area of crops, particularly wheat and paddy, is Supervised (ISODATA).

Ambala District:

The map titled “Wheat Crop Area of Ambala District in Haryana – 2022” shows the spatial distribution of wheat cultivation during the Rabi season using Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are represented in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that wheat is widely cultivated across most parts of Ambala district, especially in Ambala-II, Shahzadpur, Naraingarh, and surrounding rural blocks, reflecting the dominance of wheat as a major Rabi crop. Non-agricultural areas are mainly concentrated in urban centers such as Ambala-I and scattered settlement zones.

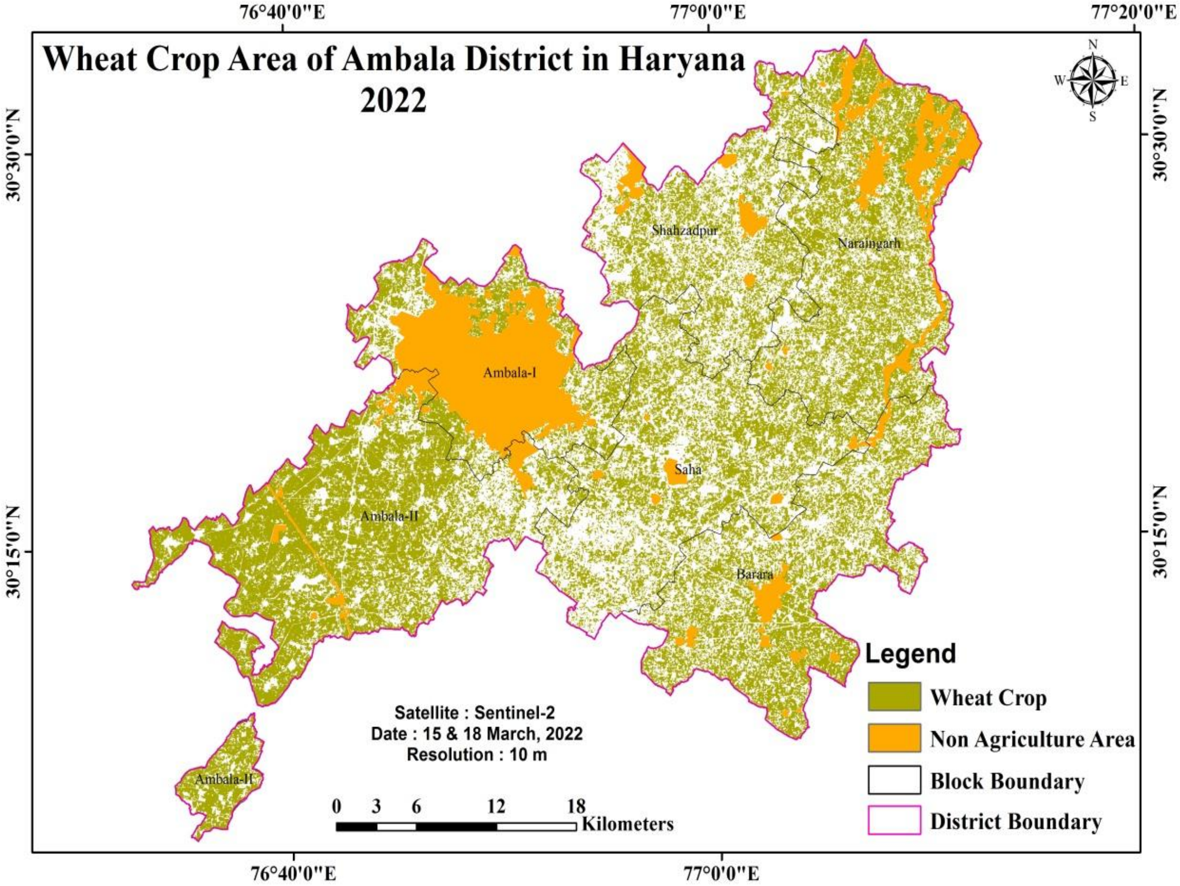


Figure 3.2: Wheat Crop Area of Ambala District in Haryana 2022 (Data Source: - Sentinel 2 Satellite Data 2022).

The table 3.2 revels to depict the area of wheat cultivation in different blocks within the Ambala region. Saha block has an area of 11,761.5 hectares dedicated to wheat cultivation, which constitutes about 16.5% of the total wheat cultivation area in the Ambala region. Barara follows closely with 11,173.8 hectares allocated for wheat cultivation, representing 15.7% of the total wheat cultivation area in Ambala. Shahzadpur wheat cultivation area in Shahzadpur is 8,187.4 hectares, contributing to 11.5% of the total.

Table: 3.2 Block wise Wheat area Estimation of Ambala District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Ambala	Saha	11761.5	16.5
2	Ambala	Barara	11173.8	15.7
3	Ambala	Shahzadpur	8187.4	11.5
4	Ambala	Ambala-Ii	21856.1	30.7
5	Ambala	Ambala-I	4826.9	6.8
6	Ambala	Naraingarh	13440.8	18.9
Total			**71246.5**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

Ambala-ii. This block has the largest wheat cultivation area among all, with 21,856.1 hectares, making up approximately 30.7% of the total wheat cultivation area in the Ambala region. Ambala-: Ambala- has a smaller wheat cultivation area compared to others, with 4,826.9 hectares, representing 6.8% of the total. Naraingarh: Naraingarh has a substantial wheat cultivation area of 13,440.8 hectares, accounting for 18.9% of the total wheat cultivation area in Ambala.

Bhiwani District:

The map titled “Wheat Crop Area of Bhiwani District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is moderately distributed across the district, with relatively higher concentration in the northern and north-eastern blocks such as Bawani Khera and parts of Bhiwani block. In contrast, western and southern areas including Siwani, Loharu, and parts of Bahal show comparatively sparse wheat coverage, reflecting semi-arid conditions and sandy soils. Non-agricultural land is mainly concentrated around Bhiwani town and scattered settlement clusters.

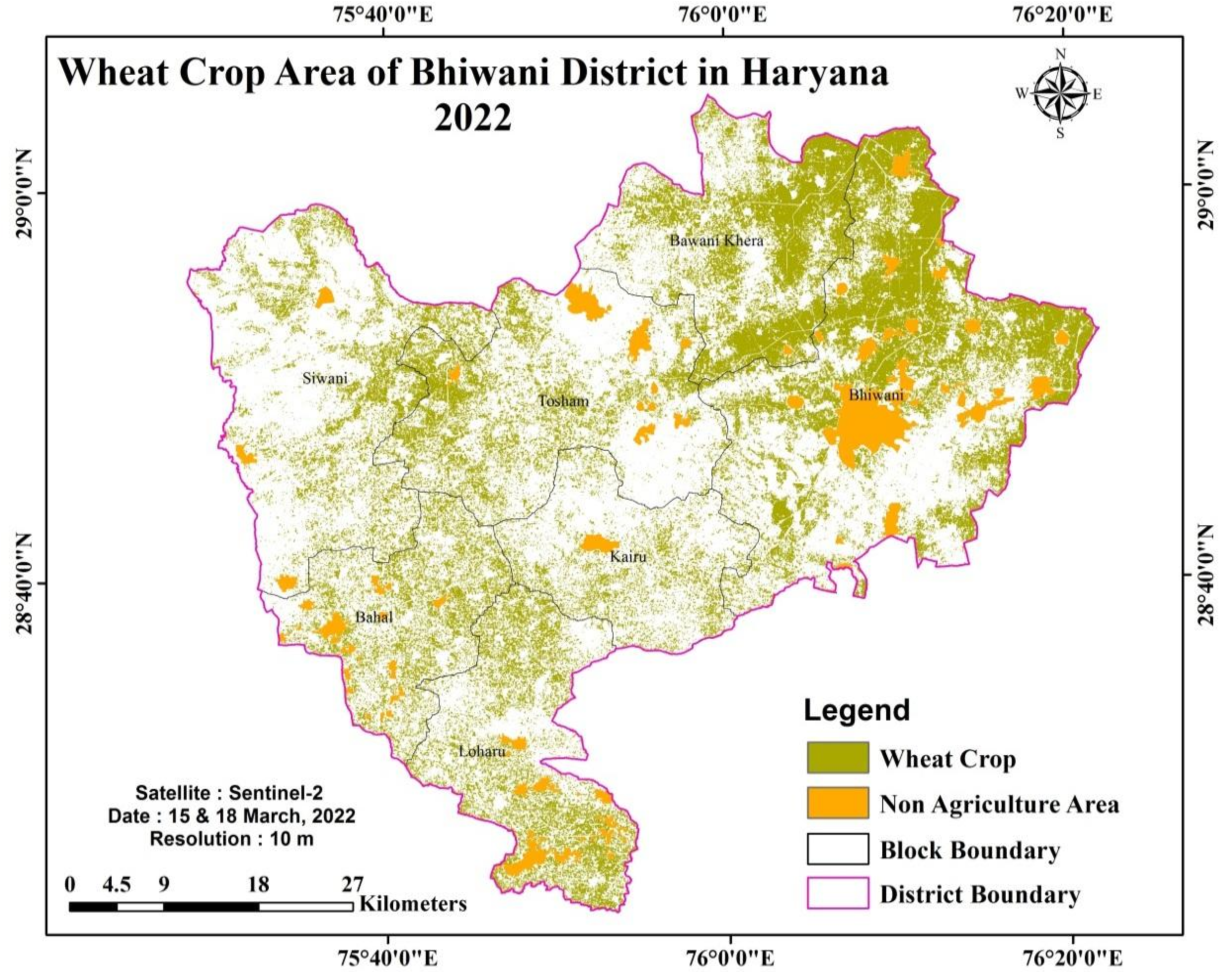


Figure 3.3: Wheat Crop Area of Bhiwani District in Haryana 2022, (Source: Sentinel 2 Satellite Data 2022)

The Bhiwani block has the highest wheat cultivation area, covering 33,657.7 hectares, which accounts for 32.5% of the total wheat cultivation area in the district. Kairu block, with 5,656.7 hectares of land, makes up 5.5% of the total wheat cultivation area. Behal Block: Covering 8,170.0 hectares of land, the Behal block contributes 7.9% of the total area under wheat cultivation Loharu Block with 12,122.1 hectares of land devoted to wheat farming, the Loharu block accounts for 11.7% of the Bhiwani District's total wheat cultivation area. Siwani Block: Covering 11,283.2 hectares of land, the Siwani block makes up 10.9% of the total area used for wheat cultivation in the district. Tosham block, with a land size of 13,301.2 hectares, accounts for 12.8% of the total area under wheat cultivation.

Table: 3.3 Block wise Wheat area Estimation of Bhiwani District

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Bhiwani	Loharu	12122.1	11.7
2	Bhiwani	Siwani	11283.2	10.9
3	Bhiwani	Tosham	13301.2	12.8
4	Bhiwani	Bawani Khera	19351.8	18.7
5	Bhiwani	Bhiwani	33657.7	32.5
6	Bhiwani	Kairu	5656.7	5.5
7	Bhiwani	Behal	8170.0	7.9
Total			103542.7	100

(Data Source: - Sentinel 2 Satellite Data)

Bawani Khera Block: With 19,351.8 hectares of land, the Bawani Khera block represents the largest portion, contributing 18.7% of the total wheat cultivated area in the district. With a land size of 13,301.2 hectares, the Toshan block accounts for 12.8% of the total area under wheat cultivation. With a land size of 19,351.8 hectares, the Bawani Khera block makes up the greatest portion, accounting for 18.7% of the total wheat cultivated area.

Charkhi Dadri District:

The map titled "Wheat Crop Area of Charkhi Dadri District in Haryana – 2022" presents the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are depicted in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that wheat is widely cultivated across most parts of the district, particularly in Dadri-I and Dadri-II blocks, where agricultural land dominates the landscape. However, the distribution appears relatively scattered and less dense compared to highly irrigated districts, reflecting semi-arid climatic conditions and variable soil characteristics. Non-agricultural land is mainly concentrated around Charkhi Dadri town and a few scattered settlement clusters. Overall, the map highlights that wheat is a major Rabi crop in the district, though its spatial spread varies due to physical constraints and irrigation availability.

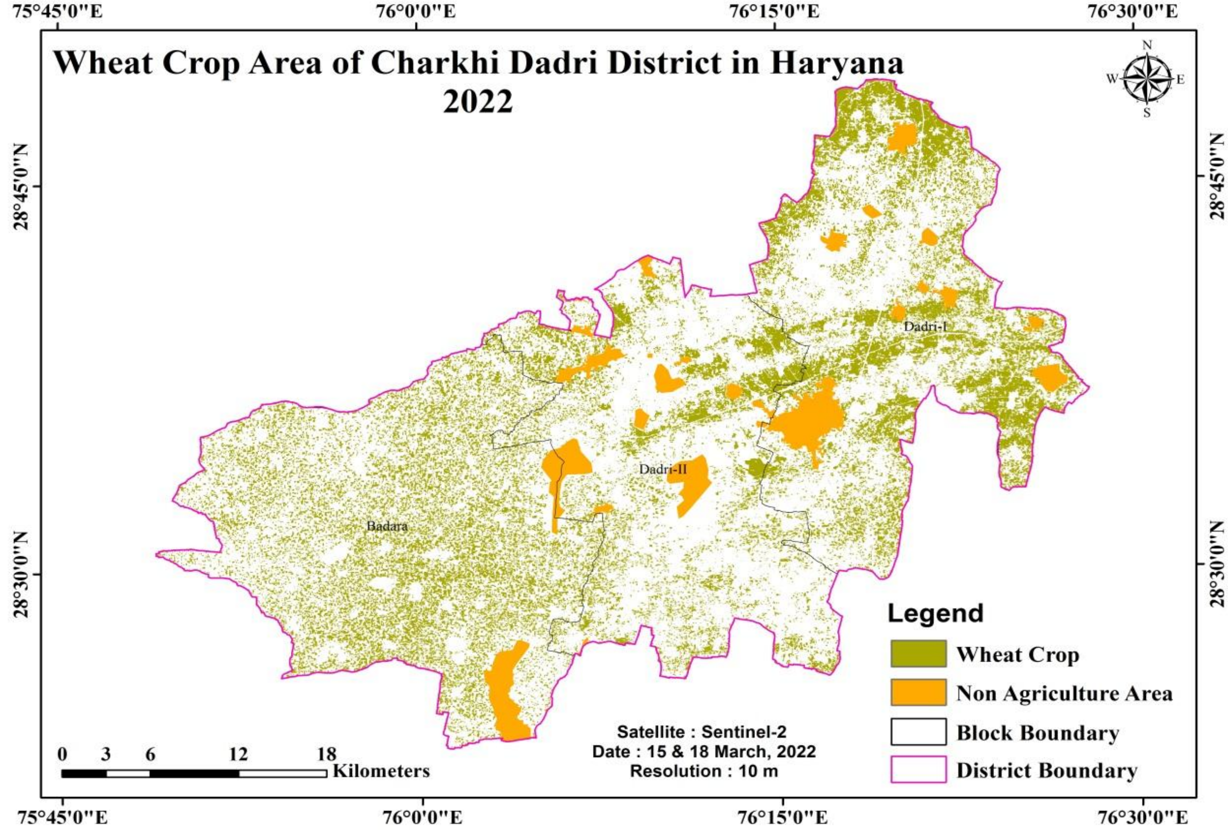


Figure 3.4: Wheat Crop Area of Charkhi Dadri District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The table 3.4 revels to depict the area of wheat cultivation in different blocks within the Charkhi Dadri region. Charkhi Dadri Block with 8,414.7 hectares of land devoted to wheat production, the block accounts for 23.7% of the region's total wheat cultivation area.The Badhra block occupies 10,453.7 hectares of land, representing 29.5% of the total area used for wheat farming in the region. Jhojhu Block land size of 6,647.5 hectares, the Jhojhu block comprises 18.7% of the total wheat cultivated area.The Baund block, with 9,970.0 hectares of land, contributes the most, making up 28.1% of the total wheat cultivated area in the region.

Table: 3.4 Block wise Wheat area Estimation of Charki Dadri District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Charki Dadri	Charkhi Dadri	8414.7	23.7
2	Charki Dadri	Badhra	10453.7	29.5
3	Charki Dadri	Jhojhu	6647.5	18.7
4	Charki Dadri	Baund	9970.0	28.1
Total			**35485.8**	**100**

(Data Source: - Sentinel 2 Satellite Data 2022)

The Badhra block occupies 10,453.7 hectares of land, or 29.5% of the entire area used for wheat farming. With a land size of 6,647.5 hectares, the Jhojhu block comprises 18.7% of the total wheat cultivated area. With a land size of 9,970.0 hectares, the Baund block contributes the most, making up 28.1% of the total wheat cultivated area.

Faridabad District:

The map titled "Wheat Crop Area of Faridabad District in Haryana – 2022" illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map clearly indicates that a large portion of Faridabad district is dominated by non-agricultural land, especially in the central and northern parts, reflecting rapid urbanization, industrial development, and expansion of built-up areas within the National Capital Region (NCR). Wheat cultivation is mainly concentrated in the eastern and south-eastern rural fringes of the district, particularly in Ballabgarh block, where agricultural land is still prevalent. The western part also shows limited agricultural patches interspersed with settlements.

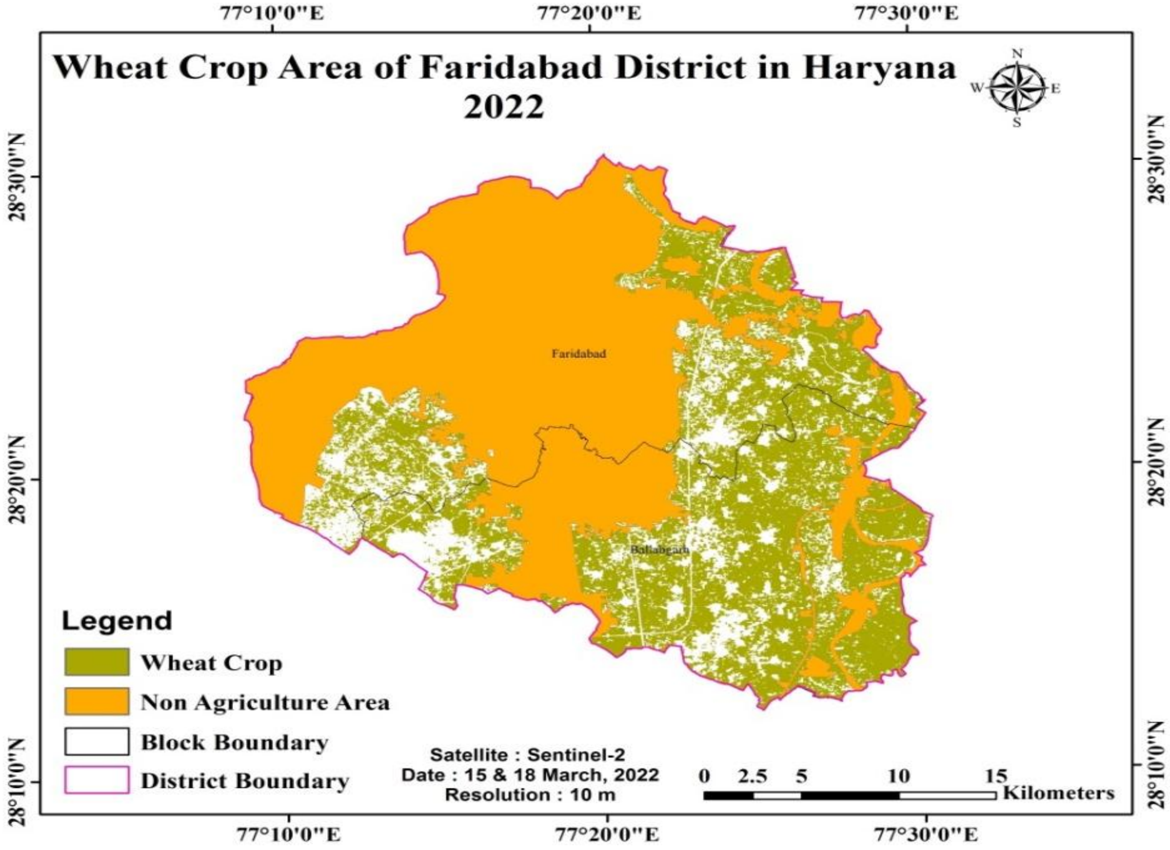


Figure 3.5: Wheat Crop Area of Faridabad District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The area of land allotted for wheat production in each of the blocks that make up the Faridabad district of Haryana is shown in this table. Now let's analyze the table 3.5 that with 6,736.9 hectares of land devoted to wheat agriculture.

Table: 3.5 Block wise Wheat area Estimation of Faridabad District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Faridabad	Faridabad	6736.9	24.5
2	Faridabad	Ballabgarh	12430.1	45.2
3	Faridabad	Tigaon	8323.6	30.3
Total			**27490.5**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The Faridabad block makes up 24.5% of the district's total area used for wheat cultivation Ballabgarh block is the largest contributor, accounting for 45.2% of the total area under wheat cultivation. 12,430.1 hectares of land are included in it that are used for wheat farming. With 8,323.6 hectares of land set aside for wheat cultivation, Tigaon Block accounts for 30.3% of the total area used for wheat cultivation.

Fatehabad District:

The map titled “Wheat Crop Area of Fatehabad District in Haryana – 2022” depicts the spatial distribution of wheat cultivation during the Rabi season using Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m spatial resolution. Wheat crop areas are represented in green, while non-agricultural areas are shown in orange, along with block and district boundaries.

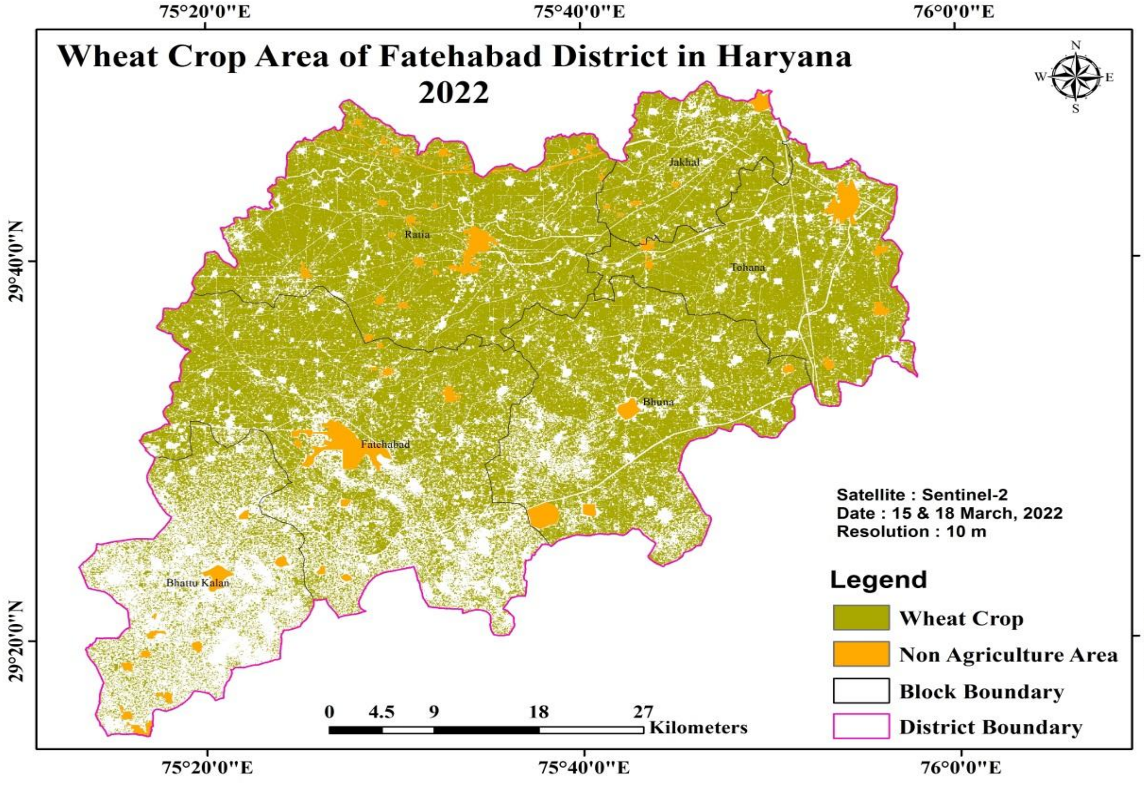


Figure 3.6: Wheat Crop Area of Fatehabad District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The map indicates that wheat is extensively cultivated across most parts of the district, particularly in blocks such as Ratia, Tohana, and Fatehabad, reflecting the district's strong agricultural base and availability of irrigation facilities. The distribution appears dense and continuous, especially in the northern and central regions, signifying fertile alluvial soils and intensive farming practices. Non-agricultural land is mainly confined to urban centers and scattered settlement clusters. Overall, the map highlights that Fatehabad is predominantly agrarian in character, with wheat serving as a major Rabi crop occupying a substantial proportion of the district's land area.

Table: 3.6 Block wise Wheat area Estimation of Fatehabad District**.**

Sr. No.	**District**	**Block Name**	**Area in Hectare (Wheat)**	**Area in %**
1	Fatehabad	Tohana	30503.1	18.9
2	Fatehabad	Bhattu Kalan	9960.3	6.2
3	Fatehabad	Nagpur	27804.6	17.2
4	Fatehabad	Ratia	28047.5	17.4
5	Fatehabad	Fatehabad	26828.5	16.6
6	Fatehabad	Bhuna	27247.5	16.9
7	Fatehabad	Jakhal	10955.7	6.8
Total			**161347.3**	**100**

(Source:- Sentinel 2 Satellite Data)

The 3.6 table gives details about the area of land in each block of the Fatehabad district in Haryana that is used for wheat farming. With 30,503.1 hectares of land devoted to wheat agriculture, the Tohana block accounts for 18.9% of the district's total wheat cultivation area in Fatehabad. Bhattu Kalan block covers 9,960.3 hectares of land, or 6.2% of the total area used for wheat cultivation. Nagpur block, which spans 27,804.6 hectares of land, accounts for 17.2% of the entire area used for wheat farming. With a land area of 28,047.5 hectares, the Ratia block also contributes 17.4% of the total wheat cultivated area. The block of Fatehabad, encompassing 26,828.5 hectares of land, accounts for 16.6% of the total area under wheat cultivation. The Bhuna block contributes similarly, with a land size of 27,247.5 hectares, or 16.9% of the total wheat cultivated area. With a land size of 10,955.7 hectares, the Jakhla block contributes the least, making just 6.8% of the total wheat cultivated area.

Gurugram District:

The map titled “Wheat Crop Area of Gurugram District in Haryana – 2022” presents the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries.

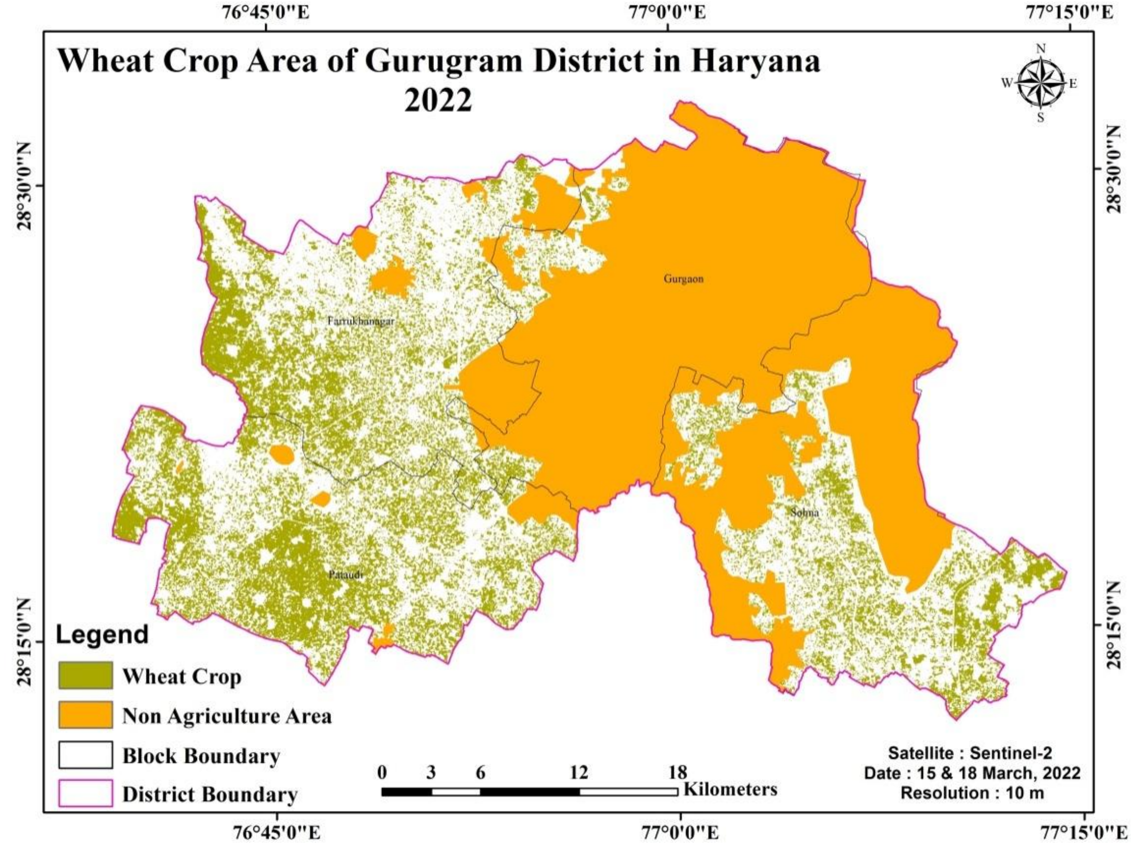


Figure 3.7: Wheat Crop Area of Gurugram District in Haryana 2022, (Data Source: Sentinel 2 Satellite Data 2022).

The map clearly indicates that a substantial portion of Gurugram district, particularly the Gurugram (Gurgaon) block in the central and northern parts, is dominated by non-agricultural land due to rapid urbanization, industrial expansion, and its integration within the National Capital Region (NCR). Wheat cultivation is mainly concentrated in the western and southern rural blocks such as Pataudi, Farrukhnagar, and Sohna, where agricultural land still prevails. The distribution of wheat appears fragmented compared to predominantly agrarian districts, reflecting land-use transformation and declining agricultural area.

The tables 3.7 represent the wheat crop area in Gurugram District With 6,248.3 hectares of land devoted to wheat agriculture, the Sohna block accounts for 21.2% of the district of Gurugram's total wheat cultivation area. With 40.7% of the total area under cultivation for wheat, the Pataudi block has the biggest share.

Table: 3.7 Block wise Wheat area Estimation of Gurugram District

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Gurugram	Sohna	6248.3	21.2
2	Gurugram	Pataudi	11985.3	40.7
3	Gurugram	Farrukh Nagar	9192.2	31.3
4	Gurugram	Gurgaon	1986.1	6.8
Total			**29411.9**	**100**

(Data Source: - Sentinel 2 Satellite Data 2022)

It includes 11,985.3 hectares of land where wheat is grown. With 9,192.2 hectares of land set aside for wheat cultivation, the Farrukh Nagar block accounts for 31.3% of the total area used for wheat cultivation. With a land area of 1,986.1 hectares, Gurgaon block contributes the least, making just 6.8% of the total wheat cultivation area.

Hisar District:

The map titled “Wheat Crop Area of Hisar District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m spatial resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map reveals that wheat cultivation is widely distributed across most parts of Hisar district, particularly in the eastern and north-eastern blocks such as

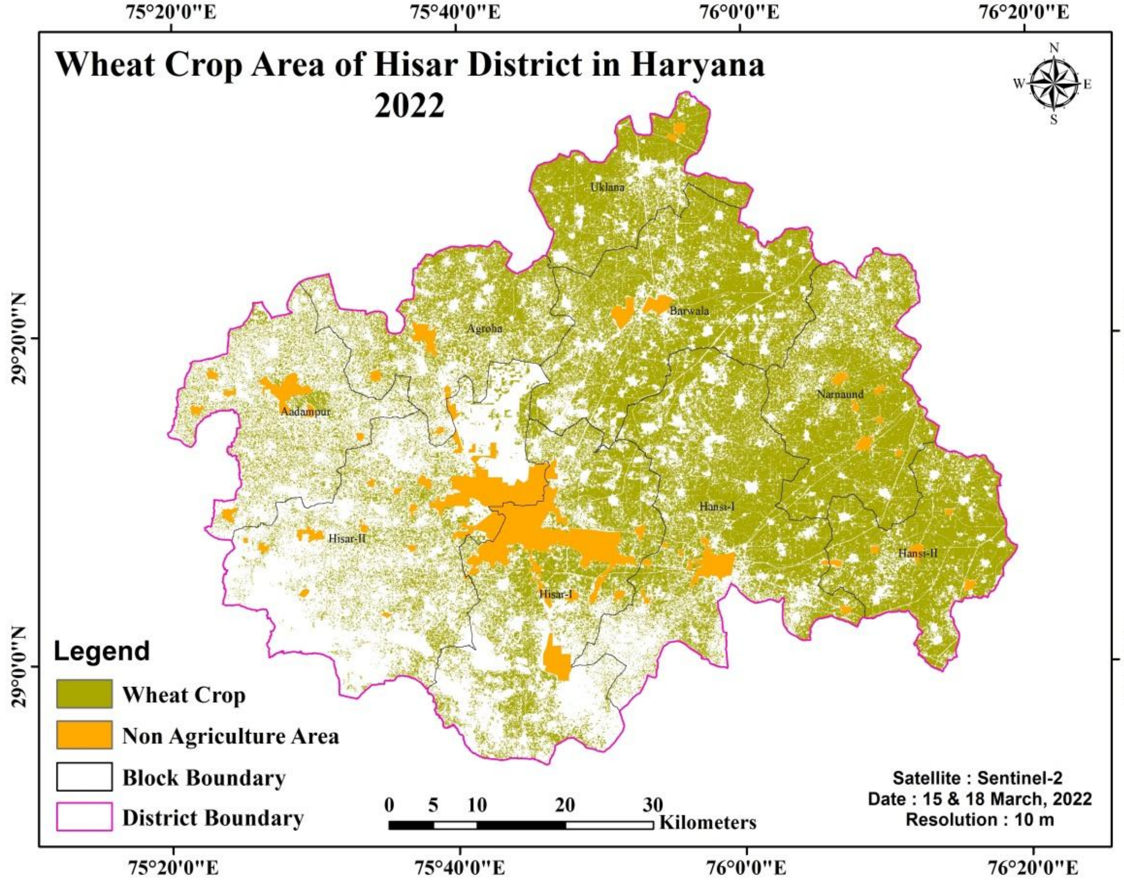


Figure 3.8: Wheat Crop Area of Hisar District in Haryana 2022 (Source: Sentinel 2 Satellite Data 2022)

Hansi-I, Hansi-II, Narnaund, and Barwala, where irrigation facilities and fertile soils support intensive agriculture. In contrast, the western and south-western parts, including parts of Adampur and Hisar blocks, show relatively lower wheat density due to semi-arid conditions and sandy soils. Non-agricultural land is mainly concentrated around Hisar city and other urban centers.

The area of land used for wheat production in each of the blocks that make up the Hisar district of Haryana is shown in this table 3.8. With 22,440.9 hectares of land devoted to wheat agriculture, the Hisar-I block accounts for 11.7% of the district's total wheat cultivation area. The Adampur block, encompassing 9,543.1 hectares of land, represents 5.0% of the total area under cultivation for wheat.

Table: 3.8 Block wise Wheat area Estimation of Hisar District.

Sr. No.	District Name	Block Name	Area in Hectare (Wheat)	Area in %
1	Hisar	Hisar-I	22440.9	11.7
2	Hisar	Adampur	9543.1	5.0
3	Hisar	Agroha	15969.3	8.3
4	Hisar	Uklana	13638.8	7.1
5	Hisar	Hansi-II	22201.9	11.5
6	Hisar	Hisar-II	11720.0	6.1
7	Hisar	Narnaund	26516.9	13.8
8	Hisar	Barwala	36261.2	18.8
9	Hisar	Hansi-I	34128.2	17.7
Total			**192420.3**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

With a total land area of 15,969.3 hectares, the Agroha block accounts for 8.3% of the total area used for wheat cultivation. The Uklana block, spanning 13,638.8 hectares of land, accounts for 7.1% of the entire area under wheat cultivation.

Jhajjar District:

The map titled “Wheat Crop Area of Jhajjar District in Haryana – 2022” shows the spatial distribution of wheat cultivation during the Rabi season using Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are represented in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that wheat is widely cultivated across most parts of the district, particularly in rural blocks such as Beri, Salhawas, and parts of Jhajjar block, reflecting the agricultural dominance of the region. However, significant non-agricultural patches are visible around Bahadurgarh and along the eastern side of the district due to urban expansion influenced by proximity to Delhi and the National Capital Region (NCR). The distribution of wheat appears moderately dense but somewhat fragmented near urban centers.

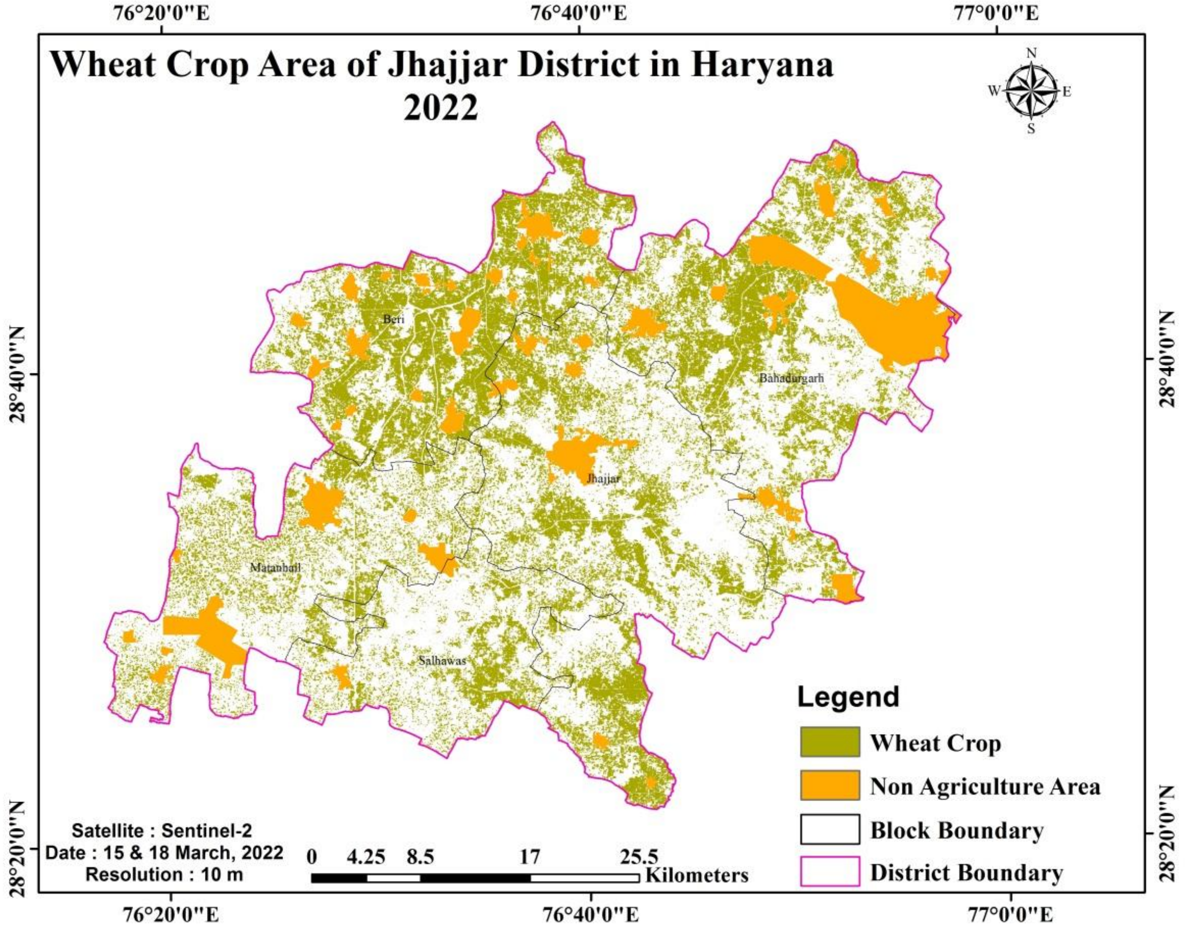


Figure 3.9: Wheat Crop Area of Jhajhar District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The area of land used for wheat production in each of the blocks that make up the Jhajhar district is shown in table 3.9. With 12,516.3 hectares of land devoted to wheat agriculture, the Bahadurgarh block accounts for 20.3% of the district of Jhajhar's total area used for wheat cultivation. The matannail block, spanning 9,032.4 hectares of land, comprises 14.7% of the entire wheat farming area.

With a land size of 3,632.1 hectares, the Salhawas block contributes 5.9% of the total area used for wheat cultivation. With a land size of 15,715.2 hectares, the Beri block makes up the highest contribution, accounting for 25.5% of the total wheat cultivated area.

Table:3.9 Block wise Wheat area Estimation of Jhajhar District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Jhajhar	Bahadurgarh	12516.3	20.3
2	Jhajhar	Matannail	9032.4	14.7
3	Jhajhar	Salhawas	3632.1	5.9
4	Jhajhar	Beri	15715.2	25.5
5	Jhajhar	Jhajhar	16257.1	26.4
6	Jhajhar	Badli	4468.3	7.3
Total			**61621.4**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The Jhajhar block, encompassing 16,257.1 hectares of land, accounts for 26.4% of the entire area under wheat cultivation. With a total land area of 4,468.3 hectares, the Badli block accounts for 7.3% of the total area under wheat cultivation.

Jind District:

The map titled "Wheat Crop Area of Jind District in Haryana – 2022" illustrates the spatial distribution of wheat cultivation during the Rabi season using Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are depicted in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map reveals that wheat cultivation is extensively and uniformly distributed across most parts of the district, particularly in blocks such as Narwana, Uchana, Alewa, Safidon, Julana, and Jind, reflecting the district's strong agricultural base and well-developed irrigation network. The density of wheat fields appears high and continuous, indicating fertile alluvial soils and intensive farming practices. Non-agricultural areas are mainly confined to urban centers and scattered settlement clusters.

The area of land used for wheat production in each of the blocks that make up Jind district, Haryana, is shown in this table 3.10. With 15,985.5 hectares of land devoted to wheat cultivation, Safidon Block makes about 11.0% of the Jind district's total wheat cultivation area. Ujhana block has a land area of 20,471.4 hectares, or 14.1% of the total area used for wheat farming. With a land size of 25,338.7 hectares, the Narwana block contributes 17.5% of the total wheat cultivated area.

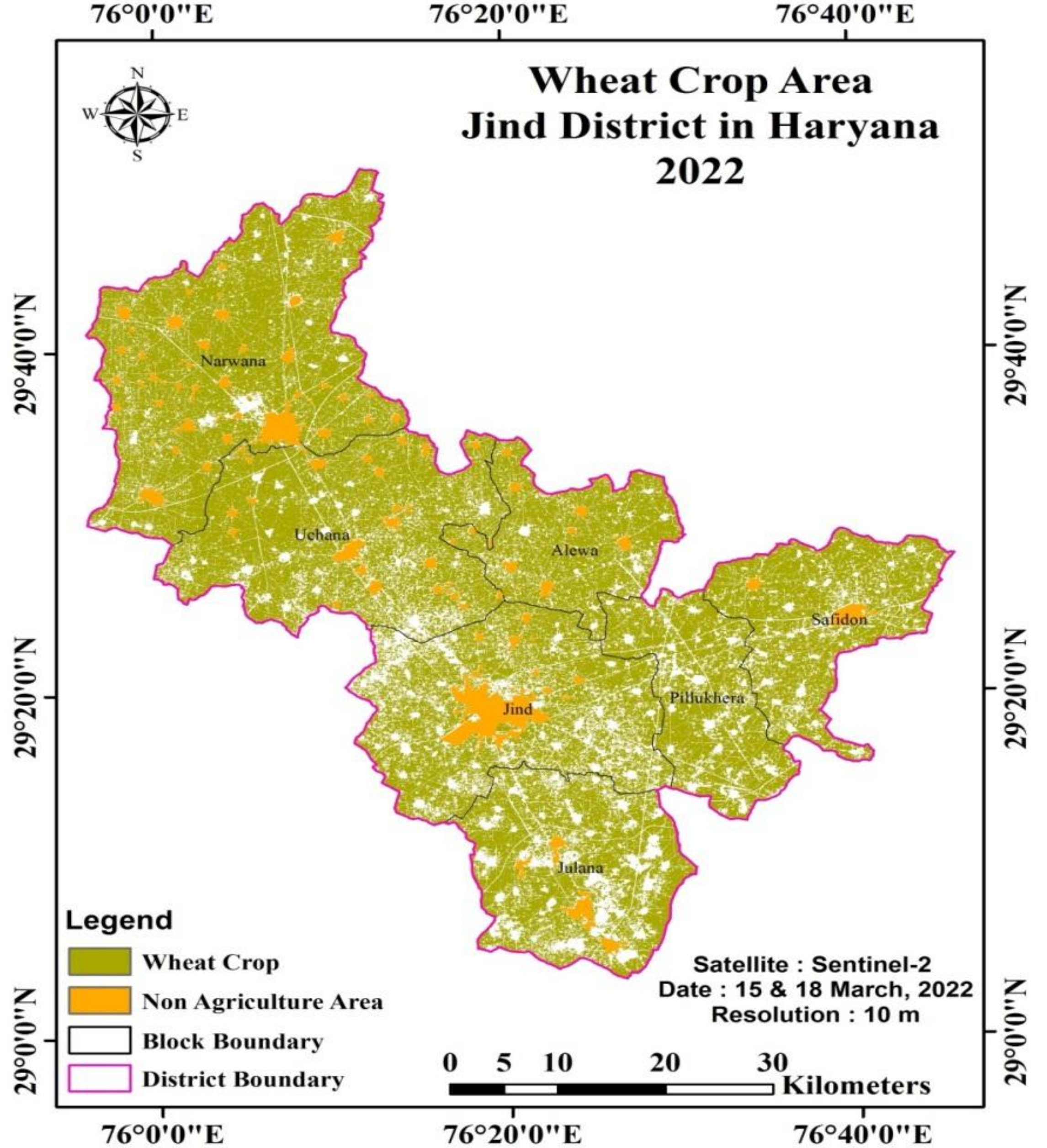


Figure 3.10: Wheat Crop Area of Jind District in Haryana 2022, (Data Source: Sentinel 2 Satellite Data 2022).

Table: 3.10 Block wise Wheat area Estimation of Jind District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Wheat)**	**Area in %**
1	Jind	Safidon	15985.5	11.0
2	Jind	Ujhana	20471.4	14.1
3	Jind	Narwana	25338.7	17.5
4	Jind	Uchana	34794.2	24.0
5	Jind	Alewa	17684.4	12.2
6	Jind	Julana	20631.8	14.2
7	Jind	Jind	28678.8	19.8
8	Jind	Pillukhera	18069.9	12.4
Total			**145197.8**	**100**

(Source: Sentinel 2 Satellite Data)

With a land area of 34,794.2 hectares, the Uchana block makes up the greatest portion, accounting for 24.0% of the total wheat cultivated area. Alewa block, which covers 17,684.4 hectares of land, accounts for 12.2% of the total area used for wheat farming. With a land size of 20,631.8 hectares, the Julana block comprises 14.2% of the total wheat cultivated area. The Jind block, encompassing 28,678.8 hectares of land, accounts for 19.8% of the total area under wheat cultivation. With a land area of 18,069.9 hectares, the Pillukhera block contributes 12.4% of the total area used for wheat cultivation.

Kaithal District:

The map titled “Wheat Crop Area of Kaithal District in Haryana – 2022” presents the spatial distribution of wheat cultivation during the Rabi season using Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map clearly indicates that wheat cultivation is extensively and uniformly distributed across almost the entire district, particularly in blocks such as Guhla, Siwan, Kaithal, Pundri, Kalayat, and Rajound. The high density and continuity of wheat fields reflect fertile alluvial soils, assured irrigation facilities, and intensive agricultural practices. Non-agricultural areas are mainly concentrated around Kaithal town and other settlement clusters, appearing as scattered patches within the dominant agricultural landscape.

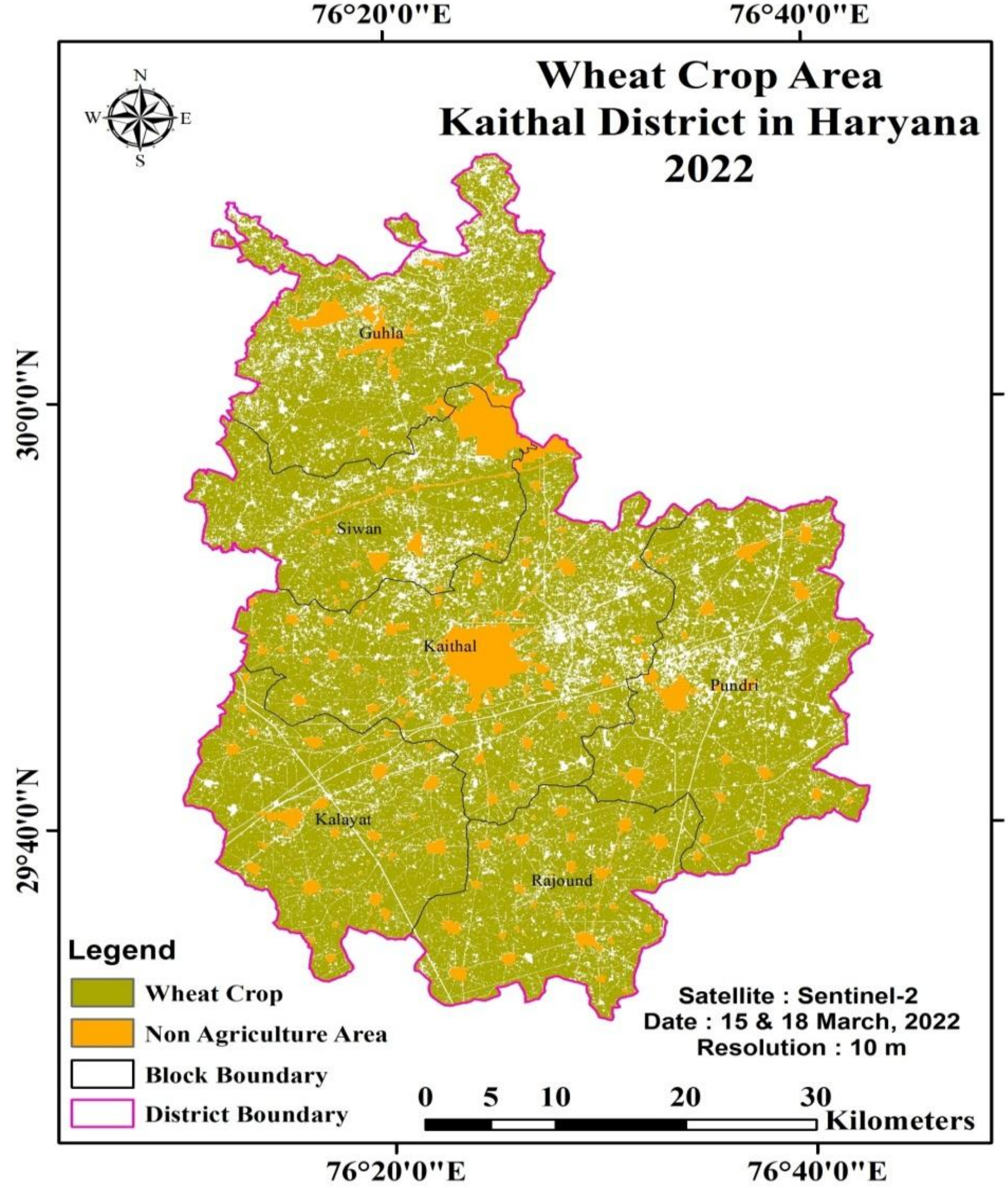


Figure 3.11: Wheat Crop Area of Kaithal District in Haryana 2022 (Data Source:- Sentinel 2 Satellite Data 2022).

Pundri Block accounts for 13.8% of the Kaithal district's total area under cultivation. With 15.4% of the total area under cultivation for wheat, the Guhla block has the biggest percentage. It includes 25,961.4 hectares of land used for wheat farming. Siwan Block, which covers 20,257.8 hectares of land, contributes 12.1% of the total area used for wheat cultivation. With a land size of 36,844.9 hectares, the Kaithal block accounts for 21.9% of the total area used for wheat farming.

Table 3.11: Block wise Wheat area Estimation of Kaithal District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Kaithal	Pundri	23130.3	13.8
2	Kaithal	Guhla	25961.4	15.4
3	Kaithal	Siwan	20257.8	12.1
4	Kaithal	Kaithal	36844.9	21.9
5	Kaithal	Dhand	16996.5	10.1
6	Kaithal	Kalayat	24502.2	14.6
7	Kaithal	Rajound	20908.1	12.4
Total			**168601.1**	**100**

(Source:- Sentinel 2 Satellite Data)

Dhand block, with a land area of 16,996.5 hectares, contributes 10.1% of the total area used for wheat cultivation. Kalayat block has a land area of 24,502.2 hectares, or 14.6% of the total area used for wheat farming. Rajound Block, which has a land size of 20,908.1 hectares, contributes 12.4% of the total area used for wheat cultivation.

Karnal District:

The map titled “Wheat Crop Area of Karnal District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m spatial resolution. Wheat crop areas are represented in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map reveals that wheat cultivation is highly extensive and uniformly distributed across almost the entire district, particularly in blocks such as

Nilokheri, Indri, Nissing, Assandh, and Gharaunda. The dense and continuous coverage of wheat fields reflects Karnal's fertile alluvial soils, well-developed canal irrigation system, and advanced agricultural practices, which make it one of the leading wheat-producing districts in Haryana. Non-agricultural areas are mainly concentrated around Karnal city and other urban centers, appearing as localized patches within the dominant agricultural landscape.

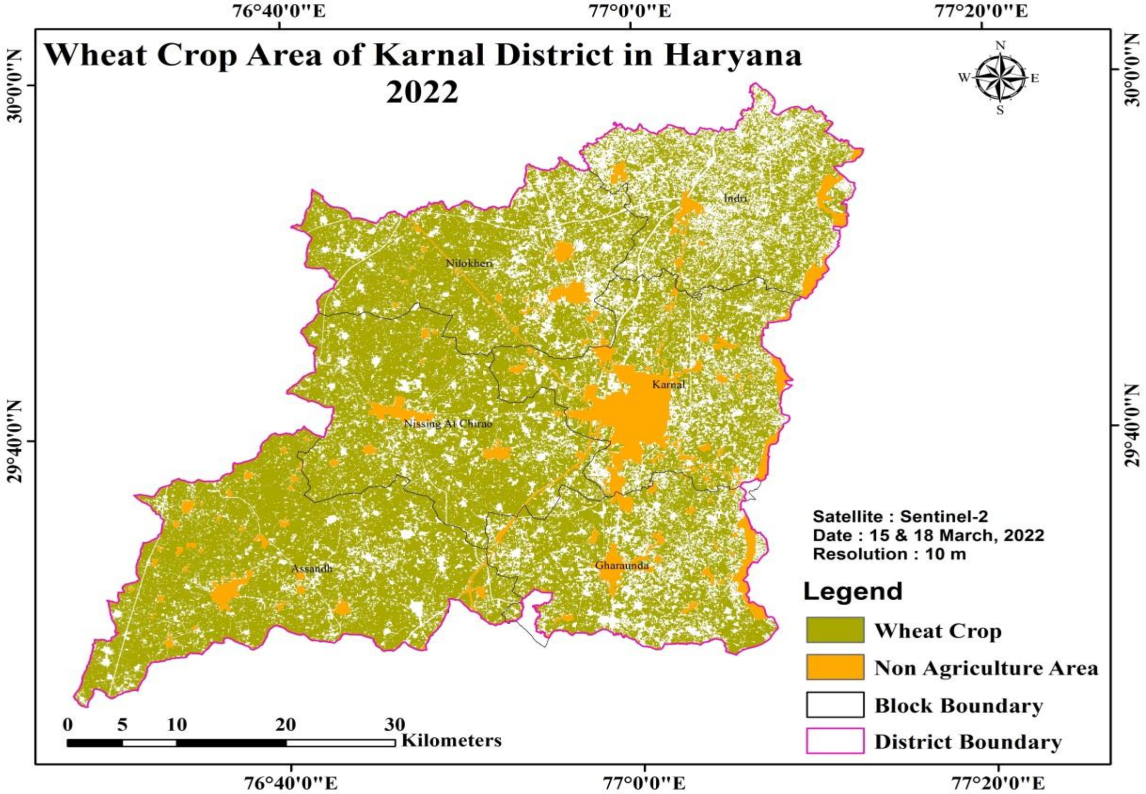


Figure 3.12: Wheat Crop Area of Karnal District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The area of land used for wheat production in each of the blocks that make up the Karnal district of Haryana is shown in this table 3.12. The table 3.12 represents With 13,067.8 hectares of land devoted to wheat farming, the Karnal block itself makes up 8.3% of the district's total wheat cultivation area. With its 20.3% contribution to the overall area under wheat production, the Assandh block has the biggest percentage.

Table: 3.12 Block wise Wheat area Estimation of Karnal District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Karnal	Karnal	13067.8	8.3
2	Karnal	Assandh	31913.6	20.3
3	Karnal	Nissing (Chirao)	21701.3	13.8
4	Karnal	Munak	14493.5	9.2
5	Karnal	Nilokheri	26094.5	16.6
6	Karnal	Indri	17881.6	11.4
7	Karnal	Kunjpura	14118.6	9.0
8	Karnal	Gharaunda (Part)	17661.5	11.3
Total			**156932.4**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

It includes 31,913.6 hectares of land used for wheat farming. With a land size of 21,701.3 hectares, nissing at Chirao block contributes 13.8% of the total wheat cultivation area. With a land size of 14,493.5 hectares, the Munak block accounts for 9.2% of the total area used for wheat cultivation. The Nilokheri block, spanning 26,094.5 hectares of land, comprises 16.6% of the entire area under wheat cultivation. With a land size of 17,881.6 hectares, the Indri block accounts for 11.4% of the total area used for wheat cultivation. Kunjpura block, which covers 14,118.6 hectares of land, accounts for 9.0% of the total area used for wheat cultivation. With a land size of 17,661.5 hectares, the Gharaunda (Part) block contributes 11.3% of the total wheat cultivated area.

Kurukshetra District:

The map titled “Wheat Crop Area of Kurukshetra District in Haryana – 2022” depicts the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is highly extensive and uniformly spread across almost the entire district, particularly in blocks such as Pehowa, Thanesar, Shahbad, Ladwa, and Ismailabad. The dense and continuous coverage reflects fertile alluvial soils, assured canal irrigation, and intensive agricultural practices, making Kurukshetra one of the prominent wheat-producing districts of Haryana. Non-agricultural land is mainly concentrated around Thanesar town and other urban centers, appearing as localized patches within the dominant agricultural landscape.

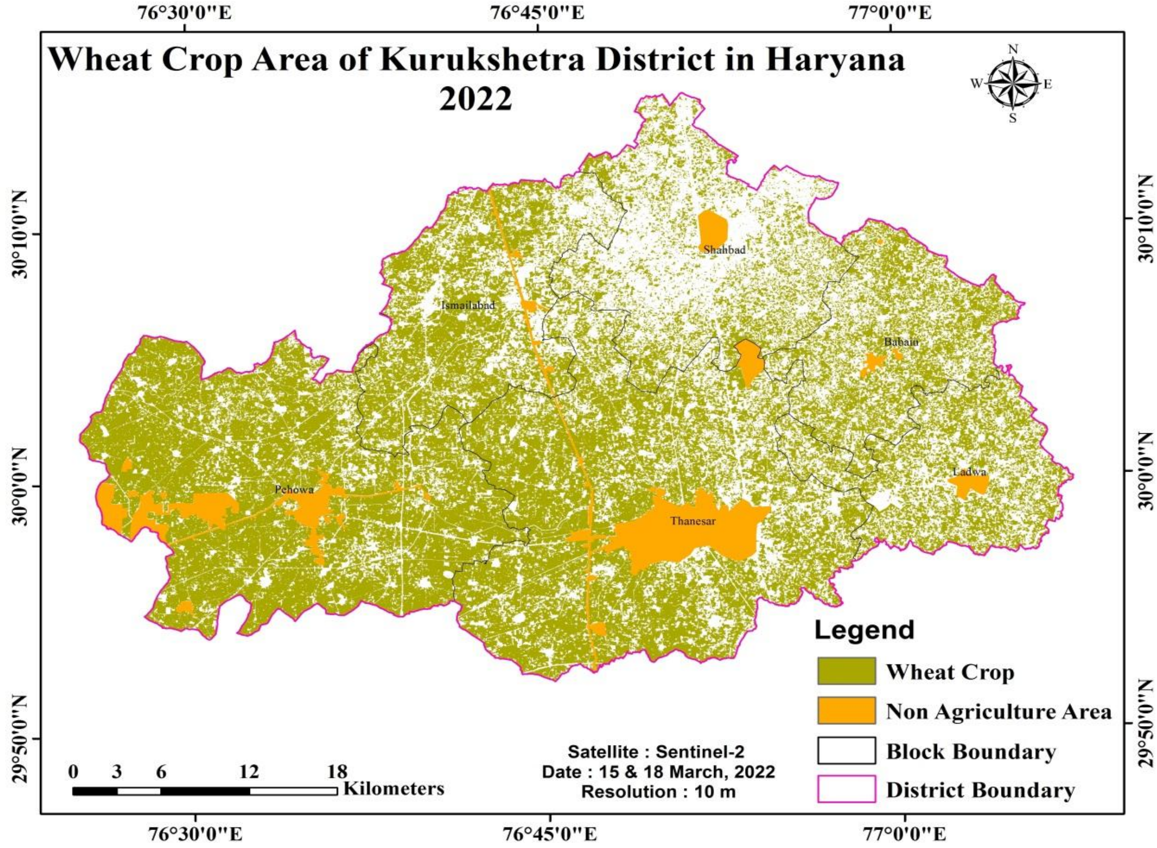


Figure 3.13: Wheat Crop Area of Kurukshetra District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The area of land used for wheat production in each of the blocks that make up the Kurukshetra district of Haryana is shown in this table 3.13. Now let's dissect the table: 3.13.

With 8,024.6 hectares of land devoted to wheat farming, the Ladwa block accounts for 8.7% of the Kurukshetra district's total area under cultivation. With 33.4% of the total area under cultivation, the Pehowa block has the biggest share. It includes 30,880.7 hectares of land where wheat is grown. With a land size of 19,321.7 hectares, the Thanesar block accounts for 20.9% of the total area used for wheat cultivation. With a land size of 11,433.1 hectares, the Ismailabad block accounts for 12.4% of the total area used for wheat cultivation.

Table: 3.13 Block wise Wheat area Estimation of Kurukshetra District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Wheat)**	**Area in %**
1	Kurukshetra	Ladwa	8024.6	8.7
2	Kurukshetra	Pehowa	30880.7	33.4
3	Kurukshetra	Thanesar	19321.7	20.9
4	Kurukshetra	Ismailabad	11433.1	12.4
5	Kurukshetra	Shahbad	7884.0	8.5
6	Kurukshetra	Pipli	8558.0	9.3
7	Kurukshetra	Babain	6316.7	6.8
Total			**92418.7**	**100**

(Data Source:- Sentinel 2 Satellite Data 2022)

With a total land area of 7,884.0 hectares, Shahbad Block accounts for 8.5% of the total area used for wheat farming. Pipli block, covering 8,558.0 hectares of land, makes up 9.3% of the entire area used for wheat farming. Babain Block, whose land area is 6,316.7 hectares, contributes 6.8% of the total area used for wheat cultivation.

Mahendergarh District:

The map titled “Wheat Crop Area of Mahendergarh District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is relatively sparse and unevenly distributed across the district compared to the eastern alluvial plains of Haryana. Higher concentrations of wheat are observed in blocks such as Kanina Khas and parts of Mahendergarh and Ateli Mandi, where irrigation facilities are available. In contrast, southern and south-western areas including Narnaul, Nizampur, and Nangal Chaudhary show fragmented and scattered wheat patches due to semi-arid climatic conditions, undulating terrain, and limited water availability. Non-agricultural land is mainly concentrated around urban centers and hilly tracts.

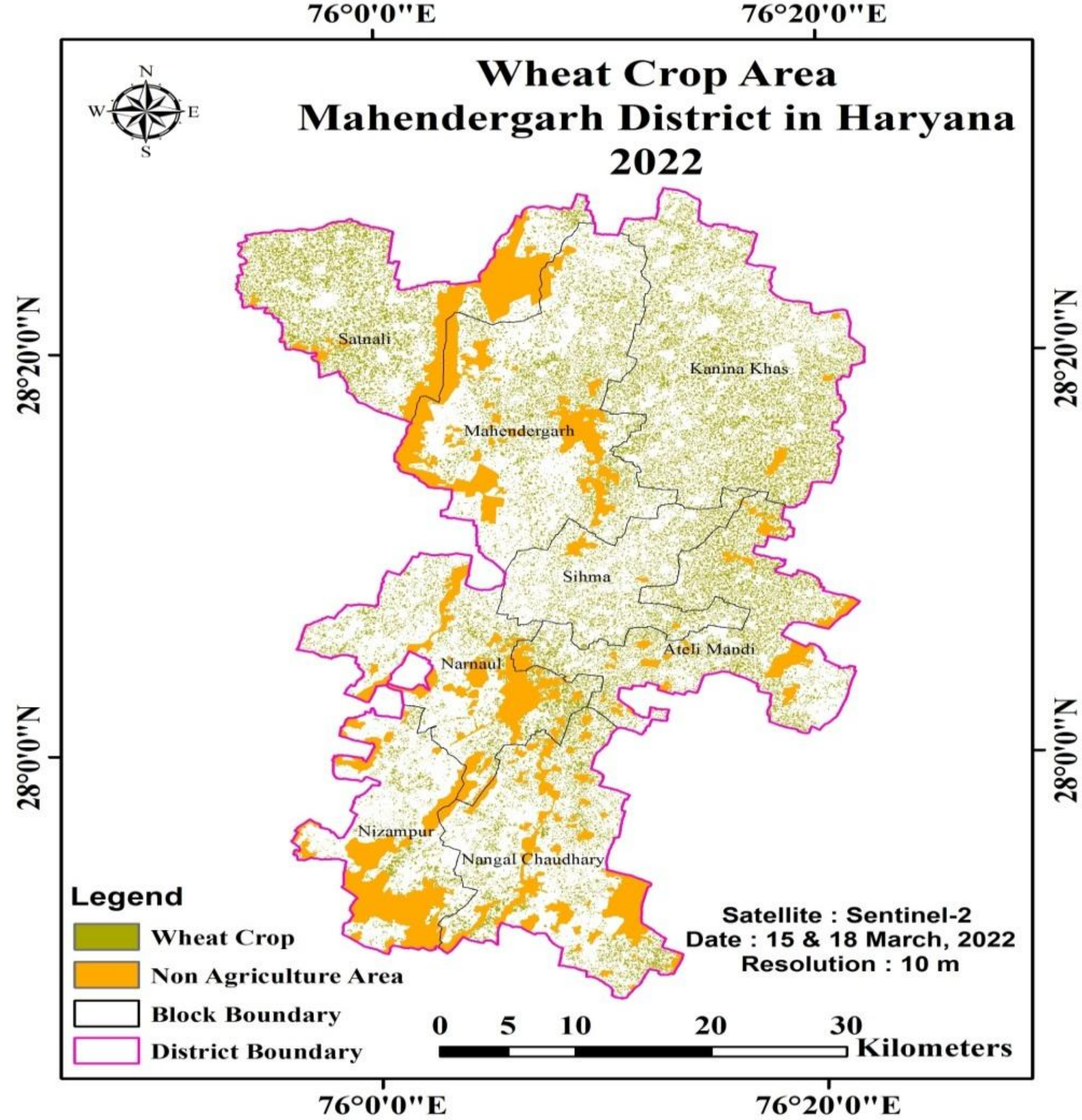


Figure 3.14: Wheat Crop Area of Mahendragarh District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The table no 3.14 is shown the distribution of wheat area among the blocks of Mahendergarh. With a particular size Ateli Nangal of 5132.2 hectares, this block accounts for 15.2% of the total area used for wheat cultivation With an area of 5083.1 hectares, Satnali contributes 15.1% as well, much as Ateli Nangal.

Table: 3.14 Block wise Wheat area Estimation of Mahendragarh District**.**

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Mahendragarh	Ateli Nangal	5132.2	15.2
2	Mahendragarh	Satnali	5083.1	15.1
3	Mahendragarh	Mahendragarh	5264.4	15.6
4	Mahendragarh	Sihma	2549.2	7.6
5	Mahendragarh	Kanina	8588.9	25.5
6	Mahendragarh	Nizampur	1198.2	3.6
7	Mahendragarh	Nangal Chaudhry	3248.2	9.6
8	Mahendragarh	Narnaul	2671.3	7.9
Total			**33735.4**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

Mahendergarh covering 5264.4 hectares, this block provides 15.6% of the total area used for wheat cultivation. With 2549.2 hectares, Sihma makes up 7.6% of the entire area used for wheat farming.

Nuh District:

The map titled “Wheat Crop Area of Nuh District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are depicted in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map reveals that wheat cultivation in Nuh district is relatively sparse and fragmented compared to the central and northern districts of Haryana. Higher concentrations of wheat are observed in parts of Taoru and Punhana blocks, whereas large portions of Nuh, Nagina, and Firozpur Jhirka show scattered and discontinuous patches of cultivation. The significant presence of non-agricultural land, especially along the western and southern margins, reflects hilly terrain of the Aravalli range, limited irrigation facilities, and semi-arid climatic conditions.

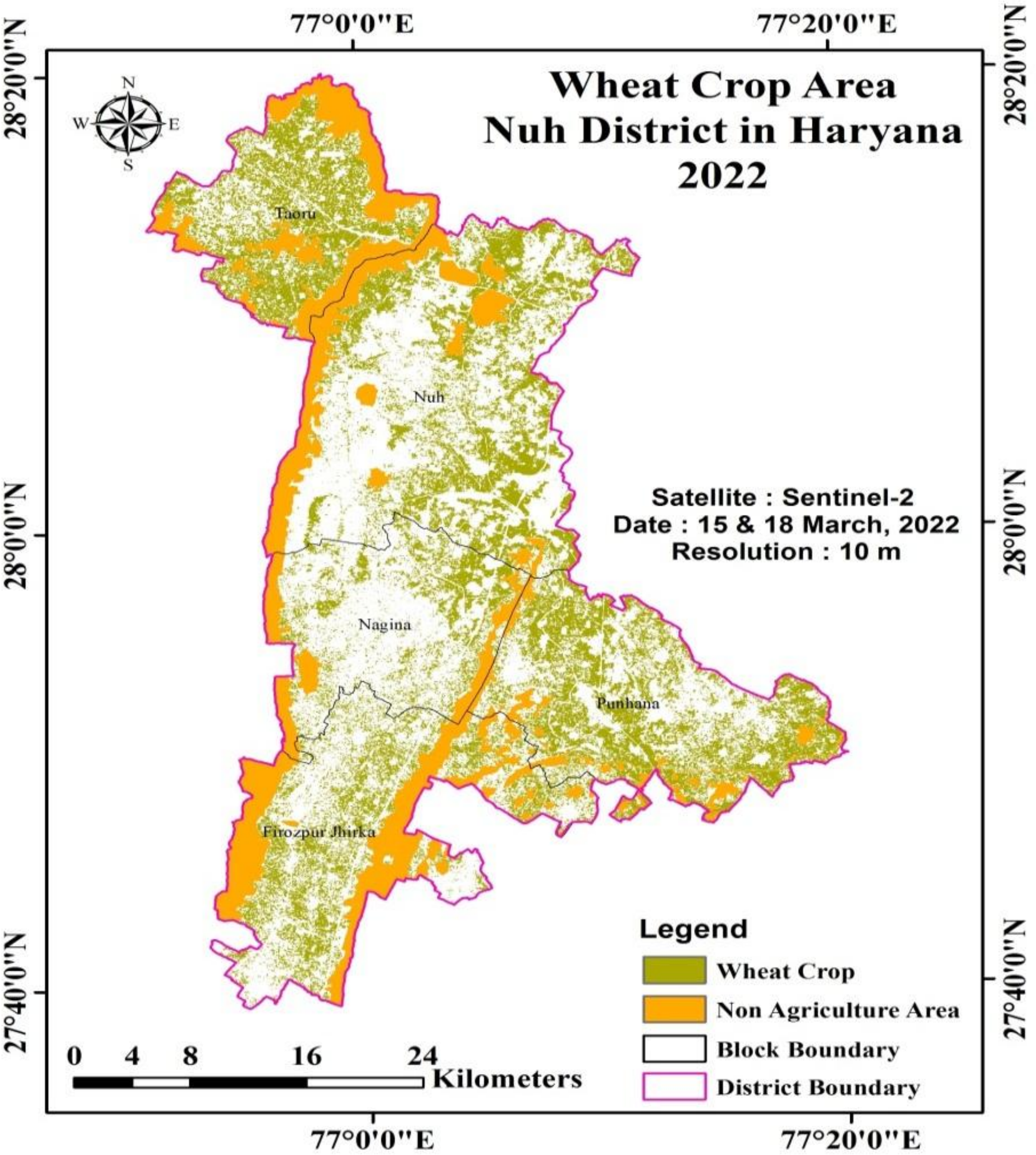


Figure 3.15: Wheat Crop Area of Nuh District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The Table no 3.15 represents the block wise area of Nuh district, Punahana block of this district total wheat area is 9464.2 hectares, or 15.8% of the district's total area under cultivation. Taoru block, with 9210.2 hectares, accounts for 15.3% of the district's wheat crop.

Table: 3.15: Block wise Wheat area Estimation of Nuh District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Nuh	Punahana	9464.2	15.8
2	Nuh	Taoru	9210.2	15.3
3	Nuh	Indri	17881.6	29.8
4	Nuh	Nuh	7971.5	13.3
5	Nuh	Nagina	3322.2	5.5
6	Nuh	Ferozepur Jhirka	6955.0	11.6
7	Nuh	Pingwan	5226.9	8.7
Total			**60031.5**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

With a total area under cultivation of 17881.6 hectares, or 29.8% of the total wheat area, Indri is the block with the biggest area under cultivation. Nuh wheat-growing area in Nuh block is 7971.5 hectares, or 13.3% of the district's total area.

Palwal District:

The map titled “Wheat Crop Area of Palwal District in Haryana – 2022” shows the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m spatial resolution. Wheat crop areas are represented in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that wheat cultivation is widely distributed across most parts of the district, particularly in blocks such as Hathin, Hodal, Hassanpur, and Palwal, reflecting the agrarian nature of the region. The coverage appears dense and continuous in rural areas, supported by irrigation facilities and fertile soils. Non-agricultural land is mainly concentrated around urban centers like Palwal and Prithla, where settlement expansion and infrastructural development are visible.

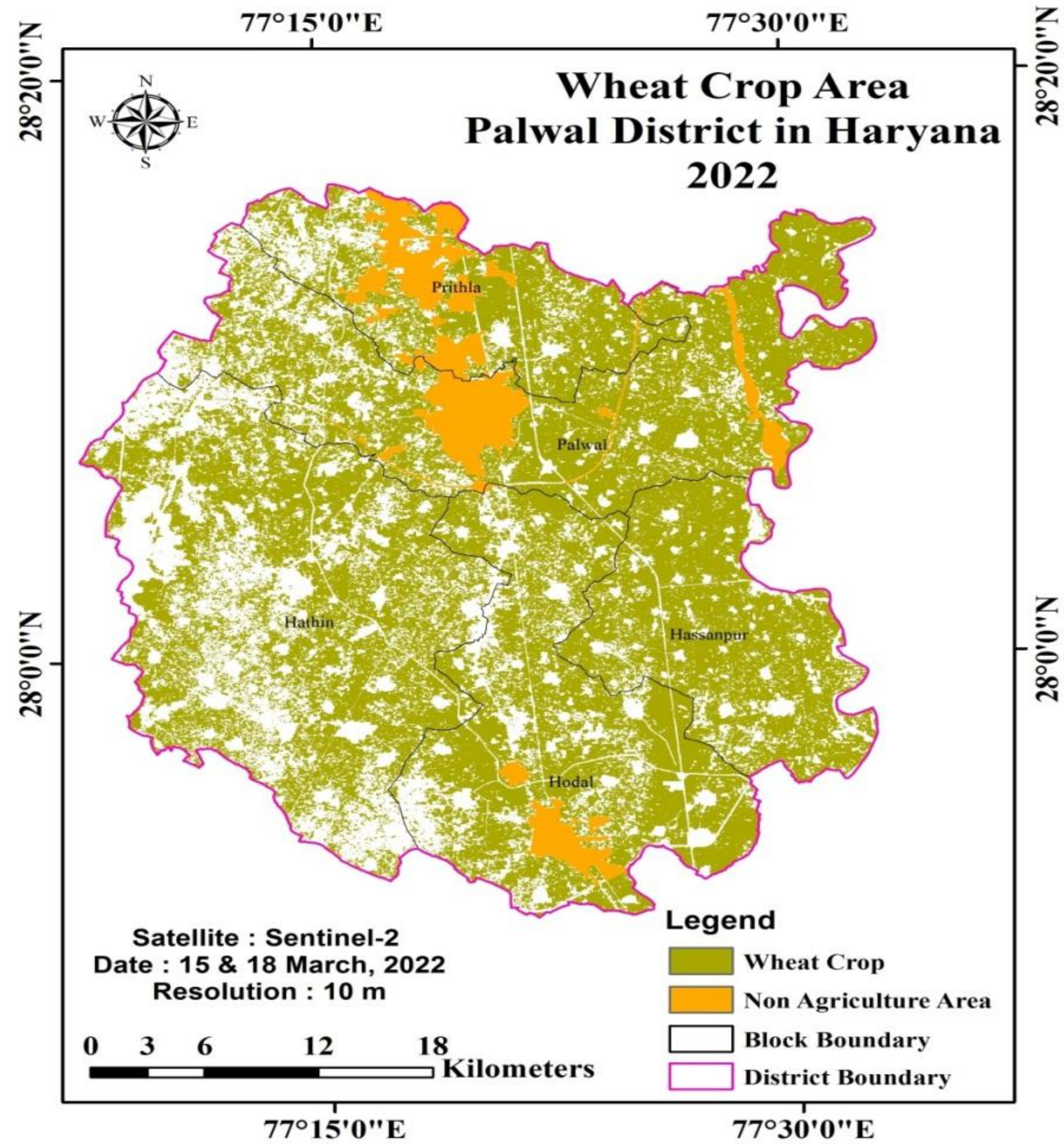


Figure 3.16: Wheat Crop Area of Palwal District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

This table 3.16 shows wheat the area in hectares and the proportion of total land allotted to wheat cultivation for each block in the Palwal region. Hodal: 18929.4 hectares, or 24.8% of the total area, are planted to wheat in this block. Prithla block 11.6% of the total area in this block, or 8883.3 hectares, is used for wheat cultivation. Badoli block, 13983.2 hectares, or 18.3% of the total area, are under wheat cultivation.

Table: 3.16: Block wise Wheat area Estimation of Palwal District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Palwal	Hodal	18929.4	24.8
2	Palwal	Prithla	8883.3	11.6
3	Palwal	Badoli	13983.2	18.3
4	Palwal	Palwal	11313.5	14.8
5	Palwal	Hathin	12100.6	15.9
6	Palwal	Hassanpur	11100.5	14.5
Total			**76310.4**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

Palwal block contains 11313.5 hectares planted to wheat, or 14.8% of it. Hathin: Of the total area in this block, 12100.6 hectares are under wheat cultivation, or 15.9% of it. Hassanpur block 5% of the total area, are used for wheat farming.

Panchkula District:

The map titled “Wheat Crop Area of Panchkula District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is limited and unevenly distributed across the district. The northern and eastern parts, particularly Morni and parts of Pinjore, are largely dominated by non-agricultural land due to hilly terrain of the Shivalik range and forest cover. Wheat cultivation is mainly concentrated in the southern and south-western blocks such as Raipur Rani and Barwala, where relatively flat plains and better soil conditions support agriculture.

The overall extent of wheat area is comparatively smaller than the central districts of Haryana. Thus, the map highlights the strong influence of physiography on land use, with agriculture confined mainly to the plain regions of Panchkula district.

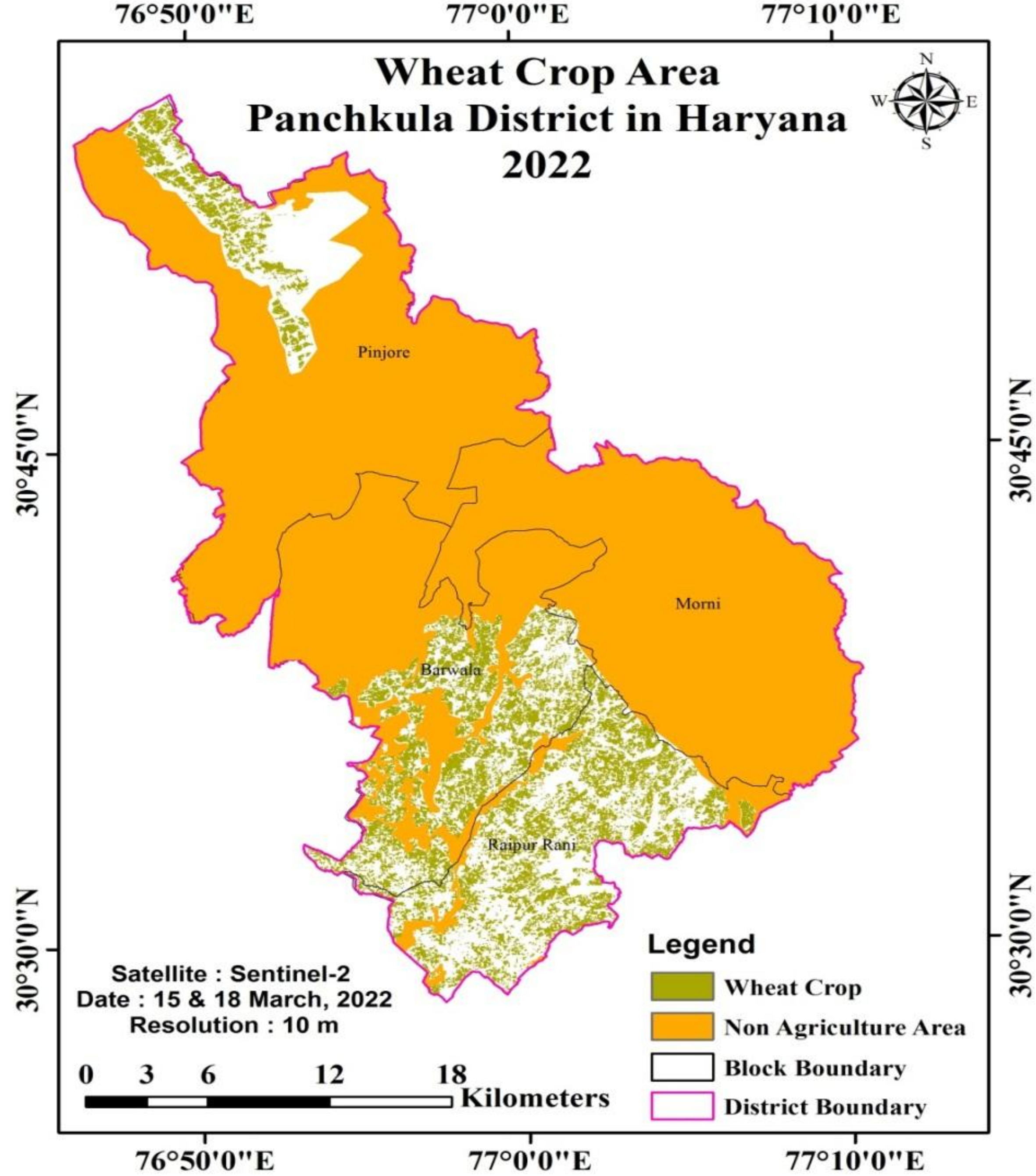


Figure 3.17: Wheat Crop Area of Panchkula District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

This table 3.17 reveals wheat area in hectares and the proportion of the total land allotted to wheat cultivation for each block in the Panchkula area that is used for wheat cultivation. Morni block 212.1 hectares, or 0.5% of the total area, are under wheat cultivation in this block.

Table: 3.17: Block wise Wheat area Estimation of Panchkula District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Panchkula	Morni	212.1	0.5
2	Panchkula	Pinjore	1698.3	3.9
3	Panchkula	Barwala	36261.2	83.6
4	Panchkula	Raipur Rani	5191.3	12.0
Total			43362.9	100

(Data Source: Sentinel 2 Satellite Data 2022)

Pinjore block total of 1698.3 hectares, or 3.9% of the total area, is planted to wheat in this block. Barwala block a sizeable portion of this block—36261.2 hectares, or 83.6% of the total area—is under wheat cultivation. Raipur rani block total area, 5191.3 hectares, or 12.0%, are devoted to wheat farming.

Panipat District:

The map titled “Wheat Crop Area of Panipat District in Haryana – 2022” depicts the spatial distribution of wheat cultivation during the Rabi season using Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are represented in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map shows that wheat cultivation is widely and densely distributed across most parts of the district, particularly in rural blocks such as Israna, Samalkha, and Bapoli, reflecting fertile alluvial soils and well-developed irrigation facilities. However, a significant concentration of non-agricultural land is visible around Panipat city and nearby urban-industrial areas, indicating settlement expansion and industrial growth. Despite urban influence, the overall landscape remains predominantly agricultural, with wheat occupying a substantial portion of cultivated land. Thus, the map highlights Panipat as an agriculturally productive district with wheat as a major Rabi crop, though urbanization has created localized non-agricultural pockets.

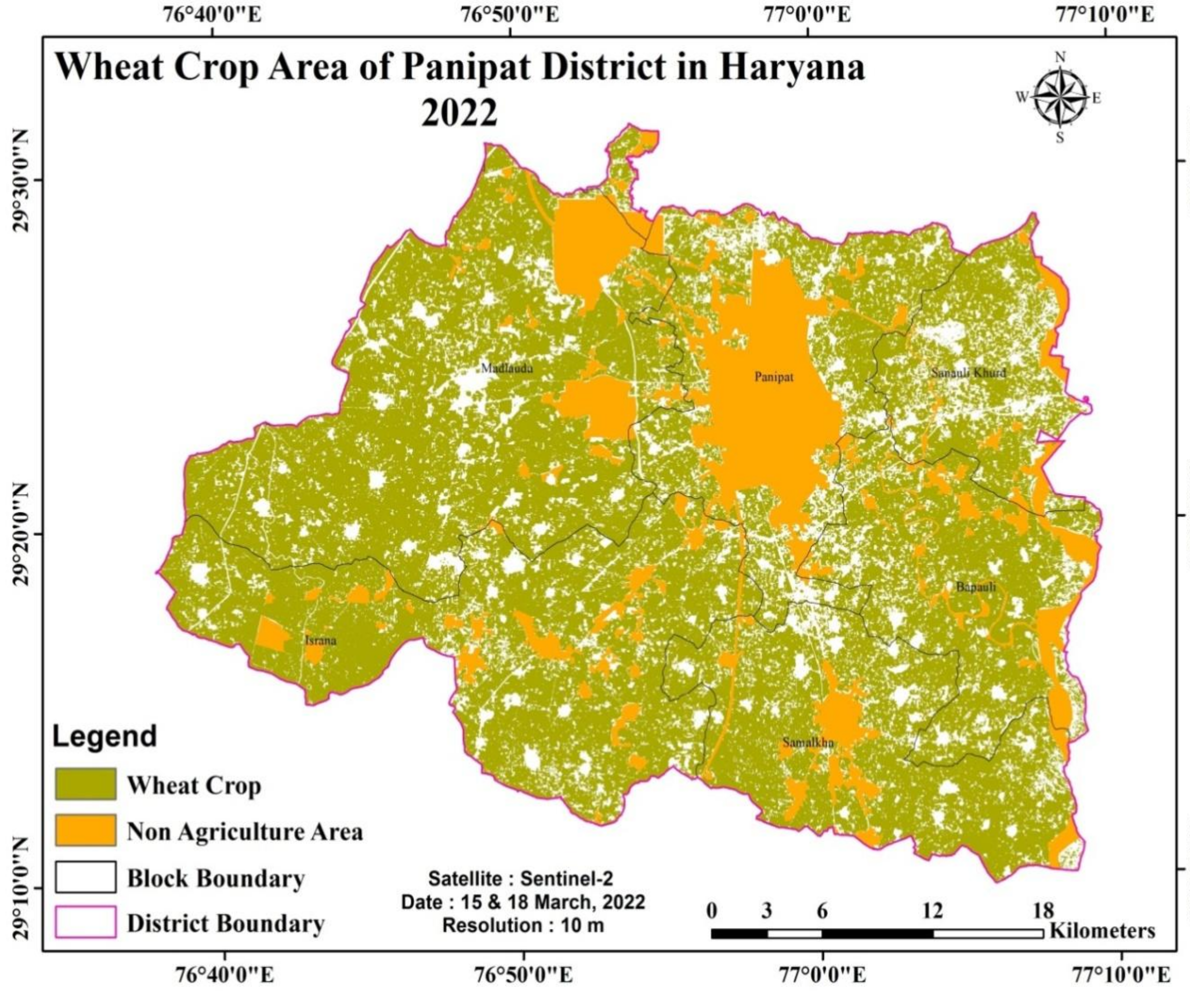


Figure 3.18: Wheat Crop Area of Panipat District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The table 3.18 shows the wheat Crop area in the Panipat region's various blocks, Bapoli block, 9678.7 hectares—or 12.6% of the total area—are under wheat production. Israna block 20944.3 hectares, or 27.2% of the total area, are planted to wheat in this block.

Samalkh block 11058.2 hectares, or 14.4% of the total area, are under wheat cultivation in this block. Panipat block's total area, 9226.3 hectares are used for wheat farming, or 12.0%. Sanauli Khurd block approximately 8.3% of the total land, or 6367.2 hectares, are planted to wheat in this block.

Table: 3.18: Block wise Wheat area Estimation of Panipat District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Wheat)**	**Area in %**
1	Panipat	Bapoli	9678.7	12.6
2	Panipat	Israna	20944.3	27.2
3	Panipat	Samalkha	11058.2	14.4
4	Panipat	Panipat	9226.3	12.0
5	Panipat	Sanauli Khurd	6367.2	8.3
6	Panipat	Madlauda	19764.0	25.7
Total			**77038.6**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

Overall, the data reveals that wheat cultivation in Panipat district is concentrated mainly in Israna and Madlauda blocks, reflecting better irrigation facilities, fertile soils, and stronger agricultural dominance in these regions compared to other blocks.

Rewari District:

The map titled “Wheat Crop Area of Rewari District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is moderately distributed across the district, with relatively higher concentration in the northern and north-eastern blocks such as Nahar and Jatusana, where irrigation facilities and comparatively better soil conditions support agriculture. In contrast, southern and south-western parts including Khol at Rewari, Bawal, and adjoining areas show more fragmented and sparse wheat patches due to semi-arid climate, sandy soils, and limited water availability. Significant non-agricultural areas are visible around Rewari town and industrial zones, reflecting urban expansion and infrastructural growth.

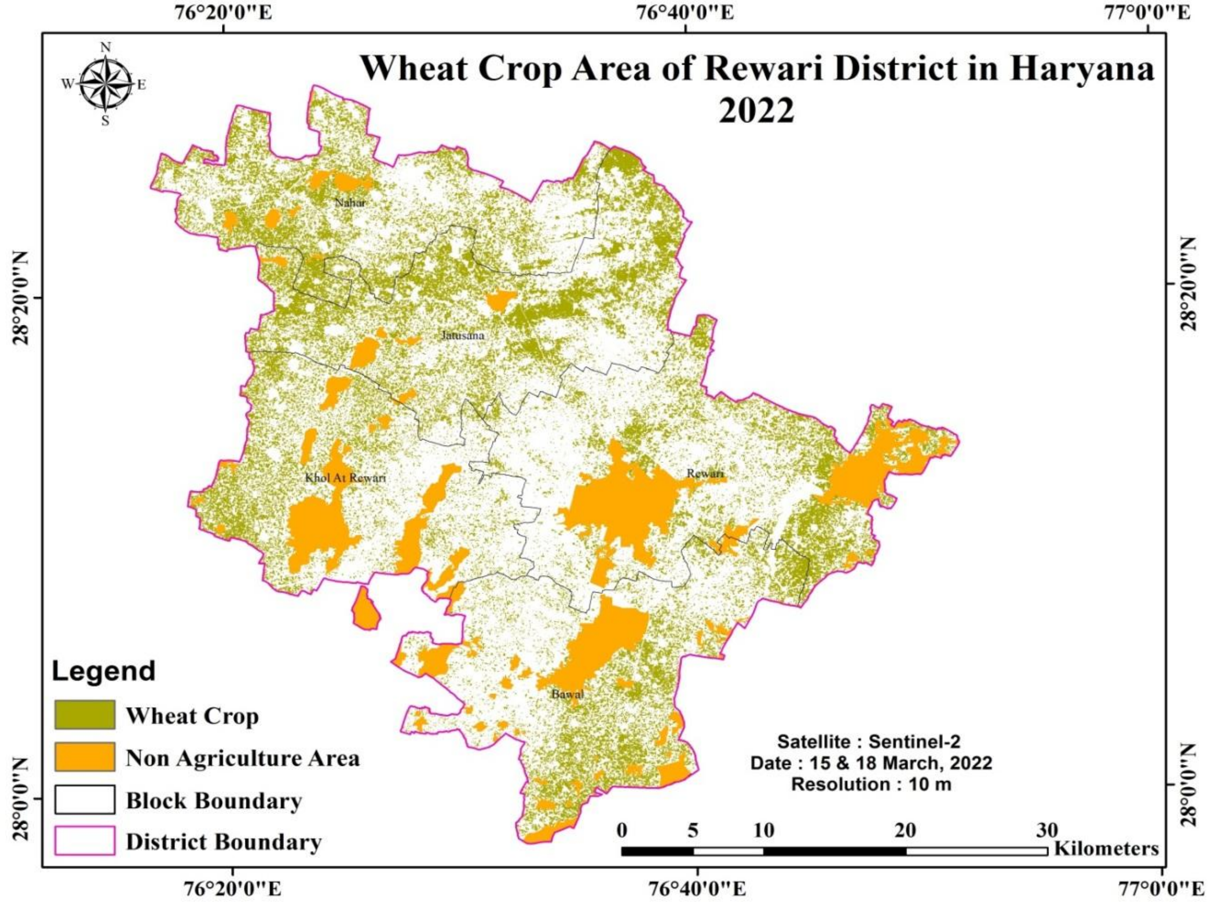


Figure 3.19: Wheat Crop Area of Rewari District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Table 3.19 shows the wheat area in hectares and the proportion of the total land allotted to wheat cultivation for each block in the Rewari region that is cultivated: Bawal block 5271.4 hectares, or 12.9% of the total area, are under wheat cultivation in this block.

Table: 3.19: Block wise Wheat area Estimation of Rewari District.

Sr. No.	District Name	Block Name	Area in Hectare (Wheat)	Area in %
1	Rewari	Bawal	5271.4	12.9
2	Rewari	Nahar	7428.9	18.2
3	Rewari	Dahina	7471.6	18.3
4	Rewari	Jatusana	7853.7	19.2
5	Rewari	Khol at Rewari	3534.3	8.7
6	Rewari	Dharuhera	9251.0	22.7
Total			**40810.8**	**100**

(Data Source:- Sentinel 2 Satellite Data 2022)

Nahar block 18.2% of the total land in this block is planted with wheat, covering 7428.9 hectares. Dahina block, 7471.6 hectares, or 18.3% of the total area, are under wheat cultivation. Jatusana block total area, 7853.7 hectares, or 19.2%, are devoted to wheat farming. Khol at Rewari: 3534.3 hectares, or 8.7% of the total area, are under wheat cultivation. Dharuhera block 22.7% of the block's total area, or 9251.0 hectares, is used for wheat cultivation.

Rohtak District:

The map titled “Wheat Crop Area of Rohtak District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 imagery (15 & 18 March 2022) with 10 m spatial resolution..

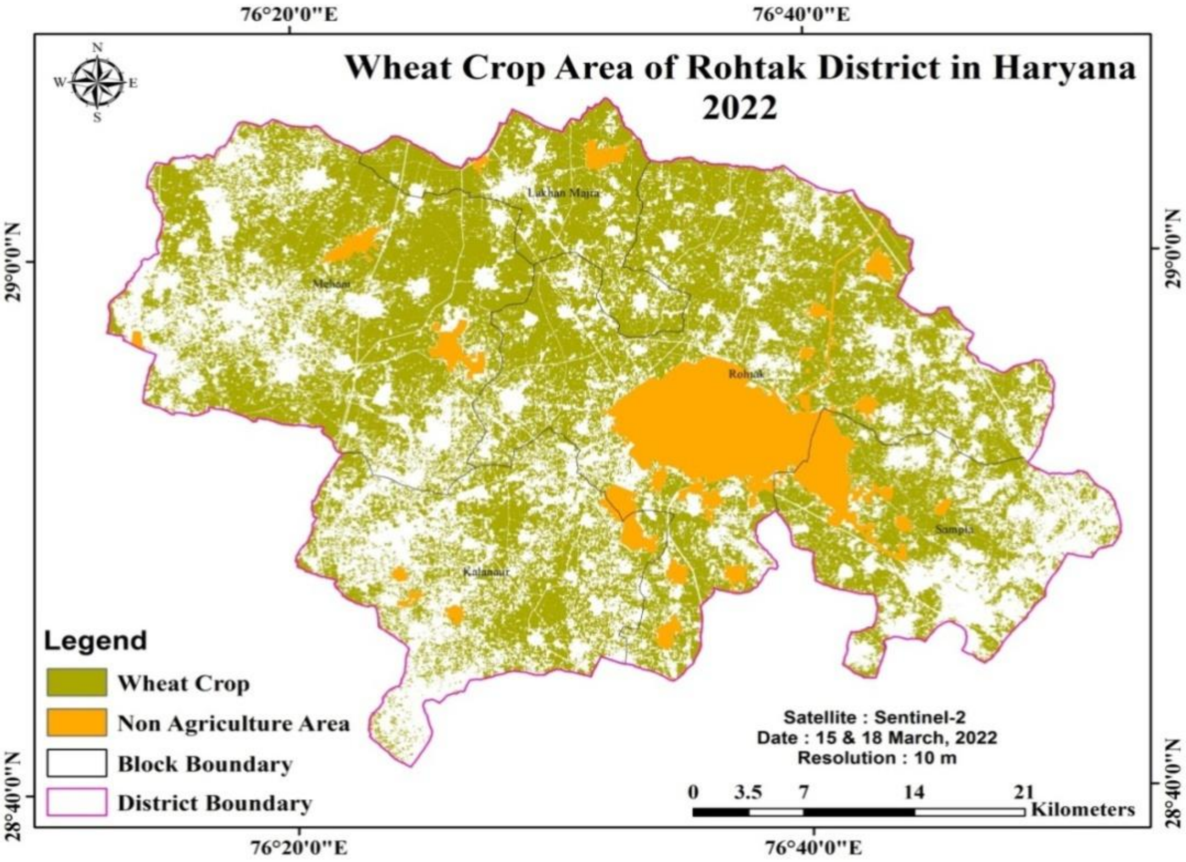


Figure 3.20: Wheat Crop Area of Rohtak District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is extensively and densely distributed across most parts of the district, particularly in blocks such as Meham, Lakhan Majra, Kalanaur, and Sampla, reflecting fertile alluvial soils and well-established irrigation facilities. A significant concentration of non-agricultural land is visible around Rohtak city, indicating urban expansion and infrastructural development. Despite the presence of urban areas, the overall landscape remains predominantly agricultural, with wheat occupying a major share of cultivated land. Thus, the map highlights Rohtak as a strong wheat-producing district where agriculture continues to play a dominant role alongside growing urban influence.

The table: 3.20 represent that wheat area in hectares and the proportion of the total land allotted to wheat cultivation for each block in the Rohtak district that is used for wheat cultivation. Rohtak block total cultivated area 29143.9 hectares, or 34.4% of the total area, are under wheat cultivation in this block.

Table-3.20: Block wise Wheat area Estimation of Rohtak District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Wheat)**	**Area in %**
1	Rohtak	Rohtak	29143.9	34.4
2	Rohtak	Sampla	9874.3	11.6
3	Rohtak	Lakhan Majra	10248.0	12.1
4	Rohtak	Maham	23120.5	27.3
5	Rohtak	Kalanaur	12430.1	14.7
Total			84816.8	100

(Data Source: Sentinel 2 Satellite Data 2022)

Sampla block total area of this block, 9874.3 hectares are used for wheat cultivation, or 11.6%. Lakhan majra block, 10248.0 hectares—or 12.1% of the total area—are under wheat production. Maham block 27.3% of the block's total area, or 23120.5 hectares, are used for wheat farming. Kalanaur block entire area in this block, 12430.1 hectares are used for wheat cultivation, or 14.7%.

Sirsa District:

The map titled “Wheat Crop Area of Sirsa District in Haryana – 2022” presents the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are depicted in green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that wheat cultivation is widely distributed across most parts of the district, particularly in blocks such as Dabwali, Odhan, Rania, Ellenabad, and Baragudha, reflecting the district’s strong agricultural base supported by canal irrigation and fertile alluvial soils. The coverage appears relatively dense and continuous in the northern and central regions, whereas some southern parts show comparatively scattered patches due to variations in soil texture and water availability.

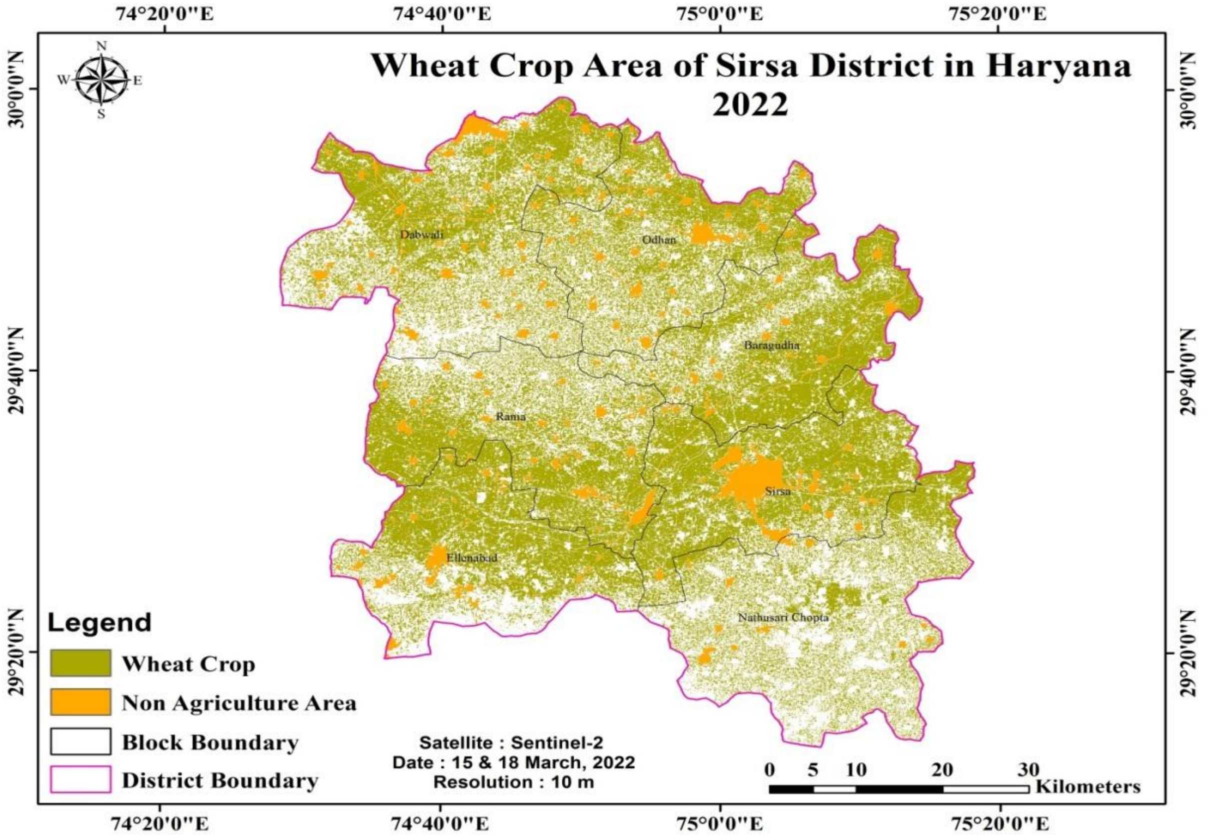


Figure 3.21: Wheat Crop Area of Sirsa District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Non-agricultural land is mainly concentrated around Sirsa town and other settlement clusters. Overall, the map highlights Sirsa as a predominantly agrarian district where wheat occupies a significant share of cultivated land during the Rabi season of 2022.

Table: 3.21: Block wise Wheat area Estimation of Sirsa District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Sirsa	Nathusari Chopta	27452.5	12.6
2	Sirsa	Dabwali	40739.1	18.7
3	Sirsa	Odhan	27371.8	12.6
4	Sirsa	Rania	25062.0	11.5
5	Sirsa	Ellenabad	30180.3	13.9
6	Sirsa	Baragudha	32983.4	15.1
7	Sirsa	Sirsa	34065.5	15.6
Total			**217854.6**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

This table 3.21 represent the area in hectares and the proportion of total land devoted to wheat cultivation for each block in the Sirsa district that is used for wheat cultivation, Nathusari Chopta block, wheat is grown on 27452.5 hectares, or 12.6% of the total area. Dabwali block Approximately 40739.1 hectares, or 18.7% of the total area, are planted to wheat in this block. Odhan block 27371.8 hectares, or 12.6% of the total area, are planted to wheat in this block. Rania block entire area, 11.5% is made up of 25062.0 hectares that are planted to wheat. Ellenabad block Thirteen percent of the entire land, or 30180.3 hectares, are planted to wheat in this block. Baragudha block 32983.4 hectares, or 15.1% of the total area, are under wheat cultivation in this block. Sirsa block 34065.5 hectares, or 15.6% of the total area, are planted to wheat in this block.

Sonipat District:

The map titled “Wheat Crop Area of Sonipat District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is extensively and densely distributed across most parts of the district, particularly in blocks such as

Gohana, Mundlana, Kharkhoda, and Kathura, reflecting fertile alluvial soils and well-developed irrigation facilities.

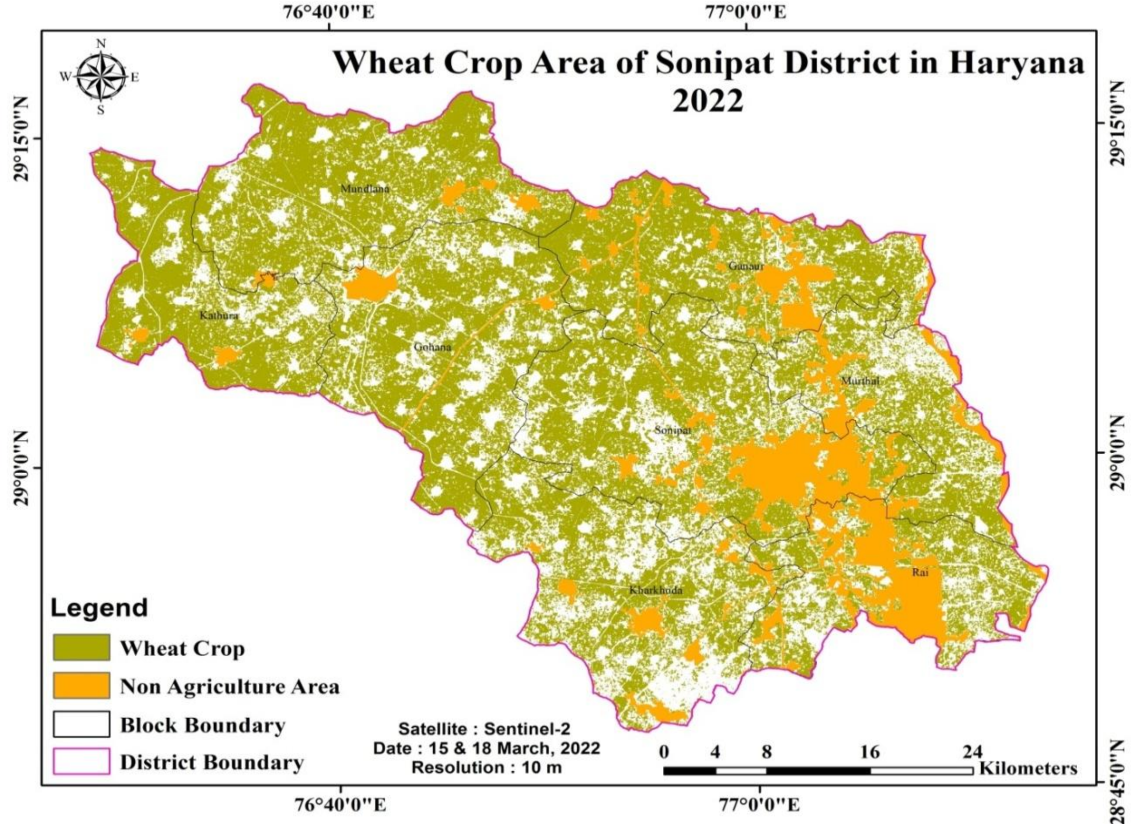


Figure 3.22: Wheat Crop Area of Sonipat District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

However, a significant concentration of non-agricultural land is visible in the south-eastern part of the district, especially around Sonipat city and Rai, due to rapid urbanization and industrial development influenced by proximity to Delhi and the National Capital Region (NCR). Despite urban expansion, the overall landscape remains predominantly agricultural, with wheat occupying a substantial share of cultivated land. Overall, the map highlights Sonipat as a major wheat-producing district where agriculture coexists with growing urban-industrial activities.

The table 3.22 represent the area in hectares and the proportion of the total area allotted to wheat cultivation for each block in the Sonipat district that is used for wheat cultivation:

Table: 3.22: Block wise Wheat area Estimation of Sonipat District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Wheat)**	**Area in %**
1	Sonipat	Ganaur	17712.7	14.3
2	Sonipat	Kathura	14571.7	11.8
3	Sonipat	Gohana	20820.8	16.9
4	Sonipat	Kharkhoda	11797.9	9.6
5	Sonipat	Rai	8860.5	7.2
6	Sonipat	Murthal	10722.5	8.7
7	Sonipat	Sonipat	19139.6	15.5
8	Sonipat	Mundlana	19821.6	16.1
Total			**123447.3**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

Ganaur block 17712.7 hectares, or 14.3% of the total area, are under wheat cultivation. Kathura block has 14571.7 hectares of wheat planted on it, or 11.8% of the entire area. Gohana block 20820.8 hectares—or 16.9% of the total area—are under wheat cultivation. Kharkhoda block 11797.9 hectares, or 9.6% of the total area, are planted to wheat in this block. Rai block about 8860.5 hectares, or 7.2% of the total area, are farmed for wheat in this block. Murthal block 10722.5 hectares, or 8.7% of the total area, are under wheat cultivation. Sonipat block's wheat crop covers 19139.6 hectares, or 15.5% of the total land area. Mundlana block 16.1% of the total area in this block, or 19821.6 hectares, is used for wheat cultivation.

Yamunanagar District:

The map titled “Wheat Crop Area of Yamunanagar District in Haryana – 2022” illustrates the spatial distribution of wheat cultivation during the Rabi season based on Sentinel-2 satellite imagery (15 & 18 March 2022) with 10 m resolution. Wheat crop areas are shown in green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that wheat cultivation is widely distributed across the central and western parts of the district, particularly in blocks such as Radaur, Mustafabad, Bilaspur, and Sadhaura, reflecting fertile alluvial soils and adequate irrigation facilities. However, the eastern and north-eastern parts, especially around Chhachhrauli and adjoining Shivalik foothill regions, show larger non-agricultural areas due to forest cover, hilly terrain, and lesser suitability for intensive agriculture. Urban concentrations are visible around Jagadhri and Yamunanagar towns. Overall, the map highlights that while Yamunanagar district maintains a strong agricultural base with wheat as a major Rabi crop, its distribution is influenced by physiographic variations and forested landscapes in the eastern region.

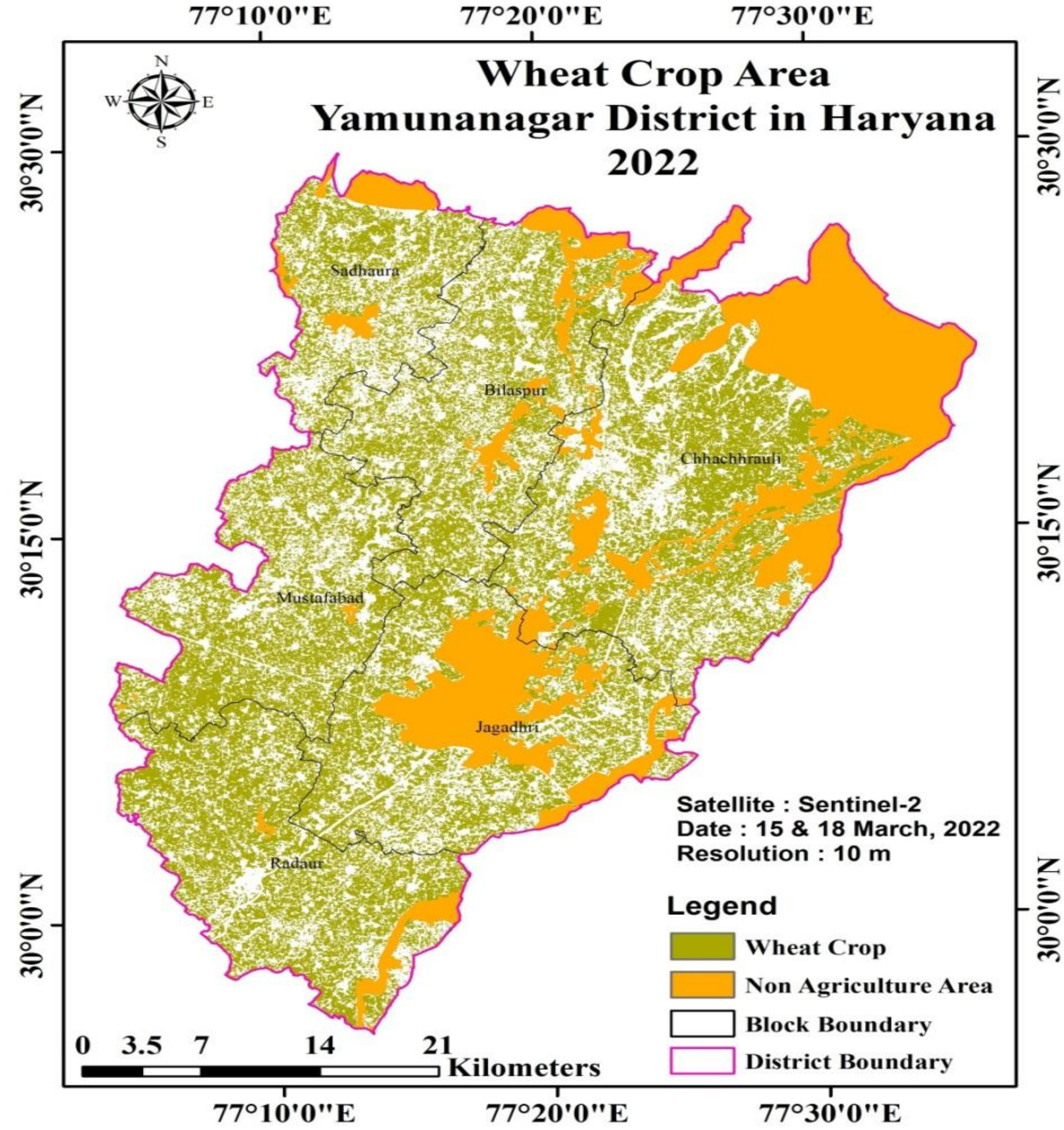


Figure 3.23: Wheat Crop Area of Yamunanagar District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Table-3.23: Block wise Wheat area Estimation of Yamunanagar District.

Sr. No.	District	Block Name	Area in Hectare (Wheat)	Area in %
1	Yamunanagar	Khizrabad	9200.8	12.4
2	Yamunanagar	Radaur	14049.5	18.9
3	Yamunanagar	Mustafabad	10853.6	14.6
4	Yamunanagar	Jagadhri	12550.5	16.9
5	Yamunanagar	Chhachhrauli	10586.7	14.2
6	Yamunanagar	Sadaura (Part)	6028.1	8.1
7	Yamunanagar	Bilaspur	11096.0	14.9
Total			**74365.1**	**100**

(Source: Sentinel 2 Satellite Data 2022)

Yamunanagar District, which is probably in India or a similar agricultural region, is presented in the table 3.23. Khizrabad block with a specific size of 9200.8 hectares, this block accounts for 12.4% of the entire wheat cultivated area. Radaur block with 14049.5 hectares or 18.9% of the total area under cultivation for wheat, Radaur is the largest contributor. Mustafabad block Mustafabad, with an area of 10853.6 hectares, contributes 14.6% of the total wheat farming area. Jagadhri block with 12550.5 hectares, this block accounts for 16.9% of all wheat cultivation land. Chhachhrauli block which has an area of 10586.7 hectares, contributes 14.2% of the total area used for wheat cultivation. Sadaura block with 6028.1 hectares, Sadaura provides 8.1% of the total wheat-growing area. With 11096.0 hectares under cultivation, Bilaspur accounts for 14.9% of the total area used for wheat production.

3.2 Rice Crop Area Estimation:

By utilizing remote sensing technology to analyze satellite images and ascertain the extent of rice cultivation in each administrative block, rice crop area assessment in Haryana using satellite data and classification algorithms is possible.

Table 3.24: District wise Paddy area.

Sr. No.	**District**	**Total Geographical Area of District (in Hectare)**	**Area in hec (Wheat Crop)**	**% between district area & wheat crop**	**Area in hec (Rice Crop)**	**% between district area & Rice crop**
1	Kaithal	227414.2	168879.0	74.3	167000.0	73.4
2	Karnal	247051.7	163111.1	66.0	174736.0	70.7
3	Kurukshetra	168420.3	92918.0	55.2	110282.0	65.5
4	Panipat	130273.2	86159.4	66.1	74033.4	56.8
5	Sonipat	215722.3	127454.1	59.1	103684.0	48.1
6	Jind	275091.5	190188.6	69.1	129153.0	46.9
7	Ambala	151203.0	71589.2	47.4	69808.0	46.2
8	Fatehabad	252512.4	161365.7	63.9	114416.0	45.3
9	Yamunanagar	171777.3	75971.5	44.2	71373.4	41.5
10	Rohtak	166907.0	84878.3	50.8	54492.7	32.6
11	Palwal	135954.8	82782.9	60.9	40604.1	29.9
12	Panchkula	88292.6	11918.0	13.5	20225.5	22.9
13	Jhajhar	190215.1	61612.2	32.4	38708.8	20.4
14	Faridabad	74264.4	27690.1	37.3	14019.5	18.9
15	Hisar	407523.7	191809.3	47.1	71921.3	17.6
16	Sirsa	426992.7	224233.3	52.5	74663.2	17.5
17	Nuh	150076.6	48332.4	32.2	17665.4	11.8
18	Bhiwani	329686.8	103480.2	31.4	24046.5	7.3
19	Charkhi Dadri	137349.6	35531.4	25.9	5952.9	4.3
20	Gurugram	125953.4	29424.9	23.4	3763.6	3.0
21	Rewari	150886.6	40779.0	27.0	1450.0	1.0
22	Mahendergarh	194082.8	33838.0	17.4	0.0	0.0
Total	**Haryana**	**4417652.0**	**2113946.6**	**100**	**1381999.3**	**100**

(Data Source: Sentinel 2 Satellite Data 2022).

The block-wise paddy acreage map of Haryana for the Kharif season 2022 depicts the spatial distribution of rice cultivation across the state using Sentinel-2 satellite data. Paddy-growing areas are shown in green, while non-paddy regions appear in lighter or blank tones. Block boundaries (black dashed lines) and district boundaries (pink outlines) help visualize administrative-level variation in paddy cultivation.

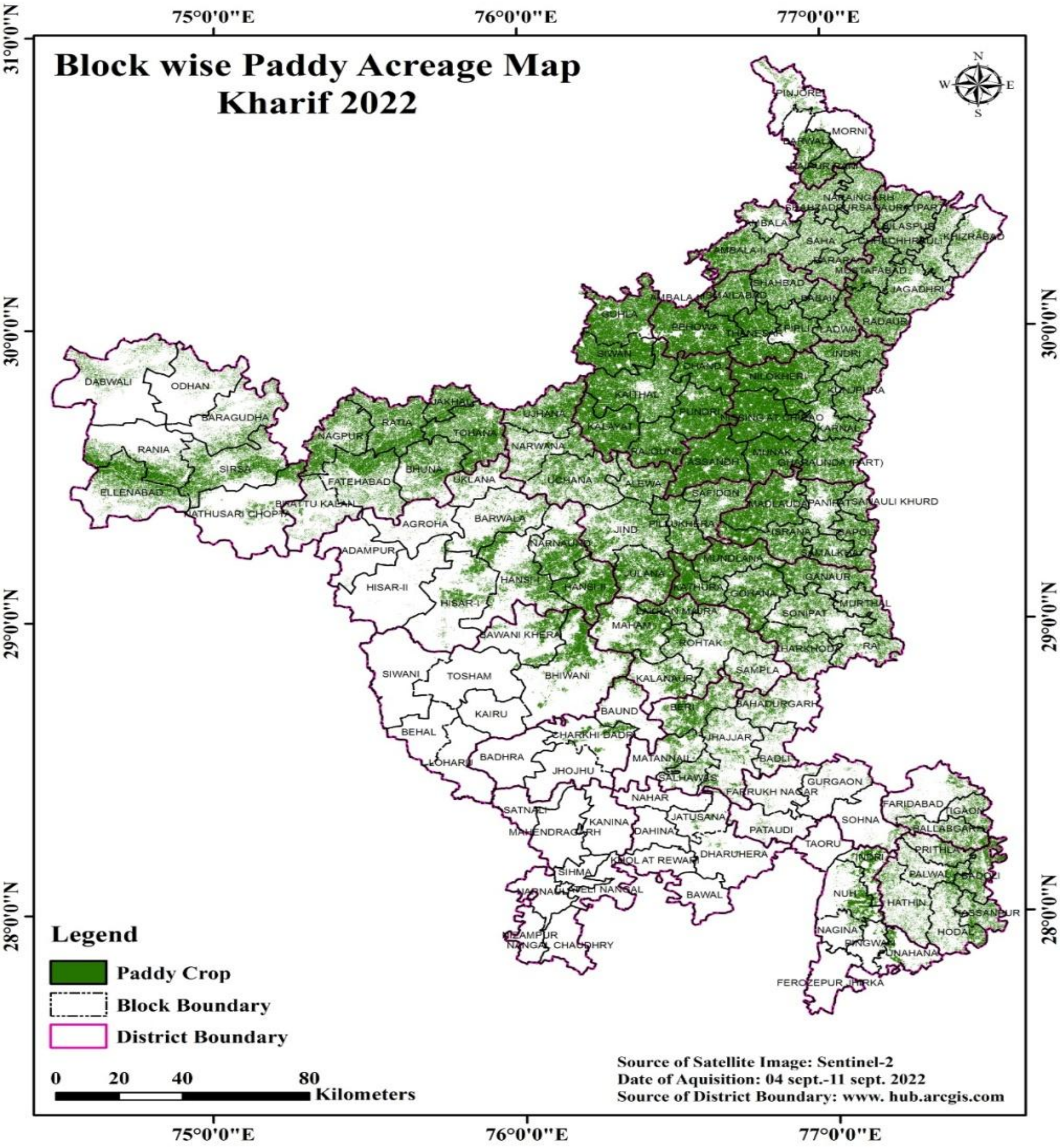


Figure 3.24: Block Wise Paddy Acreage Map Rabi 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Spatial Pattern: The map clearly shows a high concentration of paddy cultivation in northern and north-eastern Haryana, particularly in blocks of Yamunanagar, Kurukshetra, Karnal, Kaithal, Ambala, and Panipat districts. These regions benefit from abundant canal irrigation, fertile alluvial soils, and assured water availability, making them the core rice belt of the state.

Moderate Paddy Areas: Central Haryana—covering parts of Jind, Fatehabad, and Hisar-I blocks—exhibits moderate paddy coverage, reflecting mixed cropping systems where rice is cultivated alongside cotton, bajra, and other kharif crops.

Low to Negligible Paddy Cultivation: Southern and south-western Haryana, including Bhiwani, Mahendragarh, Rewari, Charkhi Dadri, and Nuh districts, shows very limited or negligible paddy acreage. This pattern is mainly due to water scarcity, sandy to loamy soils, and dependence on rainfall, which are less suitable for water-intensive rice cultivation.

Ambala District:

The map titled “Rice Crop Area of Ambala District in Haryana – 2022” illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution. Rice crop areas are represented in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is extensively distributed across most parts of the district, particularly in blocks such as Shahzadpur, Naraingarh, Barara, and Ambala-II, reflecting favorable agro-climatic conditions, fertile alluvial soils, and adequate irrigation facilities. The dense and continuous green coverage suggests intensive paddy cultivation during the monsoon season. Non-agricultural land is mainly concentrated around Ambala-I (urban center) and other settlement clusters. Overall, the map highlights Ambala as a major rice-growing district in northern Haryana, where paddy occupies a significant proportion of cultivated land during the Kharif season of 2022.

An estimate of the area used for rice cultivation in each of the district's blocks in Ambala is given in this table 3.25. With an estimated 11,769.8 hectares under cultivation, Saha block makes about 18.5% of the district of Ambala's total rice acreage.

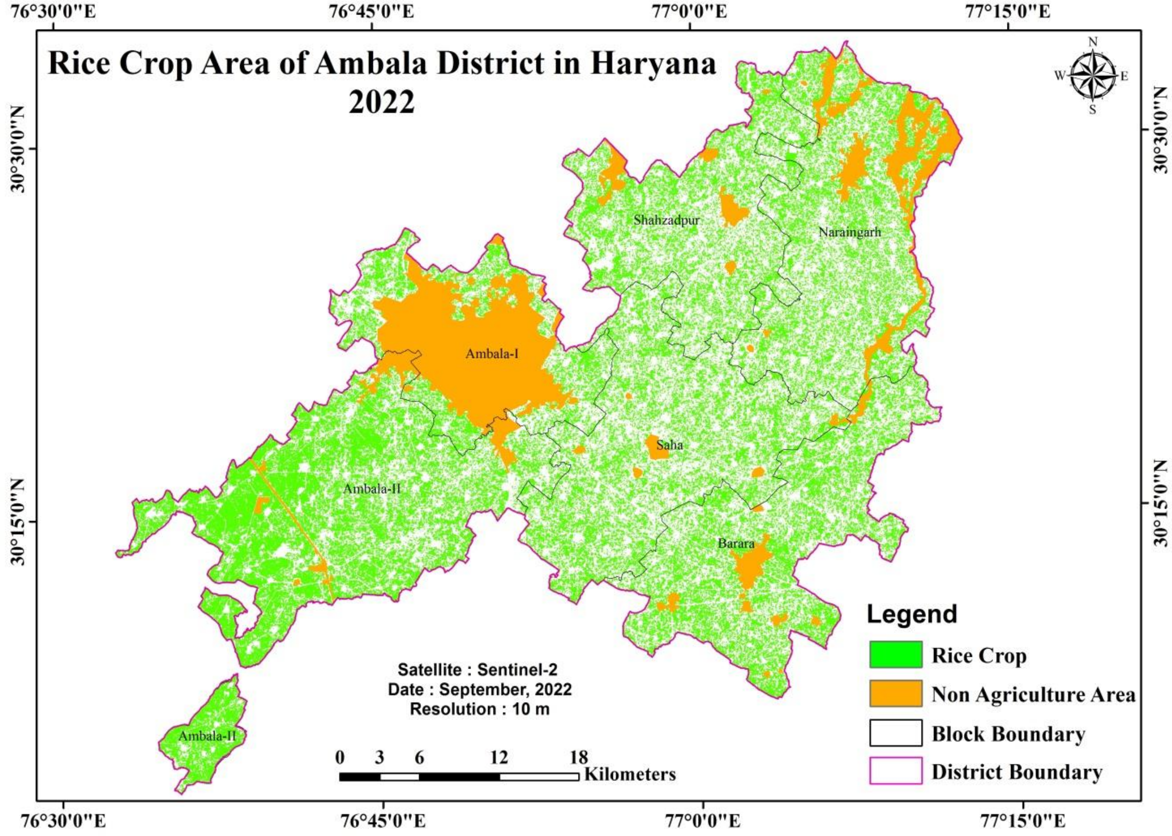


Figure 3.25: Rice Crop Area of Ambala District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The estimated 10,657.7 hectares of rice-growing land in the Barara block make up 16.7% of the overall rice area.

Table: 3.25: Block wise Rice area Estimation of Ambala District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Ambala	Saha	11769.8	18.5
2	Ambala	Barara	10657.7	16.7
3	Ambala	Shahzadpur	8801.8	13.8
4	Ambala	Ambala-Ii	15060.1	23.6
5	Ambala	Ambala-I	5352.7	8.4
6	Ambala	Naraingarh	12086.0	19.0
Total			**63728.1**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

With an estimated 8,801.8 hectares dedicated to rice cultivation, Shahzadpur block accounts for 13.8% of the total rice area. The Ambala-II block, which makes up 23.6% of the overall rice area, has the biggest estimated area for rice cultivation at 15,060.1 hectares. Ambala-I block accounts for 8.4% of the overall rice area, although having a lesser estimated rice-growing area of 5,352.7 hectares. With an estimated 12,086.0 hectares dedicated to rice cultivation, the Naraingarh block accounts for 19.0% of the total rice area.

Bhiwani District:

The map titled "Rice Crop Area of Bhiwani District in Haryana – 2022" illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

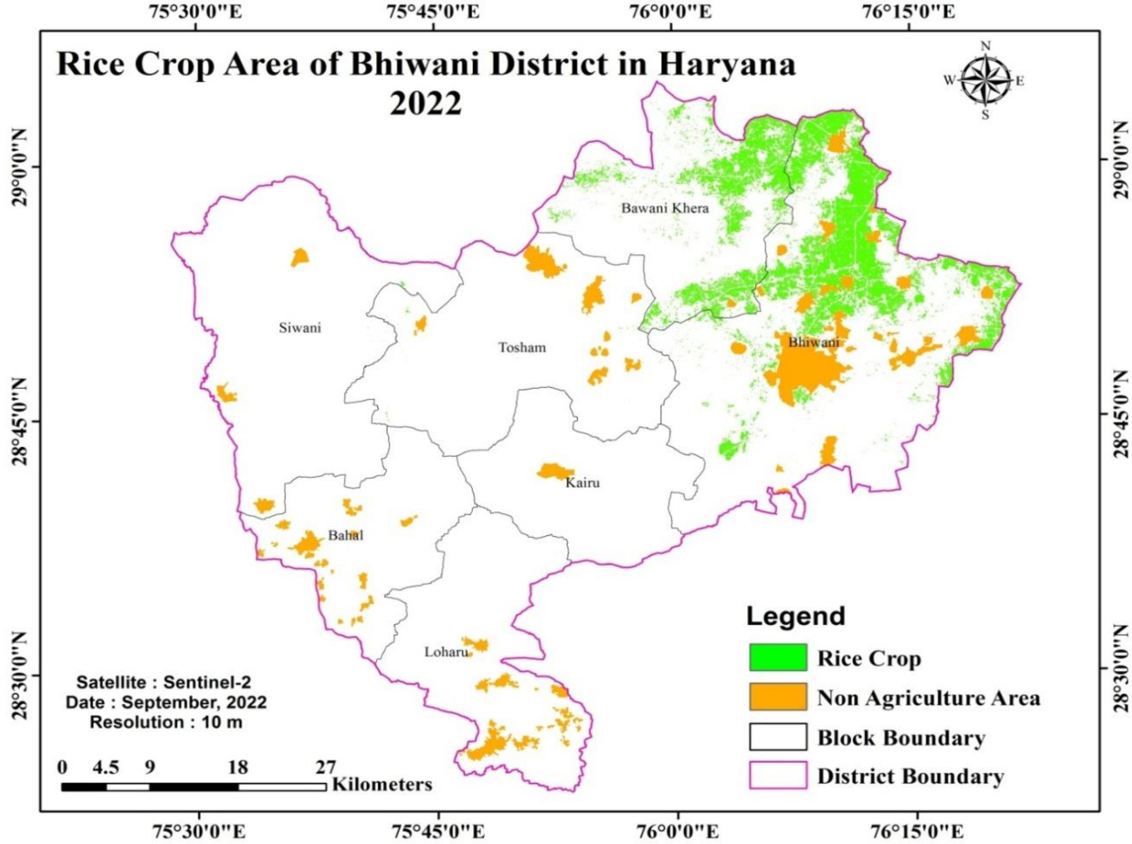


Figure 3.26: Rice Crop Area of Bhiwani District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are shown in bright green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that rice cultivation is relatively limited and unevenly distributed across the district. Higher concentrations of rice are observed mainly in the northern and north-eastern blocks such as Bawani Khera and parts of Bhiwani block, where irrigation facilities are comparatively better. In contrast, western and southern blocks including Siwani, Loharu, Bahal, and Tosham show very sparse or negligible rice cultivation due to semi-arid climate, sandy soils, and limited water availability. Non-agricultural land is mainly concentrated around Bhiwani town and scattered settlement clusters.

Table: 3.26: Block wise Rice area Estimation of Bhiwani District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Bhiwani	Loharu	0.6	0.0
2	Bhiwani	Siwani	19.5	0.1
3	Bhiwani	Tosham	176.9	0.7
4	Bhiwani	Bawani Khera	7992.4	33.2
5	Bhiwani	Bhiwani	15862.8	66.0
6	Bhiwani	Kairu	0.1	0.0
7	Bhiwani	Behal	0.0	0.0
Total			**24052.3**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The table 3.26 shows the rice-growing area in each of the district of Bhiwani's blocks is estimated. The estimated 0.6 hectares of rice-growing land in the Loharu block account for 0.0 percent of the district of Bhiwani's total rice acreage. Siwani block accounts for just 0.1% of the overall rice area, although having a significantly greater estimated rice-growing area of 19.5 hectares. With an estimated 176.9 hectares of rice-growing land. Tosham Block makes up 0.7% of the total rice acreage. The estimated rice-growing area of the Bawani Khera block is 7,992.4 hectares, which accounts for 33.2% of the total rice area. With an estimated area of 15,862.8 hectares, or 66.0% of the total rice acreage, Bhiwani block has the greatest rice-growing area. The blocks of Kairu and Behal have very little area used for rice cultivation—0.1 hectares and 0.0 hectares, respectively—making up 0.0% of the total area used for rice cultivation.

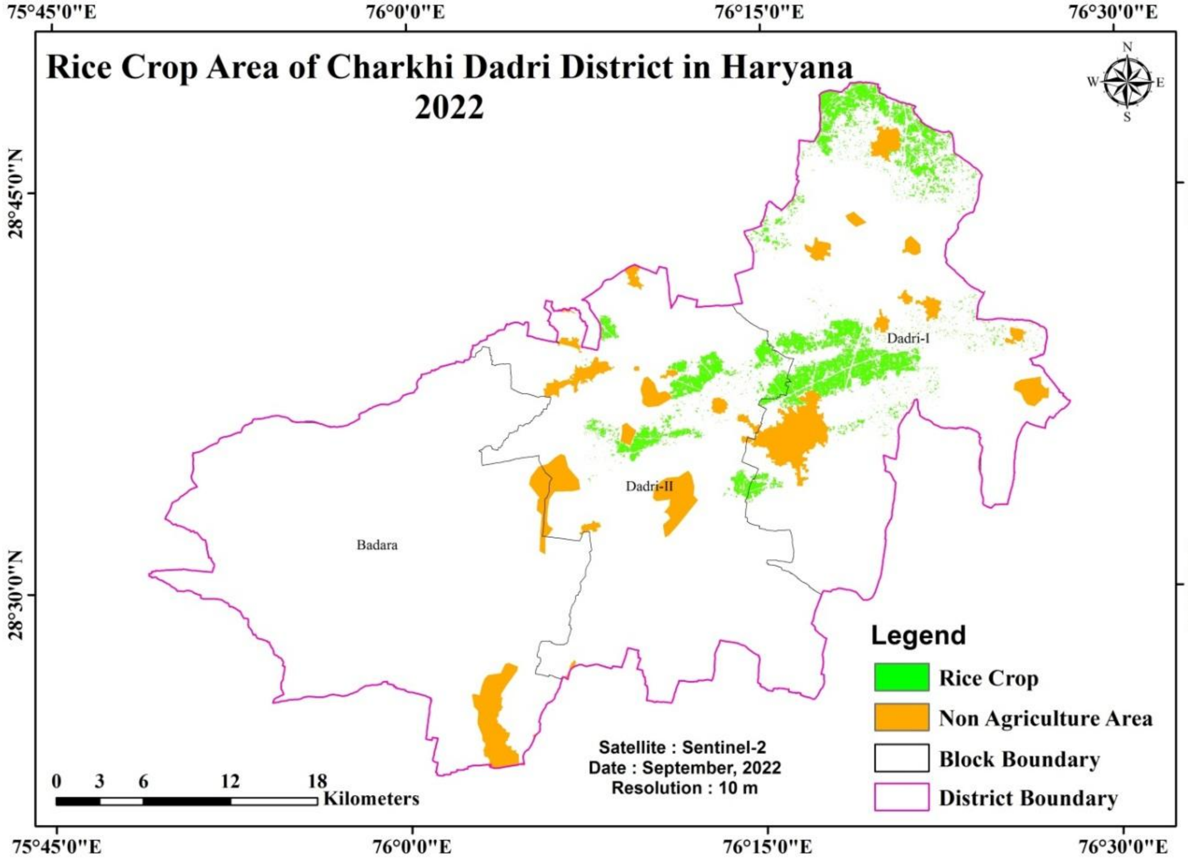


Figure 3.27: Rice Crop Area of Charkhi Dadri District in Haryana 2022 (Source: - Sentinel 2 Satellite Data).

Table: 3.27: Block wise Rice area Estimation of Charkhi Dadri District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Rice)**	**Area in %**
1	Charkhi Dadri	Charkhi Dadri	3332.3	56.1
2	Charkhi Dadri	Badhra	0.4	0.0
3	Charkhi Dadri	Jhojhu	149.1	2.5
4	Charkhi Dadri	Baund	2463.3	41.4
Total			**5945.1**	**100**

(Source:- Sentinel 2 Satellite Data)

An estimate of the area used for rice cultivation in blocks of the Charkhi Dadri district is shown in this table 3.27. With an estimated 3,332.3 hectares of rice-growing land, Charkhi Dadri block accounts for a substantial 56.1% of the district's total rice acreage.

The projected rice-growing area of the Badhra block is 0.4 hectares, which accounts for 0.0% of the total rice acreage. The very small estimated rice-growing area of 149.1 hectares in Jhojhu block accounts for 2.5% of the overall rice acreage. With an estimated 2,463.3 hectares of rice-growing land, Baund block makes up a sizable 41.4% of the total rice area.

Faridabad District:

The map titled "Rice Crop Area of Faridabad District in Haryana – 2022" illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

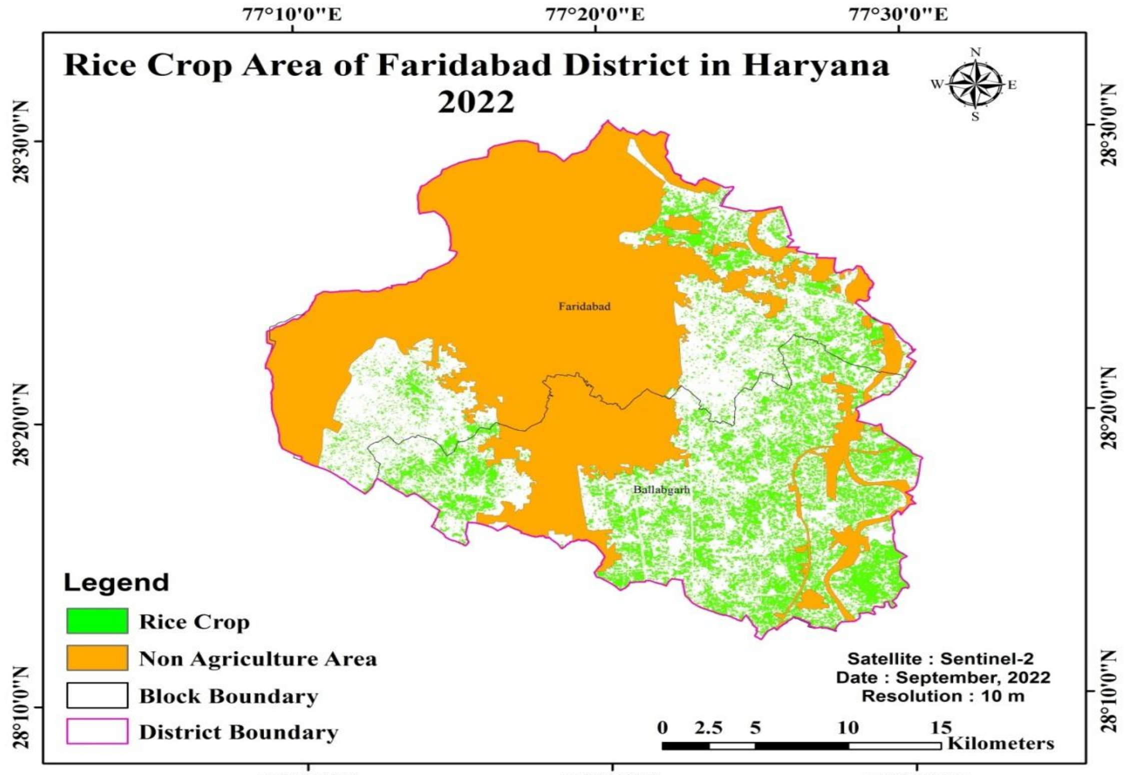


Figure 3.28: Rice Crop Area of Faridabad District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are represented in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map clearly indicates that a large portion of the district, particularly the central and northern parts, is dominated by non-agricultural land due to rapid urbanization, industrial development, and expansion within the National Capital Region (NCR). Rice cultivation is mainly concentrated in the eastern and south-eastern rural areas, especially around Ballabgarh block, where agricultural land and irrigation facilities are available. The western side also shows limited and fragmented rice patches.

Table: 3.28: Block wise Rice area Estimation of Faridabad District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Faridabad	Faridabad	2722.5	19.6
2	Faridabad	Ballabgarh	7146.7	51.5
3	Faridabad	Tigaon	4004.0	28.9
Total			**13873.2**	**100**

(Source: Sentinel 2 Satellite Data 2022)

The rice-growing area in each of the district of Faridabad's blocks is estimated shows table 3.28. With an estimated 2,722.5 hectares of rice-growing land, Faridabad block accounts for 19.6% of the district's total rice area. The biggest estimated rice-growing area, 7,146.7 hectares, or 51.5% of the total rice area, is found in the Ballabgarh block.

With an estimated 4,004.0 hectares, the Tigaon block has a sizable portion of the rice-growing area—28.9%.

Fatehabad District:

The map titled “Rice Crop Area of Fatehabad District in Haryana – 2022” presents the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution. Rice crop areas are depicted in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is extensively and densely distributed across most parts of the district, particularly in blocks such as Ratia, Jakhal, Tohana, and Fatehabad, reflecting assured canal irrigation, fertile alluvial soils, and intensive agricultural practices. The northern and central regions show continuous and high concentration of paddy fields, whereas the south-western parts, including Bhattu Kalan, display comparatively sparse and scattered rice patches due to relatively drier conditions. Non-agricultural land is mainly confined to urban centers and settlement clusters. Overall, the map highlights Fatehabad as a major rice-growing district in Haryana, where paddy occupies a significant proportion of cultivated land during the Kharif season of 2022.

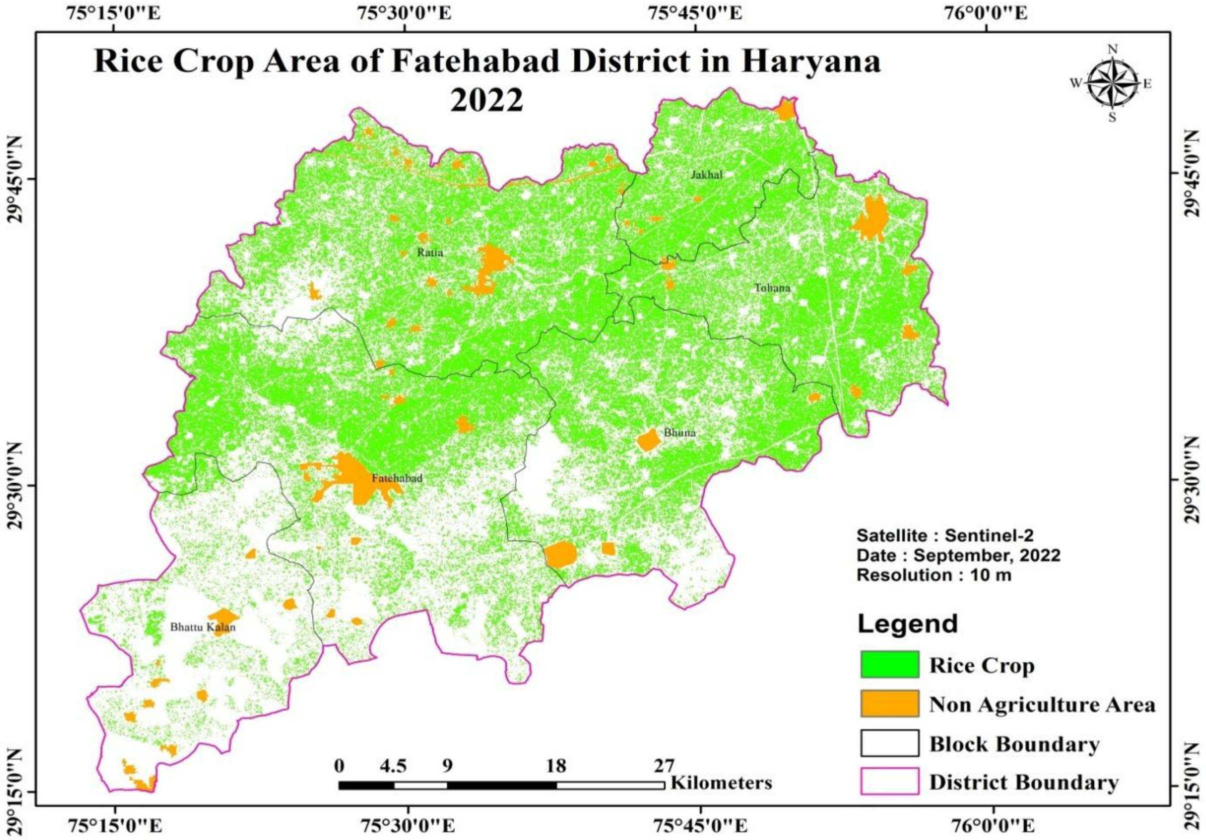


Figure 3.29: Rice Crop Area of Fatehabad District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

An estimate of the area used for rice cultivation in different blocks of the Fatehabad district is shown in this table 3.29. At 24,762.7 hectares, Tohana block is believed to have the greatest rice-growing area in the Fatehabad district, accounting for 21.7% of the total area. With a lesser estimated rice-growing area of 4,310.9 hectares, the Bhattu Kalan block accounts for 3.8% of the overall rice area. At 17,974.6 hectares, the Nagpur block is predicted to have a considerable rice-growing area, making about 15.7% of the overall rice area. Additionally, a sizeable estimated 22,019.9 hectares, or 19.3% of the total rice area, are planted to rice in the Ratia block.

Table: 3.29: Block wise Rice area Estimation of Fatehabad District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Rice)**	**Area in %**
1	Fatehabad	Tohana	24762.7	21.7
2	Fatehabad	Bhattu Kalan	4310.9	3.8
3	Fatehabad	Nagpur	17974.6	15.7
4	Fatehabad	Ratia	22019.9	19.3
5	Fatehabad	Fatehabad	18119.9	15.9
6	Fatehabad	Bhuna	17536.4	15.3
7	Fatehabad	Jakhal	9568.7	8.4
Total			**114293.0**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

With an estimated 18,119.9 hectares dedicated to rice cultivation, the Fatehabad block accounts for 15.9% of the total rice area. With an estimated 17,536.4 hectares dedicated to rice cultivation, Bhuna block accounts for 15.3% of the total rice area. Jakhai block makes about 8.4% of the total rice area, with the smallest estimated rice-growing area at 9,568.7 hectares.

Gurugram District:

The map titled "Rice Crop Area of Gurugram District in Haryana – 2022" illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution. Rice crop areas are shown in bright green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map clearly indicates that a major portion of the district, particularly the Gurugram (Gurgaon) and Sohna blocks, is dominated by non-agricultural land due to rapid urbanization, industrial expansion, and integration within the National Capital Region (NCR). Rice cultivation is limited and sparsely distributed, mainly concentrated in rural blocks such as Pataudi and Farrukhnagar, where some irrigated agricultural land still exists. The distribution of rice appears fragmented and comparatively small in extent, reflecting declining agricultural land and high groundwater stress in the district. Overall, the map highlights that rice is not a dominant crop in Gurugram district, with urban land use significantly shaping the spatial pattern of cultivation.

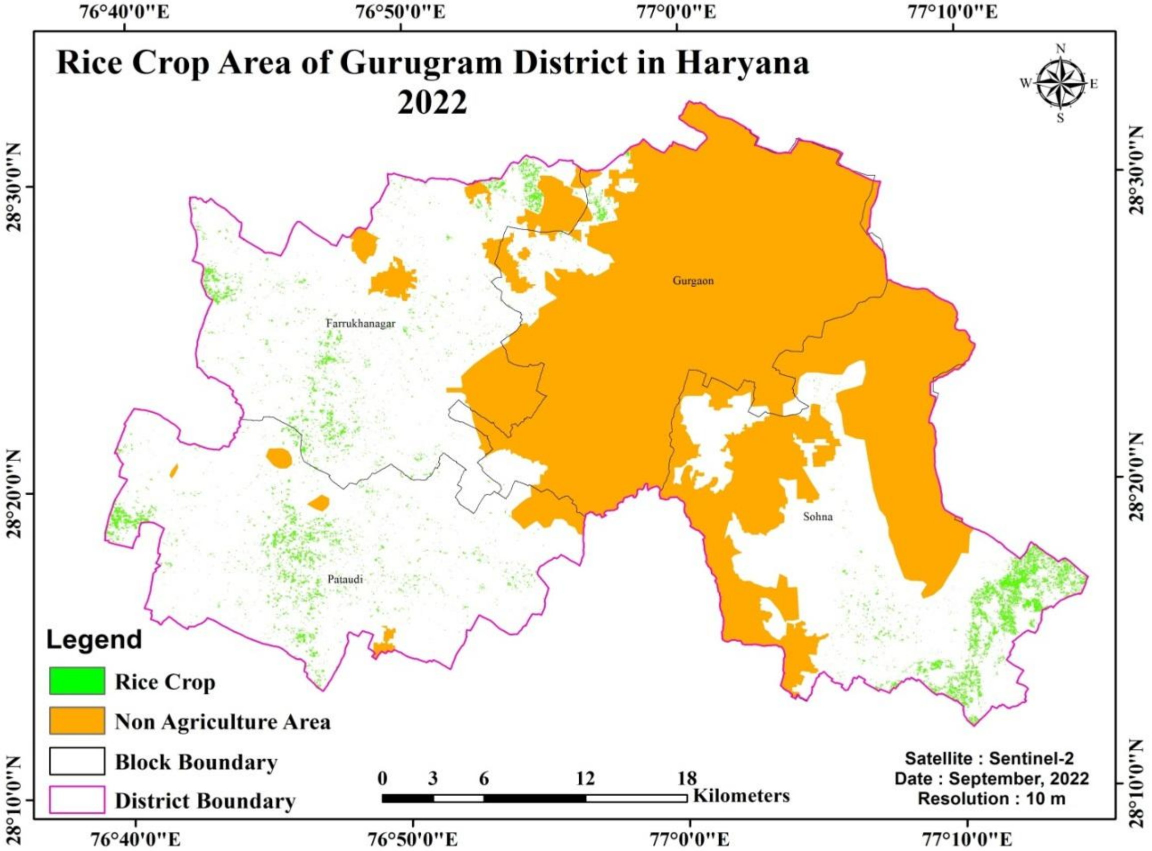


Figure 3.30: Rice Crop Area of Gurugram District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The table 3.30 shows an estimate of the area used for rice production in each block of the Gurugram district is given in With an estimated 1,236.0 hectares dedicated to rice cultivation, Sohna block accounts for 32.9% of the district of Gurugram's total rice acreage. With an estimated 842.4 hectares dedicated to rice cultivation, the Pataudi block accounts for 22.4% of the total rice area.

Table: 3.30: Block wise Rice area Estimation of Gurugram District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Gurugram	Sohna	1236.0	32.9
2	Gurugram	Pataudi	842.4	22.4
3	Gurugram	Farrukh Nagar	891.0	23.7
4	Gurugram	Gurgaon	787.4	21.0
Total			**3756.8**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The estimated 891.0 hectares of rice-growing land in the Farrukh Nagar block make up 23.7% of the total rice area. With an estimated 787.4 hectares, Gurgaon block has the smallest area dedicated to rice cultivation, accounting for 21.0% of the entire area.

Hisar District:

The map titled "Rice Crop Area of Hisar District in Haryana – 2022" illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

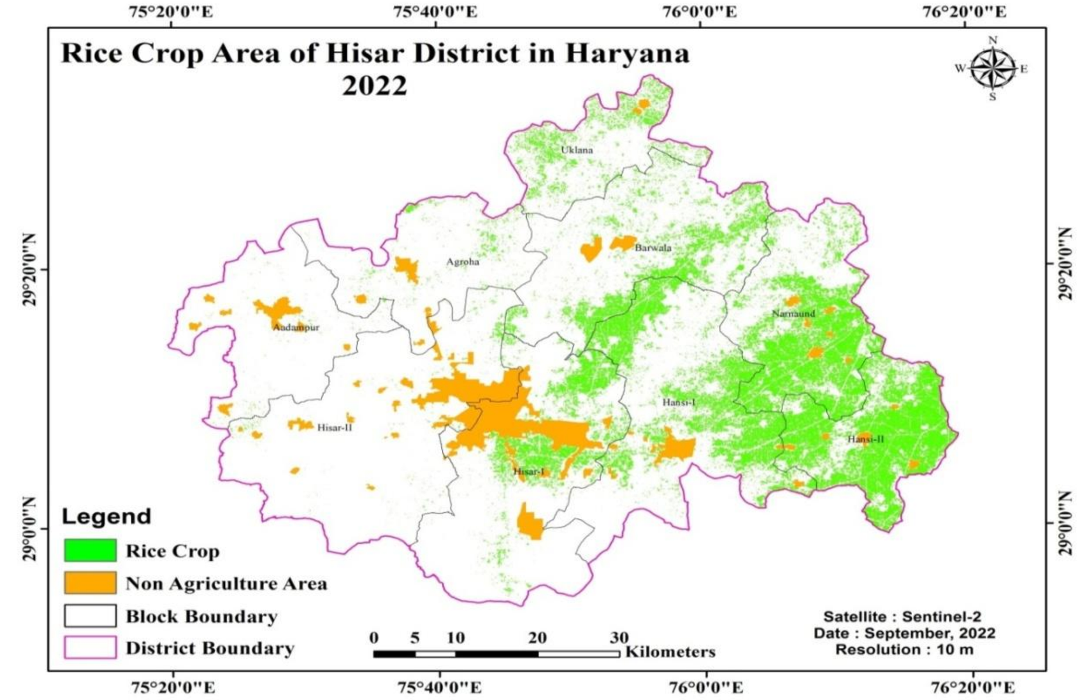


Figure 3.31: Rice Crop Area of Hisar District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are shown in bright green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that rice cultivation in Hisar district is unevenly distributed and relatively limited compared to eastern Haryana. Higher concentrations of rice are observed mainly in the eastern and south-eastern blocks such as Hansi-I, Hansi-II, Narnaund, and parts of Barwala, where irrigation facilities are more developed. In contrast, western and central blocks including Adampur, Agroha, and parts of Hisar show sparse rice coverage due to semi-arid climatic conditions, sandy soils, and water scarcity. Non-agricultural land is primarily concentrated around Hisar city and other settlement clusters.

Table: 3.31: Block wise Rice area Estimation of Hisar District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Hisar	Hisar-I	7660.2	9.6
2	Hisar	Adampur	248.1	0.3
3	Hisar	Agroha	1048.4	1.3
4	Hisar	Uklana	4223.9	5.3
5	Hisar	Hansi-II	19023.4	23.8
6	Hisar	Hisar-II	527.9	0.7
7	Hisar	Narnaund	14803.4	18.5
8	Hisar	Barwala	16366.5	20.5
9	Hisar	Hansi-I	16053.9	20.1
Total			**79955.6**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

An estimate of the area used for rice cultivation in each of the block of Hisar's blocks is shown in this table 3.31With an estimated 7,660.2 hectares of rice-growing land, Hisar-I block accounts for 9.6% of the district's total rice area. The estimated area used for rice cultivation in the Adampur block is 248.1 hectares, which accounts for 0.3% of the total area used for rice production. With an estimated 1,048.4 hectares dedicated to rice cultivation, the Agroha block makes about 1.3% of the total rice area. With an estimated 4,223.9 hectares of rice-growing land, the Uklana block accounts for 5.3% of the total rice area. At 19,023.4 hectares, Hansi-II block has the biggest estimated rice-growing area, accounting for 23.8% of the total rice area. At 527.9 hectares, the estimated rice-growing area of the Hisar-II block makes up just 0.7% of the overall rice acreage. At

14,803.4 hectares, the Narnaund block is predicted to have a considerable rice-growing area, making about 18.5% of the overall rice area. Barwala block accounts for 20.5% of the overall rice area with an estimated large growing area of 16,366.5 hectares. Additionally, a sizeable estimated 16,053.9 hectares, or 20.1% of the total rice area, are planted to rice in the Hansi-I block.

Jhajjar District:

The map titled "Rice Crop Area of Jhajjar District in Haryana – 2022" illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

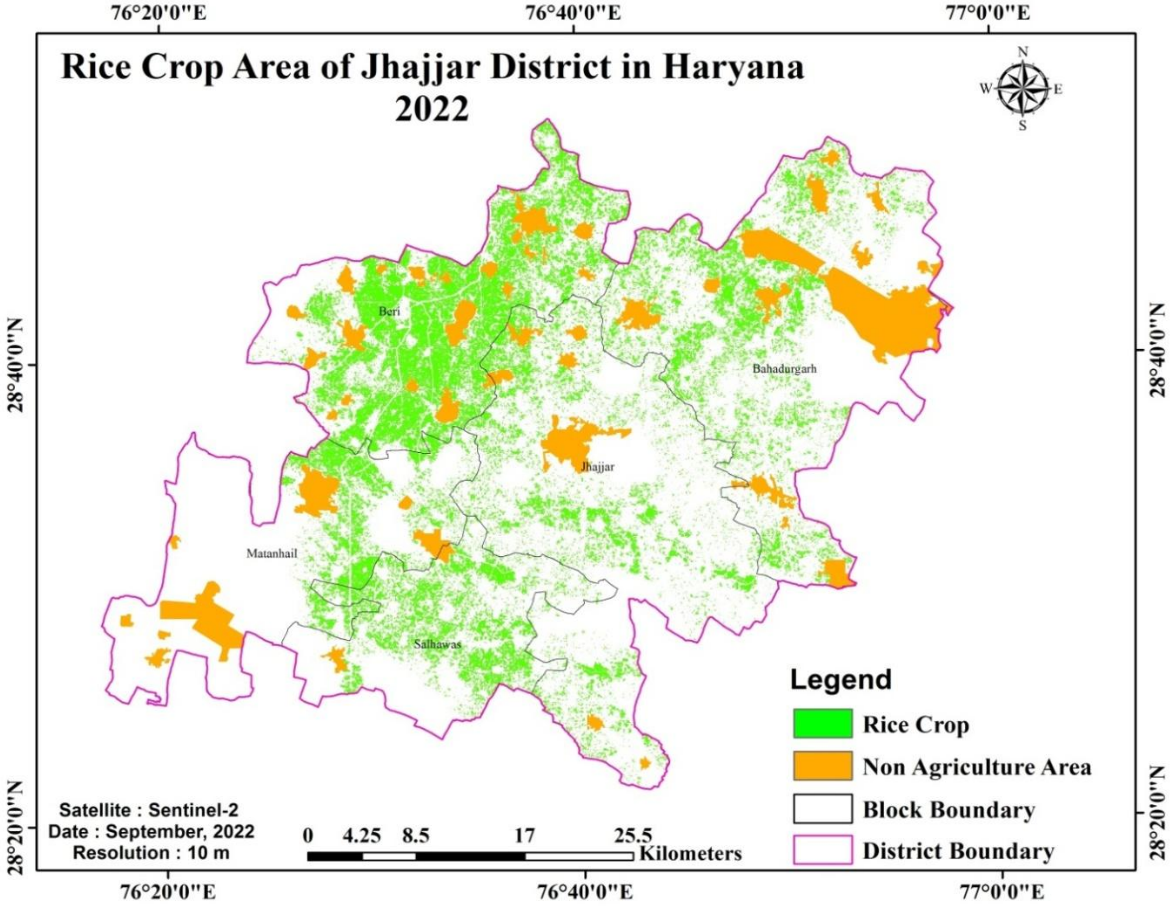


Figure 3.32: Rice Crop Area of Jhajhar District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are depicted in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is moderately distributed across the district, with relatively higher concentration in blocks such as Beri, Salhawas, and parts of Jhajjar block where irrigation facilities support paddy cultivation. However, the overall distribution appears scattered and less dense compared to the northern and north-eastern districts of Haryana. Significant non-agricultural areas are visible around Bahadurgarh and certain peripheral zones due to urban expansion influenced by proximity to Delhi and the National Capital Region (NCR). Overall, the map highlights that rice is cultivated in irrigated pockets of Jhajjar district, but its extent is moderate and influenced by both water availability and growing urbanization.

The rice-growing area in each of the blocks in the Jhajhar district is estimated in this table 3.32 with an estimated 4,020.9 hectares dedicated to rice cultivation, Bahadurgarh block accounts for 11.1% of the district of Jhajhar's total rice area.

Table: 3.32: Block wise Rice area Estimation of Jhajhar District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Jhajjar	Bahadurgarh	4020.9	11.1
2	Jhajjar	Matannail	4612.7	12.8
3	Jhajjar	Salhawas	3806.5	10.5
4	Jhajjar	Beri	13785.3	38.2
5	Jhajjar	Jhajjar	7584.5	21.0
6	Jhajjar	Badli	2311.0	6.4
Total			**36120.9**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

With an estimated 4,612.7 hectares dedicated to rice cultivation, the Matannail block accounts for 12.8% of the total rice area. With an estimated 3,806.5 hectares dedicated to rice cultivation, the Salhawas block makes about 10.5% of the overall rice area. With an estimated 13,785.3 hectares, or 38.2% of the total rice acreage, the Beri block is the largest rice-growing area. The Jhajhar block accounts for 21.0% of the overall rice area, with an estimated area of 7,584.5 hectares dedicated to rice cultivation. With an estimated 2,311.0 hectares of rice-growing land, the Badli block accounts for 6.4% of the total rice area.

Jind District:

The map titled “Rice Crop Area of Jind District in Haryana – 2022” presents the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution. Rice crop areas are depicted in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries.

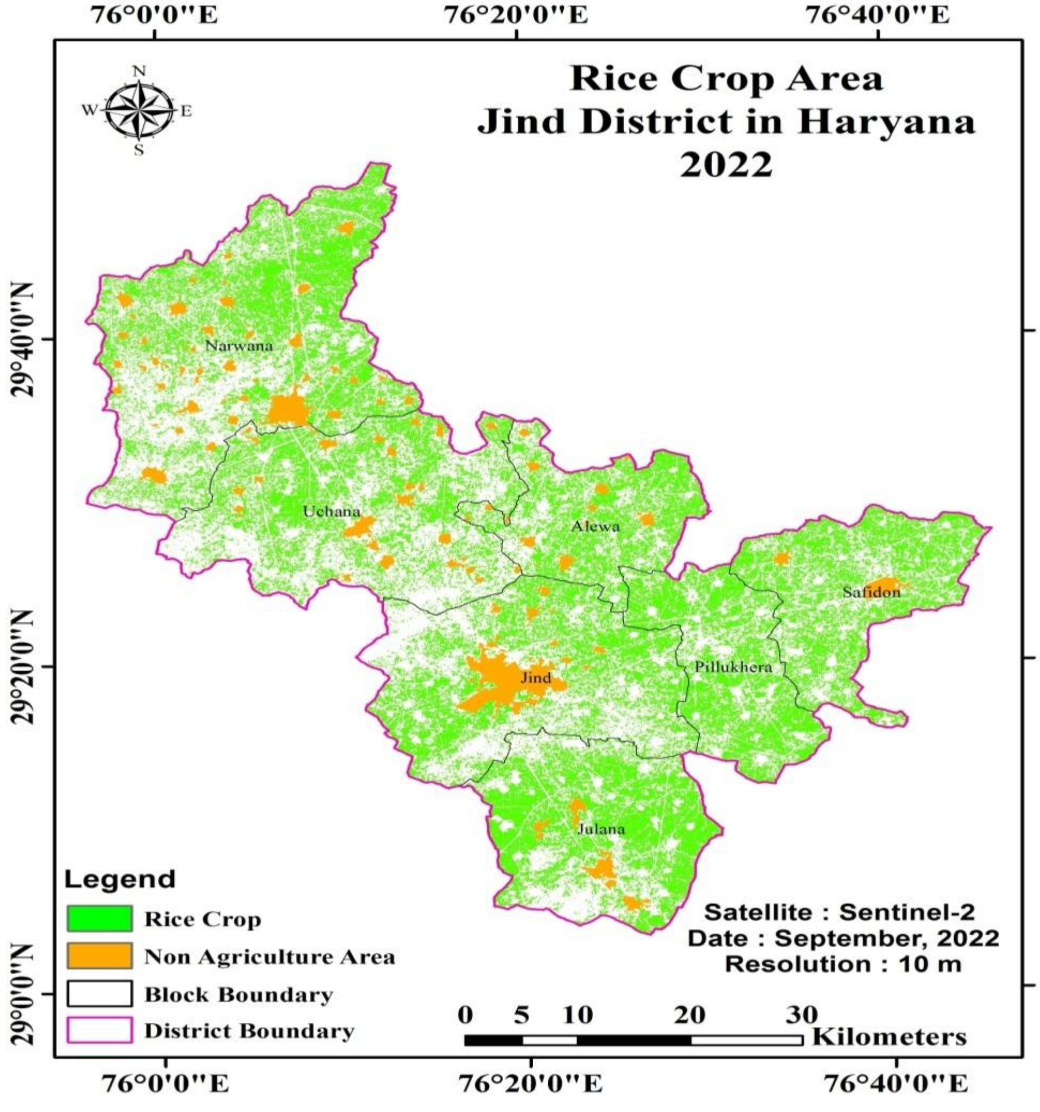


Figure 3.33: Rice Crop Area of Jind District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

The map indicates that rice cultivation is extensively and uniformly distributed across most parts of the district, particularly in blocks such as Narwana, Uchana, Alewa, Safidon, Julana, and Jind, reflecting well-developed canal irrigation systems and fertile alluvial soils. The dense and continuous green coverage suggests intensive paddy cultivation during the monsoon season. Non-agricultural land is mainly confined to urban centers and settlement clusters. Overall, the map highlights Jind as one of the major rice-growing districts of Haryana, where paddy occupies a substantial proportion of cultivated land during the Kharif season of 2022.

The table no 3.33 shows that estimate of the area used for rice cultivation in each of the blocks in Jind district is. Let's examine the data shown in each column: With an estimated 15,082.1 hectares of rice-growing land, Safidon Block accounts for 11.6% of Jind district's total rice area.

Table 3.33: Block wise Rice area Estimation of Jind District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Jind	Safidon	15082.1	11.6
2	Jind	Ujhana	17843.9	13.8
3	Jind	Narwana	11948.6	9.2
4	Jind	Uchana	18621.8	14.4
5	Jind	Alewa	12182.7	9.4
6	Jind	Julana	18594.2	14.4
7	Jind	Jind	20150.1	15.6
8	Jind	Pillukhera	15058.8	11.6
Total			**129482.2**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

With an estimated 17,843.9 hectares dedicated to rice cultivation, Ujhana block accounts for 13.8% of the total rice area. The estimated area used for rice cultivation in the Narwana block is 11,948.6 hectares, or 9.2% of the total area used for rice production. At 18,621.8 hectares, the Uchana block has the greatest estimated rice-growing area, accounting for 14.4% of the overall rice area. Alewa block accounts for 9.4% of the total rice area with an estimated 12,182.7 hectares under cultivation. With an estimated 18,594.2 hectares dedicated to rice cultivation, the Julana block accounts for 14.4% of the total rice area. With an estimated 20,150.1 hectares of rice-growing land, Jind block accounts for 15.6% of the total rice area. With an estimated 15,058.8 hectares dedicated to rice cultivation, the Pillukhera block makes for 11.6% of the total rice area.

Kaithal District:

The map titled “Rice Crop Area of Kaithal District in Haryana – 2022” depicts the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

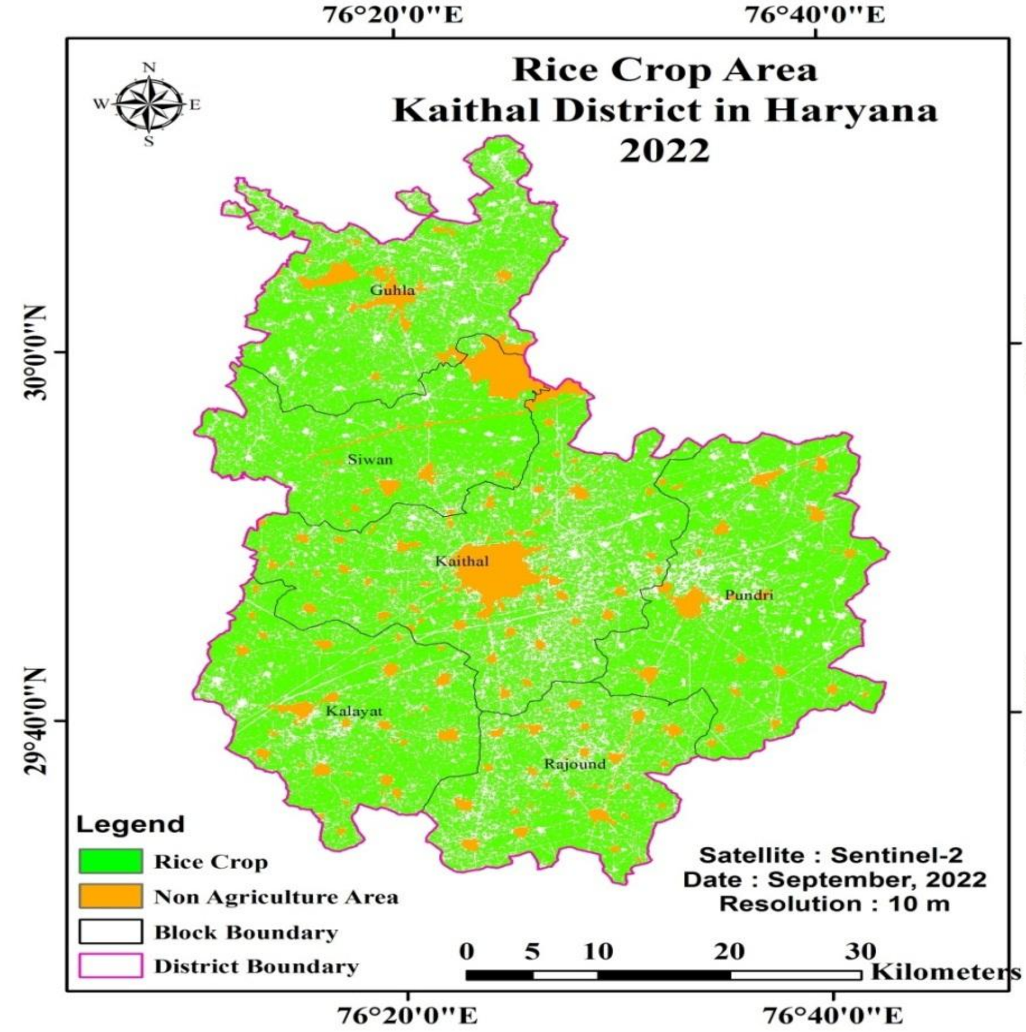


Figure 3.34: Rice Crop Area of Kaithal District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are represented in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is extensively and uniformly distributed across almost the entire district, particularly in blocks such as Guhla, Siwan, Kaithal, Pundri, Kalayat, and Rajound. The dense and continuous coverage of paddy fields reflects assured canal irrigation, fertile alluvial soils, and intensive agricultural practices. Non-agricultural land is mainly concentrated around Kaithal town and other settlement clusters, appearing as scattered patches within the dominant agricultural landscape. Overall, the map highlights Kaithal as one of the major rice-producing districts of Haryana, where paddy occupies a substantial proportion of cultivated land during the Kharif season of 2022.

Table: 3.34: Block wise Rice area Estimation of Kaithal District.

Sr. No.	District Name	Block Name	Area in Hectare (Rice)	Area in %
1	Kaithal	Pundri	23052.3	13.8
2	Kaithal	Guhla	26546.9	15.9
3	Kaithal	Siwan	21395.3	12.8
4	Kaithal	Kaithal	35830.8	21.5
5	Kaithal	Dhand	17994.2	10.8
6	Kaithal	Kalayat	23410.6	14.0
7	Kaithal	Rajound	18416.9	11.1
Total			**166647.0**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The table 3.34 show estimate of the area used for rice cultivation in each of the district's blocks in Kaithal .With an estimated 23,052.3 hectares of rice-growing land, Pundri Block accounts for 13.8% of Kaithal district's total rice area. With an estimated 26,546.9 hectares dedicated to rice cultivation,

Guhla Block accounts for 15.9% of the total rice area. With an estimated 21,395.3 hectares of rice-growing land, Siwan Block makes up 12.8% of the total rice area. At 35,830.8 hectares, the Kaithal block has the greatest estimated rice-growing area, accounting for 21.5% of the overall rice area. With an estimated 17,994.2 hectares dedicated to rice cultivation, Dhand block accounts for 10.8% of the total rice area.

With an estimated 23,410.6 hectares of rice-growing land, the Kalayat block accounts for 14.0% of the total rice area. The estimated 18,416.9 hectares of rice-growing land in the Rajound block make up 11.1% of the total rice area.

Karnal District:

The map titled “Rice Crop Area of Karnal District in Haryana – 2022” illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

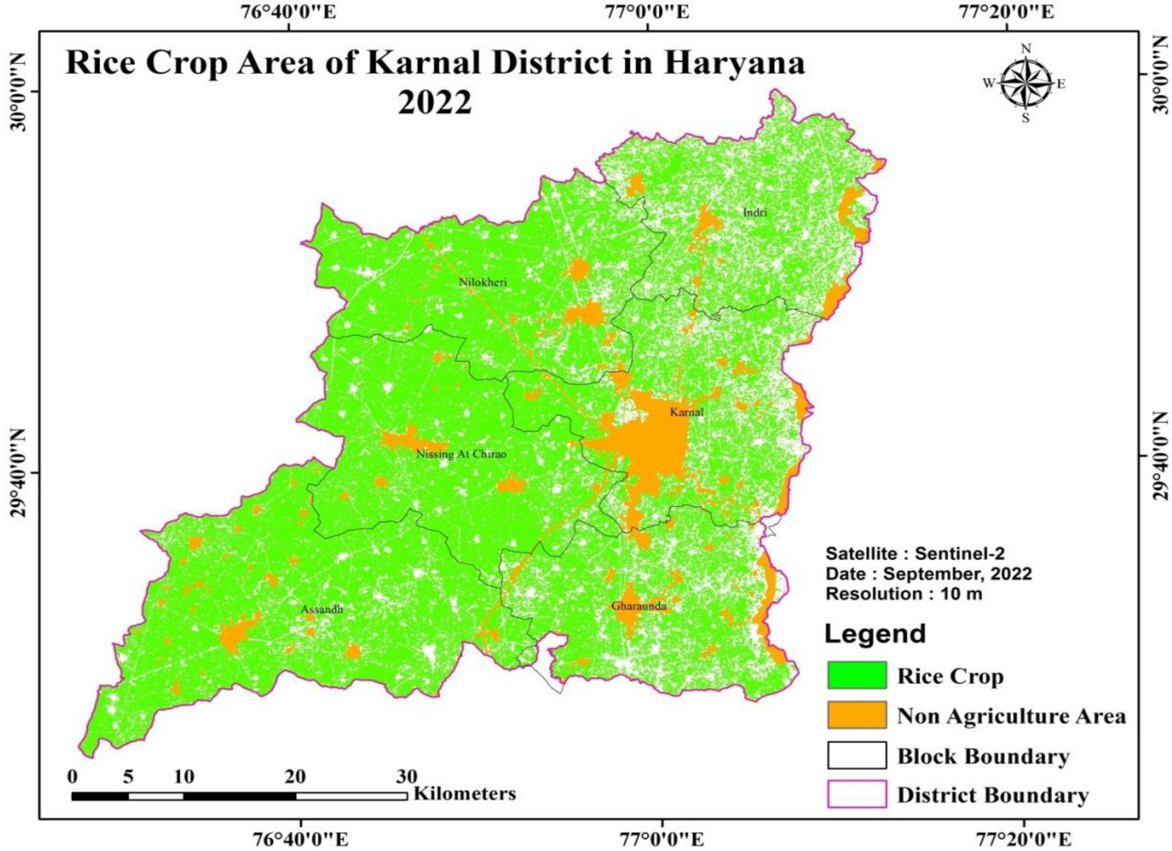


Figure 3.35: Rice Crop Area of Karnal District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are shown in bright green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map clearly indicates that rice cultivation is extensively and uniformly distributed across almost the entire district, particularly in blocks such as Nilokheri, Indri, Nissing, Assandh, and Gharaunda. The dense and continuous coverage of paddy fields reflects fertile alluvial soils, assured canal irrigation, and advanced agricultural practices, making Karnal one of the leading rice-producing districts in Haryana. Non-agricultural land is mainly concentrated around Karnal city and other urban centers, appearing as localized patches within the dominant agricultural landscape. Overall, the map highlights Karnal as a major paddy-growing district where rice occupies a substantial proportion of cultivated land during the Kharif season of 2022.

The table 3.35 represents the estimate of the land used for rice cultivation in each of the district's blocks in Karnal. With an approximate 14,904.7 hectares under cultivation, Karnal block accounts for 8.7% of the district's total rice acreage. At 32,370.2 hectares, the Assandh block has the biggest projected rice-growing area (18.9% of the total rice area). Nissing With an estimated 31,508.3 hectares dedicated to rice cultivation, the Chirao block makes up 18.4% of the total rice area.

The estimated rice-growing area in the Munak block is 20,529.5 hectares, or 12.0% of the total rice area. The estimated 29,320.1 hectares of rice-growing land in the Nilokheri block make up 17.1% of the total rice area.

Table 3.35: Block wise Rice area Estimation of Karnal District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Rice)**	**Area in %**
1	Karnal	Karnal	14904.7	8.7
2	Karnal	Assandh	32370.2	18.9
3	Karnal	Nissing at Chirao	31508.3	18.4
4	Karnal	Munak	20529.5	12.0
5	Karnal	Nilokheri	29320.1	17.1
6	Karnal	Indri	11203.5	6.5
7	Karnal	Kunjpura	13372.6	7.8
8	Karnal	Gharaunda (Part)	18226.6	10.6
Total			**171435.5**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

With an estimated 11,203.5 hectares dedicated to rice cultivation, the Indri block accounts for 6.5% of the total rice area. The estimated rice-growing area in Kunjpura block is 13,372.6 hectares, or 7.8% of the total rice area. The estimated rice-growing area of the Gharaunda (Part) block is 18,226.6 hectares, or 10.6% of the total rice area.

Kurukshetra District:

The map titled "Rice Crop Area of Kurukshetra District in Haryana – 2022" depicts the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

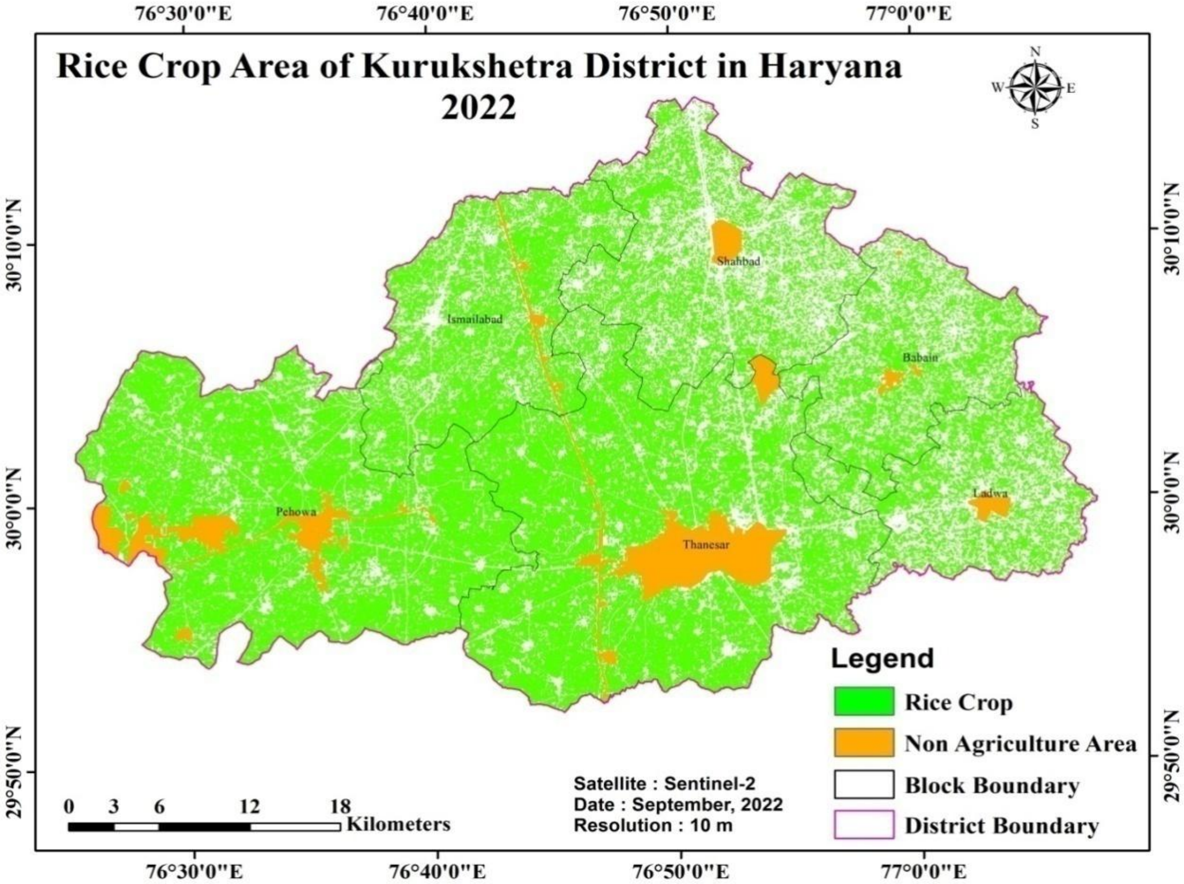


Figure 3.36: Rice Crop Area of Kurukshetra District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are represented in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is extensively and uniformly spread across almost the entire district, particularly in blocks such as Pehowa, Thanesar, Shahbad, Ladwa, and Ismailabad. The dense and continuous green coverage reflects fertile alluvial soils, assured canal irrigation, and intensive paddy cultivation practices. Non-agricultural land is mainly concentrated around Thanesar town and other urban centers, appearing as localized patches within the predominantly agricultural landscape. Overall, the map highlights Kurukshetra as one of the leading rice-producing districts of Haryana, where paddy occupies a substantial proportion of cultivated land during the Kharif season of 2022.

Table 3.36: Block wise Rice area Estimation of Kurukshetra District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Kurukshetra	Ladwa	8836.7	8.1
2	Kurukshetra	Pehowa	32577.6	29.7
3	Kurukshetra	Thanesar	22445.1	20.5
4	Kurukshetra	Ismailabad	13454.5	12.3
5	Kurukshetra	Shahbad	14368.9	13.1
6	Kurukshetra	Pipli	10943.2	10.0
7	Kurukshetra	Babain	7105.2	6.5
Total			**109731.3**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The rice-growing area in each of the district of Kurukshetra's blocks is estimated in this table 3.36.With an estimated 8,836.7 hectares dedicated to rice cultivation, Ladwa block accounts for 8.1% of the district of Kurukshetra's total rice area.

The greatest projected rice-growing area, 32,577.6 hectares, is found in the Pehowa block, accounting for 29.7% of the total rice area. Twenty.5% of the total rice area, or 22,445.1 hectares, are anticipated to be under rice cultivation in the Thanesar block. With an estimated 13,454.5 hectares dedicated to rice cultivation, the Ismailabad block accounts for 12.3% of the total rice area. With an estimated 14,368.9 hectares dedicated to rice cultivation, Shahbad Block accounts for 13.1% of the total rice area. With an estimated 10,943.2 hectares of rice-growing land, Pipli Block accounts for 10.0% of the total rice area. Babain block makes up 6.5% of the overall rice area, with the smallest estimated rice-growing area at 7,105.2 hectares.

Palwal District:

The map titled “Rice Crop Area of Palwal District in Haryana – 2022” illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

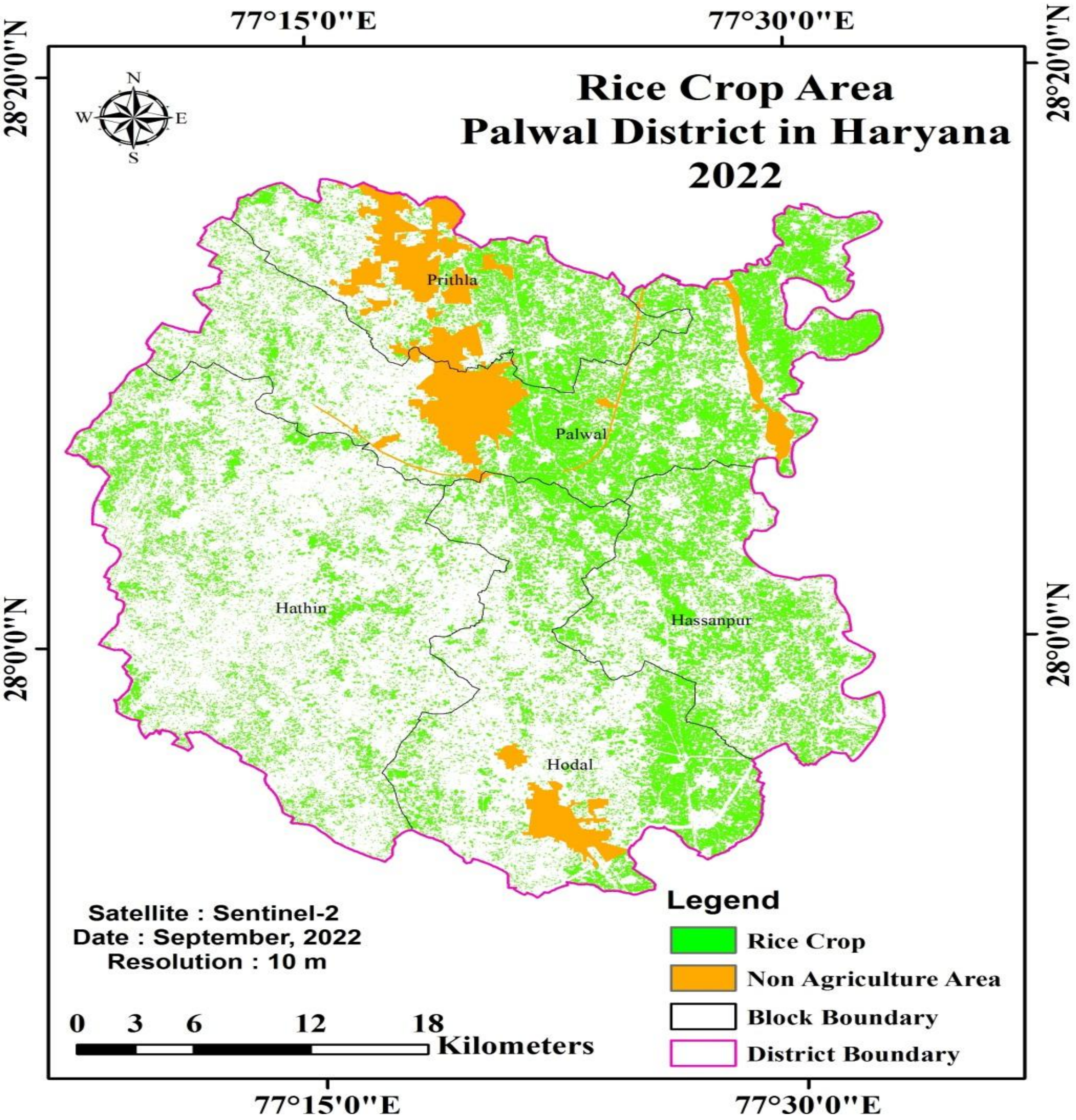


Figure 3.37: Rice Crop Area of Palwal District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022)

Rice crop areas are represented in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is moderately distributed across the district, with higher concentration in blocks such as Hassanpur, Hodal, and parts of Palwal block where irrigation facilities and suitable soil conditions support paddy cultivation. In contrast, the western block of Hathin shows comparatively sparse and scattered rice patches due to relatively drier conditions and limited water availability. Non-agricultural land is mainly concentrated around urban centers like Palwal and Prithla, reflecting settlement expansion and infrastructural development. Overall, the map highlights that rice cultivation in Palwal district is significant but not uniformly dense, with its distribution influenced by irrigation access and urban growth patterns.

The table no 3.37 show the an estimate of the rice-growing area in each of the blocks in the Palwal district. With an estimated 8,027.1 hectares of rice-growing land, Hodal block accounts for 19.8% of Palwal district's total rice area.

With an estimated 5,048.1 hectares dedicated to rice cultivation, the Prithla block accounts for 12.5% of the total rice area. At 9,264.9 hectares, the Badoli block has the greatest projected rice-growing area, making up 22.9% of the overall rice acreage. Palwal block accounts for 12.2% of the total rice area, with an estimated 4,939.8 hectares under cultivation.

Table: 3.37: Block wise Rice area Estimation of Palwal District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Rice)**	**Area in %**
1	Palwal	Hodal	8027.1	19.8
2	Palwal	Prithla	5048.1	12.5
3	Palwal	Badoli	9264.9	22.9
4	Palwal	Palwal	4939.8	12.2
5	Palwal	Hathin	7341.8	18.2
6	Palwal	Hassanpur	5824.5	14.4
Total			**40446.1**	**100**

(Data Source: Sentinel 2 Satellite Data 2020**)**

With an estimated 7,341.8 hectares dedicated to rice cultivation, Hathin Block accounts for 18.2% of the total rice area. With an estimated 5,824.5 hectares dedicated to rice cultivation, the Hassanpur block accounts for 14.4% of the total rice area.

Panchkula District:

The map titled "Rice Crop Area of Panchkula District in Haryana – 2022" illustrates the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

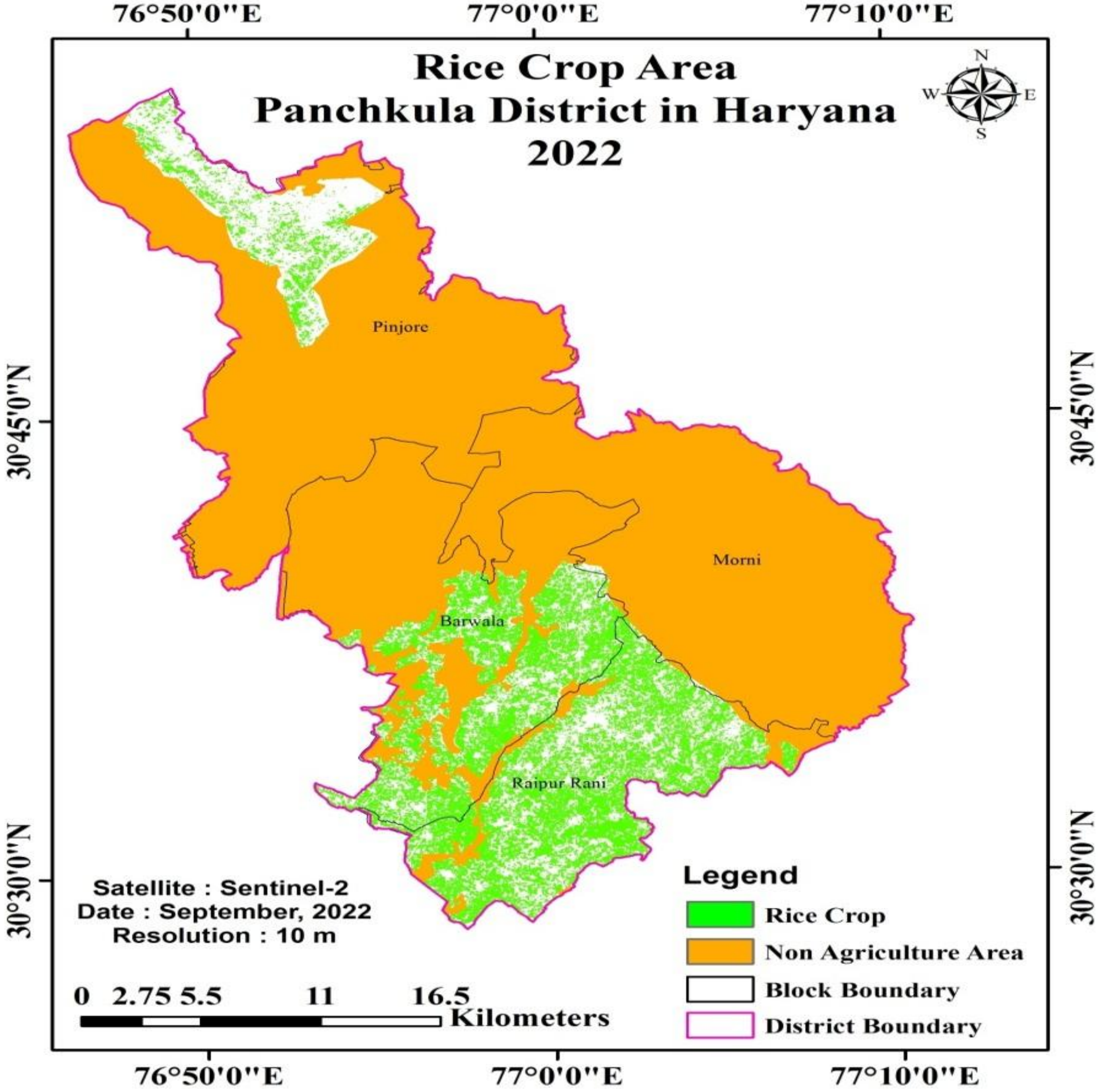


Figure 3.38: Rice Crop Area of Panchkula District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are shown in bright green, while non-agricultural areas are represented in orange, along with block and district boundaries. The map indicates that rice cultivation is limited and unevenly distributed across the district. The northern and eastern parts, particularly Morni and much of Pinjore block, are largely dominated by non-agricultural land due to hilly terrain, forest cover, and Shivalik foothill conditions that restrict intensive farming. Rice cultivation is mainly concentrated in the southern and south-western blocks such as Raipur Rani and Barwala, where relatively flat plains, better soil conditions, and irrigation facilities support paddy cultivation. Overall, the map highlights the strong influence of physiography on land use, with rice cultivation confined primarily to the plain and irrigated regions of Panchkula district.

Table: 3.38: Block wise Rice area Estimation of Panchkula District.

Sr. No.	**District**	**Block Name**	**Area in Hectare (Rice)**	**Area in %**
1	Panchkula	Morni	426.4	1.5
2	Panchkula	Pinjore	2885.6	10.1
3	Panchkula	Barwala	16366.5	57.5
4	Panchkula	Raipur Rani	8766.4	30.8
Total			**28444.8**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The table no 3.38 show the rice area in each of the district of Panchkula's blocks is estimated. With an estimated 426.4 hectares of rice growing, Morni Block makes up just 1.5% of Panchkula district's total rice area. With an estimated 2,885.6 hectares dedicated to rice cultivation, the Pinjore block accounts for 10.1% of the total rice area. At 16,366.5 hectares, the biggest estimated rice-growing area, or 57.5% of the total rice area, is found in the Barwala block. The Raipur Rani block accounts for 30.8% of the total rice area with an estimated 8,766.4 hectares under cultivation.

Panipat District:

The map titled “Rice Crop Area of Panipat District in Haryana – 2022” presents the spatial distribution of rice cultivation during the Kharif season based on Sentinel-2 satellite imagery (September 2022) with 10 m spatial resolution. Rice crop areas are shown in bright green, while non-agricultural areas are depicted in orange, along with block and district boundaries. The map reveals that rice cultivation is widely and intensively distributed across almost the entire district, reflecting the dominance of irrigated agriculture and fertile alluvial soils.

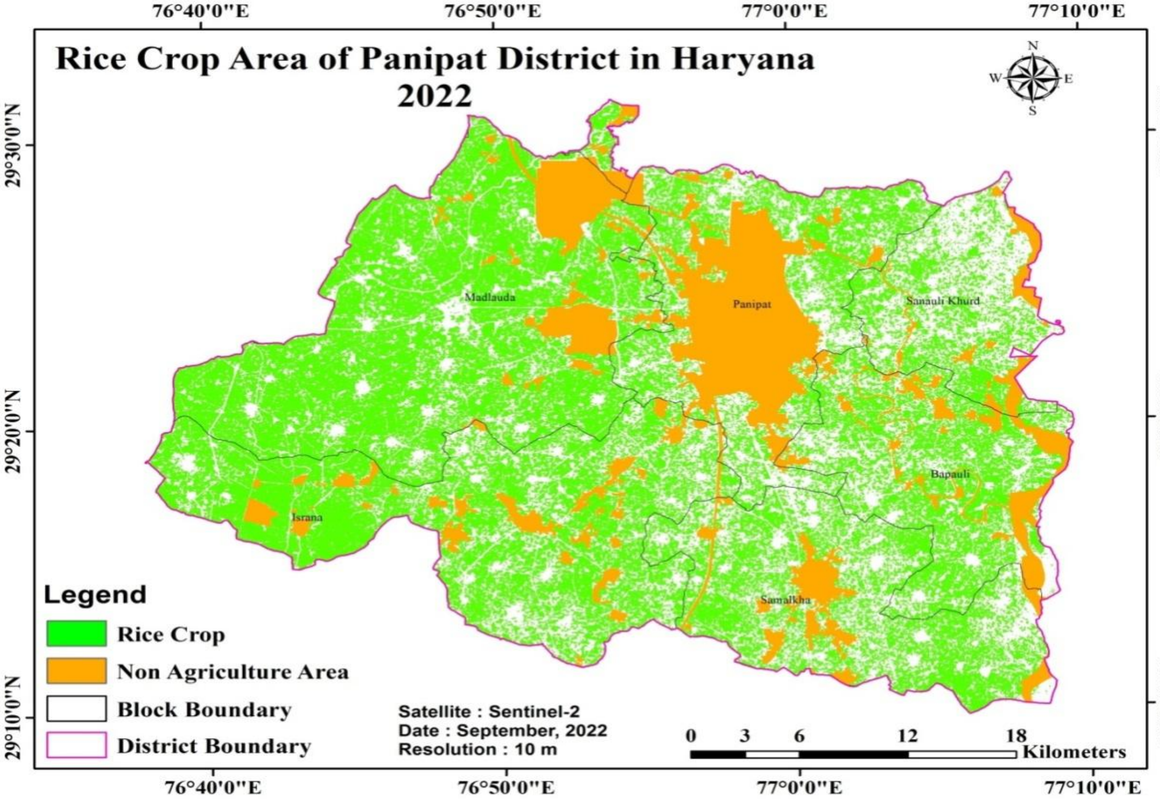


Figure 3.39: Rice Crop Area of Panipat District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Blocks such as Israna, Madlauda, Samalkha, and Bapoli exhibit dense and continuous rice coverage, indicating high cropping intensity and assured canal as well as groundwater irrigation. Non-agricultural land is mainly concentrated around Panipat town and other urban centers, appearing as prominent orange patches amid the agricultural landscape. Overall, the map highlights Panipat as a major rice-growing district of Haryana, with extensive paddy cultivation supported by developed irrigation infrastructure and favorable agro-climatic conditions.

The table no 3.39 rice cultivation in each of the district's blocks in Panipat. The estimated 8,290.5 hectares of rice-growing land in the Bapoli block make up 11.2% of the district of Panipat's total rice acreage.

Table: 3.39: Block wise Rice area Estimation of Panipat District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Panipat	Bapoli	8290.5	11.2
2	Panipat	Israna	17818.0	24.1
3	Panipat	Samalkha	9585.0	13.0
4	Panipat	Panipat	8198.1	11.1
5	Panipat	Sanauli Khurd	4481.1	6.1
6	Panipat	Madlauda	25514.0	34.5
Total			**73886.5**	**100**

(Data Source:- Sentinel 2 Satellite Data 2022)

With an estimated area of 17,818.0 hectares, or 24.1% of the total rice acreage, the Israna block has the largest area for rice cultivation. The estimated area used for rice cultivation in Samalkha block is 9,585.0 hectares, or 13.0% of the total area used for rice production. With 8,198.1 hectares of rice-growing land, Panipat Block accounts for 11.1% of the total rice area. An estimated 4,481.1 hectares, or 6.1% of the total rice area, are planted to rice in the Sanauli Khurd block. At 25,514.0 hectares, the Madlauda block has the largest estimated area used for rice cultivation, accounting for 34.5% of the total area.

Rohtak District:

The map titled “Rice Crop Area of Rohtak District in Haryana – 2022” illustrates the spatial distribution of rice cultivation during the Kharif season using Sentinel-2 satellite imagery (September 2022) with 10 m spatial resolution. Rice crop areas are depicted in bright green, while non-agricultural areas are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is moderately widespread across the district, with relatively higher concentration in blocks such as Lakhan Majra, Meham, and parts of Kalanaur where irrigation facilities support paddy farming.

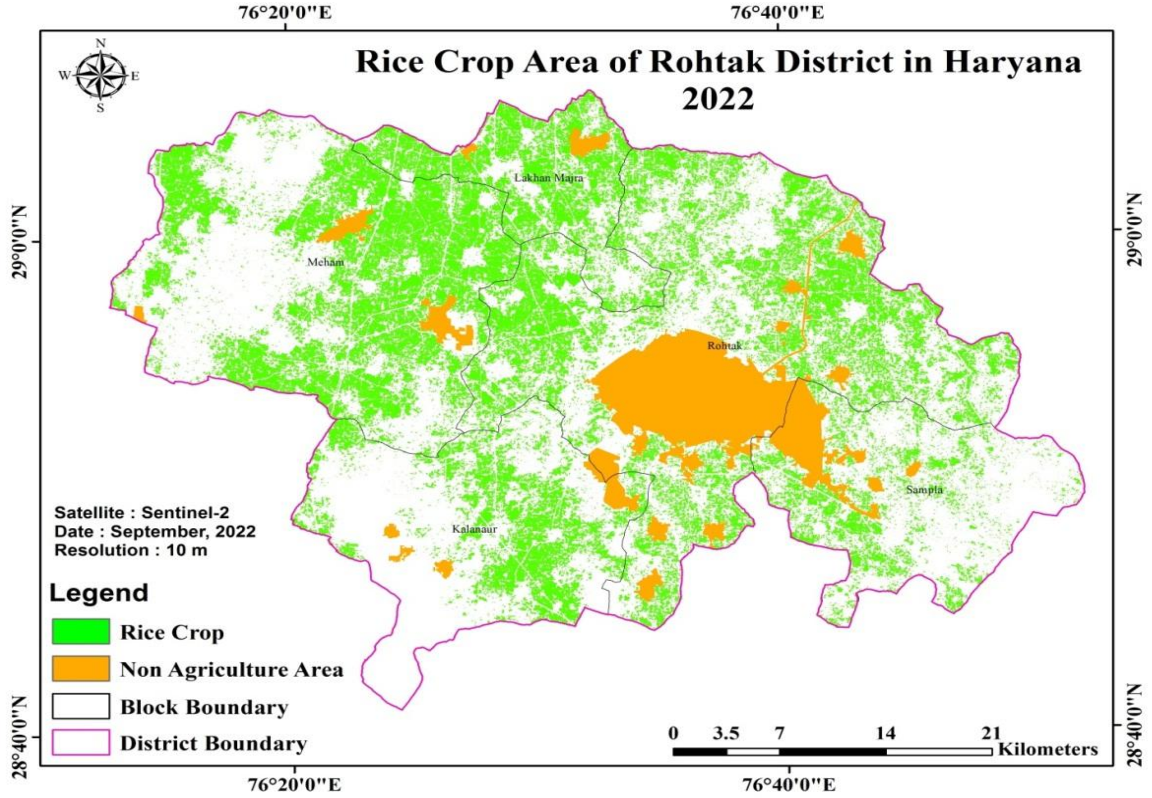


Figure 3.40: Rice Crop Area of Rohtak District in Haryana 2022 (Data Source: Sentinel-2 Satellite Data 2022).

However, rice coverage appears less dense compared to major paddy-dominant districts of eastern Haryana. A significant non-agricultural patch is visible around Rohtak city, reflecting urban expansion and built-up land. Scattered orange patches across other blocks represent settlements and infrastructural areas within the agricultural landscape.

Table: 3.40: Block wise Rice area Estimation of Rohtak District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Rohtak	Rohtak	18571.4	34.1
2	Rohtak	Sampla	4627.6	8.5
3	Rohtak	Lakhan Majra	7860.7	14.4
4	Rohtak	Maham	16063.9	29.5
5	Rohtak	Kalanaur	7347.1	13.5
Total			**54470.7**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

An estimate of the area used for rice cultivation in each of the district of Rohtak's blocks is shown in this table 3.40. Let's examine the data presented. With an estimated 18,571.4 hectares of rice-growing land, Rohtak block accounts for 34.1% of the district's total rice area. With an estimated 4,627.6 hectares dedicated to rice cultivation, Sampla Block accounts for 8.5% of the total rice area. The estimated area used for rice cultivation in the Lakhan Majra block is 7,860.7 hectares, or 14.4% of the total area used for rice production. The largest projected rice-growing block, Maham block, covers 16,063.9 hectares, or 29.5% of the total rice acreage. With an estimated 7,347.1 hectares dedicated to rice cultivation, the Kalanaur block accounts for 13.5% of the total rice area.

Sirsa District:

The map titled “Rice Crop Area of Sirsa District in Haryana – 2022” presents the spatial distribution of rice cultivation during the Kharif season using Sentinel-2 satellite imagery (September 2022) with 10 m resolution.

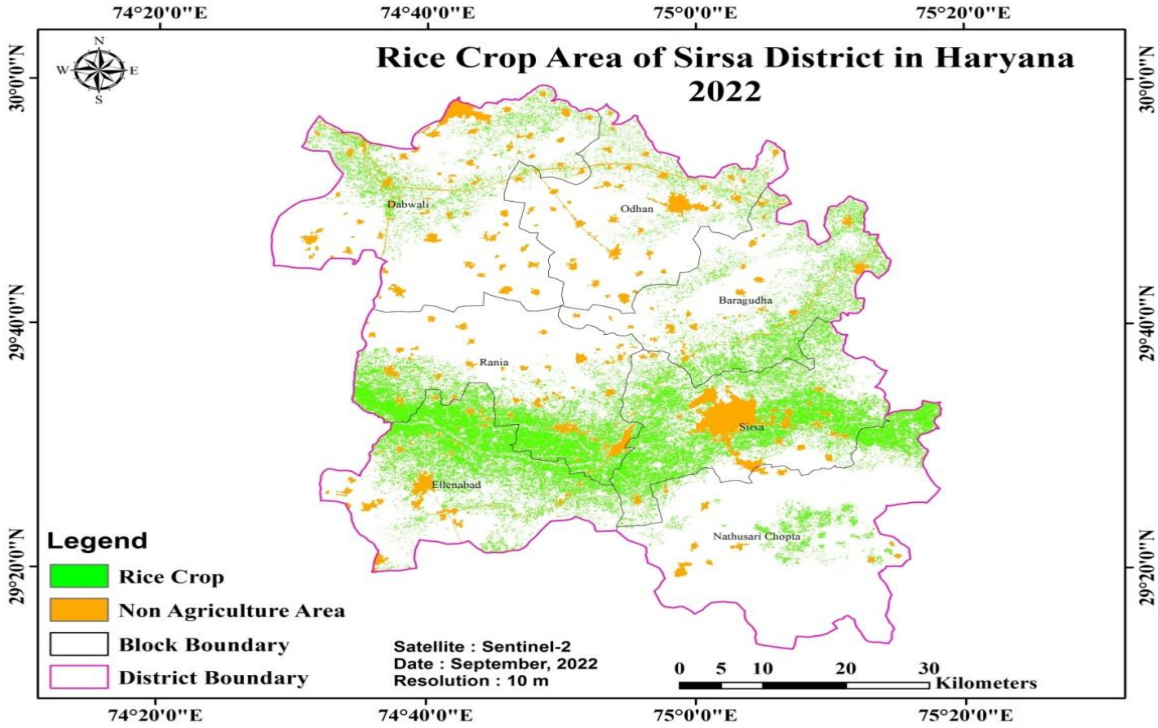


Figure 3.41: Rice Crop Area of Sirsa District in Haryana 2022 (Data Source: Sentinel 2 Satellite Data 2022).

Rice crop areas are shown in green, while non-agricultural areas such as settlements and built-up land are depicted in orange, along with block and district boundaries. The distribution pattern reveals that rice cultivation is mainly concentrated in the southern and south-eastern parts of the district, particularly around Sirsa, Ellenabad, and Nathusari Chopta blocks, where canal irrigation and relatively better water availability support paddy farming. In contrast, the northern and north-western blocks such as Dabwali, Odhan, and parts of Rania show comparatively sparse rice coverage, indicating limited irrigation or preference for alternative crops like cotton. Large scattered orange patches represent urban centers and non-agricultural land uses within the predominantly agricultural landscape.

Table: 3.41: Block wise Rice area Estimation of Sirsa District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Sirsa	Nathusari Chopta	6272.4	9.3
2	Sirsa	Dabwali	5937.0	8.8
3	Sirsa	Odhan	2859.8	4.2
4	Sirsa	Rania	12675.3	18.8
5	Sirsa	Ellenabad	11020.7	16.3
6	Sirsa	Baragudha	8795.4	13.0
7	Sirsa	Sirsa	20016.9	29.6
Total			**67577.6**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The table no 3.41 shows rice cultivation area in each of the district's blocks in Sirsa .With an estimated 6,272.4 hectares dedicated to rice cultivation, Nathusari Chopta block accounts for 9.3% of the district of Sirsa's total rice acreage. The estimated rice-growing area in the Dabwali block is 5,937.0 hectares, or 8.8% of the total rice area. The estimated area used for rice cultivation in the Odhan block is 2,859.8 hectares, or 4.2% of the total area used for rice production. The Rania block accounts for 18.8% of the overall rice area with an estimated rice-growing area of 12,675.3 hectares. With an estimated 11,020.7 hectares of rice-growing land, Ellenabad Block accounts for 16.3% of the total rice area. The estimated 8,795.4 hectares of rice-growing land in the Baragudha block account for 13.0% of the total rice area. At 20,016.9 hectares, the Sirsa block has the greatest projected rice-growing area, making up 29.6% of the overall rice area.

Sonipat District:

The map titled "Rice Crop Area of Sonipat District in Haryana – 2022" illustrates the spatial distribution of rice cultivation during the Kharif season using Sentinel-2 satellite imagery (September 2022) with 10 m spatial resolution.

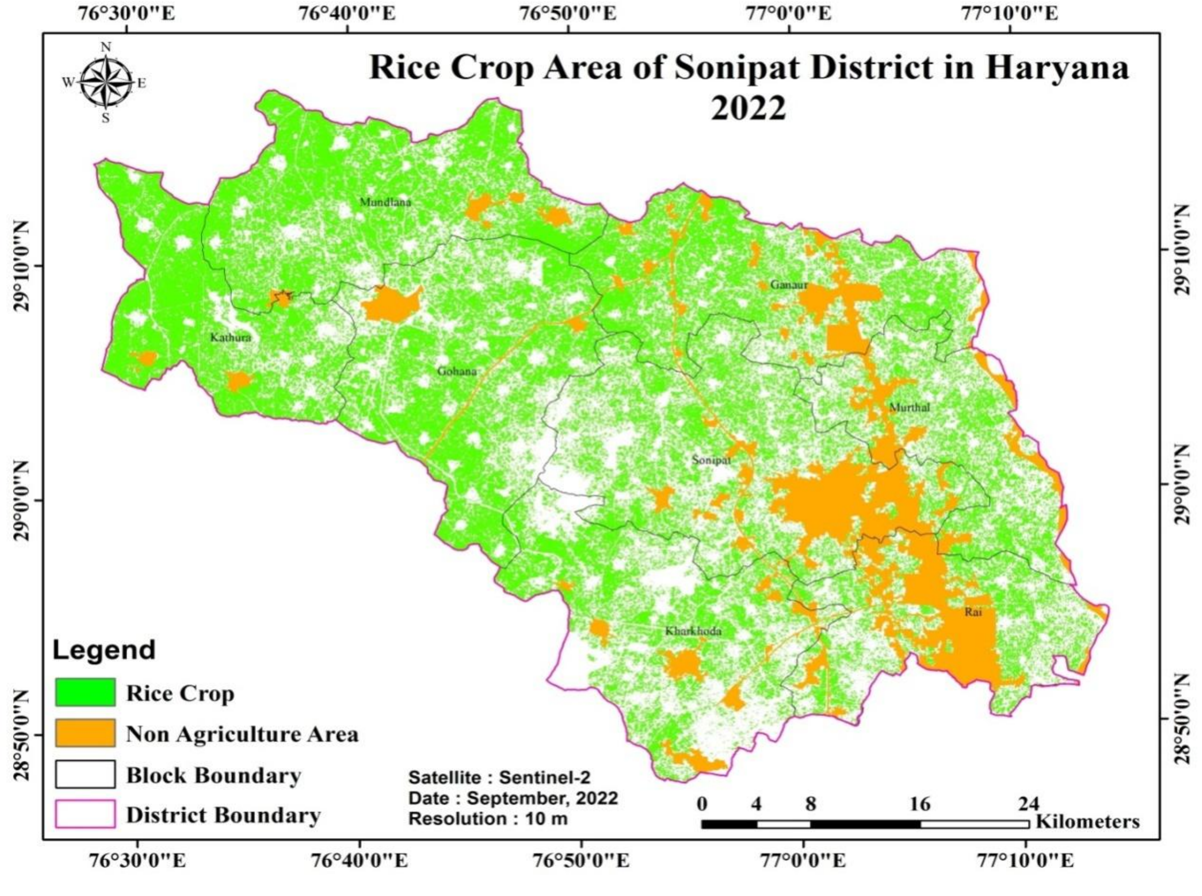


Figure 3.42: Rice Crop Area of Sonipat District in Haryana 2022 (Data Source: Sentinel-2 Satellite Data 2022).

Rice crop areas are represented in green, while non-agricultural areas such as urban settlements, industrial zones, and built-up land are shown in orange, along with block and district boundaries. The map indicates that rice cultivation is widely distributed across the district, particularly in the central, northern, and western blocks such as Gohana, Mundlana, and Kathura, where irrigation facilities and fertile alluvial soils support intensive paddy farming. However, large orange patches are visible in the south-eastern part of the district, especially around Sonipat city, Rai, and Murthal, reflecting urban expansion and industrial development along the Delhi–National Capital Region corridor. Comparatively, rice cultivation is relatively fragmented near these urban centers but remains dominant in rural tracts. Overall, the map highlights that Sonipat district has substantial rice coverage, though urbanization significantly influences land use patterns in its eastern and southern parts.

Table: 3.42: Block wise Rice area Estimation of Sonipat District.

Sr. No.	District	Block Name	Area in Hectare (Rice)	Area in %
1	Sonipat	Ganaur	14056.1	14.1
2	Sonipat	Kathura	14247.4	14.2
3	Sonipat	Gohana	18291.8	18.3
4	Sonipat	Kharkhoda	12192.3	12.2
5	Sonipat	Rai	6236.0	6.2
6	Sonipat	Murthal	8397.7	8.4
7	Sonipat	Sonipat	9504.8	9.5
8	Sonipat	Mundlana	17112.9	17.1
Total			**100039.0**	**100**

(Data Source: Sentinel 2 Satellite Data 2022)

The table no 3.42 shows rice cultivation area in each of the district's blocks in Sonipat district .With an estimated 14,056.1 hectares dedicated to rice cultivation, Ganaur block accounts for 14.1% of the district of Sonipat's total rice acreage. The Kathura block accounts for 14.2% of the total rice area, with an estimated 14,247.4 hectares planted to rice. At 18,291.8 hectares, the Gohana block has the greatest estimated rice-growing area (18.3% of the total rice area). The estimated rice-growing area in the Kharkhoda block is 12,192.3 hectares, or 12.2% of the total rice area. With an estimated 6,236.0 hectares of rice-growing land, Rai Block accounts for 6.2% of the total rice area. With an estimated 8,397.7 hectares dedicated to rice cultivation, the Murthal block accounts for 8.4% of the total rice area. The estimated 9,504.8 hectares of rice-growing land in the Sonipat block make up 9.5% of the total rice area. The estimated 17,112.9 hectares of rice-growing land in the Mundlana block make up 17.1% of the total rice area.

Yamunanagar District:

The map titled “Rice Crop Area of Yamunanagar District in Haryana – 2022” depicts the spatial distribution of rice cultivation during the Kharif season using Sentinel-2 satellite imagery (September 2022) with 10 m spatial resolution.

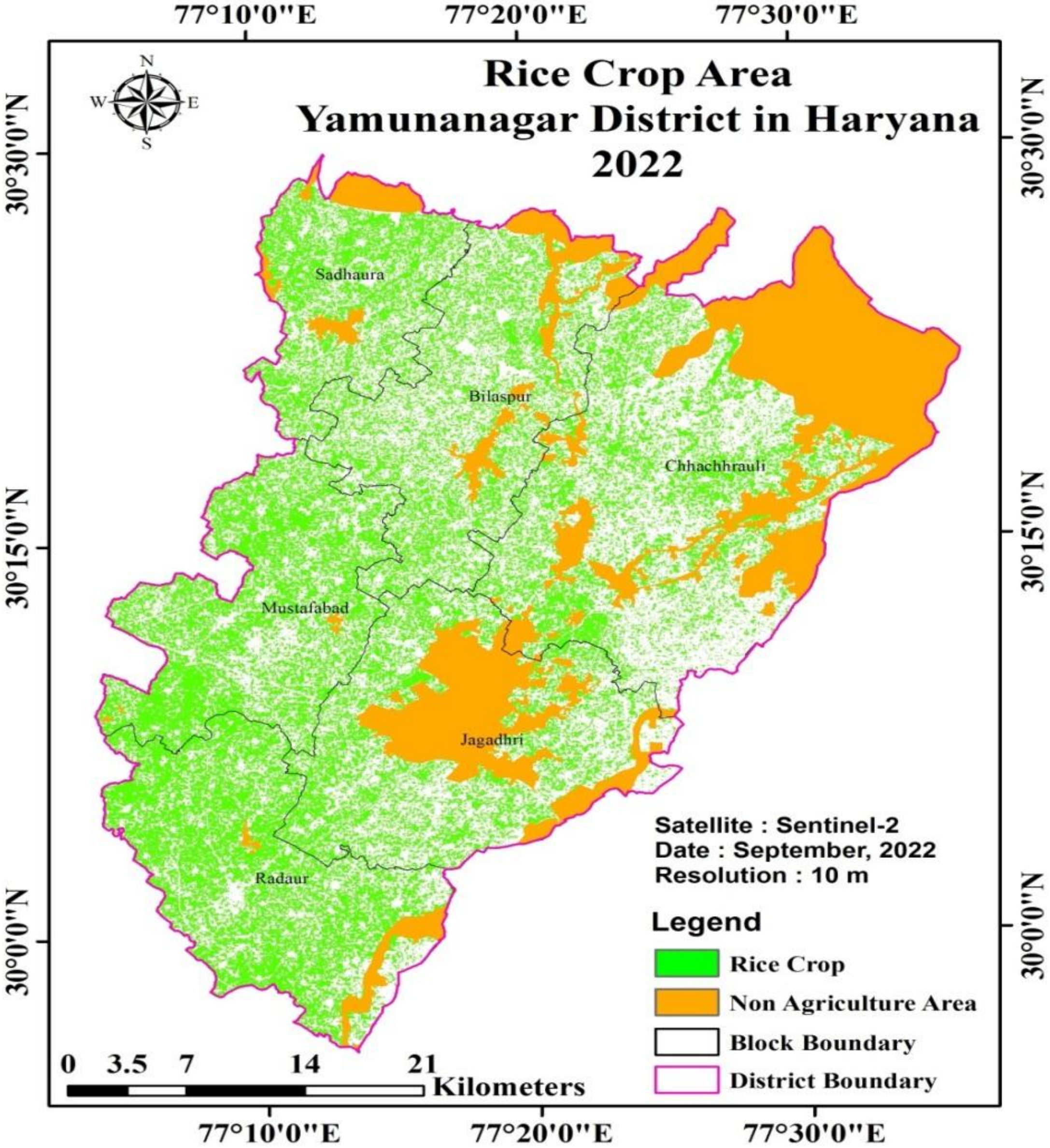


Figure 3.43: Rice Crop Area of Yamunanagar District in Haryana 2022 (Data Source: Sentinel-2 Satellite Data 2022).

Rice crop areas are shown in green, while non-agricultural areas such as urban settlements, forested/hilly terrain, and built-up land are represented in orange, along with block and district boundaries. The map reveals that rice cultivation is extensively distributed across the central and western blocks, including Bilaspur, Mustafabad, and Radaur, where fertile alluvial soils and assured canal irrigation from the Western Yamuna Canal system favor intensive paddy farming. However, the eastern part of the district, particularly in Chhachhrauli block near the Shivalik foothills, shows larger orange patches indicating forested and non-agricultural land, resulting in comparatively lower rice coverage. Significant urban concentration is visible around Jagadhri and Yamunanagar town, where agricultural land is replaced by built-up areas. Overall, the district exhibits a high proportion of rice cultivation, especially in the irrigated plains, while topography and land use constraints limit paddy expansion in the hilly eastern region.

Table: 3.43: Block wise Rice area Estimation of Yamunanagar District.

Sr. No.	District Name	Block Name	Area in Hectare (Rice)	Area in %
1	Yamunanagar	Khizrabad	6304.4	9.7
2	Yamunanagar	Radaur	11009.1	17.0
3	Yamunanagar	Mustafabad	11215.4	17.3
4	Yamunanagar	Jagadhri	9056.8	14.0
5	Yamunanagar	Chhachhrauli	8754.3	13.5
6	Yamunanagar	Sadaura (Part)	6948.1	10.7
7	Yamunanagar	Bilaspur	11394.2	17.6
		Total	64682.3	100

(Data Source: Sentinel 2 Satellite Data 2022)

The rice-growing area in each of the district of Yamunanagar's blocks is estimated in this table 3.43. With an estimated 6,304.4 hectares dedicated to rice cultivation, Khizrabad block accounts for 9.7% of Yamunanagar district's total rice area. With an estimated 11,009.1 hectares dedicated to rice cultivation, the Radaur block accounts for 17.0% of the total rice area. Similar to the Mustafabad block, which accounts for 17.3% of the total rice acreage, the block is anticipated to cover 11,215.4 hectares for rice production. With an estimated 9,056.8 hectares dedicated to rice cultivation, Jagadhri block accounts for

14.0% of the total rice area. With an estimated 8,754.3 hectares dedicated to rice cultivation, the Chhachhrauli block accounts for 13.5% of the total rice area. The estimated rice-growing area in the Sadaura (Part) block is 6,948.1 hectares, or 10.7% of the total rice area. With an estimated 11,394.2 hectares of rice-growing land, the Bilaspur block accounts for 17.6% of the total rice area.

No Rice Production Zone:

Rewari, Nuh, and Mahendragarh districts in southern Haryana have no rice production primarily due to acute water scarcity. These regions fall under a semi-arid to arid climatic zone with low and erratic annual rainfall (400–600 mm), insufficient to support water-intensive crops like rice. Groundwater levels are critically low and often saline, making them unsuitable for irrigation, and canal irrigation infrastructure is largely absent. Additionally, the sandy loam to loamy sand soils in these districts have poor water-holding capacity, further limiting rice cultivation. As a result, farmers prefer drought-resistant crops such as bajra, Pulses and guar, which are better suited to local agro-climatic conditions.

3.3 Summary:

The chapter titled "Area Estimation of Wheat and Rice Crop Using DIP (Digital Image Processing)" focuses on using Sentinel-2A/B satellite data and digital image processing techniques to estimate the crop area of wheat and rice in Haryana. The process involves image preprocessing, vegetation index calculation (such as NDVI), classification (using supervised ISODATA methods), and post-processing to enhance accuracy. The crop area is derived through pixel counting or polygon conversion, validated against field data. For wheat, Haryana—being the fourth-largest wheat-producing state—shows significant spatial variation, with central districts like Karnal, Kaithal, Kurukshetra and Sirsa contributing majorly due to favorable soils and irrigation. District-wise and block-wise analysis reveals the largest wheat-growing areas in blocks such as Ambala-II, Bhiwani, Baund (Charkhi Dadri), Ballabgarh (Faridabad), Tohana (Fatehabad), Pataudi (Gurugram), Hisar-I, Jhajhar, Uchana (Jind), Kaithal, Assandh (Karnal), Pehowa

(Kurukshetra) and Mahendragarh. Variations in wheat area across blocks and districts reflect differences in soil type, irrigation availability, and climatic conditions, with southern and southwestern Haryana showing lower wheat coverage due to arid conditions and dominance of other crops like mustard and pulses. The study demonstrates how satellite-based DIP methods can offer an efficient, scalable, and accurate approach to agricultural monitoring and crop area estimation across diverse agro-climatic zones.

Rice Crop Area Estimation utilizes remote sensing and classification algorithms to evaluate rice cultivation areas in Haryana at the block level across multiple districts. By interpreting satellite imagery, the spatial extent of rice-growing land was assessed, providing district-wise and block-wise estimates. For instance, in Ambala, Ambala-II had the highest rice area (23.6%), whereas Bhiwani saw most cultivation in Bhiwani block (66%). In Charkhi Dadri, the Charkhi Dadri block led with 56.1% of the rice area, while Faridabad had the highest cultivation in Ballabgarh (51.5%). In Fatehabad, Tohana block (21.7%) had the largest share. Gurugram, though having modest cultivation overall, saw highest activity in Sohna (32.9%). Hisar recorded the largest area in Hansi-II (23.8%), with Barwala and Hansi-I close behind. Jhajhar saw Beri block lead (38.2%). In Jind, the highest rice area was in Jind block (15.6%), followed by Uchana and Julana. Kaithal’s Kaithal block accounted for 21.5%, the highest in the district. Karnal saw peak cultivation in Assandh (18.9%) and Chirao (18.4%). In Kurukshetra, Pehowa block dominated with 29.7%. Palwal had Badoli block leading at 22.9%. Panchkula’s major cultivation was in Barwala (57.5%). In Panipat, Madlauda block had the highest rice area (34.5%). Rohtak saw most cultivation in Rohtak block (34.1%) and Maham (29.5%), while Sirsa recorded significant cultivation in Nathusari Chopta and Dabwali blocks. These spatial insights are critical for agricultural planning and monitoring, showcasing how satellite data supports crop estimation at micro-administrative levels.

CHAPTER: 4

ESTIMATION OF METHANE EMISSION

Introduction:

Methane (CH_4) is among the most significant greenhouse gases contributing to global climate change. While traditionally associated with rice cultivation due to anaerobic flooded conditions, methane emissions from wheat cultivation, particularly in regions of intensive agriculture such as Haryana, India, have started to gain attention. Wheat, a Rabi season crop, is generally grown under aerobic conditions; however, certain agronomic practices and legacy impacts from the previous Kharif (rice) season—such as soil moisture retention, residue management, and fertilizer application—can influence microbial activity in the soil, resulting in localized and measurable methane emissions.

This chapter aims to explore the semi-monthly spatial distribution of methane emissions during the wheat season, with a specific focus on the period from 12 March to 18 March 2022, utilizing Sentinel-5P satellite data. The data has been processed and categorized into five methane concentration classes based on methane mixing ratios measured in parts per billion (ppb), each associated with a defined land area in hectares across Haryana.

The assessment distinguishes between the Kharif and Rabi seasons, correlating elevated methane levels with periods of intense cultivation and crop-specific agronomic practices. Methane emissions from rice cultivation, typically associated with flooded field conditions during the Kharif season, are contrasted with emissions from wheat cultivation during the Rabi season, where emissions are generally lower but still significant in certain districts.

Spatial analysis using GIS tools has enabled the identification of methane emission hotspots and seasonal variations in mixing ratios. This temporal and spatial mapping provides valuable insights into the role of crop type, irrigation practices, and land use intensity in influencing greenhouse gas emissions from agriculture.

The semi-monthly resolution of the data allows for detailed tracking of emission dynamics, supporting improved methane mitigation strategies and aiding policy development aimed at sustainable agriculture and climate change adaptation in Haryana. Detailed methodology related to methane estimation from sentinel satellite data is discussed in chapter 2.

4.1 Methodology for Sentinel-5P Methane Data Processing

To assess methane emissions during rice and wheat seasons in Haryana, methane data from the Sentinel-5 Precursor (Sentinel-5P) mission, equipped with the **TROPOMI sensor**, were utilized. TROPOMI provides total column methane (XCH_4) at a spatial resolution of approximately 7 km × 7 km in the shortwave infrared (SWIR) band (2.3 μm).

4.1.1 Data Preprocessing:

Sentinel-5P CH_4 Level-2 products were acquired from the Copernicus Open Access Hub for the study period. To ensure data reliability, scenes with a quality assurance value (qa_value < 0.5) were excluded in order to minimize retrieval uncertainties and measurement errors. Subsequently, appropriate radiometric and atmospheric corrections were applied to improve the accuracy of methane concentration estimates. The processed data were then re-projected into the WGS 84 coordinate reference system to maintain spatial consistency with other geospatial datasets. Finally, the dataset was clipped and subsetted according to the administrative boundary of Haryana to facilitate district-level analysis and interpretation.

4.1.2 Interpolation and Aggregation:

Given the coarse resolution of Sentinel-5P, Ordinary Kriging interpolation was applied to estimate methane values at unmeasured locations and refine spatial patterns. The interpolated data were then aggregated at the district level for both Rabi (wheat) and Kharif (rice) seasons.

4.1.3 Ground Methane Validation:

Ground-based methane concentration measurements were collected using portable methane analyzers at selected crop sites. Field surveys were carried out during:

- **Rice peak growth stage** (anaerobic flooded fields).
- **Wheat post-harvest period** (stubble burning-prone areas).

The field methane values were correlated with Sentinel-5P tropospheric methane retrievals (XCH_4) using Pearson's correlation and R^2 statistics, ensuring the reliability of satellite-derived methane estimates.

4.1.4 Integration with Crop Mapping:

District-level methane estimates were compared with crop distribution maps from Sentinel-2 classification. This spatial overlay enabled the identification of methane emission hotspots associated with rice paddies and stubble burning zones.

4.1.5 Field Findings

During the wet season, represented by triangular symbols, methane emissions are recorded at a very high level of approximately 350 kg CH_4-C per hectare, while the corresponding grain yield is relatively low at about 3.7 t/ha. These elevated methane emissions are mainly associated with flooded paddy fields, where anaerobic soil conditions enhance methanogenic microbial activity. Continuous water stagnation reduces soil aeration, thereby increasing methane production but often limiting optimal crop growth. In contrast, the dry season, indicated by black squares, shows significantly lower methane emissions of nearly 50 kg CH_4-C per hectare. At the same time, grain yield rises substantially to around 8 t/ha, reflecting improved crop performance. Reduced flooding during the dry season creates better soil aeration, which suppresses methane formation and supports efficient nutrient uptake. This clear inverse relationship suggests that higher methane emissions correspond with lower grain output. The findings highlight the environmental cost of conventional flooded rice systems. Therefore, improved water management practices, such as alternate wetting and drying (AWD), may help reduce methane emissions while sustaining or even enhancing grain yield.

4.2 How Sentinel-5P XCH_4 Connects

Sentinel-5P measures **tropospheric column-averaged methane (XCH_4)**. It does not give per-field methane fluxes directly (like 350 CH_4-C/ha), but it captures **regional methane concentration anomalies** that can be linked to crop seasons:

- **Wet Season (Paddy Rice in Philippines / Haryana Kharif):**
    - Flooded conditions → anaerobic soils → higher methane release.
    - Sentinel-5P XCH_4 maps show **elevated methane columns over rice belts**.
    - Matches with field observation: higher methane = lower yield efficiency.
- **Dry Season (Wheat or Dry Rice in Philippines / Haryana Rabi):**
    - Less standing water, better aeration → reduced methane flux.
    - Sentinel-5P XCH_4 maps show **lower methane concentrations**.
    - Matches with higher grain output in field data.

4.3 Correlation Framework

To correlate Maligaya field findings with Sentinel-5P XCH_4 (and your Haryana case):

i. **Field Scale vs. Satellite Scale:** At the field level, such as in the Maligaya study (Philippines), methane emissions were directly measured using chamber-based techniques and expressed as methane flux in CH_4-C per hectare. This method captures localized emissions from specific rice plots under controlled agronomic conditions. In contrast, Sentinel-5P measures atmospheric methane as a column-averaged dry-air mixing ratio (XCH_4) in parts per billion (ppb), representing total methane concentration in the atmospheric column over a large spatial footprint. Although the units and scales differ—surface flux versus atmospheric concentration—the seasonal emission patterns remain comparable. Both datasets indicate higher methane levels during the wet (flooded rice) season and lower levels during the dry season, demonstrating consistency between ground-based and satellite observations.

ii. **Validation Approach:** To validate satellite-derived methane data, the rice cropping calendar of Haryana can be overlaid with seasonal Sentinel-5P XCH_4 trends. The Kharif season (wet rice cultivation) should correspond with elevated XCH_4 concentrations, while the Rabi season (primarily wheat cultivation under drier conditions) should show comparatively lower methane levels. Further validation can be achieved by generating correlation plots between grain yield and Sentinel-5P XCH_4 concentration, replicating the inverse emission–yield relationship observed in the Maligaya field study. This approach enables scaling the field-based findings to a regional context.

iii. **Expected Outcome:** The anticipated results suggest that during the wet Kharif rice season, methane concentrations (XCH_4) will be higher, accompanied by relatively lower yield efficiency due to flooded anaerobic conditions. Conversely, during the dry Rabi wheat season, methane concentrations are expected to decrease significantly, while crop yields improve. Such findings would confirm that Sentinel-5P XCH_4 data effectively captures the same emission–yield tradeoff documented in Maligaya (Philippines) and supported by Epule et al. (2011), thereby validating satellite-based methane monitoring for regional agricultural assessments.

4.4 Methane Emission from Wheat:

The table 4.1 provides data on methane emissions during the wheat-growing season in Haryana, India. It is categorized into five classes based on the concentration of methane in parts per billion (ppb) and the corresponding wheat methane mixing ratio area in hectares.

Very Low Concentration: This category has the lowest methane concentration at 1890 ppb, covering a vast area of 2,845,764.2 hectares. This suggests that methane emissions are relatively minimal in a large portion of Haryana.

Low Concentration: The "Low" category exhibits a slightly higher methane concentration at 1900 ppb but covers a smaller area of 799,894.3 hectares. This indicates a somewhat higher concentration of methane emissions in a more limited region.

Moderate Concentration: With a methane concentration of 1910 ppb and an area of 374,418.5 hectares, the "Moderate" category suggests a moderate level of methane emissions in a specific area.

Table-4.1: Category wise Methane Mixing Ratio emission from wheat crop season.

Methane Mixing Ratio emission from wheat crop season		
Classes	Categories value parts-per-billion	Wheat Methane Mixing ratio Area (in Hectare)
Very Low	1890	2845764.2
Low	1900	799894.3
Moderate	1910	374418.5
High	1920	279703.0
Very High	1968	117642.4

(Data Source: Sentinel 5P Processed Data).

High Concentration**:** The "High" category demonstrates a methane concentration of 1920 ppb over an area of 279,703.0 hectares. This indicates a higher methane concentration in a relatively smaller region.

Very High Concentration**:** This category exhibits the highest methane concentration at 1968 ppb, but it covers the smallest area of 117,642.4 hectares, suggesting concentrated and notably elevated methane emissions in this specific area.

The table 4.1 highlights the variation in methane emissions across Haryana during the wheat season, with different regions experiencing different levels of emissions. It is essential to consider the potential environmental implications, sources of methane, and their impact on climate change when analyzing this data. Reducing methane emissions is crucial for mitigating climate change, so understanding the regional variations is important for targeted environmental policies and initiatives in the agricultural sector.

The figure 4.1 presents data on methane emissions during the wheat-growing season in Haryana, (India). It is organized into five categories, each representing a different level of methane concentration measured in parts per billion (ppb) and the corresponding area in hectares where these concentrations were observed. Here's a breakdown of the information:

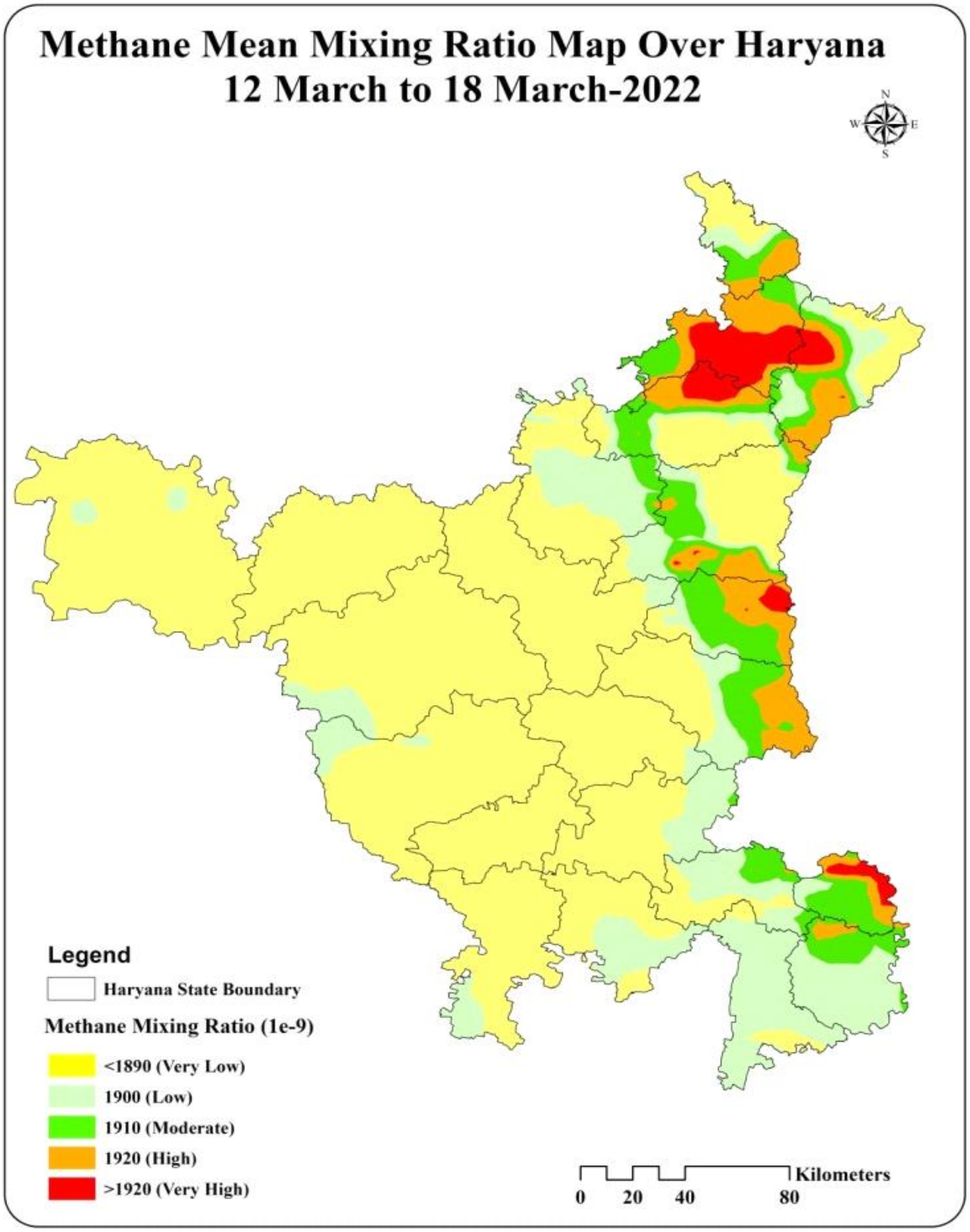


Figure 4.1: Map of Methane Mixing Ratio emission from wheat crop season (12 march to 18 march 2022 Source: Sentinel 5P Processed Data).

Classes (Categories): These categories classify the levels of methane emissions, ranging from "Very Low" to "Very High." They serve as a way to categorize and compare the concentrations of methane in the air during the wheat season in Haryana.

Value (Parts per Billion): This column provides the actual methane concentration in the atmosphere for each category. It ranges from 1890 ppb in the "Very Low" category to 1968 ppb in the "Very High" category. The concentration of methane is measured in parts per billion, which indicates the amount of methane in one billion parts of air.

Table: 4.2 Methane mixing ratio from rice crop in Haryana.

Methane mixing ratio from rice crop in Haryana		
Classes	**Categories value parts-per-billion**	**Rice Methane Mixing ratio Area (in Hectare)**
Very Low	1890	0
Low	1900	0
Moderate	1910	430622.9
High	1920	632663.6
Very High	1968	3354135.8

(Data Source: Sentinel 5P Processed Data).

Wheat Methane Mixing Ratio Area (in Hectare): This column specifies the area in hectares over which the methane concentration was measured for each category. It gives us an understanding of the spatial distribution of methane emissions within Haryana during the wheat season.

In summary, table 4.2 conveys information about the variation in methane emissions in Haryana's wheat fields. The data shows that methane concentrations increase from "Very Low" to "Very High" categories, with corresponding variations in the area covered by these concentrations. Understanding this data's environmental implications would require additional context, as methane emissions can result from various sources, including agricultural practices and natural processes. Analyzing this data in conjunction with information about emission sources and environmental impacts would provide a more comprehensive understanding of the region's methane emissions during the wheat season.

4.5 Methane Emission from Rice

Methane Emission Ratios from rice seasons in Haryana reveals significant variations in methane concentrations across different categories. This analysis provides valuable insights into the contribution of rice cultivation to methane emissions in the region.

The table 4.1 provides information about different class categories of methane mean mixing ratio on the basis of value parts-per-billion (ppb). Calculate area of rice fields in hectare as per different classes in which methane gas observed.

The "Very Low" category has a methane mixing ratio of 1890 ppb and is associated no any area From Paddy. The "Low" category has a methane mixing ratio of 1900 ppb and is also associated with an area of 0 hectares. Similarly, rice fields with low methane levels appear to cover no area. The "Moderate" category has a methane mixing ratio of 1910 ppb and is associated with an area of 430,622.9 hectares. This indicates that rice fields with moderate methane levels cover a substantial area in this dataset. The "High" category has a methane mixing ratio of 1920 ppb and is associated with an area of 632,663.6 hectares. This suggests that rice fields with high methane levels cover a significant area. The "Very High" category has a methane mixing ratio of 1968 ppb and is associated with a considerably larger area of 3,354,135.8 hectares. This indicates that rice fields with very high methane levels cover a substantial area in the dataset, surpassing even the "High" category.

Spatial Distribution of Methane Mixing Ratio:

The figure 4.2 demonstrates a considerable variation in methane mixing ratios within Haryana's rice fields. The "Moderate" category, with an average mixing ratio of 1910 ppb, covers 430,622.9 hectares, indicating that rice fields with moderate methane levels are distributed across a significant portion of the Haryana state.

High and Very High Categories:

The "High" and "Very High" categories, with mixing ratios of 1920 ppb and 1968 ppb, respectively, cover substantial areas of 632,663.6 hectares and 3,354,135.8 hectares, indicating that areas with high methane emissions are more widely distributed and not just isolated pockets. Because these locations may contribute significantly to regional greenhouse gas emissions, rice growers and environmental officials may find them particularly concerning.

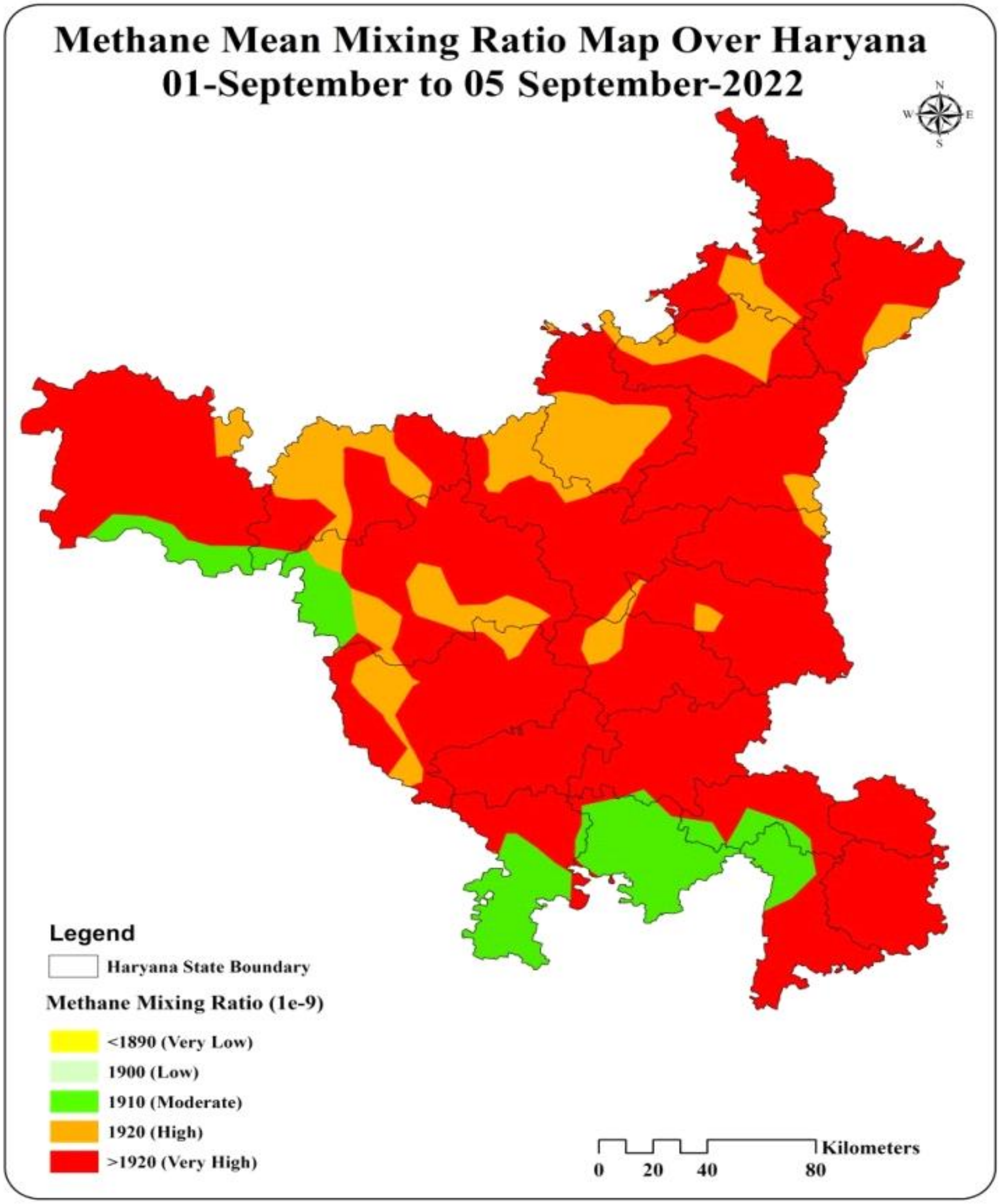


Figure 4.2: Map of Methane Mixing Ratio emission from wheat crop season (12 Sept.to 1Sept. 2022) (Source: Sentinel 5P Processed Data).

Justification of the methane emission from the Mahendergarh, Rewari and Mewat

The elevated atmospheric methane mixing ratios (XCH_4) observed in Haryana's Mahendergarh, Rewari, and Nuh districts, despite negligible rice cultivation, can be attributed to several factors:

Livestock-Related Methane Emissions

Methane is a significant byproduct of enteric fermentation in ruminant animals. In Rewari, Nuh and Mahendergarh districts, for instance, there were approximately 290,272 livestock as of 2012, accounting for 3.3% of Haryana's total livestock population. Even in the absence of extensive rice cultivation, such substantial livestock numbers contribute notably to methane emissions [Samal et al] A study assessing methane emissions from Indian livestock estimated that enteric fermentation contributed approximately 11.63 Tg CH_4 per year in 2019, with manure management adding another 1.11 Tg CH_4 per year, highlighting the significant role of livestock in methane emissions .

Open Dumping and Anaerobic Decomposition

In Rewari's Dharuhera town, several industrial units have been reported to dump waste openly, including untreated sewage, due to the lack of sewerage connections and sewage treatment plants. This waste accumulates in nearby vacant plots and along roads, especially during monsoon seasons, creating anaerobic conditions conducive to methane production.

Similarly, in Nuh district, residents have raised concerns about illegal waste dumping along the Nuh-Tauru Road and surrounding areas. A private contractor, under a municipal waste management project, has been allegedly dumping untreated garbage late at night, leading to pollution and health risks for local communities.

4.6 Analysis of Semi-Monthly Methane Emission Mixing Ratio from Major Crops (Wheat and Rice) over Haryana

Low and Very Low Categories:

On the other hand, mixing ratios of 1900 ppb and 1890 ppb, respectively, are displayed in the "Low" and "Very Low" categories, with no corresponding area measured in hectares.

This would suggest that in the research area, areas with lower methane emissions are comparatively rare or nonexistent.

The analysis of semi-monthly methane emission mixing ratios from major crops, specifically wheat and rice, over the Haryana region using geo-informatics techniques has yielded valuable insights into the environmental impact of agricultural practices in this region. Below, we discuss some month wise key findings and their implications:

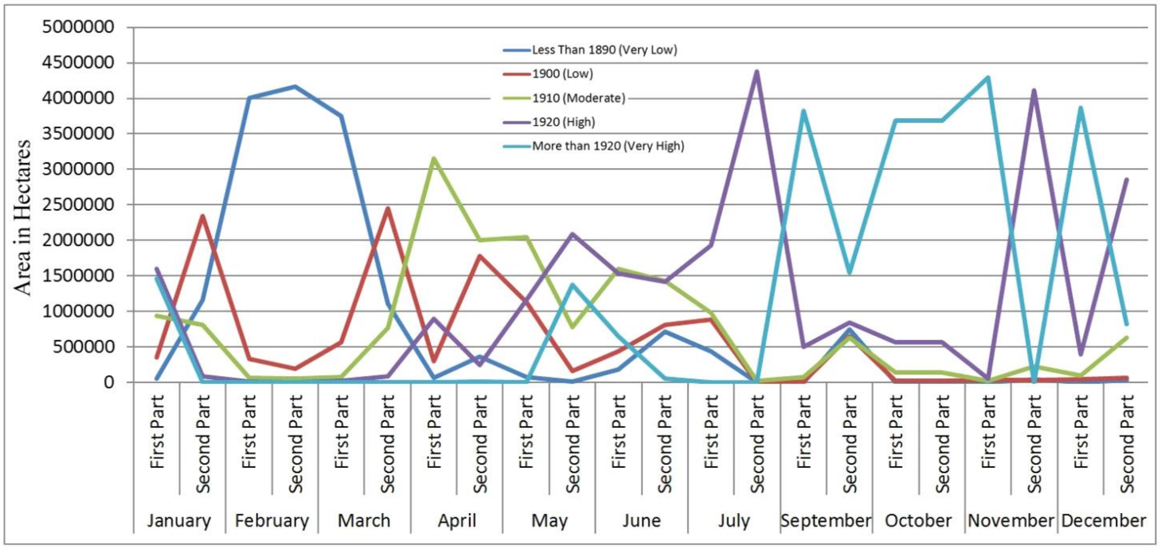


Figure:-4.3 Month wise methane mixing ratio emission comparative graph (Source: Sentinel 5P Processed Data).

In January, data is categorized into five classes based on certain criteria. The "Less Than 1890 (Very Low)" class has 57,102 hectare in the "First Part" and 1,167,402 hectare in the "Second Part." The "1900 (Low)" class has 357,123 hectare in the "First Part" and 2,349,203 in the "Second Part." The "1910 (Moderate)" class has 938,503 hectare in the "First Part" and 812,015 hectare in the "Second Part." The "1920 (High)" class has 1,602,315 hectare in the "First Part" and 85,031 in the "Second Part." The "More than 1920 (Very High)" class has 1,462,601 in the "First Part" and 3,992 hectare in the "Second Part." These values likely represent some form of statistical or categorical data for the specified classes in the month of January, possibly for analysis or comparison purposes. (Figure:- 4.2)

Table-4.3: Semi Monthly Methane mixing ratio from crop in Haryana.

Month	**Class**	**Less Than 1890(Very Low)**	**1900 (Low)**	**1910 (Moderate)**	**1920 (High)**	**More than 1920 (Very High)**
January	First Part	57102	357123	938503	1602315	1462601
	Second Part	1167402	2349203	812015	85031	3992
February	First Part	4009224	327137	65939	15342	
	Second Part	4168609	194118	54915	0	
March	First Part	3753617	569199	75622	19205	0
	Second Part	1109919	2453766	769922	84036	0
April	FirstPart	68428	301555	3154058	893601	0
	SecondPart	368260	1782306	2006867	251987	8222
May	FirstPart	81358	1129140	2042718	1164427	0
	SecondPart	8635	160754	778884	2094224	1375145
June	FirstPart	181857	441920	1598376	1540028	655462
	SecondPart	715922	807754	1425637	1415415	52915
July	FirstPart	433816	887815	979199	1930160	0
	SecondPart	3338	5514	25619	4383171	0
September	FirstPart	6567	11894	74814	500542	3822782
	SecondPart	749358	648722	630225	841438	1547900
October	FirstPart	79	21474	137991	570431	3687667
	SecondPart	79	21474	137991	570431	3687667
November	FirstPart	2887	37600	28426	57368	4291362
	SecondPart	44231	35253	224047	4114112	0
December	FirstPart	1265	44130	101911	400498	3869839
	SecondPart	35235	67368	629701	2860585	824753

(Data Source: Sentinel 5P Processed Data 2022)

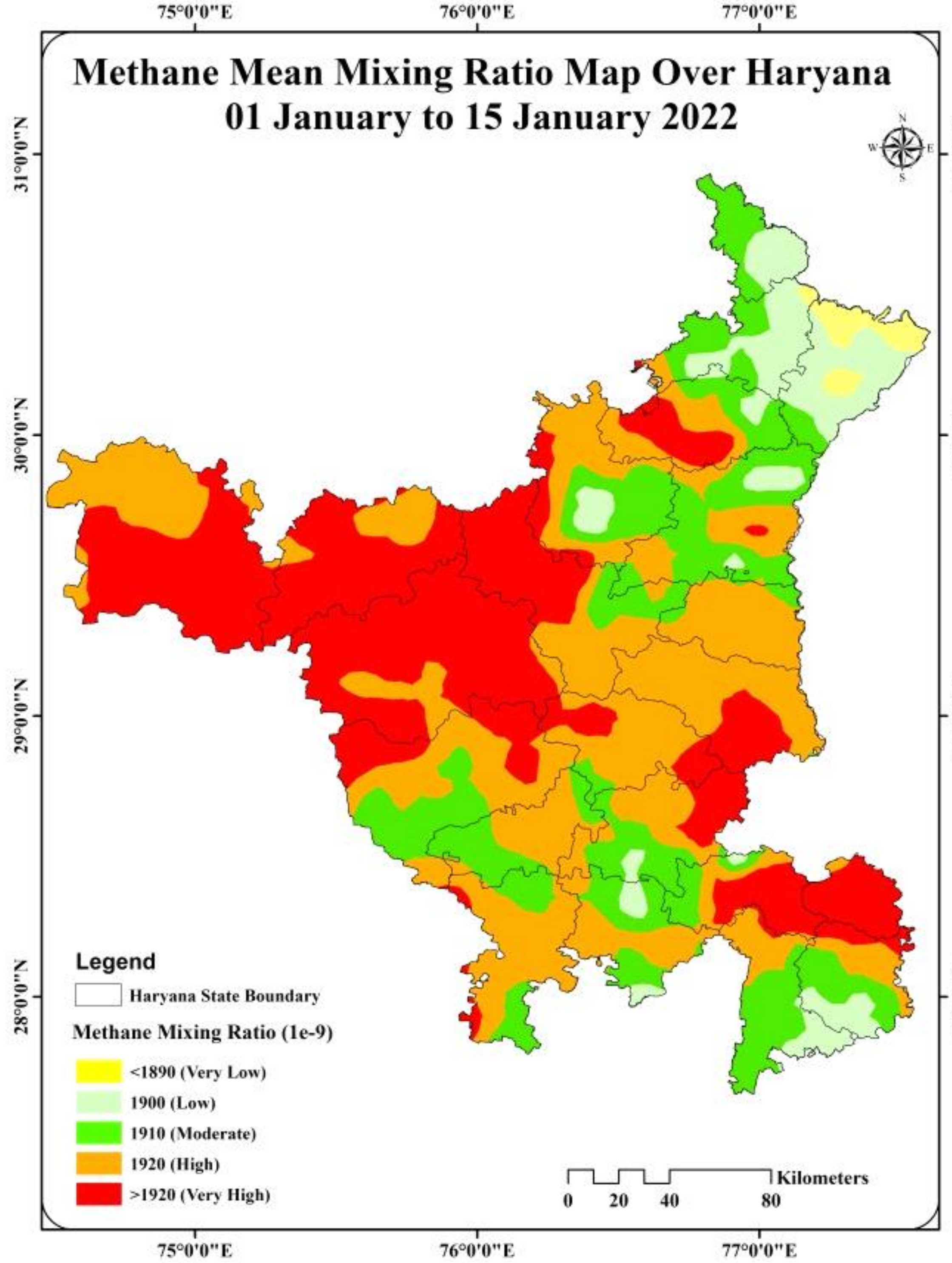


Figure 4.4 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana(1Jan to 15 Jan 2022 Source: Sentinel 5P Processed Data).

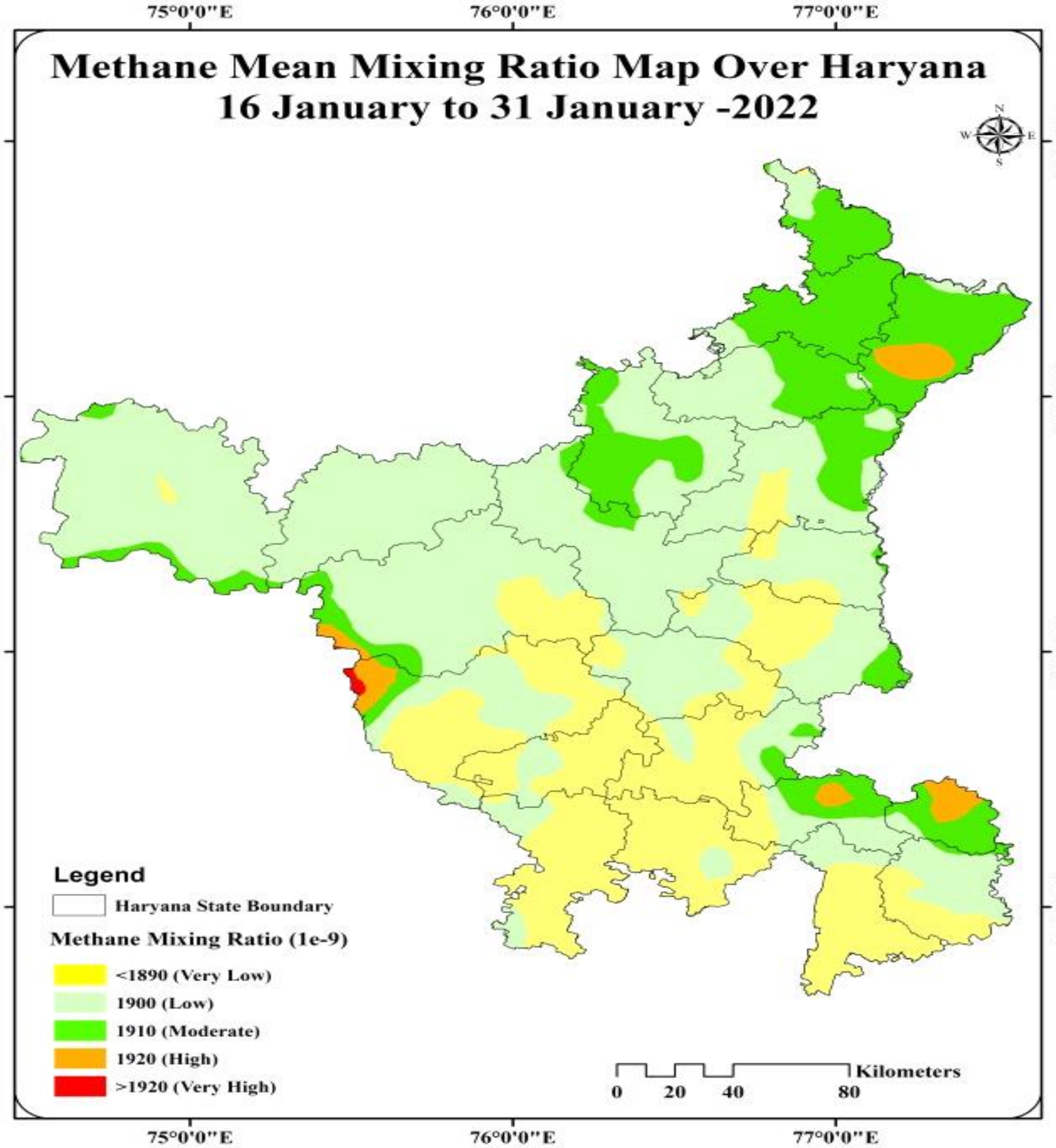


Figure 4.5 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana (16 Jan to 31 Jan 2022, Source: Sentinel 5P Processed Data).

In January, data is categorized into five classes based on certain criteria. The "Less Than 1890 (Very Low)" class has 57,102 hectare in the "First Part" and 1,167,402 hectare in the "Second Part." The "1900 (Low)" class has 357,123 in the "First Part" and 2,349,203 hectare in the "Second Part." The "1910 (Moderate)" class has 938,503 hectare in the "First Part" and 812,015 in the "Second Part." The "1920 (High)" class has 1,602,315 hectare in the "First Part" and 85,031 in the "Second Part." The "More than 1920 (Very High)" class has 1,462,601 hectare in the "First Part" and 3,992 hectare in the "Second Part." These values likely represent some form of statistical or categorical data for the specified classes in the month of January, possibly for analysis or comparison purposes. (Figure: - 4.4 and 4.5)

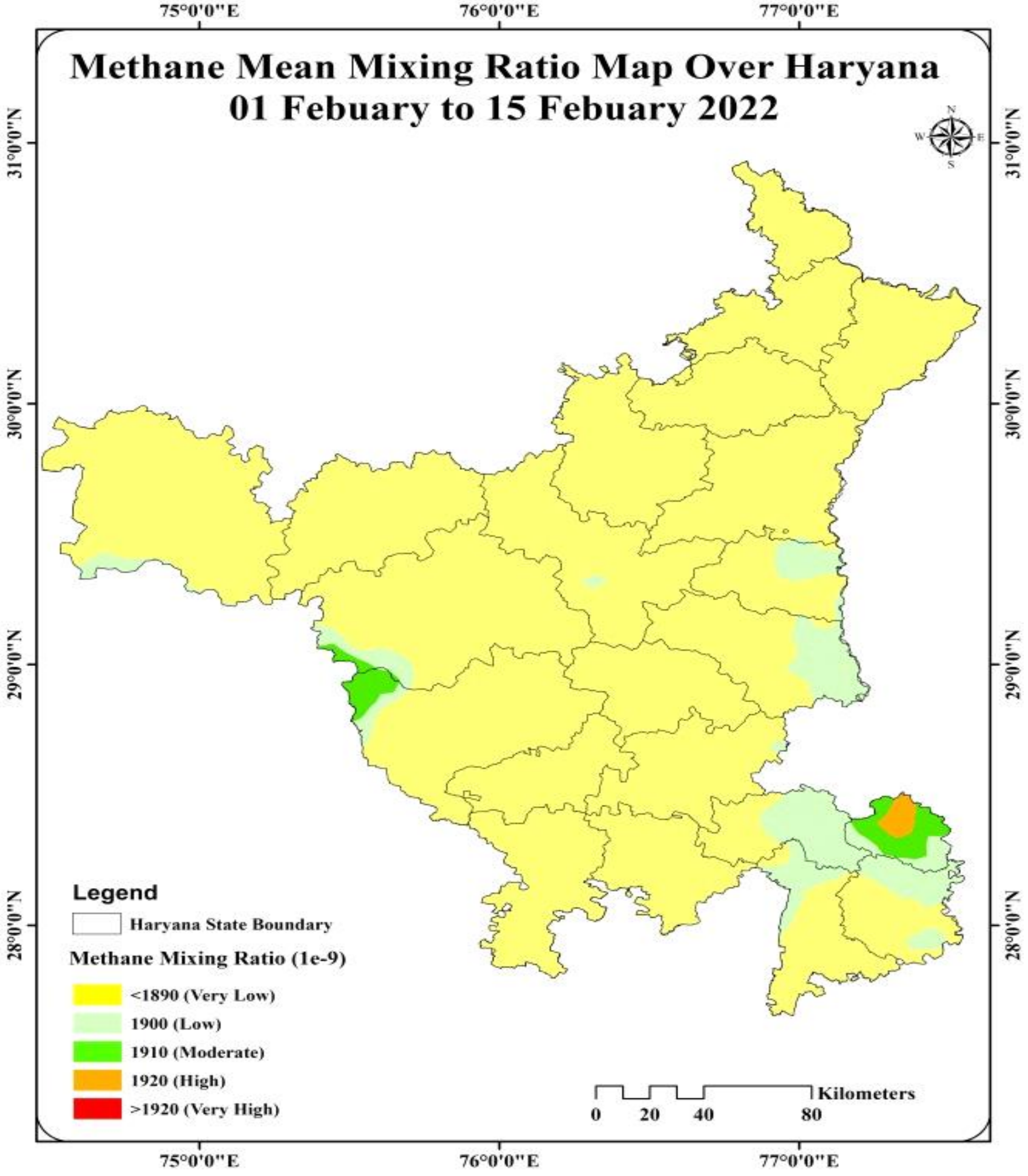


Figure 4.6 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1 Feb to 15 Feb 2022. (Data Source: Sentinel 5P Processed Data 2022).

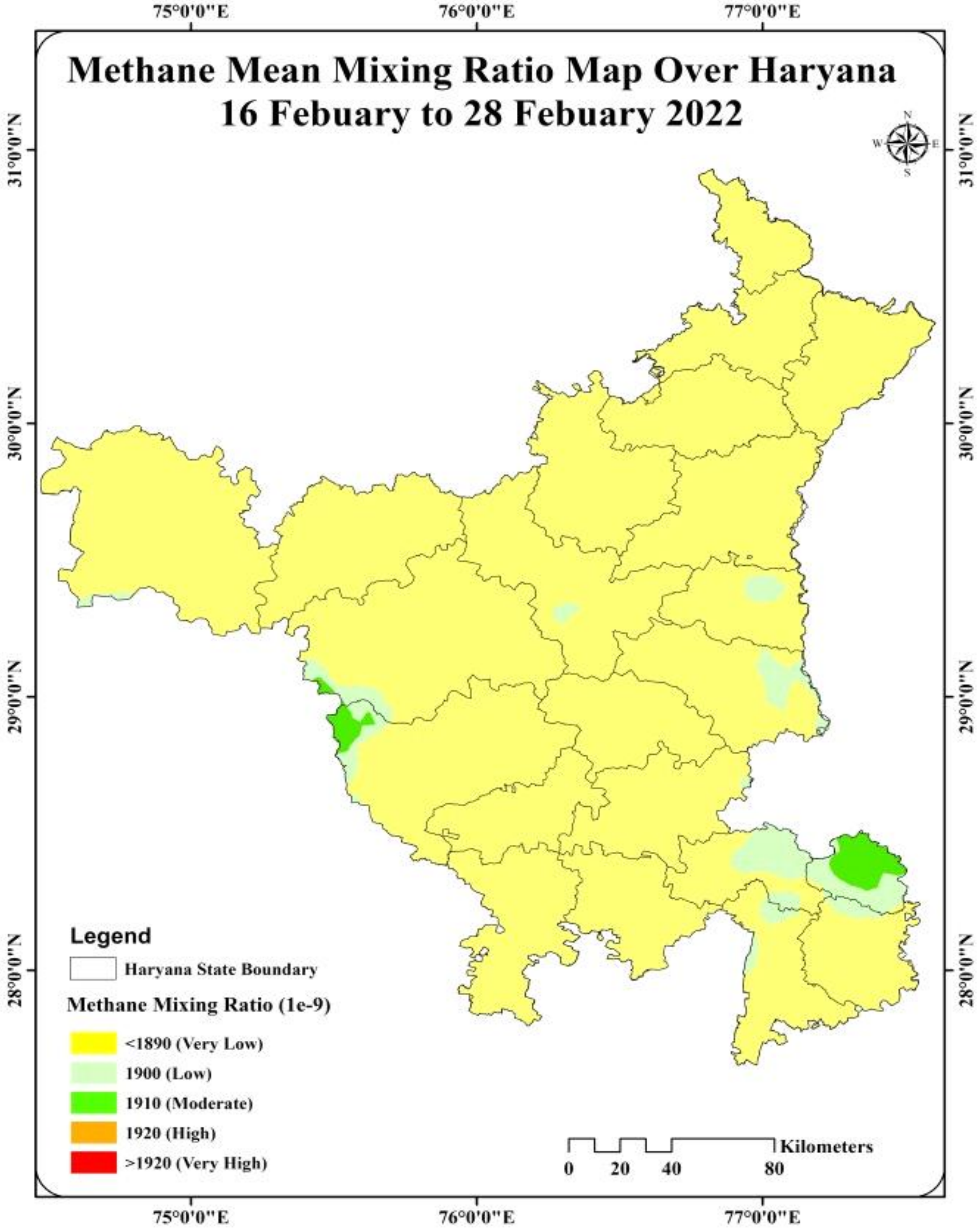


Figure 4.7 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 16 Feb to 28 Feb 2022. (Data Source: Sentinel 5P Processed Data 2022).

In February, data is categorized into five classes. The "Less Than 1890 (Very Low)" class has 4,009,224 hectare in the "First Part" and 4,168,609 hectare in the "Second Part." The "1900 (Low)" class has 327,137 in the "First Part" and 194,118 in the "Second Part." The "1910 (Moderate)" class has 65,939 hectare in the "First Part" and 54,915 hectare in the

"Second Part." The "1920 (High)" class has 15,342 hectare in the "First Part," while the "Second Part" is zero. The "More than 1920 (Very High)" class has zero in both the "First Part" and "Second Part." These values likely represent statistical or categorical data for the specified classes in the month of February, possibly for analysis or comparison purposes. (Figure:- 4.6 and 4.7).

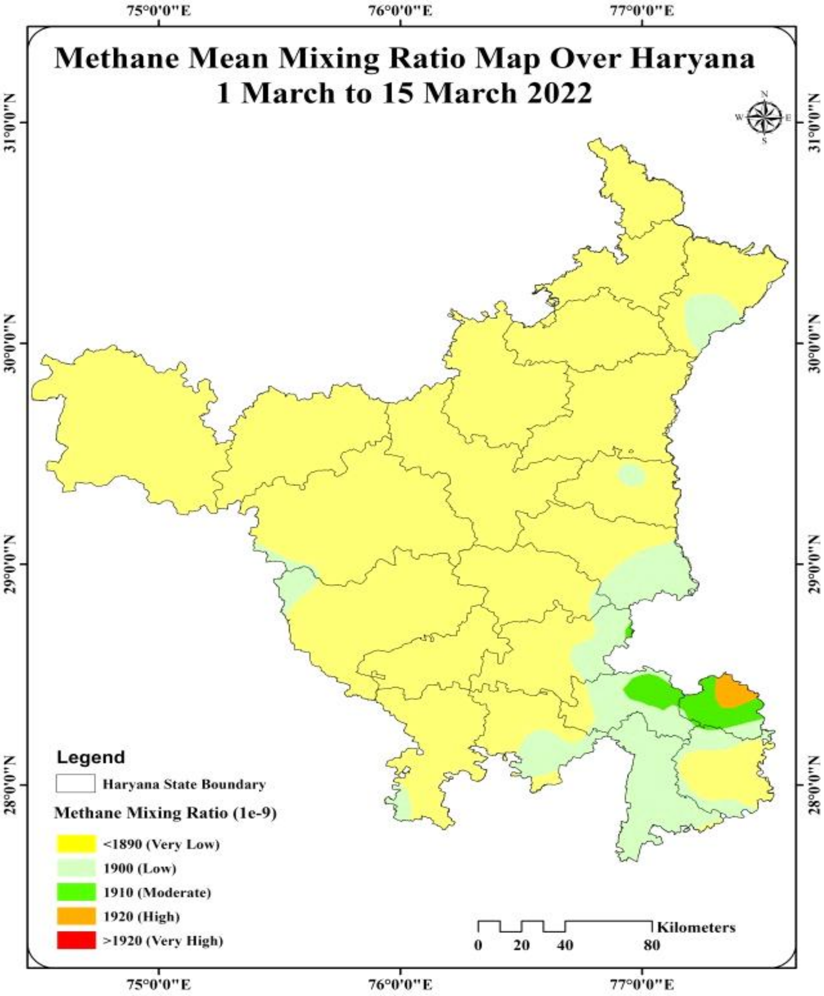


Figure 4.8 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana (1March to 15 March 2022 (Data Source: Sentinel 5P Processed Data 2022).

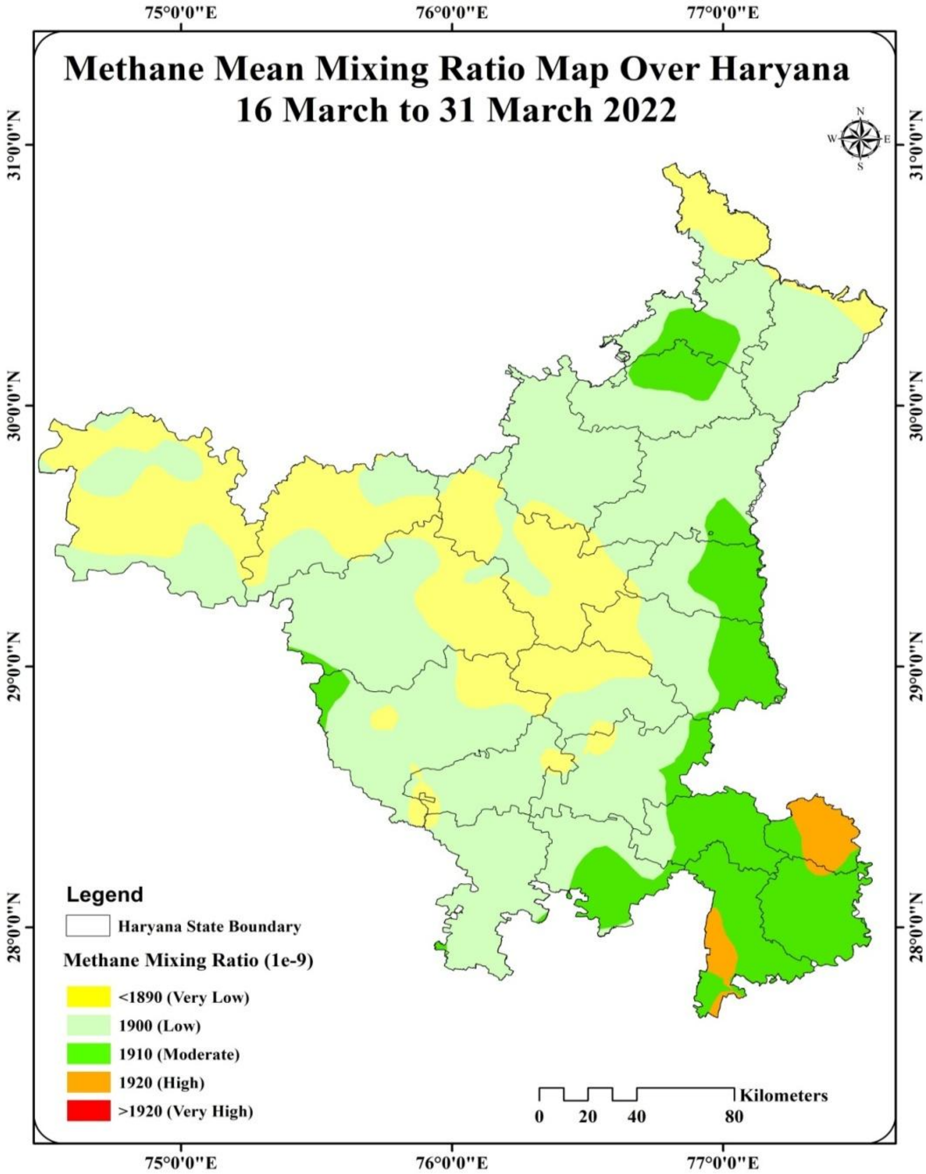


Figure 4.9 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 16 March to 31 March 2022 (Data Source: Sentinel 5P Processed Data 2022).

In March, data is categorized into five classes. The "Less Than 1890 (Very Low)" class has 3,753,617 hectare in the "First Part" and 1,109,919 hectare in the "Second Part." The "1900 (Low)" class has 569,199 hectare in the "First Part" and 2,453,766 hectare in the "Second Part." The "1910 (Moderate)" class has 75,622 in the "First Part" and 769,922 hectare in the "Second Part." The "1920 (High)" class has 19,205 hectare in the "First

Part" and 84,036 hectare in the "Second Part." The "More than 1920 (Very High)" class has zero in both the "First Part" and "Second Part." These values likely represent statistical or categorical data for the specified classes in the month of March, possibly for analysis or comparison purposes. (Figure:-4.8 and 4.9).

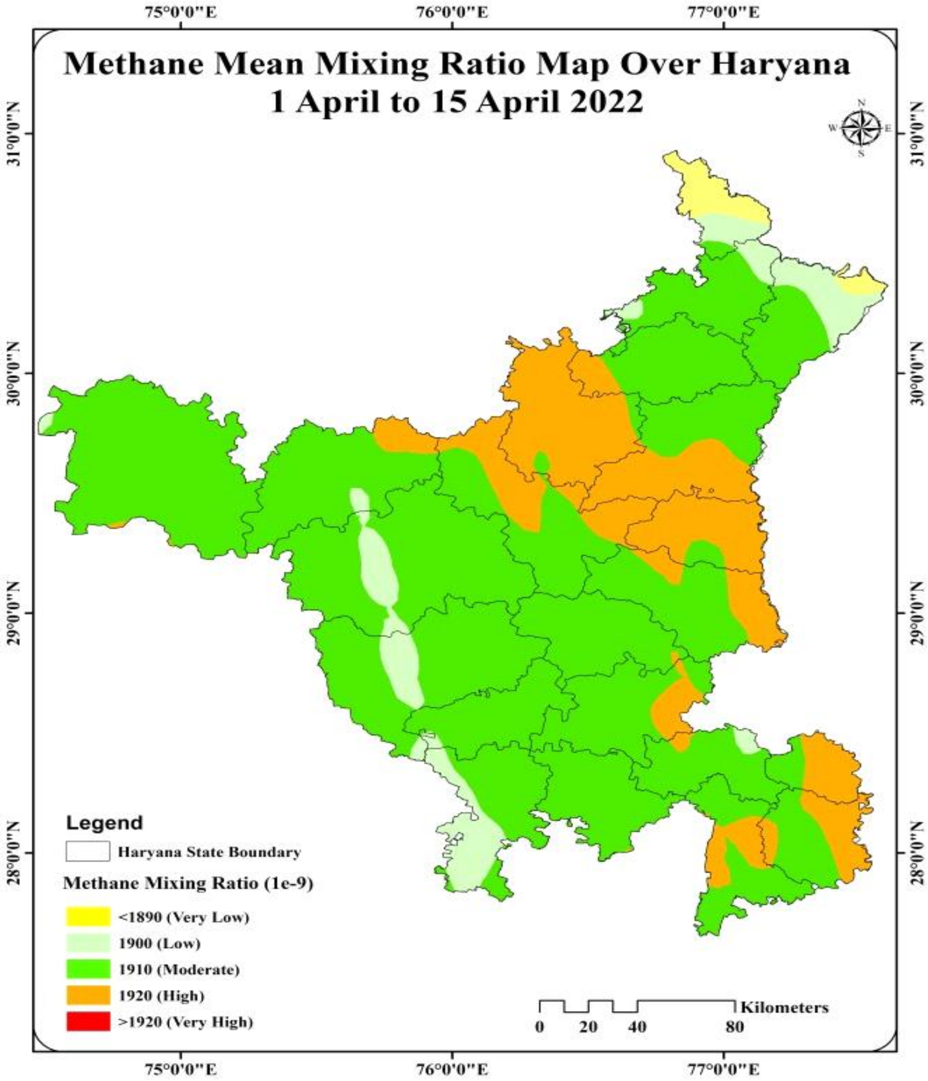


Figure 4.10 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1 April to 15 April 2022 (Data Source: Sentinel 5P Processed Data 2022).

In April, data is categorized into five classes. The "Less Than 1890 (Very Low)" class has 68,428 hectare in the "First Part" and 368,260 hectare in the "Second Part." The

"1900 (Low)" class has 301,555 hectare in the "First Part" and 1,782,306 hectare in the "Second Part." The "1910 (Moderate)" class has 3,154,058 hectare in the "First Part" and 2,006,867 hectare in the "Second Part." The "1920 (High)" class has 893,601 hectare in the "First Part" and 251,987 hectare in the "Second Part." The "More than 1920 (Very High)" class has zero in the "First Part" and 8,222 in the "Second Part." These values likely represent statistical or categorical data for the specified classes in the month of April, possibly for analysis or comparison purposes. (Figure: - 4.10 and 4.11)

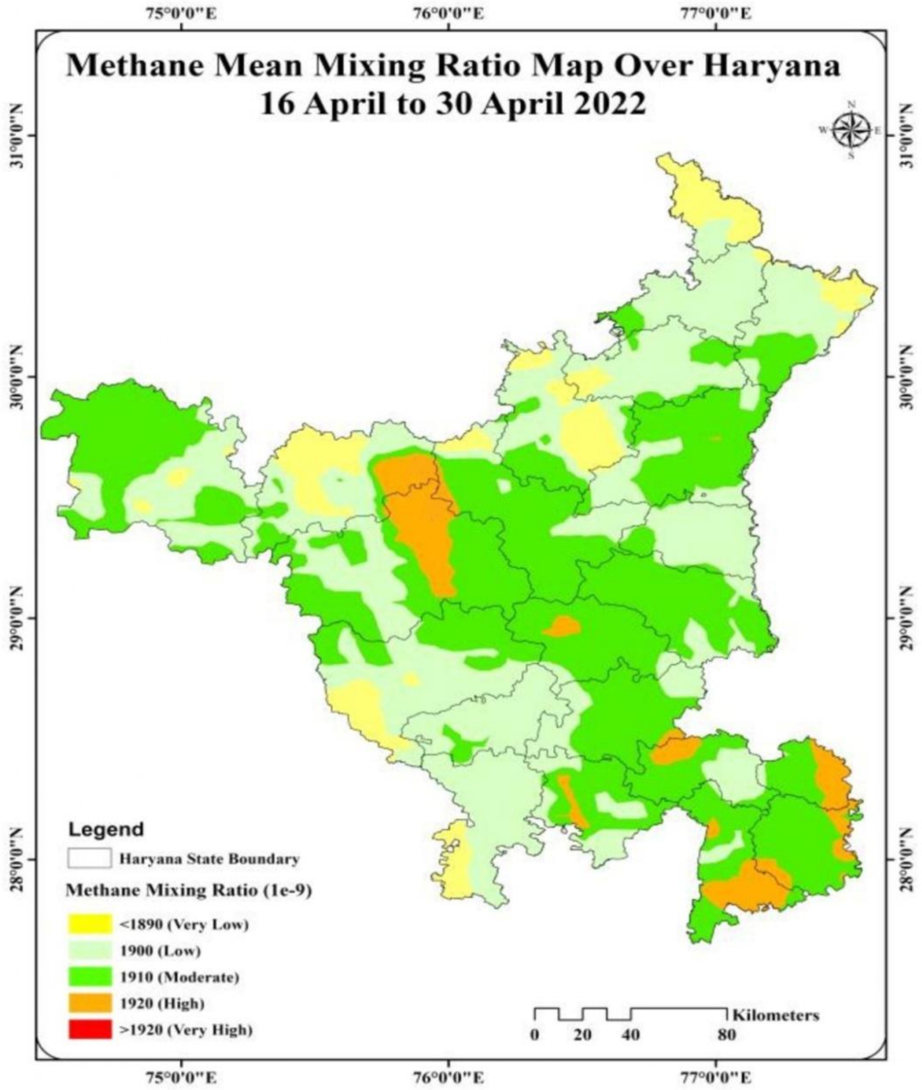


Figure 4.11 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana (16 April to 30 April 2022 (Data Source: Sentinel 5P Processed Data 2022).

In May, the data is presented for five classes, with two sets of values: "Area in Hectare (First Part)" and "Area in Hectare (Second Part)." The "Less Than 1890 (Very Low)" class covers 81,358 hectares in the "First Part" and 8,635 hectares in the "Second Part."

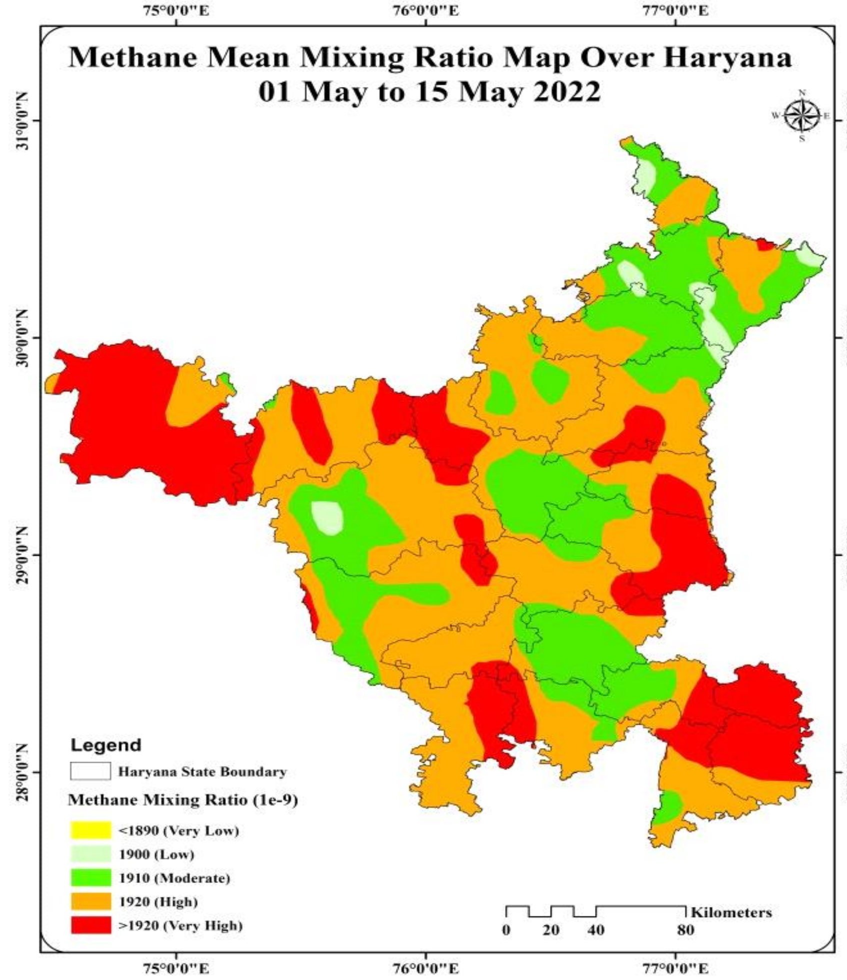


Figure 4.12 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1-May to 15 May 2022, (Data Source: Sentinel 5P Processed Data 2022)**.**

The "1900 (Low)" class includes 1,129,140 hectares in the "First Part" and 160,754 hectares in the "Second Part." The "1910 (Moderate)" class encompasses 2,042,718 hectares in the "First Part" and 778,884 hectares in the "Second Part." The "1920 (High)" class has 1,164,427 hectares in the "First Part" and 2,094,224 hectares in the "Second Part." The "More than 1920 (Very High)" class contains zero hectares in the "First Part" and 1,375,145 hectares in the "Second Part." These values likely represent land area data for various classes in the month of May, possibly for agricultural or geographic analysis. (Figure:- 4.12 and 4.13).

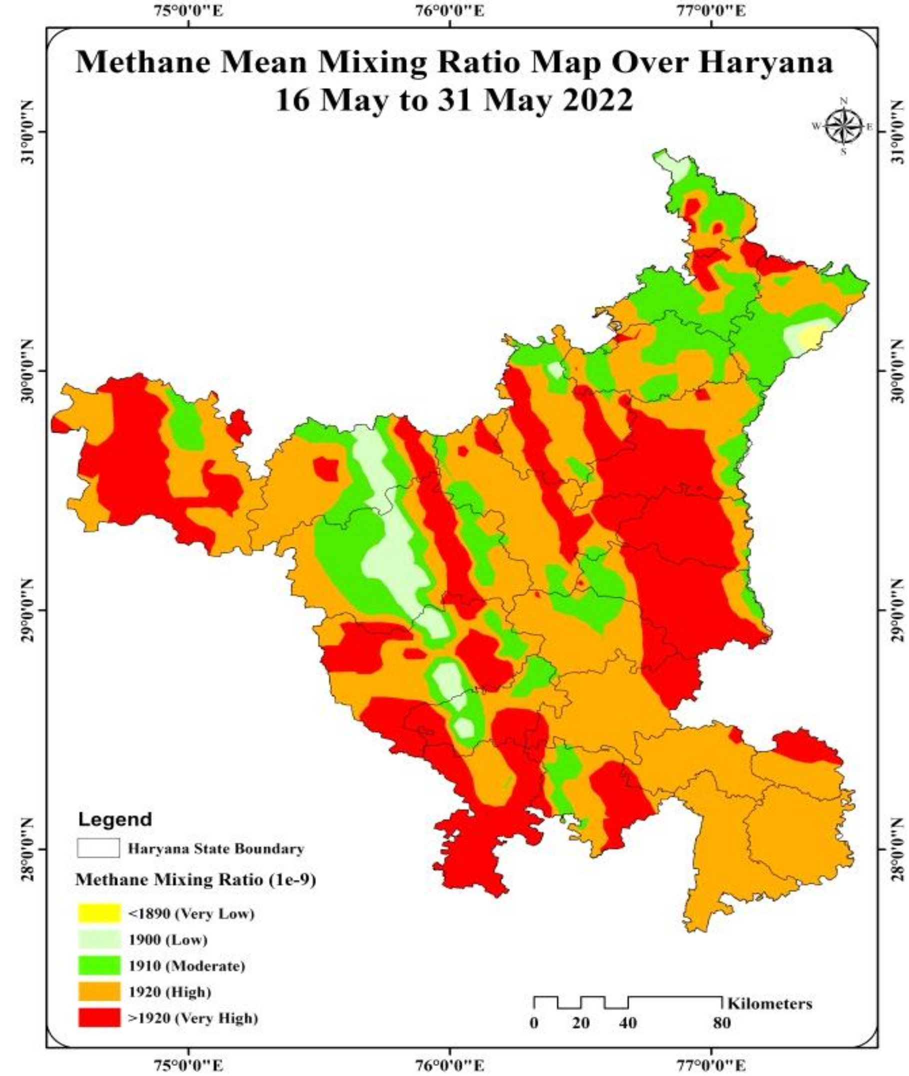


Figure 4.13 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana (16 May to 31 May 2022 (Data Source: Sentinel 5P Processed Data 2022).

In June, the data is presented for five classes, with two sets of values: "Area in Hectare (First Part)" and "Area in Hectare (Second Part)." The "Less Than 1890 (Very Low)" class encompasses 181,857 hectares in the "First Part" and 715,922 hectares in the "Second Part." The "1900 (Low)" class covers 441,920 hectares in the "First Part" and 807,754 hectares in the "Second Part." The "1910 (Moderate)" class includes 1,598,376 hectares in the "First Part" and 1,425,637 hectares in the "Second Part." The "1920 (High)" class has 1,540,028 hectares in the "First Part" and 1,415,415 hectares in the "Second Part." The "More than 1920 (Very High)" class contains 655,462 hectares in the "First Part" and 52,915 hectares in the "Second Part." These values likely represent land area data for various classes in the month of June, possibly for agricultural or geographic analysis. (Figure: 4.14 and 4.15)

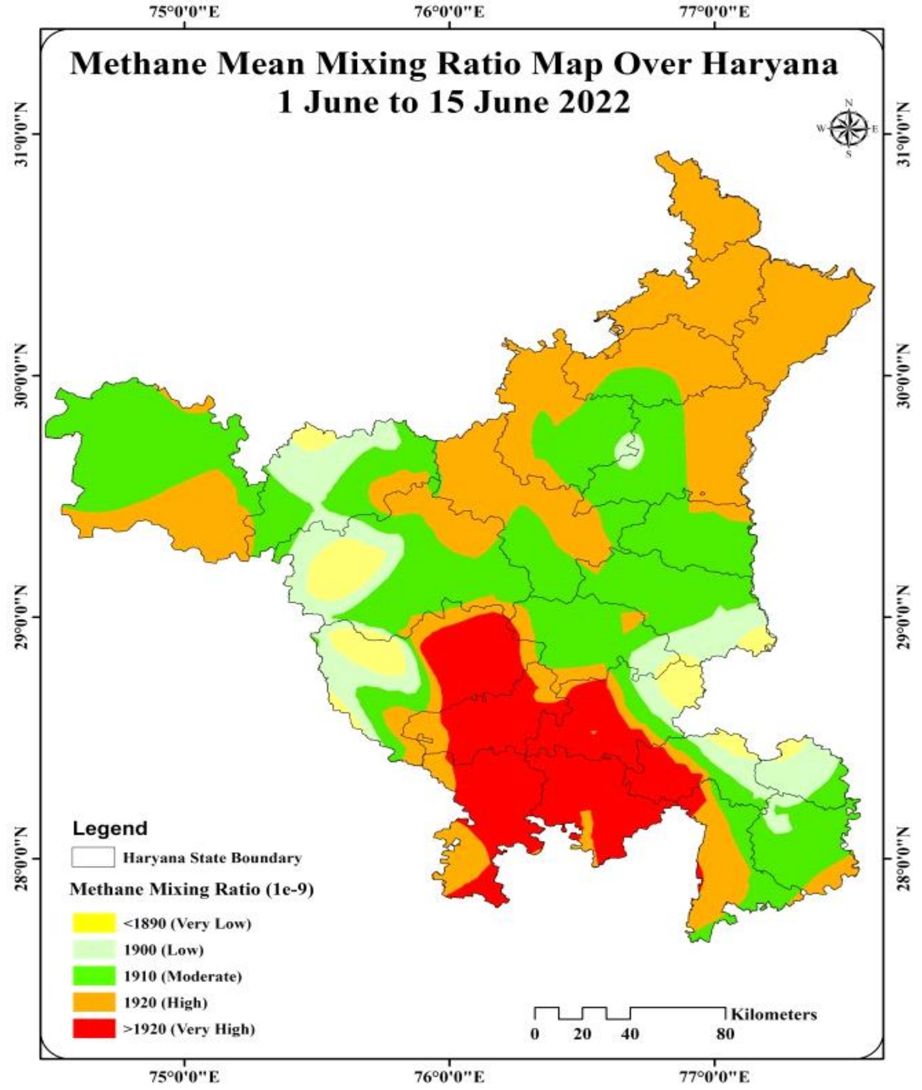


Figure 4.14 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1June to 15 June 2022 (Data Source: Sentinel 5P Processed Data).

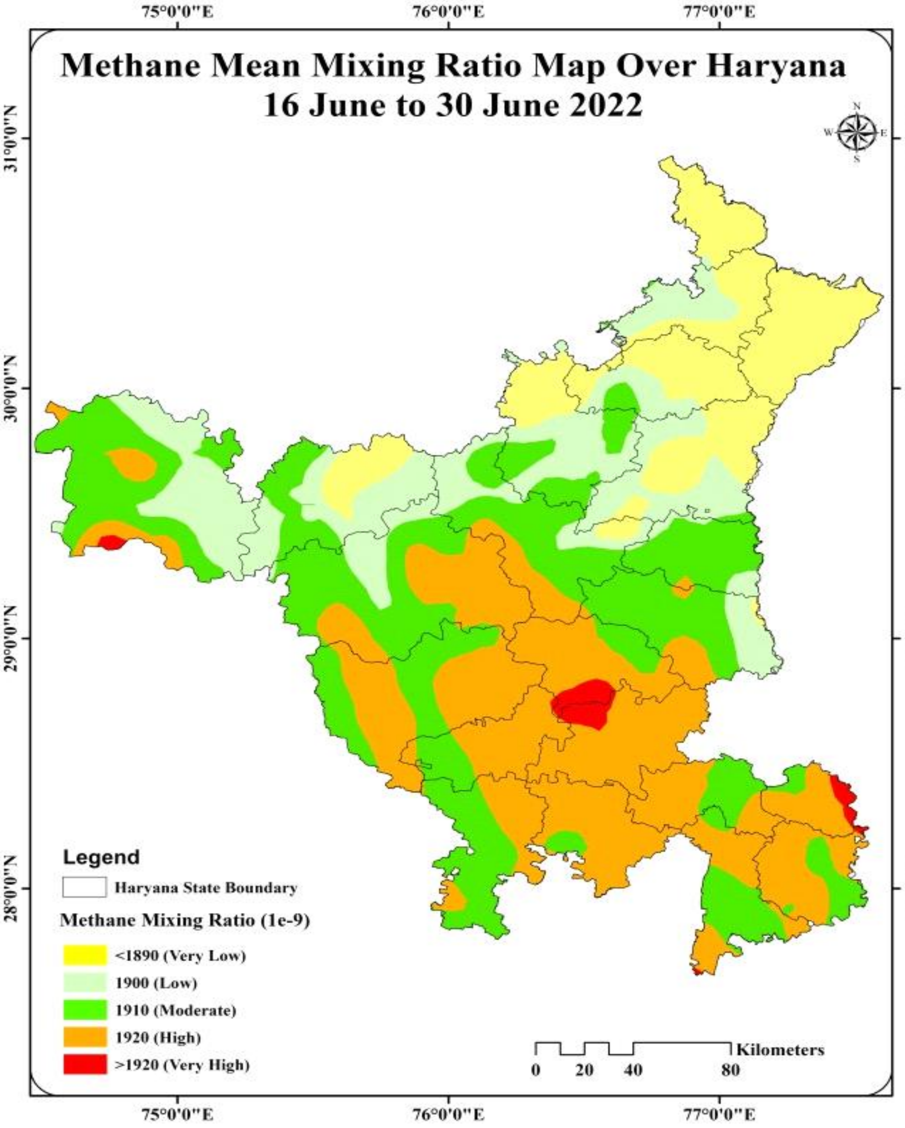


Figure 4.15 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 16 June to 30 June 2022 (Data Source: Sentinel 5P Processed Data 2022).

In July, the data is presented for five classes, with two sets of values: "Area in Hectare (First Part)" and "Area in Hectare (Second Part)." The "Less Than 1890 (Very Low)" class encompasses 433,816 hectares in the "First Part" and 3,338 hectares in the "Second Part." The "1900 (Low)" class covers 887,815 hectares in the "First Part" and 5,514 hectares in the "Second Part." The "1910 (Moderate)" class includes 979,199 hectares in the "First Part" and 25,619 hectares in the "Second Part." The "1920 (High)" class has 1,930,160 hectares in the "First Part" and 4,383,171 hectares in the "Second Part." The

"More than 1920 (Very High)" class contains zero hectares in both the "First Part" and "Second Part." These values likely represent land area data for various classes in the month of July, possibly for agricultural or geographic analysis. (Figure: - 4.16 and 4.17)

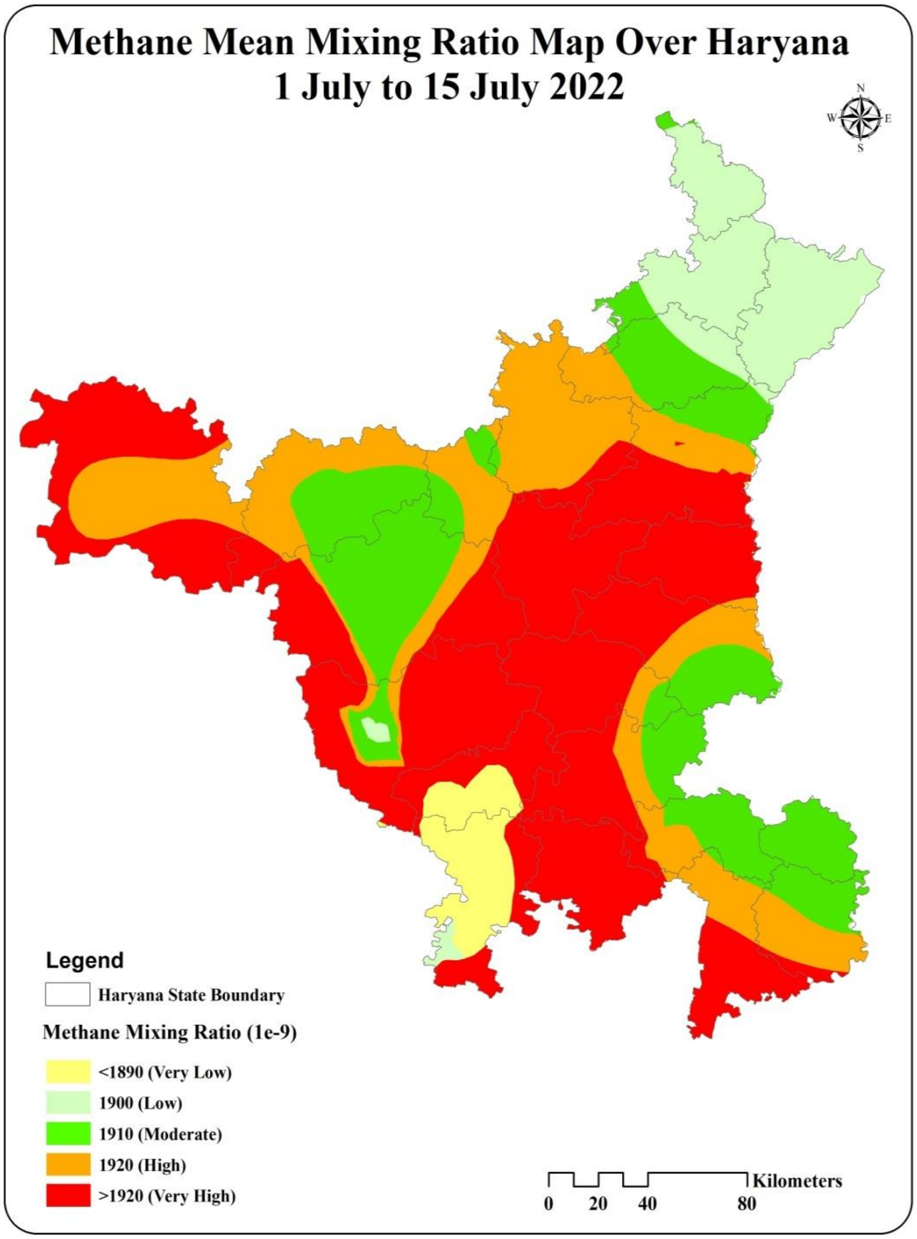


Figure 4.16 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1 July to 15 July 2022 (Data Source: Sentinel 5P Processed Data 2022).

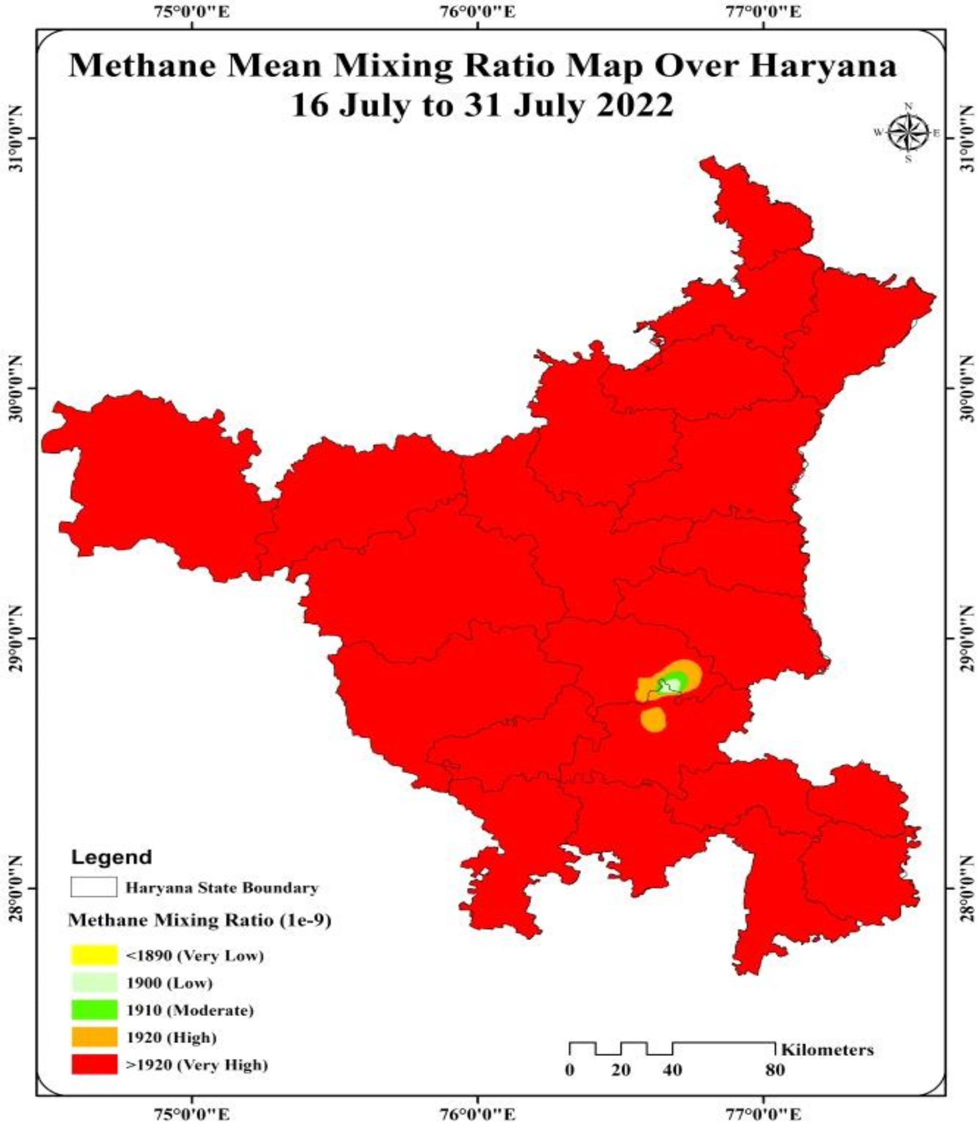


Figure 4.17 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 16 July to 31 July 2022 (Data Source: Sentinel 5P Processed Data 2022).

In September, the data is presented for five classes, with two sets of values: "Area in Hectare (First Part)" and "Area in Hectare (Second Part)." The "Less Than 1890 (Very Low)" class encompasses 6,567 hectares in the "First Part" and 749,358 hectares in the "Second Part." The "1900 (Low)" class covers 11,894 hectares in the "First Part" and 648,722 hectares in the "Second Part." The "1910 (Moderate)" class includes 74,814 hectares in the "First Part" and 630,225 hectares in the "Second Part." The "1920 (High)" class has 500,542 hectares in the "First Part" and 841,438 hectares in the "Second Part."

The "More than 1920 (Very High)" class contains 3,822,782 hectares in the "First Part" and 1,547,900 hectares in the "Second Part." These values likely represent land area data for various classes in the month of September, possibly for agricultural or geographic analysis. (Figure: - 4.18 and 4.19)

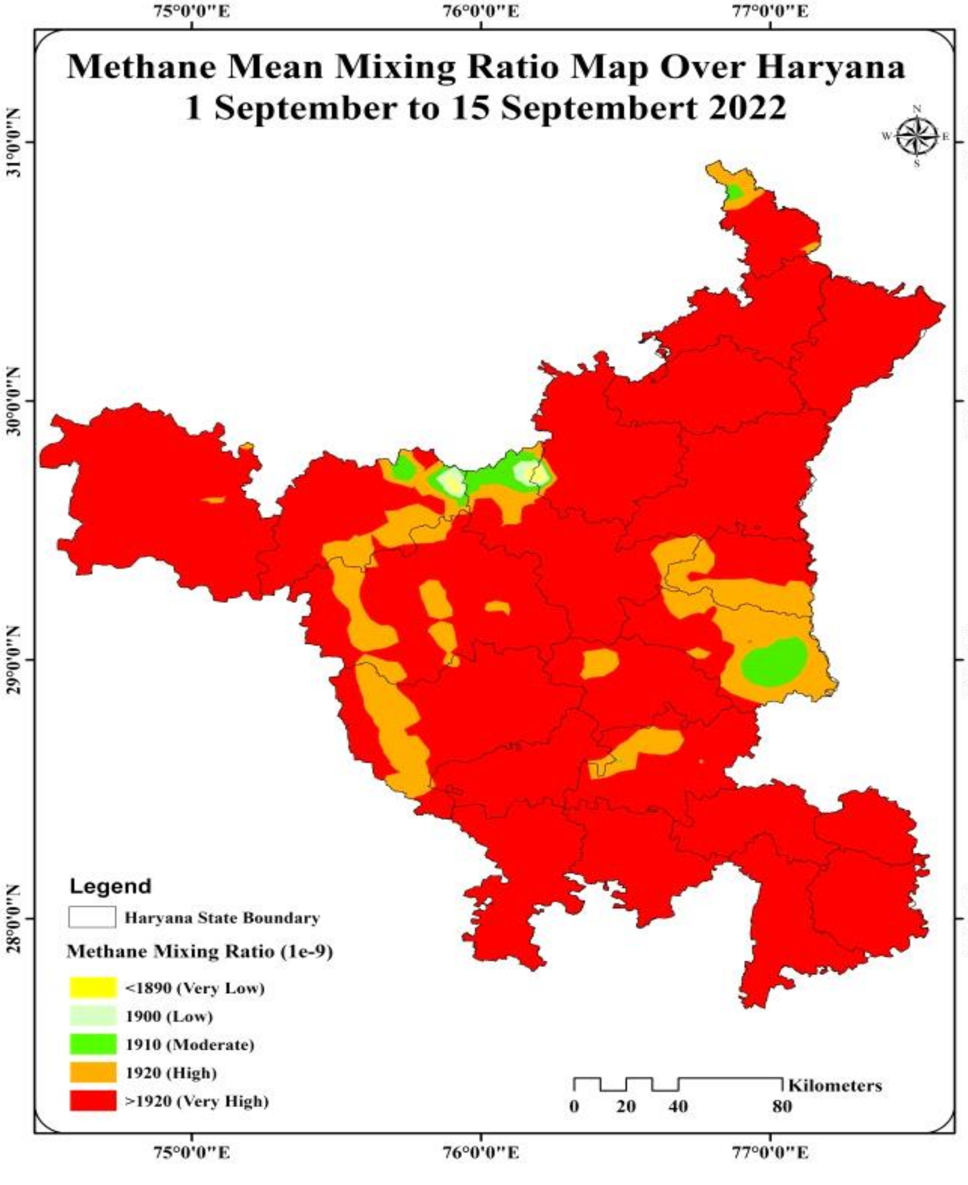


Figure 4.18 Spatial Distribution of Methane Mixing Ratio emission map of Haryana, 1 Sept. to 15 Sept. 2022, (Data Source: Sentinel 5P Processed Data 2022).

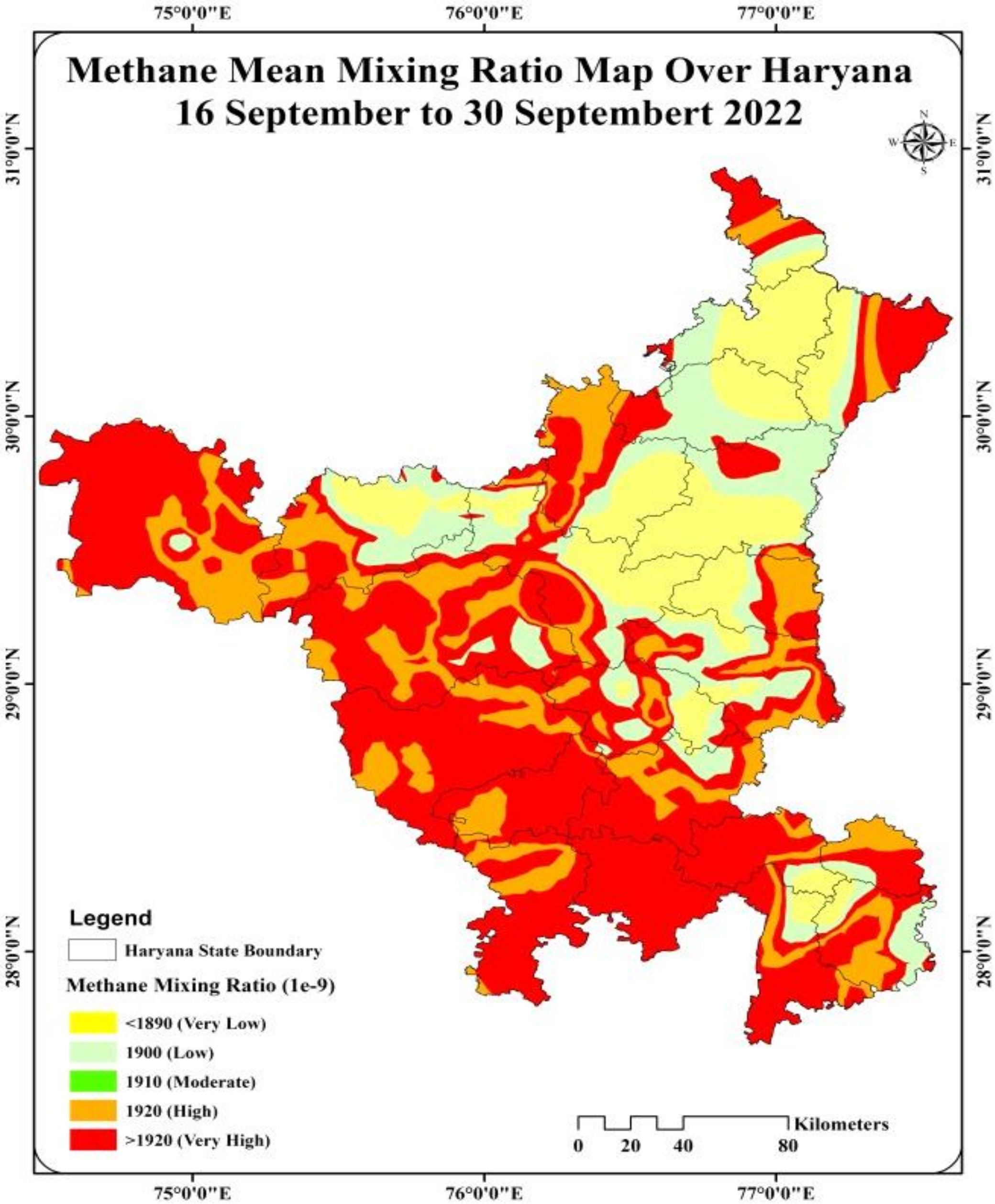


Figure 4.19 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 16 Sept.to 30 Sept. 2022. (Data Source: Sentinel 5P Processed Data 2022).

In October, the data is presented for five classes, with two sets of values: "Area in Hectare (First Part)" and "Area in Hectare (Second Part)." The "Less Than 1890 (Very Low)" class encompasses 79 hectares in both the "First Part" and "Second Part." The "1900 (Low)" class covers 21,474 hectares in both the "First Part" and "Second Part."

The "1910 (Moderate)" class includes 137,991 hectares in both the "First Part" and "Second Part." The "1920 (High)" class has 570,431 hectares in both the "First Part" and "Second Part." The "More than 1920 (Very High)" class contains 3,687,667 hectares in both the "First Part" and "Second Part." These values likely represent land area data for various classes in the month of October, with the same area in both parts, possibly for agricultural or geographic analysis. (Figure:- 4.20 and 4.21)

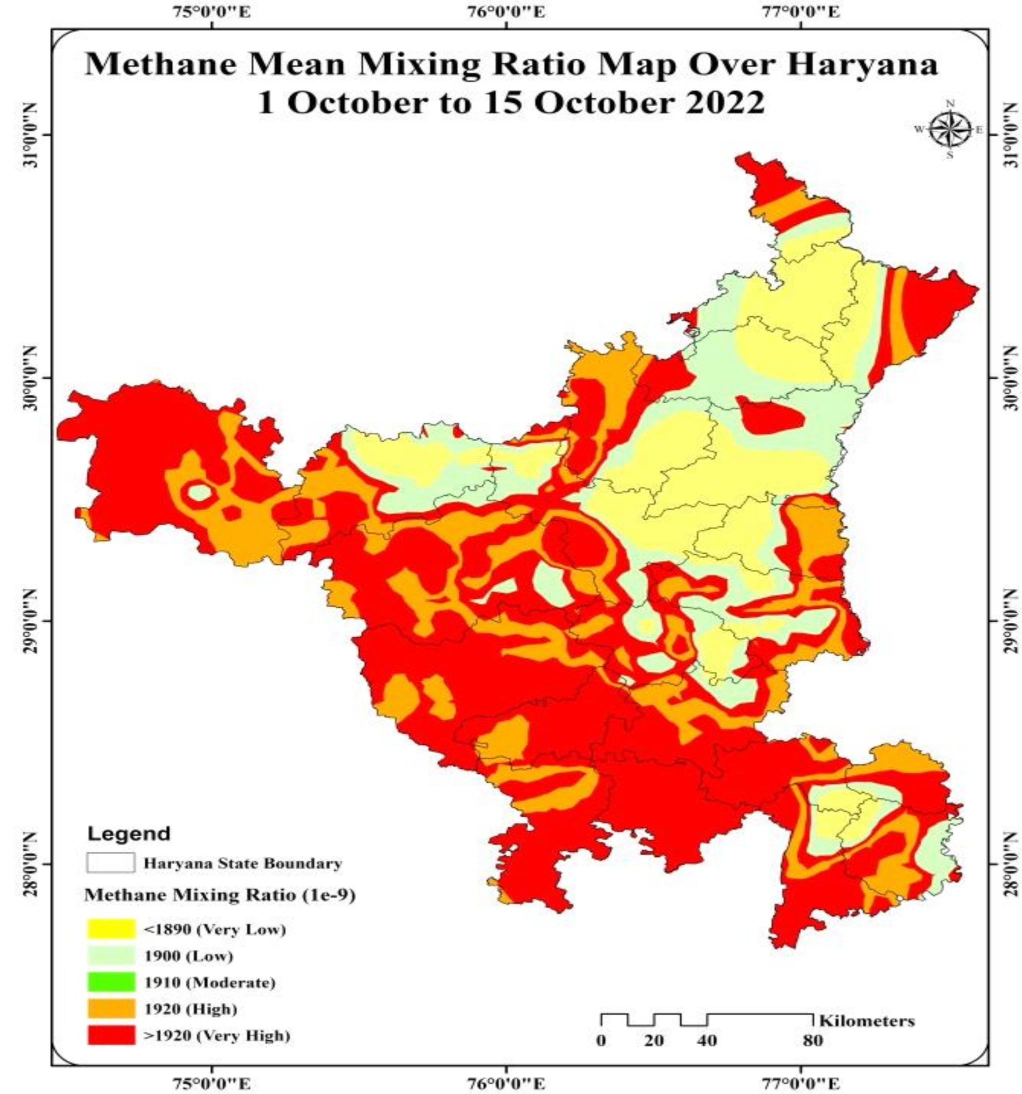


Figure 4.20 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1Oct. to 15 Oct. 2022. (Data Source: Sentinel 5P Processed Data 2022).

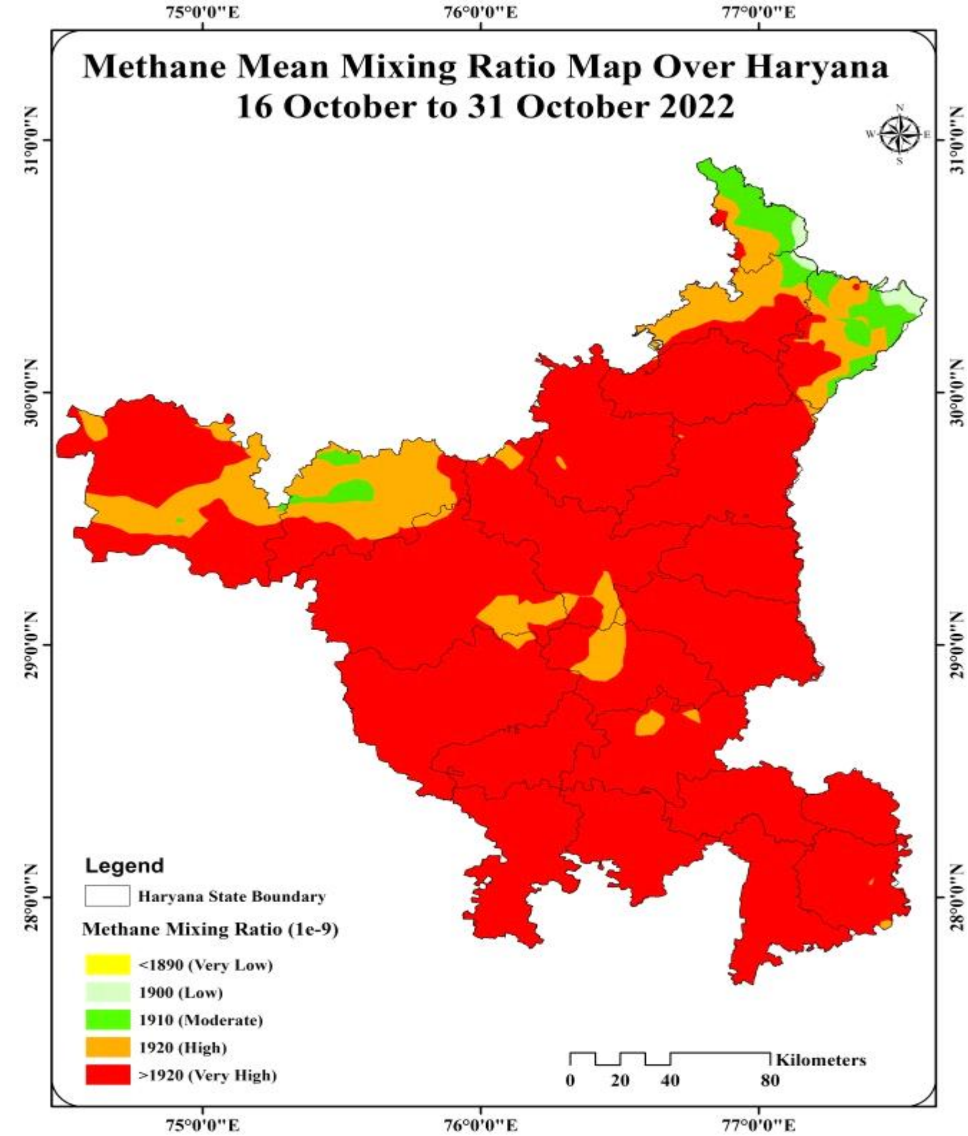


Figure 4.21 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana (16 Oct. to 31 Oct. 2022. (Data Source: Sentinel 5P Processed Data 2022).

In November, the data is presented for five classes, with two sets of values: "Area in Hectare (First Part)" and "Area in Hectare (Second Part)." The "Less Than 1890 (Very Low)" class encompasses 2,887 hectares in the "First Part" and 44,231 hectares in the "Second Part." The "1900 (Low)" class covers 37,600 hectares in the "First Part" and 35,253 hectares in the "Second Part." The "1910 (Moderate)" class includes 28,426 hectares in the "First Part" and 224,047 hectares in the "Second Part." The "1920 (High)" class has 57,368 hectares in the "First Part" and 4,114,112 hectares in the "Second Part." The "More than 1920 (Very High)" class contains 4,291,362 hectares in the "First Part" and zero hectares in the "Second Part." These values likely represent land area data for various classes in the month of November, possibly for agricultural or geographic analysis. (Figure:- 4.22 and 4.23).

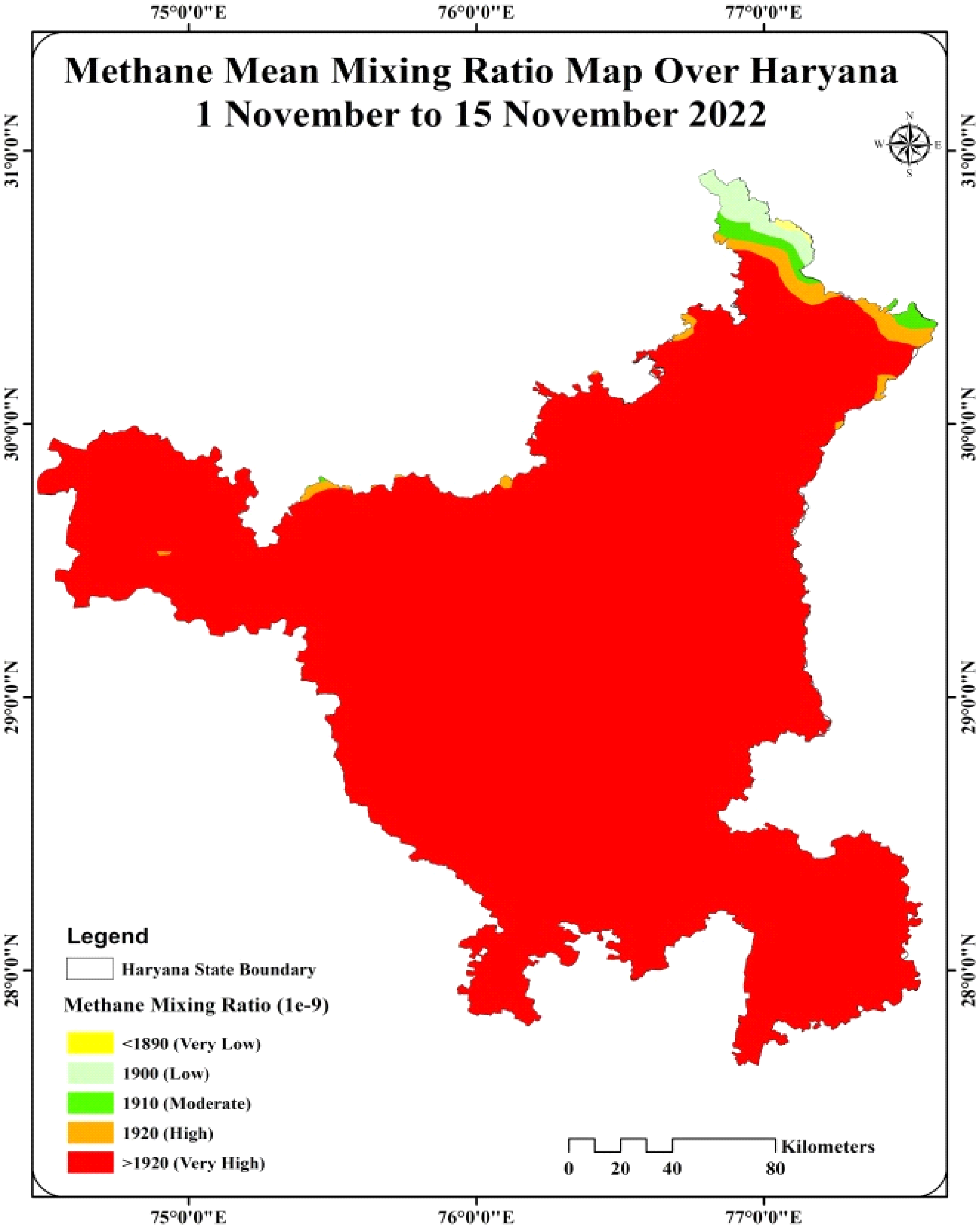


Figure 4.22 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1 Nov. to 15 Nov. 2022. (Data Source: Sentinel 5P Processed Data 2022).

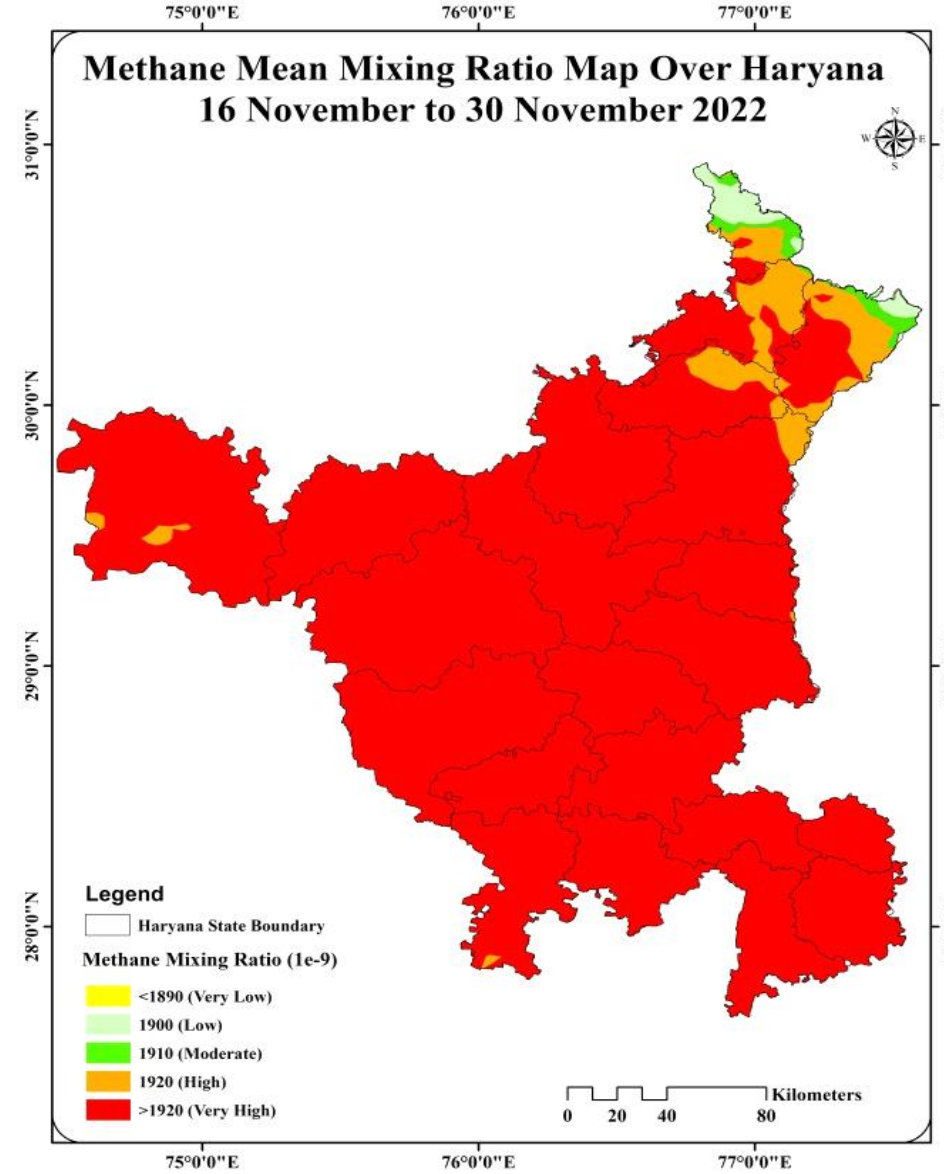


Figure 4.23 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 16 Nov. to 30 Nov. 2022. (Data Source: Sentinel 5P Processed Data 2022).

In December, the data is presented for five classes, with two sets of values: "Area in Hectare (First Part)" and "Area in Hectare (Second Part)." The "Less Than 1890 (Very Low)" class encompasses 1,265 hectares in the "First Part" and 35,235 hectares in the "Second Part." The "1900 (Low)" class covers 44,130 hectares in the "First Part" and 67,368 hectares in the "Second Part." The "1910 (Moderate)" class includes 101,911 hectares in the "First Part" and 629,701 hectares in the "Second Part." The "1920 (High)" class has 400,498 hectares in the "First Part" and 2,860,585 hectares in the "Second Part." The "More than 1920 (Very High)" class contains 3,869,839 hectares in the "First Part" and 824,753 hectares in the "Second Part." These values likely represent land area data for various classes in the month of December, possibly for agricultural or geographic analysis. (Figure:- 4.24 and 4.25).

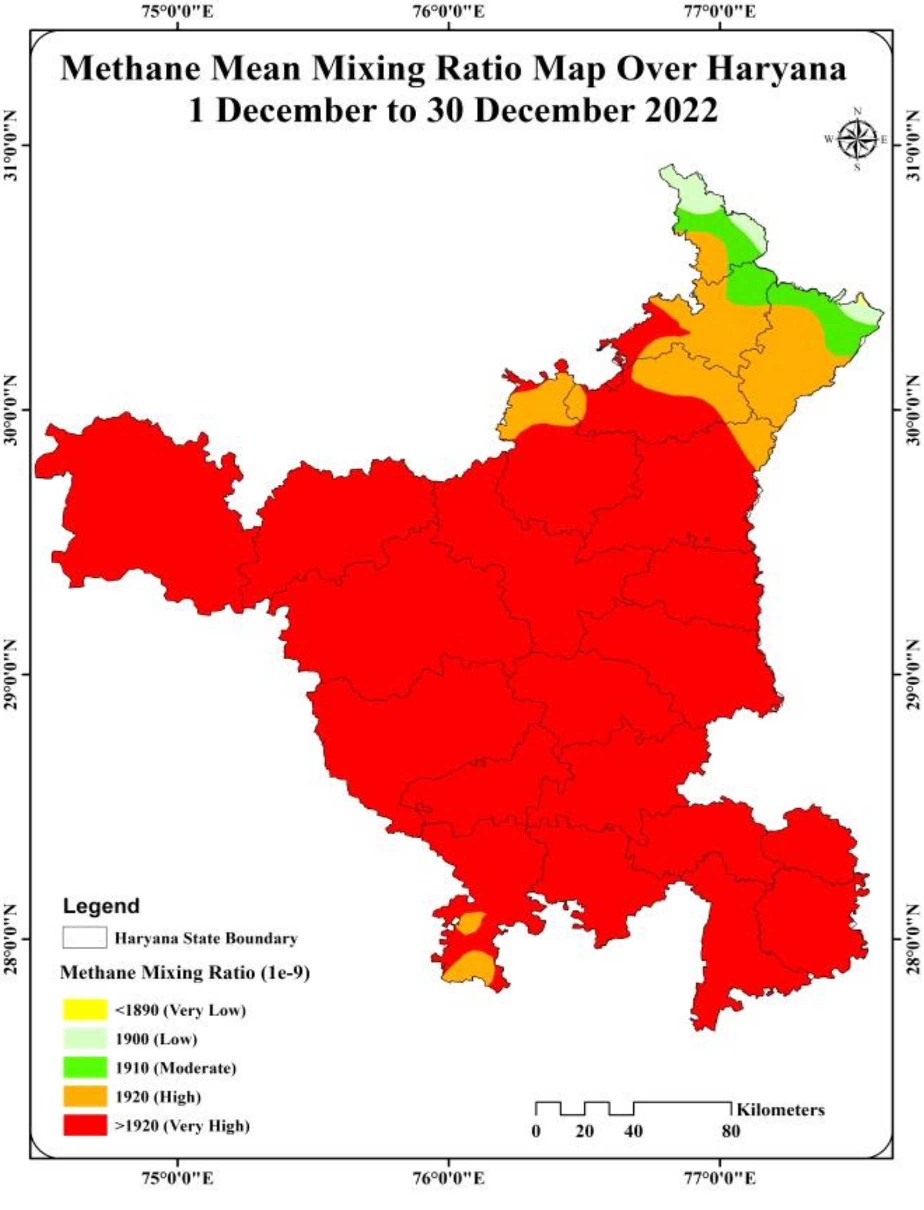


Figure 4.24 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 1 Dec. to 15 Dec. 2022. (Data Source: Sentinel 5P Processed Data 2022).

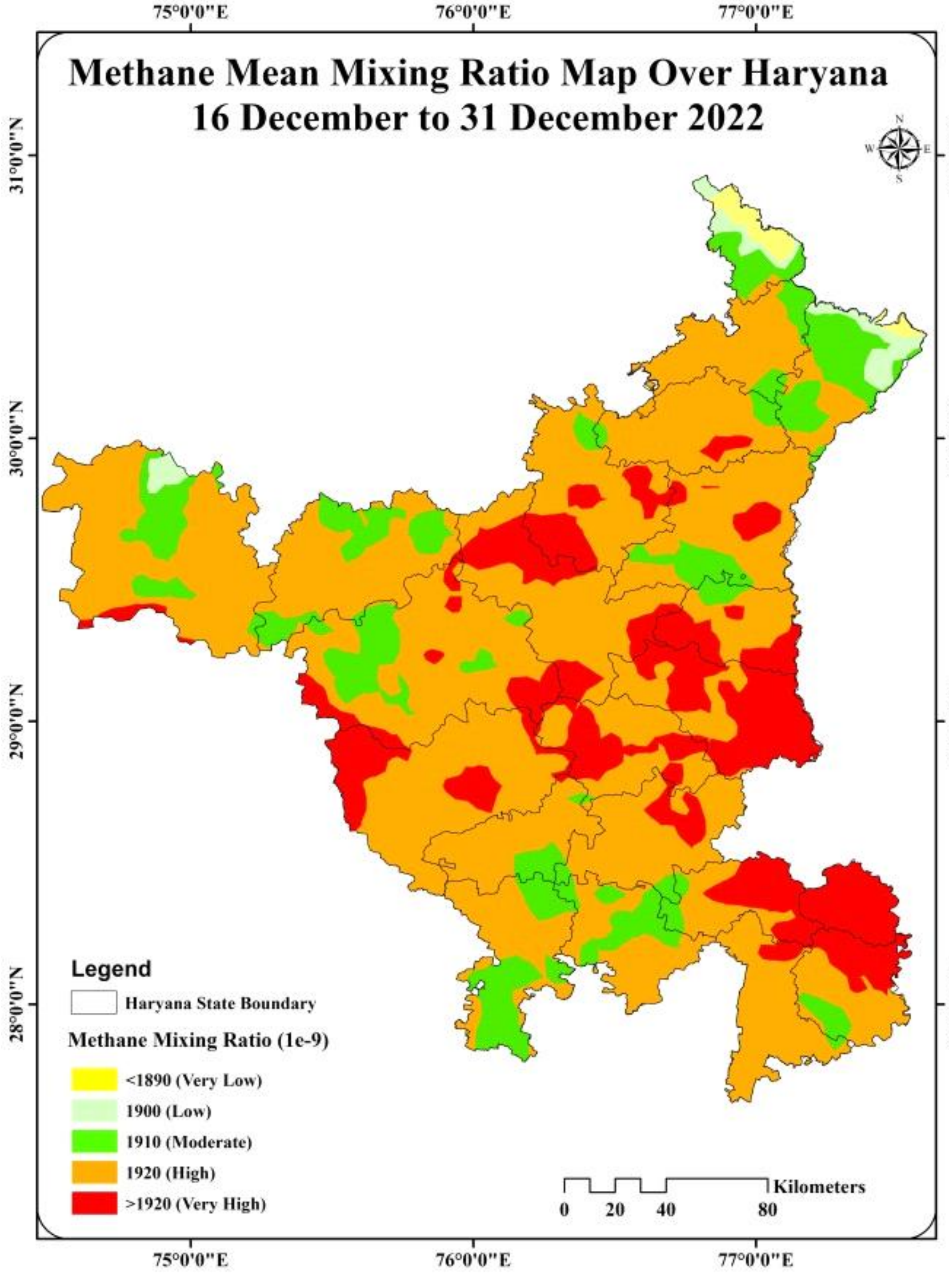


Figure 4.25 Spatial Distribution of Methane Mixing Ratio emission Map of Haryana, 16 Dec. to 30 Dec. 2022. (Data Source: Sentinel 5P Processed Data 2022).

4.7 Comparative Analysis of Methane Emissions

Methane (CH_4) is a potent greenhouse gas that significantly contributes to global warming and climate change. Agricultural activities, particularly rice cultivation, are major sources of methane emissions due to anaerobic conditions in flooded paddy fields. Wheat cultivation, though less associated with methane emissions, also contributes to greenhouse gas emissions through soil microbial activity and residue decomposition. This chapter provides a comparative analysis of methane emissions from rice and wheat crops in Haryana, India, based on the data presented in Chapter 4. The analysis aims to identify spatial and temporal variations, quantify emission levels, and explore the factors influencing methane emissions in these two major cropping systems.

4.7.1 Spatial Distribution

- **Rice Crops**: Methane emissions from rice cultivation are significantly higher compared to wheat. The "Very High" category (1968 ppb) covers the largest area (3,354,135.8 hectares), indicating that rice fields are major contributors to methane emissions in Haryana Fig 5.3. The spatial distribution shows that high methane emissions are concentrated in regions with extensive rice cultivation, particularly during the monsoon season when fields are flooded.
- **Wheat Crops**: Methane emissions from wheat cultivation are relatively lower. The "Very Low" category (1890 ppb) covers the largest area (2,845,764.2 hectares), suggesting minimal methane emissions. High methane emissions from wheat are limited to smaller areas, primarily due to soil microbial activity and residue management practices Fig 5.4.

4.7.2 Temporal Distribution

- **Rice Crops**: Methane emissions from rice are highest during the monsoon season (July to September) when fields are flooded, creating anaerobic conditions conducive to methane production. The data shows a sharp increase in emissions during this period, with the "Very High" category dominating.

- **Wheat Crops**: Methane emissions from wheat are relatively stable throughout the growing season (November to April), with minor fluctuations. The "Very Low" and "Low" categories dominate, indicating that methane emissions are not significantly influenced by seasonal changes.

4.7.3 Emission Intensity

- **Rice Crops**: The emission intensity (methane emitted per hectare) is significantly higher for rice compared to wheat. The "Very High" category for rice covers a vast area, contributing disproportionately to regional methane emissions.
- **Wheat Crops**: The emission intensity for wheat is much lower, with the majority of emissions falling under the "Very Low" and "Low" categories. This highlights the relatively minor role of wheat cultivation in methane emissions.
- Rice Cultivation: Flooded rice fields create anaerobic conditions that promote methane production by methanogenic bacteria. Water management practices, such as continuous flooding versus intermittent irrigation, significantly influence emission levels.
- Wheat Cultivation: Methane emissions from wheat are primarily influenced by soil organic matter, residue management, and microbial activity. Practices such as crop rotation, tillage, and fertilizer application also play a role.

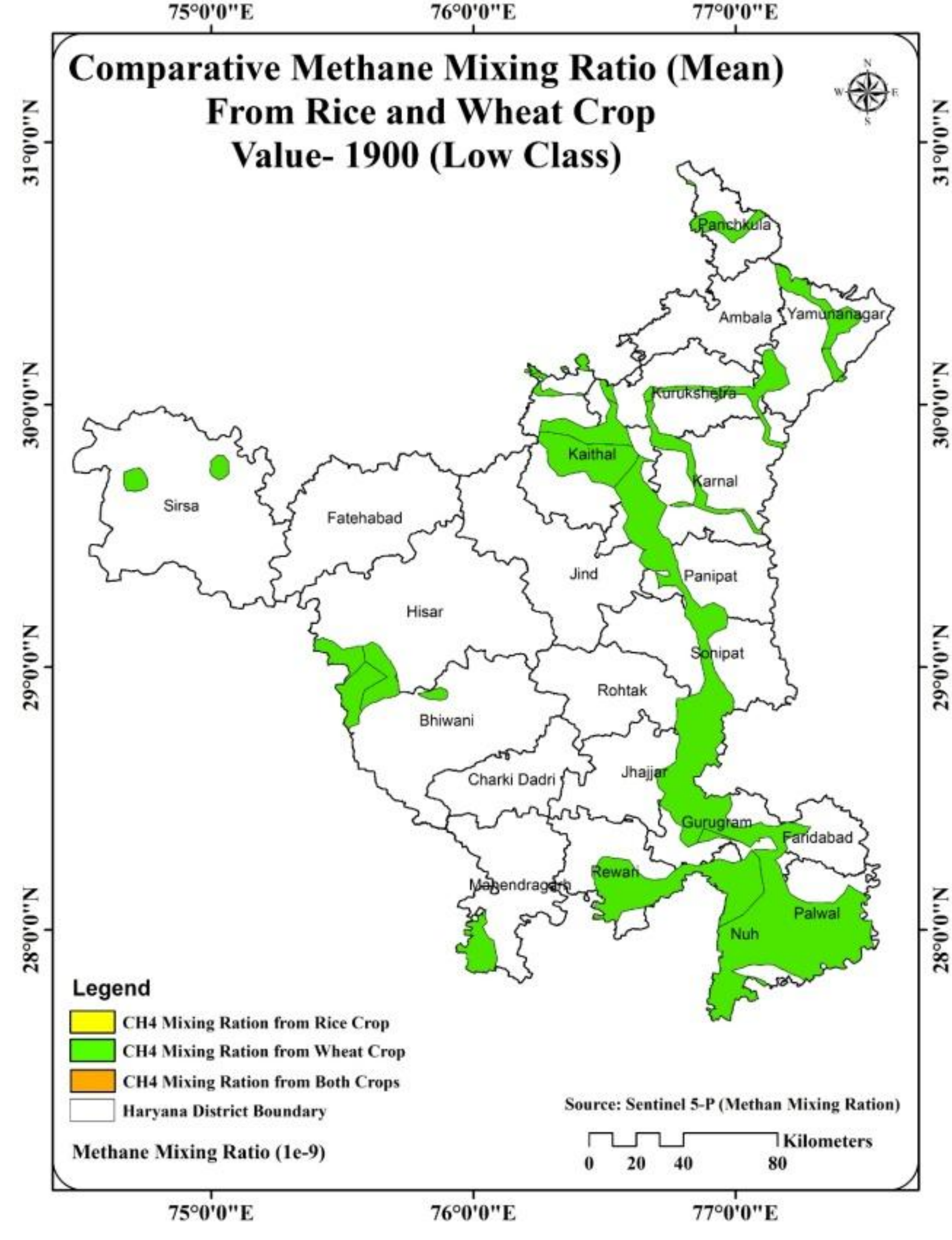


Figure 4.26 Map of Comparative Methane Mixing Ratio emission (Low Class) from rice and wheat crop of Haryana (Data Source: Sentinel 5P Processed Data 2022).

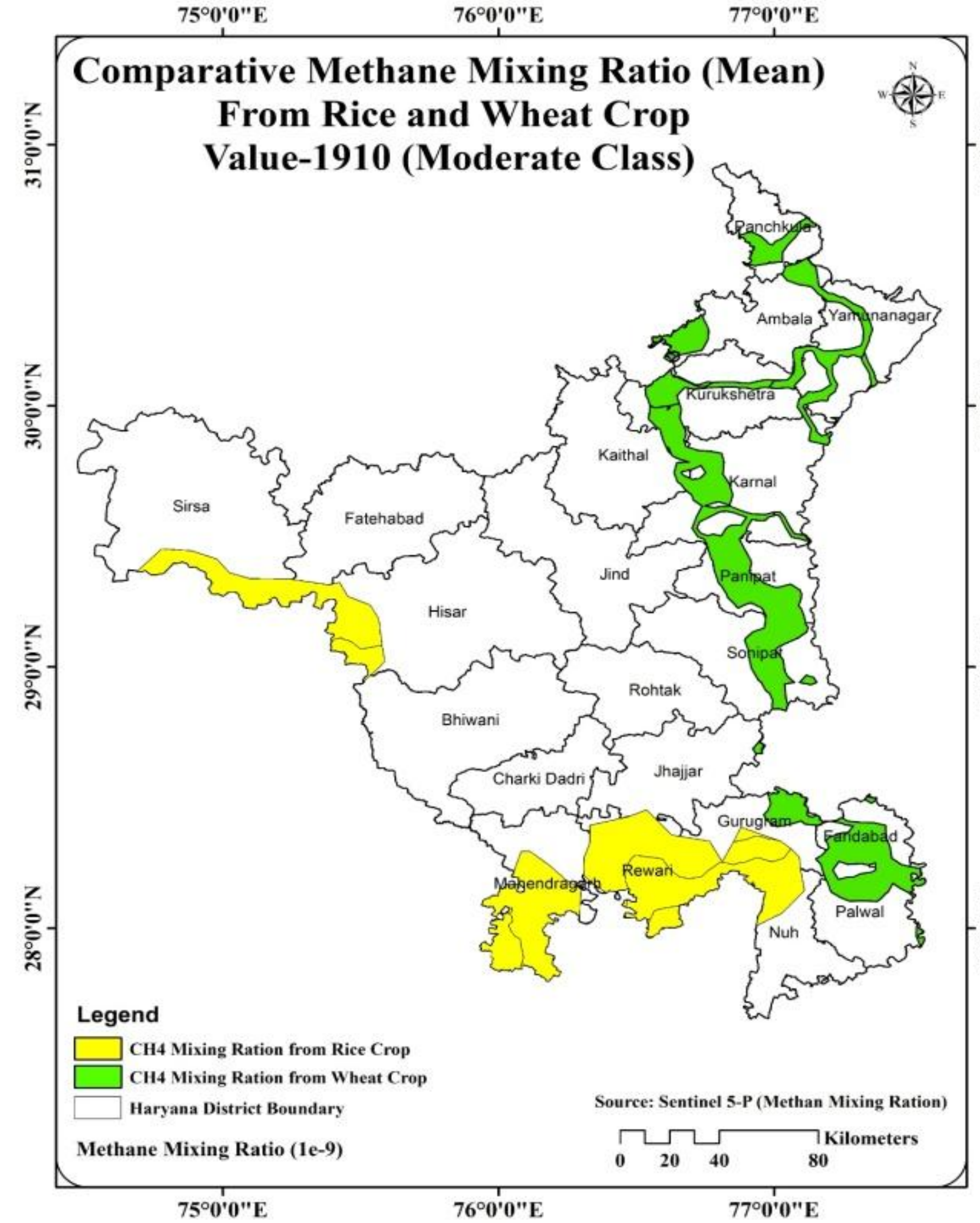


Figure 4.27 Map of Comparative Methane Mixing Ratio emission (Moderate Class) from rice and wheat crop of Haryana (Data Source: Sentinel 5P Processed Data 2022)

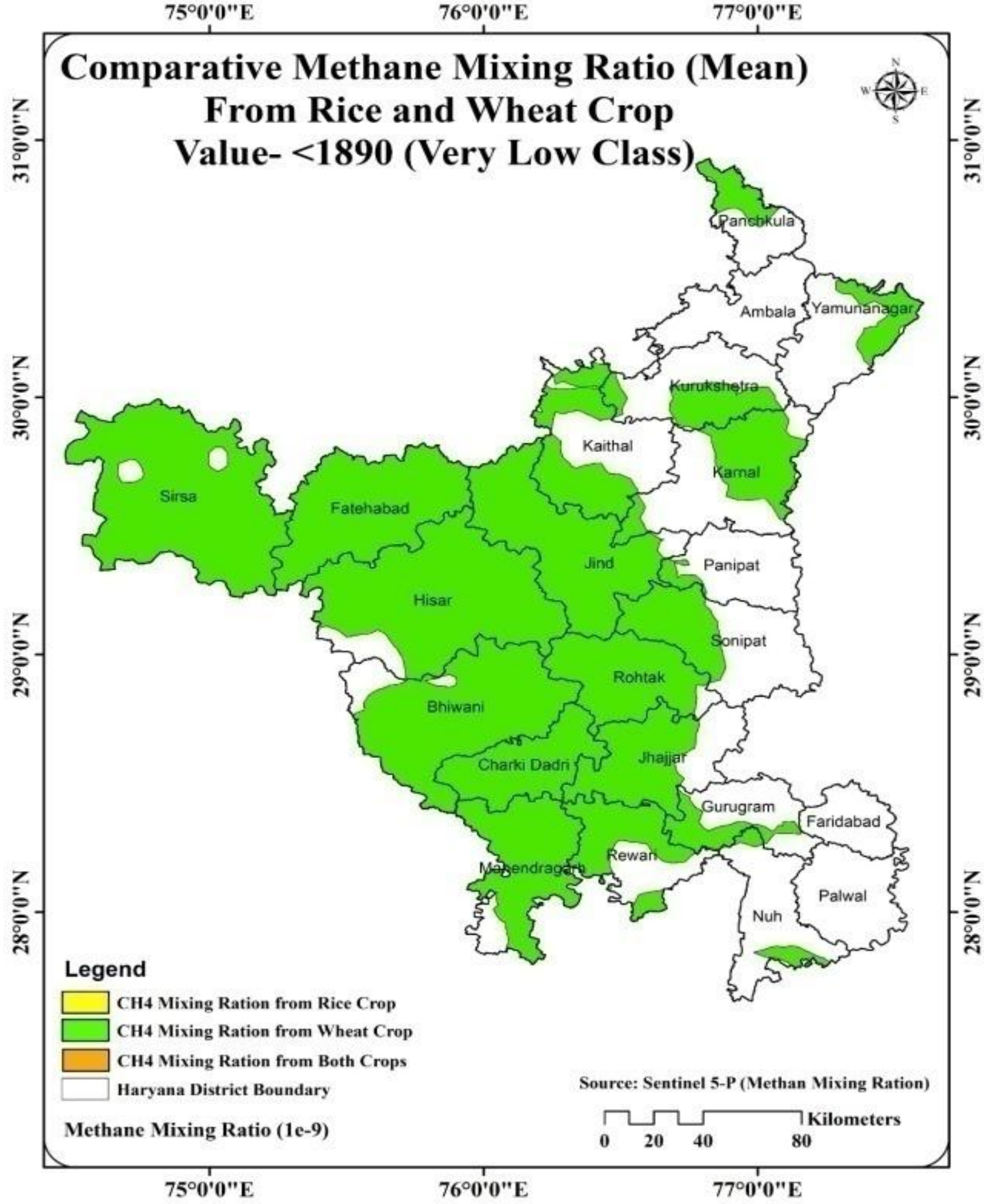


Figure 4.28 Map of Comparative Methane Mixing Ratio emission (Very High Class) from rice and wheat crop of Haryana (Data Source: Sentinel 5P Processed Data 2022).

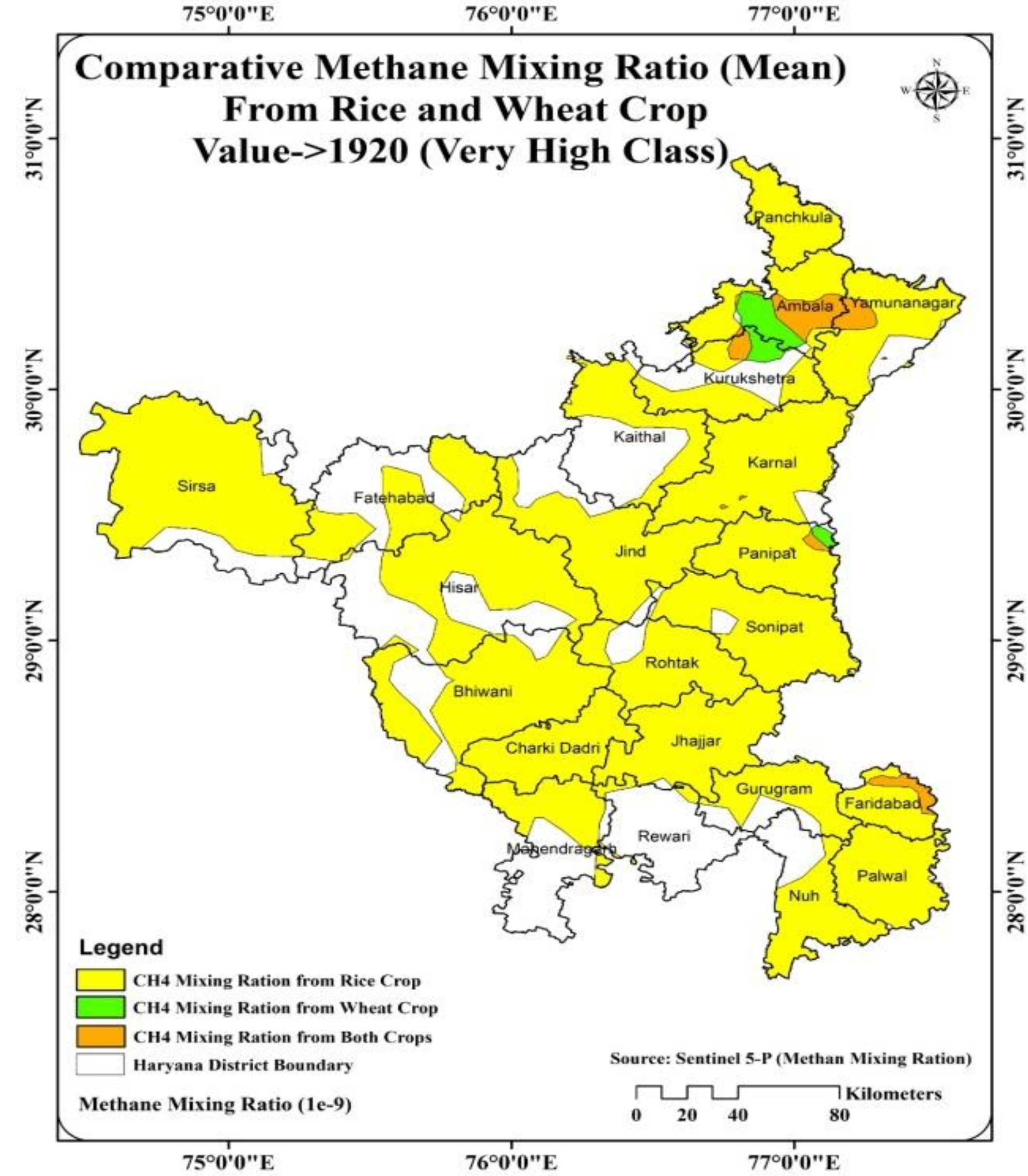


Figure 4.29 Map of Comparative Methane Mixing Ratio emission (Very Low Class) from rice and wheat crop of Haryana (Data Source: Sentinel 5P Processed Data 2022).

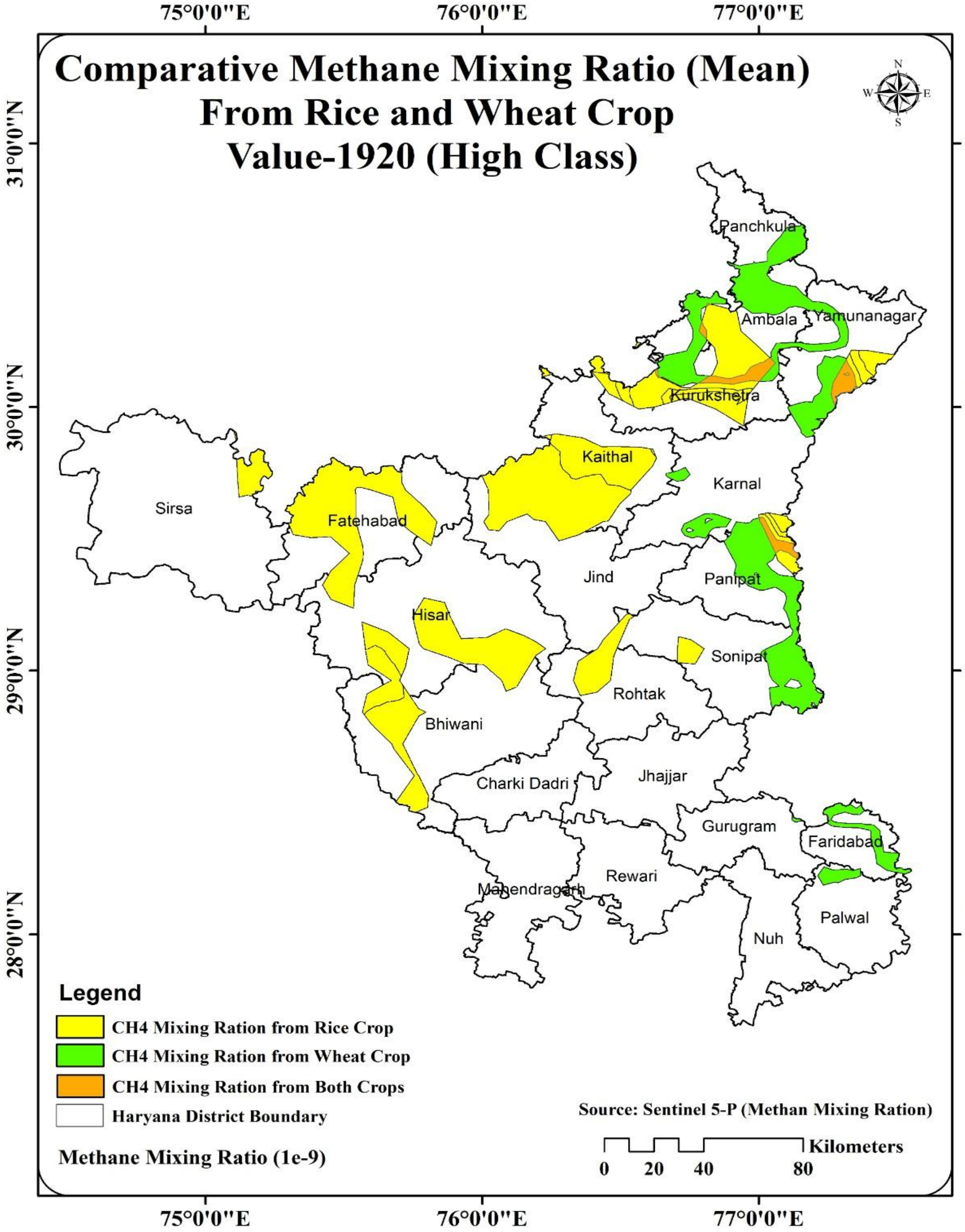


Figure 4.30 Map of Comparative Methane Mixing Ratio emission(High Class) from rice and wheat crop of Haryana (Data Source: Sentinel 5P Processed Data 2022).

Table 4.4 Methane Mixing Ratio emission from Rice & Wheat Crop Season.

Methane Mixing Ratio emission from Rice & Wheat Crop Season			
Classes	Categories value parts-per-billion	Wheat Methane Mixing ratio Area (in Hectare)	Rice Methane Mixing ratio Area (in Hectare)
Very Low	1890	2845764.2	0
Low	1900	799894.3	0
Moderate	1910	374418.5	430622.9
High	1920	279703.0	632663.6
Very High	>1920	117642.4	3354135.8

(Data Source: Sentinel 5P Processed Data 2022)

There is no data available for the rice methane mixing ratio area in the category "Very Low" (below to 1890), indicating that either rice cultivation was not substantial during this time or data collecting for rice cultivation was not done.

- The methane mixing ratio for wheat in the "Low" category (1890–1900) is 1890 ppb, and the equivalent wheat cultivation area is roughly 2,845,764.2 hectares. Methane emissions from rice farming have not been documented throughout this time.
- The "Moderate" category (1910) specifies the areas used for rice and wheat farming. Wheat has a methane mixing ratio of 1910 parts per billion and is grown on an area of about 799,894.3 hectares. The methane mixing ratio for rice is 430,622.9 ppb, which means that 374,418.5 hectares are under cultivation.
- The methane mixing ratio for wheat in the "High" category (1920) drops to 279,703.0 ppb, equivalent to a similar cultivation area of 632,663.6 hectares. Moreover, rice's methane mixing ratio drops to 632,663.6 ppb on 279,703.0 hectares of cultivation.
- Lastly, with a cultivation area of 3,354,135.8 hectares, the methane mixing ratio for wheat rises to 117,642.4 ppb in the "Very High" category (>1920). When it comes to rice, the methane mixing ratio rises to 3,354,135.8 ppb on an area of 117,642.4 hectares under cultivation.

4.8 Evaluate the role of agricultural practices responsible for methane emission

In Haryana, agriculture plays a significant role in methane emissions, particularly through rice cultivation and livestock management. Here’s a breakdown of the main agricultural practices contributing to methane emissions in the region:

4.8.1 Rice Cultivation (Paddy Fields)

- **Flooded Rice Fields**: Rice cultivation is a major source of methane in Haryana due to the practice of continuously flooding paddy fields. This creates anaerobic (oxygen-depleted) conditions, which favor the growth of methanogenic bacteria. These bacteria break down organic matter, releasing methane into the atmosphere.
- **Crop Residue Burning**: While not directly a methane source, crop residue burning (especially paddy stubble) is a widespread practice in Haryana that contributes to air pollution and indirectly influences greenhouse gas emissions.

4.9 Strategies for Mitigation

To reduce methane emissions from agriculture in Haryana, several strategies can be implemented:

- **Alternate Wetting and Drying (AWD)**: This irrigation practice in rice cultivation can reduce methane emissions by creating aerobic conditions periodically in paddy fields.
- **Improved Livestock Feeding Practices**: Enhancing the quality of livestock feed can reduce methane emissions from enteric fermentation. Introducing feed additives like tannins or fats may also reduce methane production in ruminants.
- **Biogas Plants**: Efficient manure management through biogas digesters can help capture methane emissions from livestock manure, providing renewable energy in the form of biogas.

- **Crop Diversification**: Reducing the dependence on water-intensive paddy cultivation by promoting the cultivation of alternative, less water-intensive crops could also help mitigate methane emissions.

The data on methane emissions during wheat and rice-growing seasons in Haryana highlights the substantial role agricultural practices play in methane emissions, which is a critical greenhouse gas. Here's an evaluation of the role of agricultural practices responsible for methane emissions from wheat and rice in Haryana, based on the provided data:

4.10 Wheat Methane Emissions

Methane emissions during the wheat-growing season in Haryana show varying levels across different regions, with concentrations ranging from **1890 ppb (Very Low)** to **1968 ppb (Very High)**. The largest area (2,845,764.2 hectares) falls under the "Very Low" concentration category, suggesting relatively minimal emissions over a vast region. However, smaller areas have higher methane concentrations, with the "Very High" category covering 117,642.4 hectares, where methane levels are significantly elevated.

The agricultural practices that could be contributing to these emissions include:

- **Soil management practices:** Certain soil types and tillage methods may trap organic matter, which could break down anaerobically, leading to methane emissions.
- **Fertilizer application:** Nitrogen-rich fertilizers used for wheat could enhance microbial activity in the soil, contributing to higher methane emissions, especially in waterlogged fields.

4.11 Rice Methane Emissions

Methane emissions from rice fields in Haryana show more significant emission levels compared to wheat. The data reveals a large area under "Very High" emissions, with a methane mixing ratio of **1968 ppb** covering 3,354,135.8 hectares, far surpassing the emission area for wheat.

Rice cultivation is associated with higher methane emissions due to:

- **Flooded conditions:** Rice is typically grown in waterlogged fields, where anaerobic conditions promote methane production by microorganisms. This is a significant source of methane emissions, especially in areas under prolonged flooding.
- **Paddy stubble burning:** Post-harvest burning of paddy stubble contributes to methane emissions, and this practice is prevalent in Haryana.
- **Fertilizer use and residue management:** The use of organic fertilizers, such as manure, in paddy fields enhances methane production due to the decomposition of organic material under anaerobic conditions.

4.12 Comparison and Environmental Impact

- **Wheat vs. Rice:** While wheat emits methane, its impact is considerably lower than that of rice. Rice fields, particularly in the "Very High" category, cover a much larger area and contribute more to the region's methane emissions due to the wet cultivation practices used for rice.
- **Seasonal variations:** Data from different months suggest that methane emissions fluctuate seasonally. For example, emissions rise during the wetter months when rice cultivation peaks, particularly in areas that remain waterlogged for extended periods.

4.13 Environmental Implications

Methane is a potent greenhouse gas with a global warming potential far exceeding that of CO_2. High emissions from rice cultivation, combined with emissions from wheat, contribute significantly to Haryana's greenhouse gas profile, exacerbating climate change concerns. The spatial distribution of these emissions indicates that certain regions are hotspots for methane release, necessitating targeted mitigation strategies.

4.14 Mitigation Strategies

To reduce methane emissions, Haryana can adopt several mitigation strategies in agriculture:

- **Water management:** Implementing alternate wetting and drying (AWD) irrigation techniques in rice paddies can reduce the anaerobic conditions that lead to methane emissions.
- **Fertilizer optimization:** Reducing nitrogen fertilizer application or using slow-release fertilizers can mitigate methane emissions by controlling microbial activity.
- **Stubble management:** Promoting no-burn methods for crop residue, such as mulching or using residues as biofuel, could help curb methane emissions from stubble burning.
- **Improved rice varieties:** Introducing rice varieties that produce less methane or are more water-efficient could also reduce emissions from flooded fields.

4.15 Summary:

This chapter presents a comprehensive analysis of methane emissions from rice and wheat cultivation in Haryana, integrating spatial, temporal, and intensity-based variations using Sentinel-5P satellite data. Agriculture is a major contributor to methane emissions in the state, with rice cultivation emerging as the primary source due to continuous flooding of paddy fields during the monsoon season (July–September), which creates anaerobic conditions favorable for methanogenesis. Over 3.35 million hectares of rice fields fall under the "Very High" emission category (>1920 ppb), highlighting its disproportionate contribution. In contrast, wheat cultivation during the drier months (November–April) shows lower and more stable emissions, with most of its area (2.85 million hectares) classified under the "Very Low" category (1890 ppb). However, localized high emissions in wheat fields (up to 1968 ppb over 117,642 hectares) are linked to waterlogging, residue mismanagement, and excessive fertilizer use. Spatial maps reveal clear regional contrasts, with rice belts dominating methane hotspots. The chapter also emphasizes the environmental implications of seasonal emission peaks aligned with rice farming and the added impact of stubble burning and livestock management. To address Haryana’s agricultural methane footprint, targeted mitigation strategies are suggested, including alternate wetting and drying (AWD), optimized fertilizer use, improved residue and stubble management, livestock feeding improvements, biogas adoption, and crop diversification. Overall, while both crops contribute to greenhouse gas emissions, rice cultivation remains the dominant driver of methane release, underscoring the need for region-specific, sustainable interventions.

CHAPTER-5

EVALUATE THE ROLE OF AGRICULTURAL PRACTICES RESPONSIBLE FOR METHANE EMISSION

Introduction:

Evaluating the role of agricultural practices in methane emission requires an integrated approach combining field-level observations, cropping system analysis, and satellite-based atmospheric monitoring. Advanced remote sensing platforms such as Sentinel-5P provide spatially continuous methane concentration data (XCH_4), enabling seasonal and regional assessment of emission patterns. By linking cropping calendars, irrigation methods, fertilizer application, and residue management practices with methane trends, it becomes possible to identify the key determinants responsible for emission variability.

This chapter aims to critically examine the agricultural practices that contribute to methane emissions in the study area, analyze their seasonal dynamics, and assess their environmental implications. The findings will help in understanding the emission–productivity tradeoff and in formulating mitigation strategies such as alternate wetting and drying (AWD), improved nutrient management, and sustainable residue handling practices to balance agricultural productivity with climate sustainability.

5.1 Evaluate the role of agricultural practices responsible for methane emission.

In Haryana, agriculture plays a significant role in methane emissions, particularly through rice cultivation and livestock management. Here’s a breakdown of the main agricultural practices contributing to methane emissions in the region:

The Figure (5.1) illustrates the complete pathway through which agricultural practices in Haryana contribute to methane (CH_4) emissions, eventually aggravating the issue of climate change. Each box in the flow chart represents a stage or practice, and the arrows depict the direction of influence that leads to methane generation.

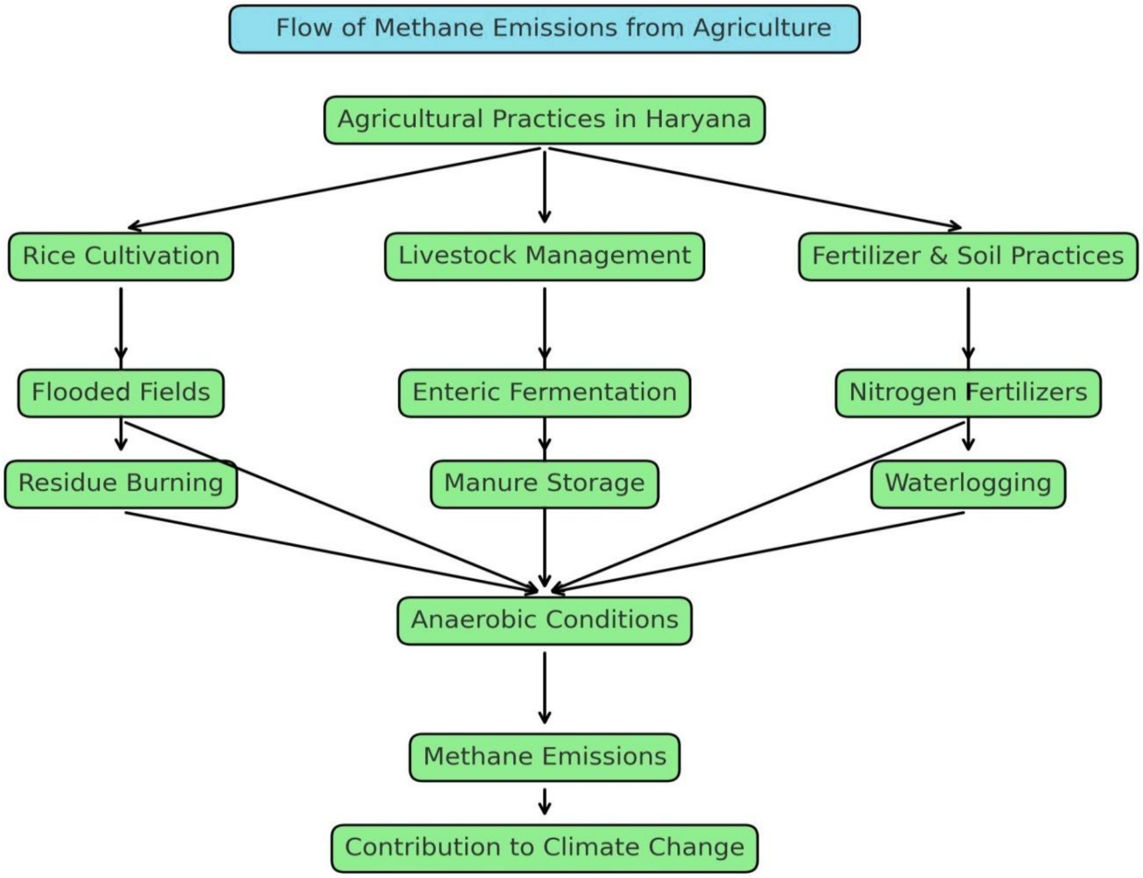


Figure-5.1: Agricultural Practices and Their Contribution to Methane Emissions in Haryana (Data Source: Conceptual framework based on literature review (IPCC, FAO, and related studies).

5.1.1. Agricultural Practices in Haryana

Haryana is one of the leading agricultural states of India, and its economy is predominantly dependent on intensive farming systems. The state is widely known for its rice–wheat cropping pattern, which forms the backbone of its agricultural production. Alongside crop cultivation, dairy farming is an equally important component of the rural economy. While these practices significantly contribute to food security and rural livelihoods, they are also associated with substantial greenhouse gas emissions, particularly methane (CH_4). The major agricultural activities contributing to methane emissions in Haryana can be broadly categorized into three groups: rice cultivation, livestock management, and fertilizer and soil management practices.

Rice cultivation is a dominant Kharif season activity in several districts such as Karnal, Kurukshetra, Kaithal, and Fatehabad. Paddy fields are typically maintained under flooded conditions, creating anaerobic (oxygen-deficient) environments in the soil. Under such conditions, organic matter decomposes through methanogenic bacteria, resulting in methane production. Continuous flooding, excessive irrigation, and high organic residue incorporation further intensify methane emissions. Thus, the traditional puddled transplanted rice system plays a crucial role in greenhouse gas generation in the state.

Livestock management represents another significant source of methane emissions. Haryana has a large cattle and buffalo population, and dairy farming is a major livelihood activity in both rural and peri-urban areas. Methane is produced during enteric fermentation in the digestive systems of ruminant animals such as cows and buffaloes. Additionally, improper manure management practices, including open storage and anaerobic decomposition of dung, further contribute to methane release into the atmosphere.

Fertilizer and soil management practices also influence greenhouse gas emissions. Although nitrogen fertilizers are primarily associated with nitrous oxide (N_2O) emissions, their excessive or imbalanced application can indirectly affect soil microbial processes and carbon cycling. Crop residue burning, common after rice harvesting, alters soil organic matter and contributes to atmospheric pollution. Moreover, intensive tillage and irrigation practices modify soil structure and moisture conditions, influencing greenhouse gas fluxes.

5.1.2. Rice Cultivation

Haryana is one of India’s leading rice-producing states, with major cultivation concentrated in districts such as Kurukshetra, Kaithal, and Karnal. Rice cultivation during the Kharif season is characterized by intensive irrigation and the widespread practice of puddled transplanted rice under flooded conditions. Among agricultural activities, rice farming is a significant contributor to methane (CH_4) emissions due to specific field management practices.

One of the primary sources of methane emissions is continuously flooded rice fields. In this system, fields remain waterlogged for extended periods, preventing oxygen diffusion into the soil. The resulting anaerobic (oxygen-deficient) environment promotes the activity of methanogenic microorganisms. These microbes decompose organic matter present in the soil and crop residues, producing methane as a by-product. The longer the duration of flooding and the higher the organic content, the greater the methane emissions. Thus, traditional irrigation practices play a critical role in greenhouse gas generation.

Another contributing factor is crop residue burning after paddy harvesting. Farmers often burn leftover rice stubble to quickly clear fields for the subsequent wheat crop. This practice directly releases methane, carbon monoxide (CO), and nitrous oxide (N_2O) into the atmosphere. Although methane emissions from residue burning are comparatively lower than those from flooded fields, the practice significantly impacts regional air quality. Seasonal stubble burning contributes to severe smog episodes, particularly affecting the Delhi NCR region during the post-monsoon months.

Rice Cultivation (Paddy Fields)

Rice cultivation is a major source of methane in Haryana due to the practice of continuously flooding paddy fields. This creates anaerobic (oxygen-depleted) conditions, which favor the growth of methanogenic bacteria. These bacteria break down organic matter, releasing methane into the atmosphere. While not directly a methane source, crop residue burning (especially paddy stubble) is a widespread practice in Haryana that contributes to air pollution and indirectly influences greenhouse gas emissions.

5.1.3. Livestock Management

Haryana is popularly known as the “Milk Bowl of India” due to its high productivity in the dairy sector and its substantial population of cattle and buffaloes. Livestock rearing forms an integral component of the rural economy and significantly contributes to household income. However, this sector is also a major source of methane (CH_4)

emissions, primarily through biological digestion processes and manure management practices.

One of the principal sources of methane from livestock is enteric fermentation. Ruminant animals such as cows and buffaloes possess a specialized digestive system in which microorganisms in the rumen break down cellulose-rich feed such as grass, fodder, and crop residues. During this fermentation process, methane is produced as a by-product. The gas is subsequently released into the atmosphere mainly through belching and exhalation. Since Haryana maintains a large dairy population, methane emissions from enteric fermentation constitute a significant share of agricultural greenhouse gas emissions in the state.

The second major source is manure storage and management. Animal dung, when stored in heaps or accumulated in anaerobic pits and lagoons, decomposes in the absence of oxygen. This anaerobic decomposition promotes the activity of methanogenic bacteria, leading to continuous methane release. In many parts of Haryana, dung is either stored openly, piled for long durations, or dried into cakes for fuel. Improper storage and delayed utilization increase methane emissions. Although the use of dung as biofuel reduces dependence on fossil fuels, unmanaged decomposition before drying still contributes substantially to atmospheric methane levels.

5.1.4 Fertilizer & Soil Practices

Intensive agricultural development in Haryana has resulted in a heavy dependence on chemical fertilizers, assured irrigation, and high-input farming systems. While these practices have significantly enhanced crop productivity, they have also influenced soil biochemical processes and greenhouse gas emissions, particularly methane (CH_4). Fertilizer application and irrigation management together modify soil moisture, nutrient availability, and microbial activity, thereby affecting methane production dynamics.

One of the major contributing factors is the extensive use of nitrogen-based fertilizers. Haryana’s rice–wheat cropping system requires substantial nitrogen inputs to sustain high yields. The application of urea and other nitrogenous fertilizers stimulates microbial activity in the soil. When nitrogen fertilizers interact with organic matter under waterlogged conditions, they accelerate microbial decomposition processes. In anaerobic environments, this can enhance methanogenic activity, indirectly increasing methane emissions. Although nitrogen fertilizers are more directly associated with nitrous oxide (N_2O) emissions, their role in intensifying soil microbial processes under flooded conditions contributes to methane generation as well.

Another significant factor is waterlogging due to over-irrigation. Excessive irrigation, particularly in paddy fields and canal-command areas, leads to prolonged water stagnation. Clay-rich and poorly drained soils common in several parts of Haryana retain water for extended periods, limiting oxygen diffusion into the soil profile. The resulting anaerobic conditions create an ideal environment for methanogenic microorganisms to thrive and produce methane. Continuous flooding, combined with high fertilizer input and organic residue incorporation, further intensifies methane emissions from agricultural fields.

5.1.5. Anaerobic Conditions

All the major agricultural practices discussed—such as flooded rice fields, crop residue burning, enteric fermentation in livestock, improper manure storage, excessive fertilizer application, and prolonged waterlogging—ultimately contribute to the creation of oxygen-deficient (anaerobic) conditions in soil and organic waste environments. In the absence of oxygen, specific microorganisms known as methanogenic archaea become highly active. These microorganisms decompose organic matter through anaerobic metabolic processes and produce methane (CH_4) as a by-product. Therefore, anaerobic conditions function as the primary and most critical trigger for methane emissions in agricultural systems, making them central to understanding and mitigating greenhouse gas production in intensive farming regions like Haryana.

5.1.6. Methane Emissions

Once methane is produced through anaerobic agricultural processes, it is released into the atmosphere, where it acts as a potent greenhouse gas. In India, agriculture contributes nearly 40 percent of total methane emissions, with a substantial share originating from states like Haryana due to its intensive rice–wheat cropping system and large livestock population. The combined effect of flooded paddy fields, enteric fermentation, manure management, and fertilizer-induced soil processes significantly elevates the state's emission levels.

These methane emissions have multiple environmental implications. They contribute to the deterioration of regional air quality, particularly when combined with residue burning and other pollutants. Additionally, they increase Haryana's overall greenhouse gas inventory, thereby influencing its climate footprint. Emissions also exhibit clear seasonal variability, with noticeable peaks during the rice cultivation period from July to October, when fields remain waterlogged and microbial methane production is at its highest.

5.1.7. Contribution to Climate Change

Methane (CH_4) is a highly potent greenhouse gas, possessing a Global Warming Potential (GWP) approximately 28–34 times greater than carbon dioxide (CO_2) over a 100-year time horizon. Due to this high radiative efficiency, even relatively smaller concentrations of methane can exert a significant warming effect on the atmosphere. In the context of Haryana, agricultural methane emissions arising from rice cultivation, livestock management, manure handling, and residue burning play a considerable role in enhancing the state's greenhouse gas burden.

These emissions contribute to rising temperatures and increasing heat stress across the region, which in turn affect agricultural sustainability and human well-being. Climate variability linked to greenhouse gas accumulation may lead to irregular rainfall patterns, extreme weather events, and declining crop productivity. Furthermore, practices such as stubble burning intensify seasonal air pollution episodes, particularly impacting the Delhi NCR region during post-harvest months. Thus, the cumulative effect of these agricultural practices ultimately contributes to broader climate change processes, highlighting the urgent need for sustainable and climate-resilient farming strategies.

5.1.8. Inefficient Water Management in Agriculture

- **Over-irrigation in Paddy Fields**: Excessive water usage in paddy cultivation contributes to prolonged anaerobic conditions, which enhances methane production. This inefficient water management is a major factor in Haryana's methane emissions profile.

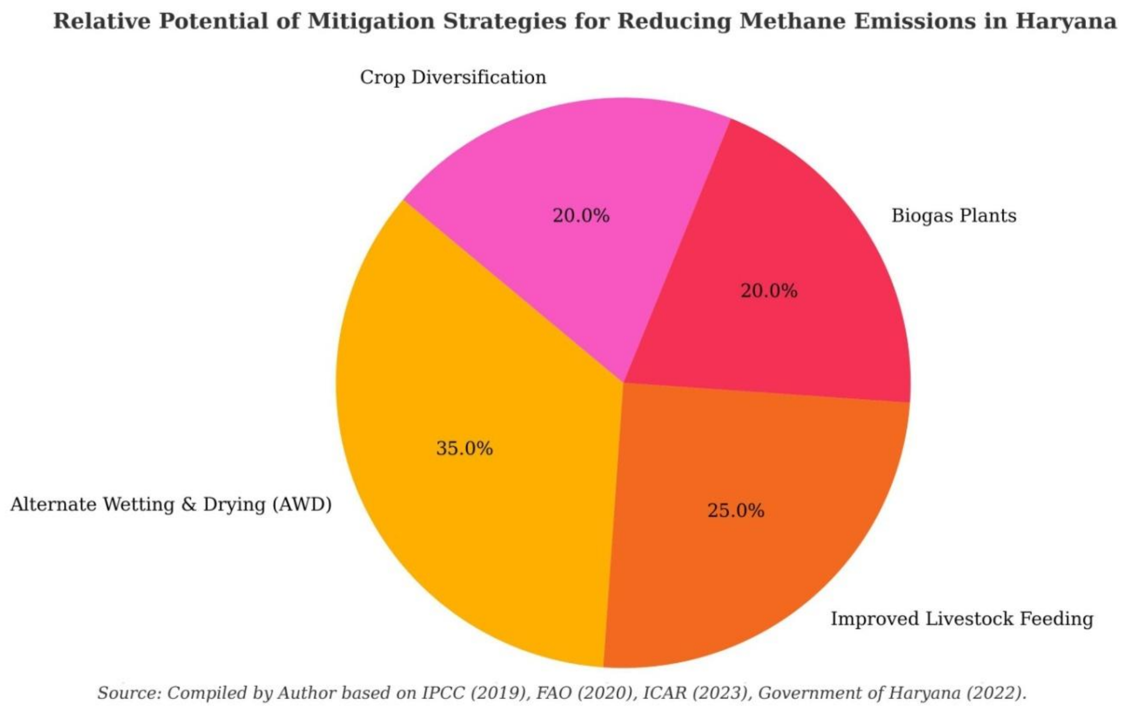
5.2 Strategies for Mitigation

Mitigating methane emissions from agriculture in Haryana requires the adoption of climate-smart and sustainable farming practices. Since methane production is largely associated with anaerobic conditions in rice fields and livestock systems, targeted interventions in irrigation management and animal husbandry can significantly reduce emissions without compromising productivity.

One effective strategy is Alternate Wetting and Drying (AWD) in rice cultivation. AWD is an improved irrigation technique in which paddy fields are not kept continuously flooded; instead, irrigation is applied intermittently after a certain level of soil drying. This periodic exposure of soil to air creates aerobic conditions, thereby suppressing the activity of methanogenic microorganisms responsible for methane generation. In addition to reducing methane emissions, AWD also conserves water and lowers irrigation costs, making it both environmentally and economically beneficial for farmers in Haryana.

Another important mitigation measure involves improved livestock feeding practices. Since methane from enteric fermentation is directly linked to digestive processes in ruminant animals, enhancing feed quality can reduce methane production per unit of milk or meat produced. Providing balanced diets with higher digestibility, incorporating green fodder, and optimizing nutrient composition improve feed conversion efficiency. Furthermore, the introduction of feed additives such as tannins, fats, or specific methane inhibitors can suppress methanogenic activity in the rumen. These interventions not only reduce greenhouse gas emissions but also enhance livestock productivity and overall farm income.

Together, improved irrigation management and scientific livestock feeding practices offer practical and scalable solutions for reducing agricultural methane emissions in Haryana while supporting sustainable agricultural development.



Relative Potential of Mitigation Strategies for Reducing Methane Emissions in Haryana

Source: Compiled by Author based on IPCC (2019), FAO (2020), ICAR (2023), Government of Haryana (2022).

Figure-5.2: Relative Potential of Different Mitigation Strategies for Reducing Methane Emissions in Haryana

- **Biogas Plants**: Efficient manure management through biogas digesters can help capture methane emissions from livestock manure, providing renewable energy in the form of biogas.
- **Crop Diversification**: Reducing the dependence on water-intensive paddy cultivation by promoting the cultivation of alternative, less water-intensive crops could also help mitigate methane emissions.

The pie chart (Figure 5.2) illustrates the relative potential of different mitigation strategies for reducing methane emissions from agriculture in Haryana. Among the options, Alternate Wetting and Drying (AWD) contributes the highest share (35%), as intermittent irrigation in rice fields substantially reduces anaerobic soil conditions responsible for methane generation. Improved livestock feeding practices account for 25%, since enhancing feed quality and using natural additives such as tannins and fats can significantly reduce methane from enteric fermentation in Haryana’s large cattle and buffalo population. Biogas plants, with a potential of 20%, provide an effective way to manage livestock manure by capturing methane for renewable energy use rather than allowing it to escape into the atmosphere. Similarly, crop diversification also accounts for 20%, as shifting from water-intensive rice cultivation to less water-demanding crops like maize, pulses, or millets helps minimize methane formation due to waterlogging. Overall, the chart highlights that water management in rice and livestock feed improvements together constitute the majority of mitigation potential, while biogas adoption and diversification provide complementary long-term strategies for reducing methane emissions and combating climate change in the region.

The data on methane emissions during wheat and rice-growing seasons in Haryana highlights the substantial role agricultural practices play in methane emissions, which is a critical greenhouse gas. Here’s an evaluation of the role of agricultural practices responsible for methane emissions from wheat and rice in Haryana, based on the provided data:

5.3 Wheat Methane Emissions:

Methane emissions during the wheat-growing season in Haryana show varying levels across different regions, with concentrations ranging from 1890 ppb (Very Low) **to** 1968 ppb (Very High). The largest area (2,845,764.2 hectares) falls under the "Very Low" concentration category, suggesting relatively minimal emissions over a vast region. However, smaller areas have higher methane concentrations, with the "Very High" category covering 117,642.4 hectares, where methane levels are significantly elevated.

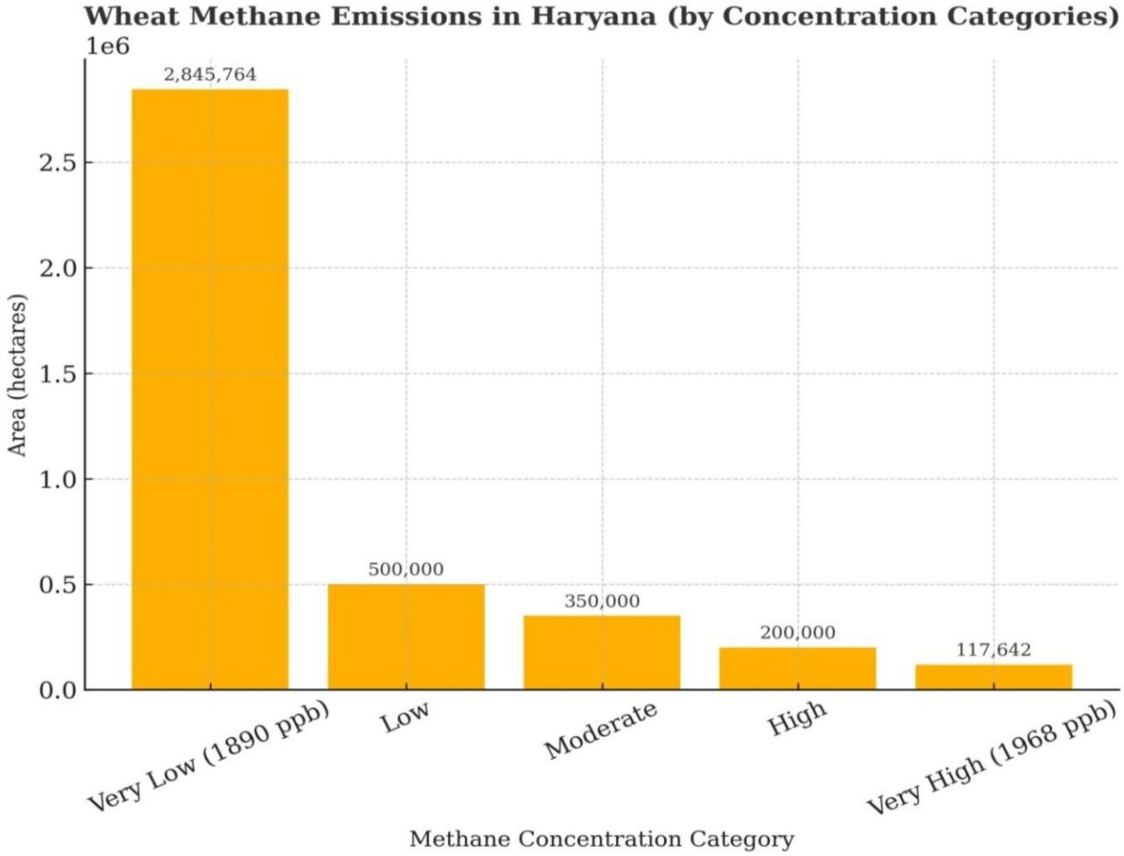


Figure-5.3: Bar Diagram of Wheat Methane Emissions in Haryana (by Concentration Categories).

The agricultural practices that could be contributing to these emissions include:

- **Soil management practices:** Certain soil types and tillage methods may trap organic matter, which could break down anaerobically, leading to methane emissions.
- **Fertilizer application:** Nitrogen-rich fertilizers used for wheat could enhance microbial activity in the soil, contributing to higher methane emissions, especially in waterlogged fields.

5.4 Rice Methane Emissions

Methane emissions from rice fields in Haryana show more significant emission levels compared to wheat. The data reveals a large area under "Very High" emissions, with a methane mixing ratio of 1968 ppb covering 3,354,135.8 hectares, far surpassing the emission area for wheat.

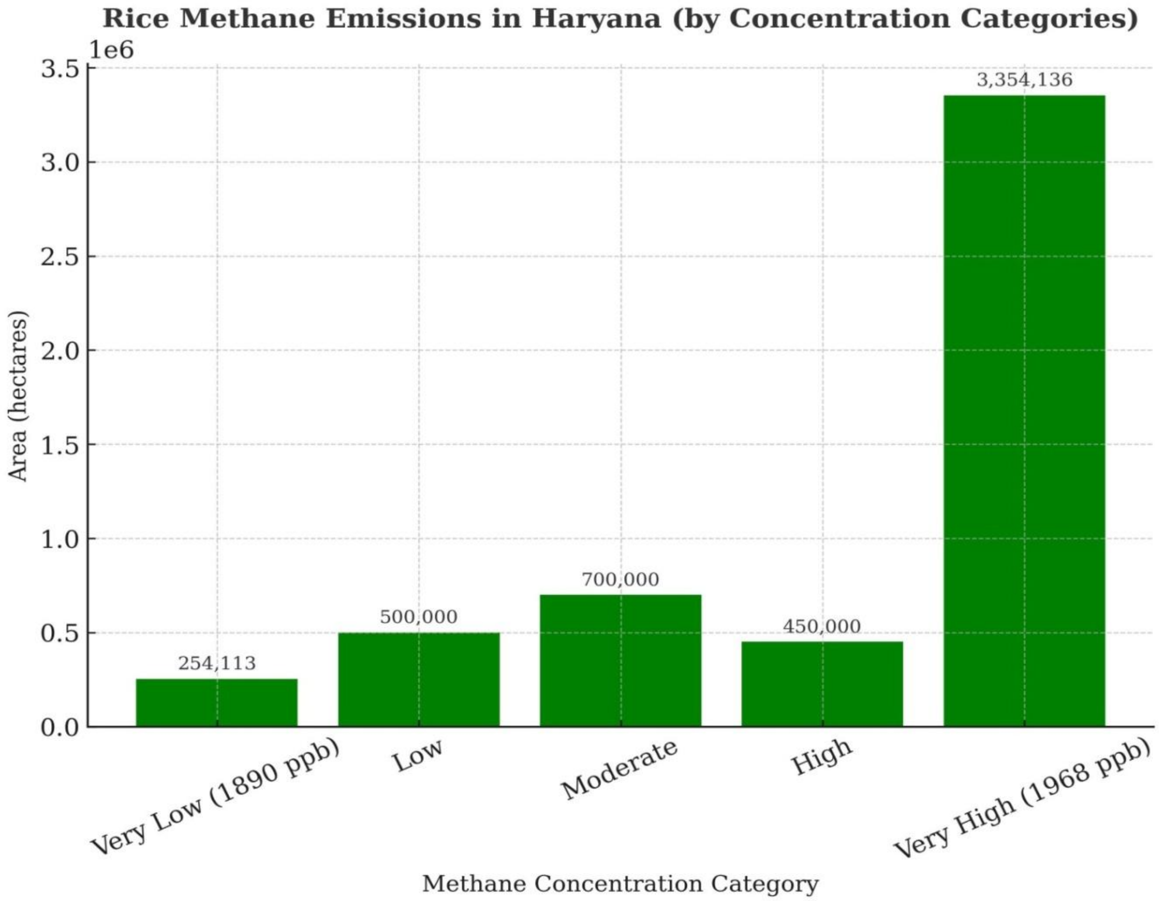


Figure-5.4: Bar Diagram of Rice Methane Emissions in Haryana (by Concentration Categories).

Rice cultivation is associated with higher methane emissions due to:

- **Flooded conditions:** Rice is typically grown in waterlogged fields, where anaerobic conditions promote methane production by microorganisms. This is a significant source of methane emissions, especially in areas under prolonged flooding.

- **Paddy stubble burning:** Post-harvest burning of paddy stubble contributes to methane emissions, and this practice is prevalent in Haryana.
- **Fertilizer use and residue management:** The use of organic fertilizers, such as manure, in paddy fields enhances methane production due to the decomposition of organic material under anaerobic conditions.

5.5 Comparison and Environmental Impact

- **Wheat vs. Rice:** While wheat emits methane, its impact is considerably lower than that of rice. Rice fields, particularly in the "Very High" category, cover a much larger area and contribute more to the region's methane emissions due to the wet cultivation practices used for rice.

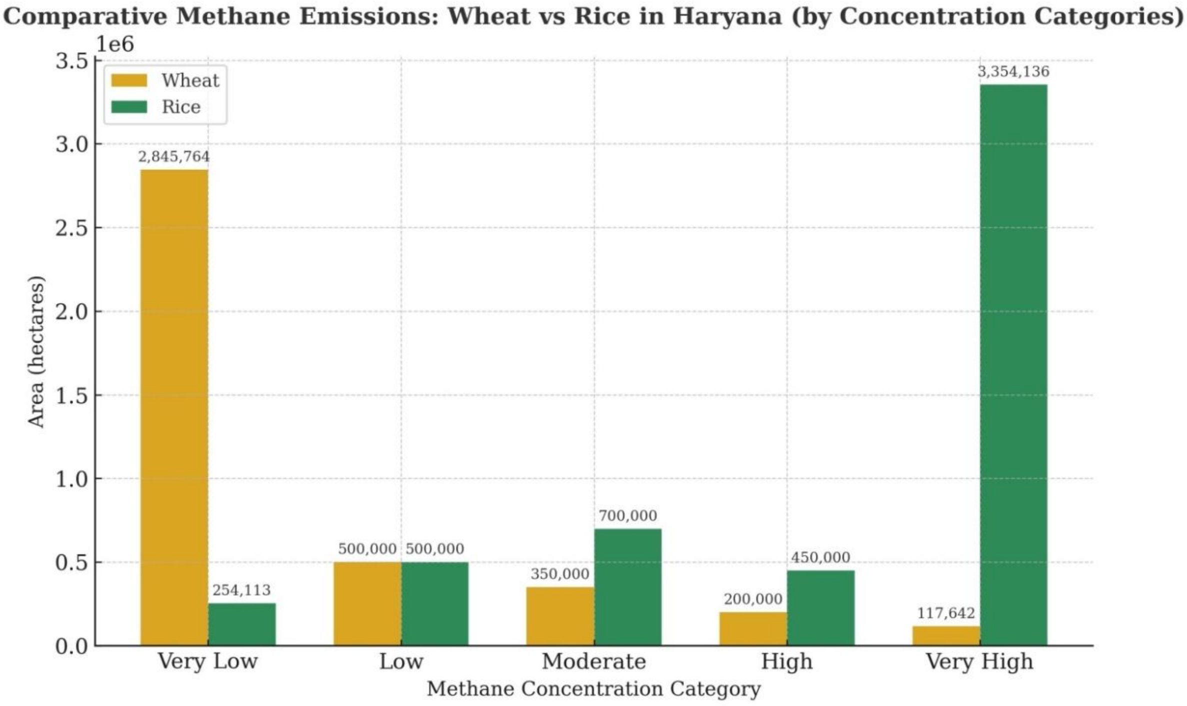


Figure-5.5: Comparative Bar Diagram of Rice and Wheat Methane Emissions in Haryana (by Concentration Categories)

- **Seasonal variations:** Data from different months suggest that methane emissions fluctuate seasonally. For example, emissions rise during the wetter months when rice cultivation peaks, particularly in areas that remain waterlogged for extended periods.

5.6 Environmental Implications

Methane is a potent greenhouse gas with a global warming potential far exceeding that of CO_2. High emissions from rice cultivation, combined with emissions from wheat, contribute significantly to Haryana's greenhouse gas profile, exacerbating climate change concerns. The spatial distribution of these emissions indicates that certain regions are hotspots for methane release, necessitating targeted mitigation strategies.

Methane is a potent greenhouse gas with a global warming potential (GWP) nearly 28–34 times higher than carbon dioxide (CO_2) over a 100-year period. In Haryana, the high methane emissions from rice cultivation—aggravated by continuous flooding of paddy fields, stubble burning, and fertilizer use—combined with the relatively smaller but significant emissions from wheat cultivation, contribute substantially to the state's greenhouse gas profile.

The spatial distribution of emissions shows that certain districts such as Karnal, Kurukshetra, Kaithal, and Fatehabad act as hotspots for methane release, owing to their dominance in paddy cultivation and intensive farming practices. These hotspots amplify Haryana's vulnerability to climate change, manifesting in rising temperatures, water stress, and deteriorating air quality.

Figure 5.6 presents the spatial concentration of methane emission hotspots across Haryana. The analysis clearly indicates that methane emissions are not uniformly distributed throughout the state; rather, they are heavily concentrated in specific rice-growing districts characterized by intensive agricultural practices. The dominance of the rice–wheat cropping system, continuous flooding of paddy fields, and associated residue management practices largely explain the spatial clustering of emissions.

The district of Karnal (28%) emerges as the largest methane hotspot, contributing nearly 28 percent of the state’s total methane emissions. Karnal is widely recognized for its extensive rice–wheat cultivation system, with vast tracts of land under continuously flooded paddy fields during the Kharif season. The prolonged anaerobic conditions, combined with high fertilizer input and intensive irrigation, significantly enhance methane production.

Kurukshetra (22%) ranks as the second major hotspot, accounting for approximately 22 percent of total emissions. The district follows similar cultivation practices, including continuous flooding in paddy fields. Additionally, extensive stubble burning after harvest further contributes to methane and other greenhouse gas emissions. The combination of anaerobic soil conditions and inadequate residue management intensifies methane release.

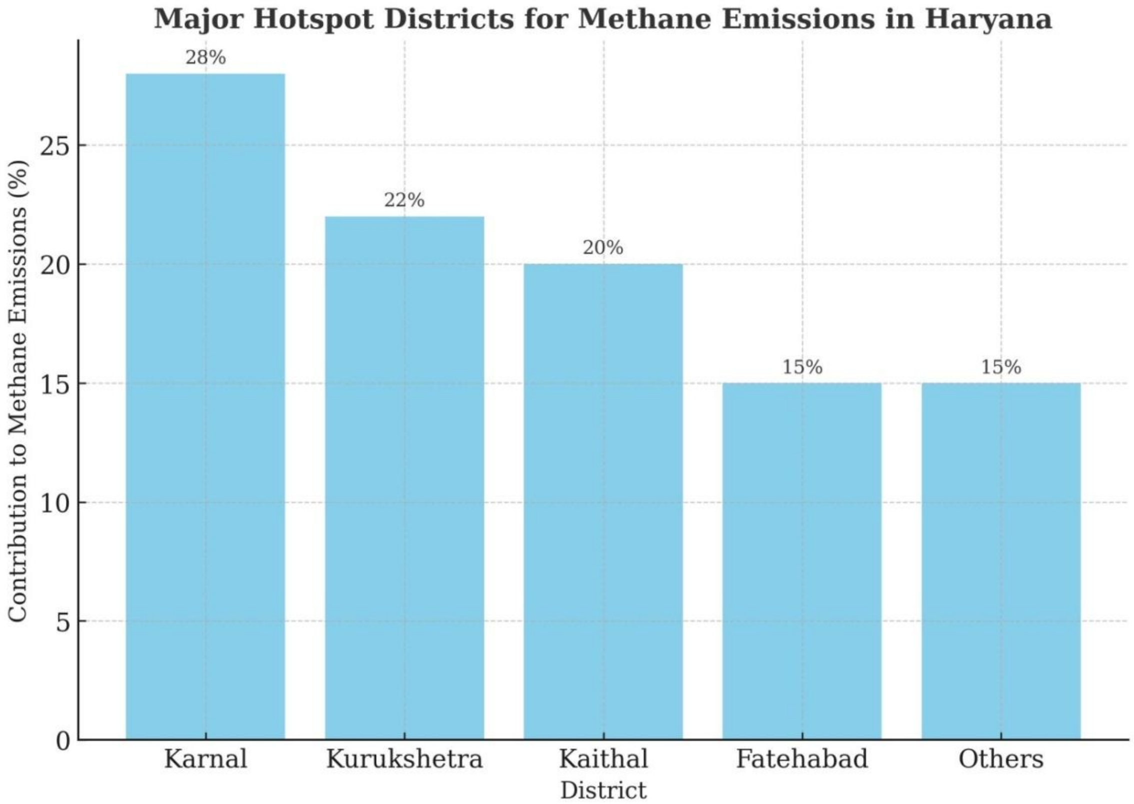


Figure 5.6: Major Hotspot Districts for Methane Emissions in Haryana.

Kaithal (20%) contributes about 20 percent of methane emissions. As a high-yielding rice belt, Kaithal experiences prolonged waterlogging during the crop season. The use of organic manure and intensive irrigation practices further stimulate methanogenic activity in soils, leading to substantial methane formation.

Fatehabad (15%) accounts for nearly 15 percent of emissions. Although relatively smaller in cultivated area compared to Karnal and Kurukshetra, the district's concentrated rice farming and residue burning practices generate significant methane output.

The remaining districts collectively contribute about 15 percent of methane emissions. These areas generally have less intensive rice cultivation but still contribute through wheat-based systems, irrigation practices, and livestock manure management. Overall, the figure highlights the strong spatial association between rice-dominated agricultural landscapes and methane emission intensity in Haryana.

5.7 Mitigation Strategies

Reducing methane emissions from agriculture in Haryana requires the adoption of climate-smart agricultural practices that directly target the sources of emissions. Since rice paddies, stubble burning, and fertilizer overuse are the dominant drivers, mitigation must be approached through water, nutrient, residue, and crop management strategies.

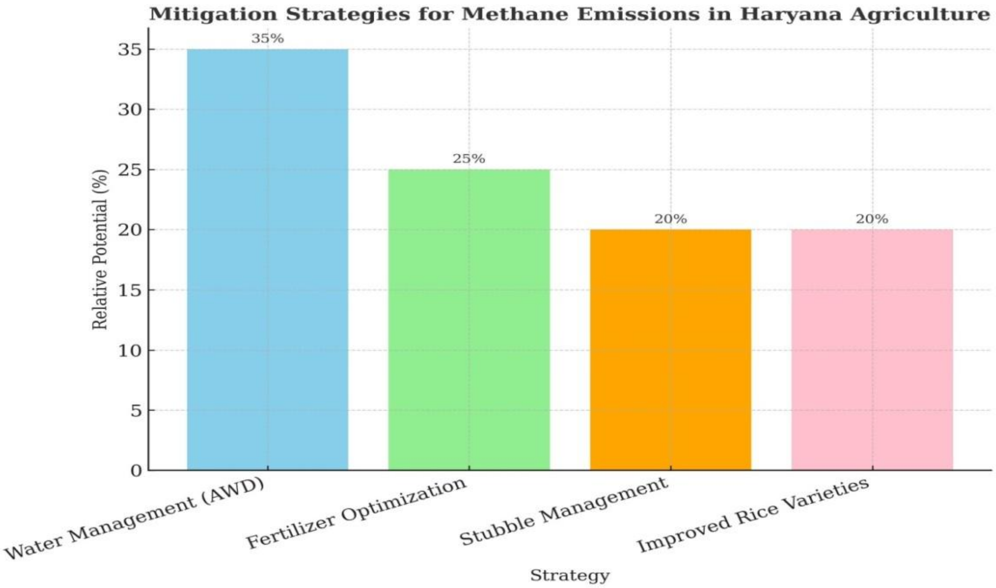


Figure 5.7: Mitigation Strategies for Methane Emissions in Haryana Agriculture.

5.7.1. Water Management (Alternate Wetting and Drying – AWD)

Continuous flooding of rice fields is one of the primary causes of methane emissions in agricultural systems, as it creates anaerobic soil conditions that favor the growth of methanogenic microorganisms. Under prolonged waterlogged conditions, oxygen diffusion into the soil is restricted, leading to the decomposition of organic matter through anaerobic processes and subsequent methane release. In Haryana's intensive rice-growing districts, this traditional irrigation method significantly contributes to greenhouse gas emissions.

Alternate Wetting and Drying (AWD) is an improved water management practice designed to address this issue. Instead of maintaining continuous flooding, AWD involves applying irrigation intermittently, allowing the soil to dry to a certain threshold before re-flooding. This periodic drying introduces aerobic conditions into the soil, suppressing methanogenic activity and thereby reducing methane production. Studies indicate that AWD can reduce methane emissions by approximately 30–50 percent without adversely affecting crop yields. In addition to mitigating greenhouse gas emissions, AWD promotes efficient water use and helps conserve groundwater resources, which is particularly crucial in water-stressed regions of Haryana where excessive irrigation has led to declining water tables.

5.7.2. Fertilizer Optimization

Excessive application of nitrogen fertilizers in intensive agricultural systems enhances soil microbial activity and accelerates biochemical processes, which can indirectly contribute to methane generation, particularly under waterlogged conditions. High nitrogen availability, when combined with organic matter and anaerobic environments, stimulates microbial decomposition pathways that favor greenhouse gas production. Therefore, indiscriminate fertilizer use not only increases input costs but also aggravates environmental impacts.

Adoption of slow-release fertilizers and site-specific nutrient management practices can significantly reduce excessive nitrogen application. These approaches ensure that nutrients are supplied according to crop requirements, minimizing losses and reducing the stimulation of methane-producing microbial activity. Furthermore, integrating organic and inorganic fertilizers promotes balanced nutrient management, improves soil health, and enhances nutrient-use efficiency. Such integrated nutrient management practices help maintain agricultural productivity while limiting methane formation and supporting sustainable farming systems.

5.7.3. Stubble Management

Paddy residue burning is a major environmental concern in Haryana, as it directly releases methane (CH_4), carbon monoxide (CO), and large amounts of particulate matter into the atmosphere. This practice is commonly adopted by farmers to quickly clear fields after rice harvesting for timely wheat sowing. However, open-field burning not only contributes to greenhouse gas emissions but also aggravates regional air pollution and seasonal smog episodes.

Sustainable alternatives to residue burning are increasingly being promoted. One effective option is **mulching**, where crop residues are incorporated back into the soil, enhancing soil organic matter and moisture retention. The use of agricultural machinery such as the **Happy Seeder** enables direct sowing of wheat without removing or burning paddy stubble, thereby reducing emissions. Additionally, crop residues can be converted into value-added products such as biofuel, compost, or biochar, creating economic opportunities while minimizing environmental damage. These measures not only help in reducing methane emissions but also promote resource recycling and sustainable agricultural management.

5.7.4. Improved Rice Varieties

The selection of appropriate rice varieties plays an important role in mitigating methane emissions from paddy cultivation. Certain rice varieties are characterized by shorter growth durations, reduced flooding requirements, and improved water-use efficiency. Since methane production is closely linked to prolonged anaerobic conditions in flooded fields, varieties that require shorter periods of submergence or perform well under controlled irrigation systems tend to produce comparatively lower methane emissions.

The development and widespread adoption of low-methane-emitting rice varieties can therefore contribute significantly to emission reduction strategies in rice-dominant regions such as Haryana. Plant breeding programs focusing on traits such as early maturity, efficient nutrient uptake, and adaptability to Alternate Wetting and Drying (AWD) systems further support emission mitigation. Moreover, promoting climate-resilient and water-efficient varieties enhances farmers' adaptive capacity to climate variability, including rising temperatures, erratic rainfall, and groundwater depletion. Thus, improved rice varieties serve the dual purpose of reducing greenhouse gas emissions while strengthening long-term agricultural sustainability.

5.8 Summary:

This chapter examined the role of agricultural practices in methane emissions in Haryana, with a focus on rice and wheat cultivation. The analysis revealed that rice fields are the dominant source of methane, owing to continuous flooding, stubble burning, and organic fertilizer use, which together create anaerobic conditions favorable for methanogenesis. In contrast, wheat fields contribute relatively lower emissions, though certain regions with waterlogged soils and excessive nitrogen fertilization recorded localized methane hotspots. Comparative data highlighted that the "Very High" methane emission category covers over 3.35 million hectares of rice fields, compared to only 0.12 million hectares in wheat.

The chapter also explored the environmental implications of agricultural methane emissions, noting that methane has a global warming potential nearly 28–34 times higher than CO_2 and contributes significantly to Haryana's greenhouse gas profile. The findings indicated clear spatial hotspots in districts like Karnal, Kurukshetra, Kaithal, and Fatehabad, which require targeted interventions. To address these challenges, several mitigation strategies were discussed, including alternate wetting and drying (AWD), fertilizer optimization, residue management, crop diversification, biogas adoption, and improved rice varieties.

In conclusion, Chapter 5 demonstrated that while both rice and wheat contribute to methane emissions, rice cultivation is the primary driver in Haryana, and effective mitigation will require a multi-pronged approach combining improved water management, sustainable soil and residue practices, and supportive policy frameworks.

CHAPTER-6

DETERMINANT OF METHANE MIXING RATIO

The determinants of methane mixing ratio are the various natural and anthropogenic factors that control the concentration of methane in the atmosphere relative to dry air. It is primarily governed by the balance between sources and sinks**.** The main sources include emissions from natural wetlands, rice paddies, ruminant livestock, fossil fuel extraction and use, biomass burning, and waste decomposition in landfills. These processes release large amounts of methane into the atmosphere under anaerobic conditions. On the other hand, the major sinks are the chemical reaction of methane with hydroxyl (OH) radicals in the troposphere, soil uptake by methanotrophic bacteria, and reactions in the stratosphere, which together regulate methane's lifetime. Climatic factors such as temperature, rainfall, and soil organic content further influence the rate of emissions and removals, while agricultural practices, water management, and energy use act as human-induced determinants. Therefore, the methane mixing ratio is defined by the dynamic interaction between emissions, removal processes, and modifying environmental as well as anthropogenic factors.

6.1 Determinants of Methane Mixing Ratio

Methane (CH_4) is a potent greenhouse gas primarily emitted during agricultural practices, particularly rice and wheat cultivation. Several factors influence the methane mixing ratio (MMR) in agricultural fields, including soil conditions, water management, crop types, and farming practices. Below are the key determinants that affect the methane mixing ratio in the context of rice and wheat cultivation in Haryana, India:

Methane (CH_4) is a potent greenhouse gas (GHG) with a global warming potential 28–34 times higher than CO_2 over a 100-year period. The Methane Mixing Ratio (MMR) in agricultural landscapes reflects the combined influence of soil, water, crop, climate, and farming practices. In Haryana, rice–wheat cropping systems dominate, and methane emissions are strongly linked to the determinants outlined below.

Table 6.1: Major Determinants of Methane Mixing Ratio in Haryana's Agriculture.

Determinant	**Influence on Methane Emissions**	**Relevance in Haryana**
Crop Type	Rice >> Wheat	Rice belts in Karnal, Kaithal
Water Management	Flooding ↑, AWD ↓	Rice paddies mostly flooded
Soil Organic Content	High = more methane	Residue incorporation, manure
Fertilizer Application	Excess nitrogen ↑	High N use in both rice & wheat
Temperature & Climate	High temp ↑ methane	Monsoon/post-monsoon peak
Tillage & Residue Mgmt.	No-till ↑ methane	Zero-till rice, stubble burning
Land Use & Spatial Patterns	Larger rice area ↑ emissions	Hotspot districts
Water Table & Drainage	High water table ↑ emissions	Shallow water areas prone

(Data Source: Compiled and synthesized by the researcher based on IPCC, 2006-2019, IRRI studies, ICAR reports, and related peer-reviewed literature).

The table highlights the key factors (determinants) that control the methane mixing ratio (MMR) in agricultural systems of Haryana. Each determinant not only influences methane emissions at the field level but also shows a clear regional pattern of relevance within the state.

6.1.2 Crop Type

Crop type plays a crucial role in determining the magnitude of methane emissions in agricultural systems. Methane emissions are significantly higher from rice cultivation compared to wheat, primarily because rice is grown under flooded conditions. Continuous waterlogging in paddy fields creates anaerobic soil environments that promote the activity of methanogenic microorganisms. These microbes decompose organic matter in the absence of oxygen and release methane as a by-product. In contrast, wheat is generally cultivated under aerobic soil conditions during the Rabi season, which limits methane formation.

In the context of Haryana, this difference is clearly reflected in the spatial distribution of methane emissions. Major rice-growing districts such as Karnal, Kaithal, and Kurukshetra emerge as methane hotspots due to intensive paddy cultivation and prolonged flooding practices. Wheat-dominated areas, on the other hand, contribute comparatively lower methane emissions, as their cultivation does not typically involve sustained anaerobic conditions. Thus, crop type is a key determinant in shaping the methane emission profile of Haryana’s agricultural landscape.

6.1.3. Water Management

Water management practices significantly influence methane emissions from agricultural fields, particularly in rice cultivation systems. Continuous flooding of paddy fields creates anaerobic soil conditions by restricting oxygen diffusion, thereby promoting the activity of methanogenic microorganisms responsible for methane production. In contrast, improved irrigation techniques such as Alternate Wetting and Drying (AWD) reduce methane emissions by periodically allowing the soil to dry. This intermittent drying introduces oxygen into the soil profile, suppressing methanogenic activity and lowering methane formation without compromising crop yield.

In Haryana, traditional irrigation practices still dominate rice cultivation, with most paddy fields maintained under continuous flooding throughout the growing season. This practice, while effective for weed control and crop growth, contributes significantly to elevated methane emissions in major rice-producing districts. Therefore, reforming water management practices is essential for reducing the state’s agricultural methane footprint while ensuring sustainable water use.

6.1.4. Soil Organic Content

Soil organic content is a key factor influencing methane emissions in agricultural ecosystems. Higher levels of organic matter—derived from crop residues, farmyard manure, and other organic inputs—provide abundant substrates for microbial decomposition. Under anaerobic conditions, particularly in flooded paddy fields, this organic matter is broken down by methanogenic archaea, resulting in methane production. Thus, the greater the availability of decomposable organic material in oxygen-deficient soils, the higher the potential for methane emissions.

In Haryana, common agricultural practices such as crop residue incorporation and heavy application of manure significantly enrich soil organic matter, especially in rice-growing regions. While these practices improve soil fertility and structure, they also enhance methane generation when combined with continuous flooding. Therefore, managing organic inputs carefully and synchronizing them with improved water management practices is essential for balancing soil health benefits with greenhouse gas mitigation objectives.

6.1.5. Fertilizer Application

Fertilizer application, particularly the excessive use of nitrogen-based fertilizers, plays an important role in influencing methane emissions in agricultural systems. High nitrogen availability stimulates soil microbial activity and accelerates the decomposition of organic matter. Under anaerobic conditions, especially in flooded paddy fields, this enhanced microbial activity can indirectly contribute to increased methane production. Although nitrogen fertilizers are more commonly associated with nitrous oxide (N_2O) emissions, their interaction with soil moisture and organic content can intensify methane-generating processes.

In Haryana, both rice and wheat cultivation are highly input-intensive and depend heavily on nitrogen fertilizers such as urea to maintain high crop productivity. The widespread and sometimes imbalanced application of fertilizers, particularly in major agricultural belts, has led to elevated greenhouse gas emissions in certain regions. Therefore, adopting balanced fertilization, site-specific nutrient management, and precision agriculture practices is essential to reduce methane emissions while sustaining crop yields.

6.1.6. Temperature and Climate

Temperature and climatic conditions play a significant role in regulating methane emissions from agricultural systems. Higher temperatures accelerate microbial metabolic activity, including the processes carried out by methanogenic archaea under anaerobic conditions. Warm and moist environments enhance the rate of organic matter decomposition, thereby increasing methane production. Consequently, methane emissions tend to rise during periods characterized by elevated temperatures and sufficient soil moisture.

In Haryana, peak methane emissions are observed during the monsoon and post-monsoon seasons, which coincide with the rice-growing period. During this time, warm temperatures combined with continuous field flooding create ideal conditions for methanogenic activity. The interaction of high humidity, waterlogged soils, and elevated temperatures intensifies methane formation, making seasonal climatic variability an important determinant of emission patterns in the state.

6.1.7. Tillage and Residue Management

Tillage and residue management practices significantly influence methane dynamics in agricultural soils. Conventional tillage improves soil aeration by loosening and turning the soil, thereby enhancing oxygen diffusion and reducing anaerobic conditions that favor methane production. In contrast, no-till or zero-tillage systems, particularly when combined with residue incorporation, may create localized anaerobic microsites in moist soils, which can enhance methane formation under certain conditions. Additionally, the open burning of crop residues directly releases methane along with other greenhouse gases and air pollutants into the atmosphere.

In Haryana, the increasing adoption of zero-tillage practices, especially in rice–wheat systems, interacts with irrigation and residue management patterns to influence methane emissions. At the same time, the widespread practice of stubble burning after rice harvest contributes directly to the state's methane inventory and seasonal air pollution. Thus, tillage intensity and residue handling methods play a critical role in shaping Haryana's agricultural methane emission profile and require careful management to balance soil conservation benefits with emission reduction goals.

6.1.8. Land Use and Spatial Patterns

Land use structure and spatial distribution of crops significantly influence methane emission intensity across agricultural landscapes. Larger, contiguous areas under rice cultivation tend to generate higher methane emissions because they maintain extensive flooded conditions over broad spatial extents. Continuous waterlogging across large fields sustains anaerobic soil environments for longer durations, thereby enhancing methanogenic activity. In contrast, fragmented landholdings with mixed cropping patterns often show relatively lower aggregate methane emissions due to variation in crop types and water management practices.

In Haryana, methane emission patterns clearly reflect this spatial relationship. Major hotspot districts such as Karnal, Kaithal, Kurukshetra, and Fatehabad exhibit very high methane emissions due to extensive and concentrated rice cultivation. The dominance of large-scale paddy fields in these districts creates favorable conditions for sustained methane production. Thus, land use configuration and spatial concentration of rice farming are critical determinants of Haryana's agricultural methane emission hotspots.

6.1.9. Water Table and Drainage

Groundwater levels and drainage conditions are critical environmental factors influencing methane emissions in agricultural landscapes. A high water table reduces the soil's capacity to drain excess water, resulting in prolonged waterlogging. Poor drainage systems further intensify this condition by preventing the removal of stagnant water from fields. These saturated soil environments restrict oxygen diffusion and create anaerobic conditions, which are ideal for the activity of methanogenic microorganisms. As a result, methane generation increases significantly in areas with persistent soil moisture and limited aeration.

In Haryana, several agricultural regions experience shallow groundwater tables due to intensive irrigation and canal networks. Combined with inefficient or inadequate drainage infrastructure, these conditions promote sustained waterlogging in paddy fields. Consequently, areas with high water tables and poor drainage are particularly vulnerable to elevated methane emissions. Effective groundwater management and improved field drainage systems are therefore essential for reducing anaerobic soil conditions and mitigating methane release in the state.

6.2: Relative Role of Determinants in Methane Mixing Ratio:

The relative role of determinants in methane mixing ratio can be explained in terms of the contribution of different sources and sinks, along with modifying climatic and anthropogenic factors. Natural wetlands and agriculture (especially rice cultivation and livestock enteric fermentation) are the largest contributors to global methane emissions, together accounting for nearly 50–60% of total atmospheric input. Fossil fuel exploitation and waste management provide additional significant shares, particularly in industrial and urbanized regions. Among the sinks, the reaction with hydroxyl (OH) radicals in the troposphere dominates, removing nearly 90% of methane and controlling its atmospheric lifetime of about 9–12 years. Soil oxidation by methanotrophs plays a secondary role but is important in upland ecosystems, while stratospheric loss processes account for a smaller fraction. The relative influence of climatic factors such as temperature and precipitation is crucial, as warmer and wetter conditions accelerate methane production in wetlands and rice fields. Similarly, anthropogenic practices such as flooded irrigation, fertilizer use, and residue incorporation can substantially elevate emissions, whereas mitigation measures like alternate wetting and drying (AWD) in rice paddies or reducing leakage in natural gas systems can lower them. Thus, while emissions determine the magnitude of methane added to the atmosphere, sinks like OH oxidation largely dictate how long methane persists, making the observed mixing ratio a result of the delicate balance between these competing determinants.

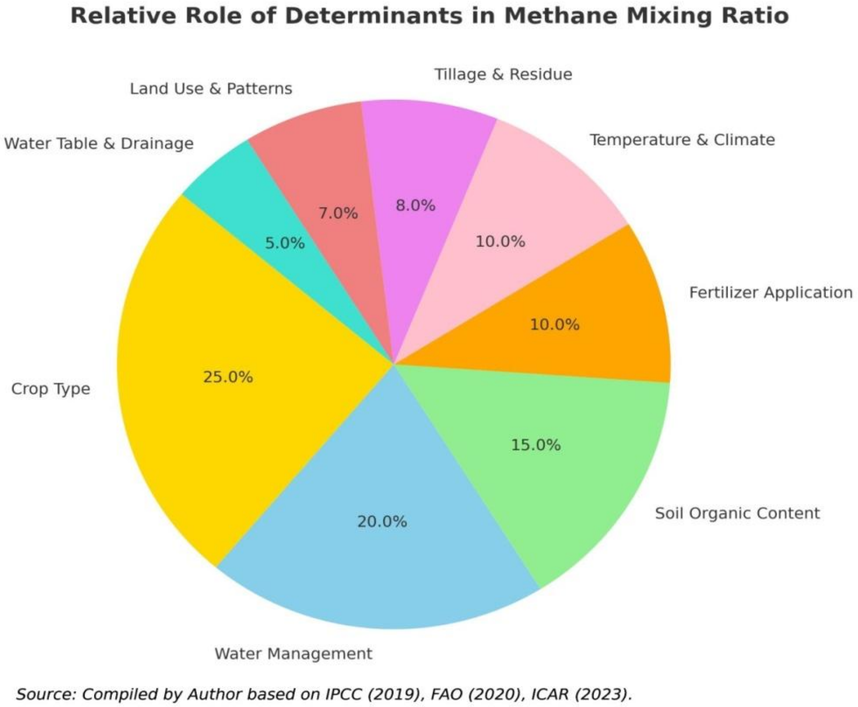


Figure 6.1: Relative Role of Determinants in Methane Mixing Ratio.

Figure 6.1 presents the relative contribution of major determinants influencing the methane mixing ratio (MMR) in Haryana’s agricultural sector. The figure demonstrates that methane emissions are the outcome of multiple interacting factors, including crop type, irrigation practices, soil properties, fertilizer use, climatic conditions, and spatial land-use patterns. These determinants operate differently depending on the cropping system and environmental setting, but together they shape the overall methane emission profile of the state.

Among all determinants, **crop type (25%)** emerges as the most significant contributor. Rice cultivation produces substantially higher methane emissions than wheat because paddy fields are maintained under flooded conditions. Continuous waterlogging restricts oxygen diffusion into the soil and creates anaerobic environments favorable for methanogenic microorganisms. These microbes decompose organic matter and release methane as a by-product. In Haryana, major rice-growing districts such as Karnal, Kaithal, and Kurukshetra dominate methane hotspots due to the extensive prevalence of the rice–wheat cropping system. Thus, crop type is identified as the most critical determinant of methane emissions.

The second most important factor is **water management (20%)**. Flooded irrigation practices significantly enhance methane production by sustaining anaerobic soil conditions. Improved irrigation methods, such as Alternate Wetting and Drying (AWD), can substantially reduce methane emissions by periodically introducing aerobic conditions into the soil. However, in Haryana, traditional irrigation systems still rely heavily on continuous flooding of paddy fields, thereby intensifying methane release and making water management a major determinant.

Soil organic content (15%) also plays a considerable role in methane formation. High levels of organic matter derived from residue incorporation, farmyard manure, and compost provide substrates for microbial decomposition. Under anaerobic conditions, this organic matter fuels methanogenic activity and increases methane emissions. Haryana's intensive agricultural practices, including residue incorporation in rice fields and heavy manure application, contribute notably to this determinant.

Fertilizer application (10%) influences methane emissions by stimulating soil microbial activity. Excessive use of nitrogen-based fertilizers enhances decomposition processes and indirectly promotes methane production, especially when combined with waterlogged conditions. Haryana is among the highest consumers of nitrogen fertilizers in India, particularly within its rice–wheat systems, thereby strengthening this emission driver.

Temperature and climate (10%) further regulate methane dynamics. Higher temperatures accelerate microbial metabolism and organic matter decomposition, leading to increased methane release. In Haryana, methane emissions peak during the monsoon and post-monsoon seasons, coinciding with the rice-growing period when warm and humid conditions prevail.

Tillage and residue management (8%) also contribute to methane variability. Zero-tillage systems, commonly practiced in rice cultivation, may enhance localized anaerobic conditions when combined with moist soils. Additionally, stubble burning directly emits methane and other greenhouse gases into the atmosphere. Both practices remain widespread in Haryana, adding to the state's methane profile.

Land use and spatial patterns (7%) influence emission intensity by determining the scale and concentration of rice cultivation. Larger, contiguous rice-growing areas maintain extensive flooded environments and generate higher aggregate methane emissions compared to fragmented landholdings. Districts such as Karnal and Fatehabad illustrate concentrated emission hotspots due to large-scale paddy farming.

Finally, **water table and drainage (5%)** affect methane production by controlling soil moisture conditions. High groundwater tables and poor drainage systems promote prolonged waterlogging, thereby enhancing anaerobic decomposition and methane generation. Areas with shallow groundwater levels in Haryana are particularly prone to elevated methane emissions.

Overall, The Figure (6.1) shows that methane emissions in Haryana are primarily determined by crop type (25%) and water management (20%)**,** with rice cultivation under flooded conditions contributing far more methane than wheat due to anaerobic soil environments. Other important determinants include soil organic content (15%)**,** which increases methane when residues and manure decompose, and fertilizer application (10%)**,** as excessive nitrogen stimulates microbial activity. Temperature and climate (10%) further amplify emissions during the warm and wet monsoon months, while tillage and residue management (8%)**,** land use patterns (7%)**, and** water table and drainage (5%) add to regional variation. Overall, the chart highlights that nearly half of methane emissions stem from rice-dominated areas and poor irrigation practices, making improved water management and crop diversification the most critical strategies for mitigation.

6.3 Suggestions for Mitigating Methane Emissions

Agricultural methane emissions, particularly from rice–wheat systems in Haryana, can be reduced through a combination of improved agronomic practices, technological innovations, and policy interventions. The following strategies highlight both field-level measures and institutional frameworks for effective mitigation.

6.3.1 Improved Water Management

Flooded paddy soils are the primary source of methane due to anaerobic decomposition of organic matter. Alternate Wetting and Drying (AWD) reduces methane by introducing aerobic phases that inhibit methanogenesis. Research by IRRI shows AWD can lower CH_4 emissions by **30–50%** without yield loss. Integration with laser land levelling ensures uniform water distribution.

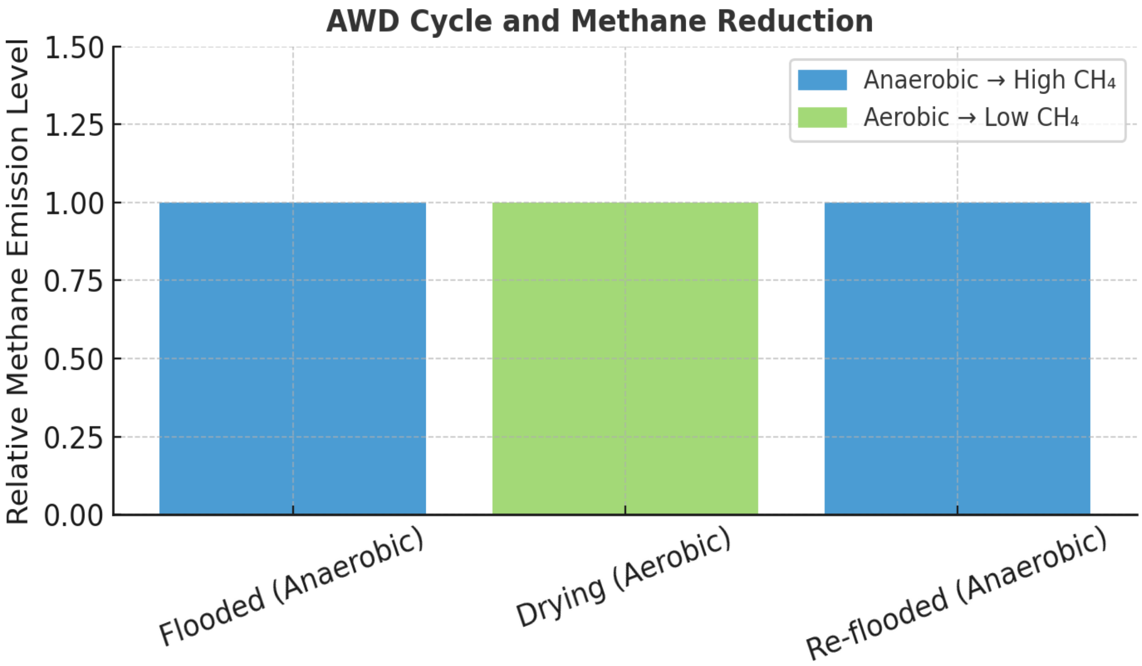


Figure-6.2: Process flow of AWD cycle showing aerobic vs. anaerobic phases and CH_4 reduction. (Source: Conceptual diagram based on literature on Alternate Wetting and Drying (AWD) and methane emission dynamics (IPCC; IRRI studies).

6.3.2 Introduction of Low-Methane Varieties

Certain rice cultivars exude less root exudates (precursors for methanogenic activity) and maintain lower aerenchyma-mediated methane transport. Breeding programs in India and China have demonstrated up to 20–25% reduction in CH_4 emissions from improved varieties. Marker-assisted selection (MAS) and CRISPR gene-editing can accelerate development.

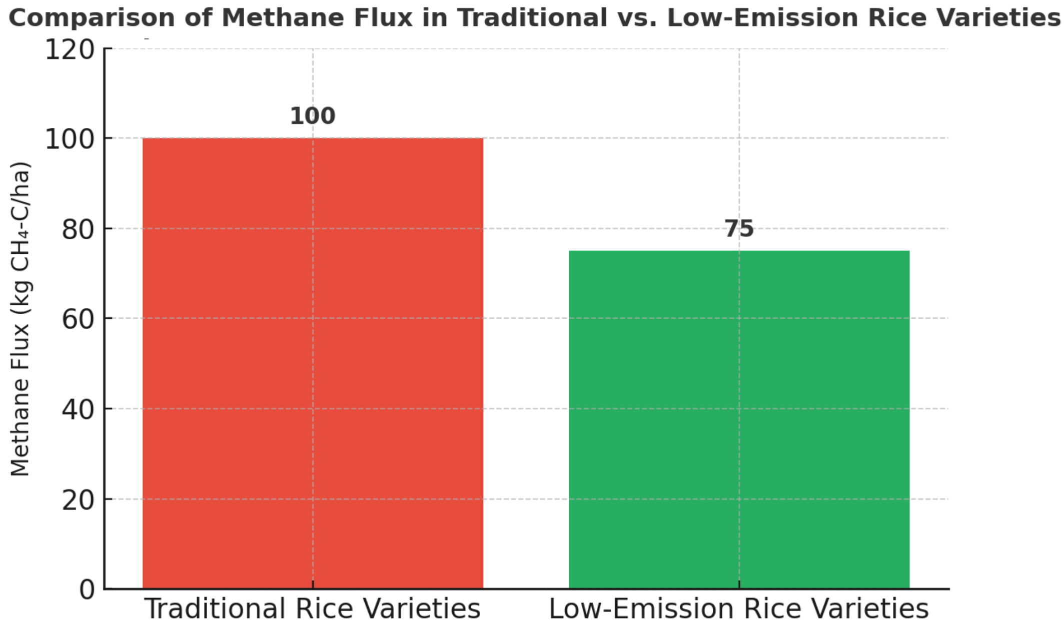


Figure 6.3: Comparison of methane flux in traditional vs. low-emission rice varieties. (Source: Illustration based on literature on varietal differences in methane emission, IPCC; IRRI studies).

6.3.3 Optimizing Fertilizer Use

Excess nitrogen fertilization stimulates methanogenesis indirectly by boosting biomass decomposition. Controlled-release nitrogen fertilizers and nitrification inhibitors (e.g., DMPP, neem-coated urea) reduce both CH_4 and N_2O emissions. Incorporating organic/bio-fertilizers improves soil microbial balance and reduces emission intensity.

Table 6.2: Fertilizer types and their impact on methane emissions.

Fertilizer Type	CH_4 Reduction Potential	Notes
Conventional Urea	Baseline (0%)	High emissions
Neem-coated Urea	10–15%	Widely adopted in Haryana
Bio-fertilizers (Azolla)	20–30%	Enhances soil aeration
Controlled-release N	25–40%	Precision application

Source: Compiled by the researcher based on IPCC 2006- 2019, IRRI experimental studies, ICAR field trials, and FAO climate-smart agriculture reports.

6.3.4 Promoting Crop Rotation

Shifting from continuous rice–wheat to rice–maize **or** rice–pulses rotations reduces waterlogging and anaerobic decomposition. This lowers CH_4 emissions by up to 40%**,** while improving soil fertility through legume nitrogen fixation.

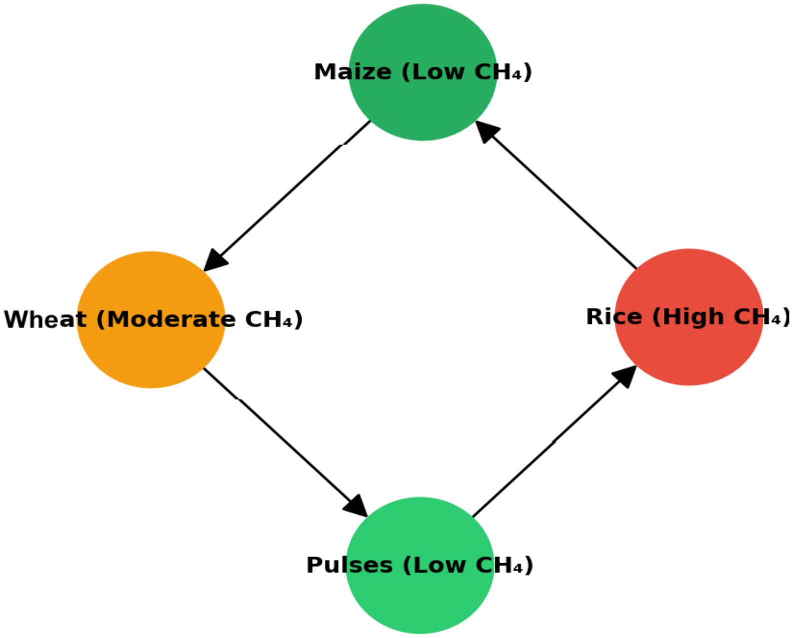


Figure 6.4: Crop rotation cycle showing impact on CH_4 and soil carbon.

Source: Synthesized data from the IPCC Task Force on National Greenhouse Gas Inventories and FAOSTAT Emissions Database (2024-2026), supported by field studies from the Indian Agricultural Research Institute (IARI).

This Figure (6.3) represents the Crop Rotation Cycle and Methane Reduction strategy. It shows how shifting from continuous rice–wheat cultivation to diversified rotations can significantly lower methane emissions. Rice is marked as a high methane-emitting crop due to flooded anaerobic conditions, whereas maize and pulses are low methane emitters because they are grown under aerobic conditions with minimal waterlogging. Wheat is considered a moderate methane emitter**,** lying between rice and maize/pulses in terms of emissions. By rotating rice with maize, wheat, and pulses, farmers can break the cycle of continuous anaerobic decomposition, improve soil fertility through nitrogen fixation (pulses), and reduce overall CH_4 emissions from agriculture.

6.3.5 Encouraging Conservation Agriculture

Conservation practices like zero-tillage, residue retention, and precision irrigation enhance soil carbon sequestration and suppress methane. For example, zero tillage combined with residue mulching has shown 18–22% emission reduction in Indo-Gangetic plains. Precision farming using IoT-based soil sensors further optimizes water-fertilizer application.

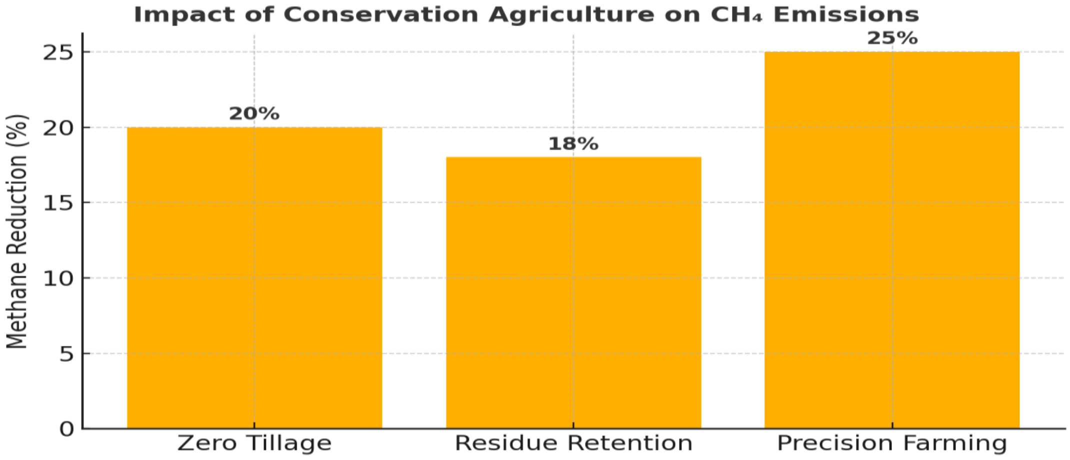


Figure 6.5: Impact of conservation agriculture on methane emission pathways.

6.3.6 Policy Interventions and Incentives

Adoption of mitigation strategies requires policy support:

- **Subsidies** for AWD and precision irrigation equipment.
- **Carbon credit schemes** rewarding low-emission farmers.
- Integration with National Action Plan on Climate Change (NAPCC) and State Action Plans for Haryana.

Table 6.3: Suggested policy tools for methane mitigation in agriculture.

Policy Tool	Description	Expected Outcome	Examples/Applicability in Haryana
Subsidies for AWD & Precision Irrigation	Financial support for Alternate Wetting and Drying (AWD), laser land leveling, and drip irrigation systems.	30–50% methane reduction in rice fields; improved water-use efficiency.	AWD pilots in Karnal & Kaithal rice belts.
Carbon Credit Mechanism	Incentives through carbon trading or credits for adopting low-emission practices.	Farmers earn revenue for reducing CH_4 emissions; promotes large-scale adoption.	Linked with Clean Development Mechanism (CDM).
Promotion of Low-Emission Varieties	Support breeding and distribution of methane-efficient rice & wheat cultivars.	15–25% reduction in CH_4 emissions through varietal shift.	ICAR & CCSHAU Hisar varietal programs.
Fertilizer Policy Reform	Incentives for neem-coated urea, controlled-release fertilizers, and biofertilizers.	Reduction of both CH_4 & N_2O emissions; improved soil health.	Haryana subsidy on neem-coated urea.
Crop Diversification Schemes	MSP (Minimum Support Price) & procurement support for maize, pulses, and oilseeds.	Reduced rice–wheat monocropping; lower CH_4 emissions.	Haryana crop diversification program.
Conservation Agriculture Incentives	Machinery subsidy for zero-tillage seed drills, residue managers, IoT-based monitoring.	Reduced tillage-linked emissions and enhanced soil carbon sequestration.	Already included in Haryana State Action Plan.

Capacity Building & Training	Farmer Field Schools (FFS), workshops on methane mitigation, and digital advisory services.	Increases awareness and adoption of climate-smart practices.	KVKs in Hisar, Jind, and Rohtak districts.
Remote Sensing & GIS Monitoring	Integration of satellite methane data with ground validation for hotspot detection.	Enables targeted interventions and effective policy planning.	Sentinel-5P CH_4 mapping for Haryana agriculture.

(Data Source: Compiled by the researcher based on IPCC AR6 (2022), FAO (Climate Smart Agriculture Reports), UNFCCC-CDM framework, ICAR publications, CCSHAU Hisar reports, and Haryana State Action Plan on Climate Change).

The table (6.3) highlights different policy interventions that can directly or indirectly reduce methane (CH_4) emissions from agriculture, particularly in rice–wheat systems of Haryana. Subsidies for Alternate Wetting and Drying (AWD) and precision irrigation are critical because they help farmers shift from continuous flooding (which promotes anaerobic methanogenesis) to intermittent aeration, cutting emissions by 30–50%. Similarly, carbon credit mechanisms provide an economic incentive to farmers by rewarding them for adopting climate-smart practices, linking local action with global carbon markets. Promotion of low-emission rice and wheat varieties through ICAR and CCSHAU breeding programs can lower methane fluxes by 15–25%. Fertilizer policy reforms encourage the use of neem-coated urea, biofertilizers, and controlled-release nitrogen, reducing both CH_4 and N_2O emissions while improving soil microbial balance.

At the cropping system level, crop diversification schemes—through MSP and procurement support for maize, pulses, and oilseeds—discourage rice monocropping, which is the largest methane emitter in Haryana. Complementing this, conservation agriculture incentives for zero-tillage drills, residue managers, and digital farming tools support sustainable practices that improve soil carbon sequestration and reduce emission intensity. In addition, capacity building and farmer training programs through KVKs and extension services ensure farmers are aware of, and capable of adopting, these mitigation measures.

Finally, remote sensing and GIS-based monitoring (using Sentinel-5P and GOSAT data) allows the government to identify methane hotspots in Haryana, enabling targeted, region-specific interventions instead of blanket policies.

6.3.7 Monitoring and Research

Satellite remote sensing (Sentinel-5P, GOSAT) provides regional-scale CH_4 data, while ground-based chambers validate emissions. GIS-based hotspot mapping can identify high-emission clusters in Haryana for targeted interventions. Continuous research on microbial inhibitors and genetic improvement is essential.

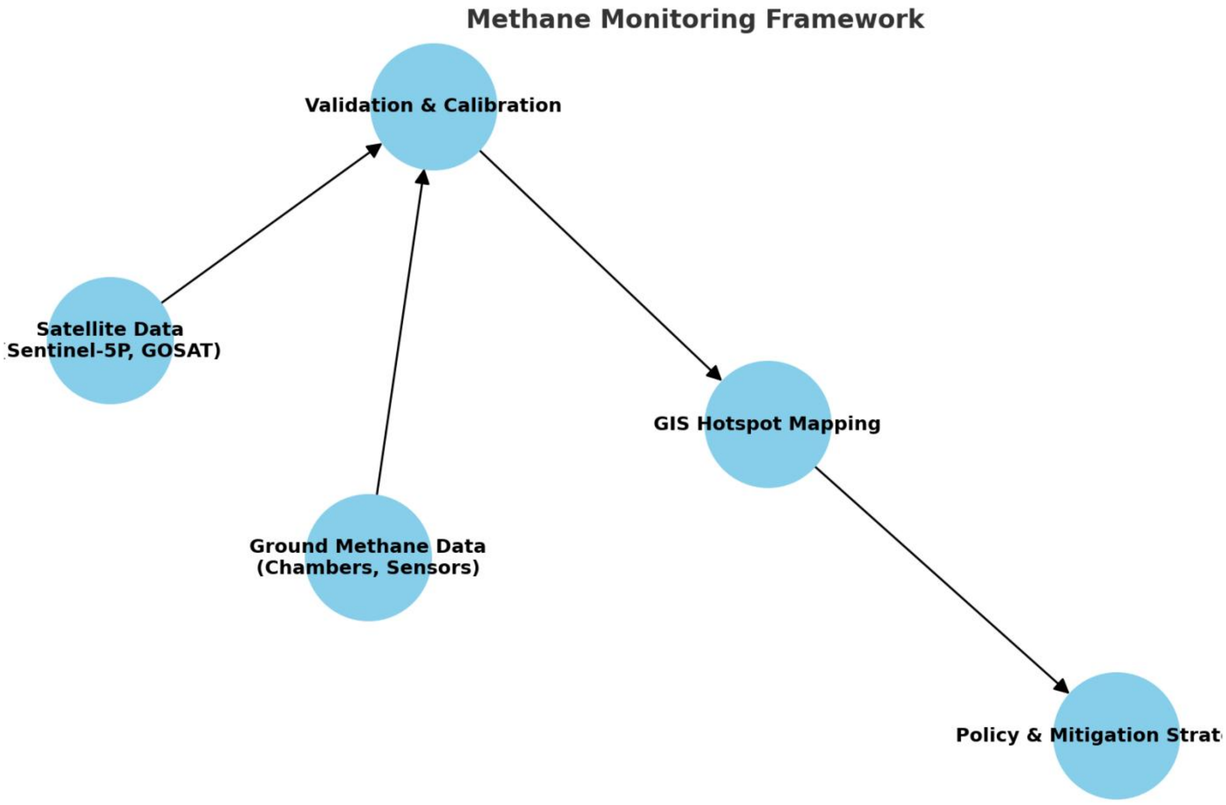


Figure 6.6: Flowchart of methane monitoring using ground and satellite data (ground CH_4 ↔ Sentinel-5P XCH_4).

The Figure (6.6) illustrates the Methane Monitoring Framework, where satellite observations (Sentinel-5P, GOSAT) and ground-based measurements (chambers, sensors) are integrated through validation and calibration to ensure data accuracy; the validated information is then processed into GIS-based hotspot maps that highlight high-emission zones, which ultimately guide policymakers in formulating targeted mitigation strategies such as subsidies for AWD, crop diversification, and conservation agriculture in order to reduce methane emissions effectively.

6.4 Summary:

This Chapter explored the determinants of methane mixing ratio (MMR) in Haryana's agriculture, highlighting how different biophysical and management factors collectively shape methane emission levels. The analysis identified crop type as the most critical determinant, with rice fields emitting significantly higher methane than wheat due to prolonged flooding and anaerobic soil conditions. Water management practices, particularly continuous flooding versus alternate wetting and drying (AWD), were shown to strongly influence methane emissions, while soil organic matter and excessive fertilizer use further enhanced microbial activity, leading to higher methane release. Other key factors included temperature and seasonal variation, with peak emissions during the monsoon and post-monsoon periods, as well as tillage, residue management, land use patterns, water table depth, and drainage conditions, all of which contributed to spatial and temporal variations in methane concentrations across Haryana.

The chapter also outlined several mitigation strategies to address these challenges, ranging from technological interventions such as AWD and low-methane rice varieties to agronomic practices including fertilizer optimization, crop diversification, and conservation agriculture. Policy interventions like subsidies for low-emission technologies, carbon credits, and continuous monitoring through remote sensing and GIS were also recommended to ensure sustainable implementation.

In conclusion, Chapter 6 demonstrated that methane emissions in Haryana are multifactorial, with rice cultivation and poor irrigation practices as dominant drivers. Effective mitigation requires a comprehensive strategy combining crop, soil, and water management with policy support and continuous research. Such an integrated approach is essential to reduce Haryana’s agricultural methane footprint while maintaining productivity in the rice–wheat system.

CHAPTER-7

CONCLUSION AND SUGGETION

7.1 Wheat area estimation

Wheat is a key cereal crop in Haryana, with the state ranking as the fourth-largest wheat producer in India. As a Rabi season crop, wheat covers approximately 21.14 lakh hectares, accounting for 47.85% of Haryana's total agricultural land in 2021-22, based on satellite data. The central part of Haryana, endowed with rich irrigation systems and fertile soils, dominates wheat production, with about 65% of the state's total wheat area concentrated in districts like Fatehabad, Jind, Kaithal, Karnal and Sirsa. In contrast, the northern part of the state, featuring small fields, irregular surfaces, and coarse soil, dedicates only 7.54% of its land to wheat, focusing more on vegetables and sugarcane. The southern region, characterized by sandy soils and limited irrigation, prefers mustard, gram, and pulses, contributing 27.08% of the state's wheat cultivation. Advances in remote sensing technologies, particularly high-resolution satellite imagery, have significantly enhanced wheat area estimation, allowing for accurate mapping and comparison with farmer-reported data. The ISODATA classification method has proven particularly effective in mapping wheat and other major crops, as seen in districts like Ambala, Bhiwani and Karnal where substantial wheat cultivation is supported by favorable conditions.

7.2 Rice area estimation

Crop area estimation in Haryana relies on remote sensing technology, which utilizes satellite imagery and classification algorithms to assess the extent of rice cultivation across various districts and blocks. For instance, Ambala district shows Saha block with 18.5% of the rice area, while Ambala-II holds the largest share at 23.6%. Similarly, Bhiwani district has Bhiwani block occupying 66.0% of the total rice area. The estimation also reveals that some districts, like Mahendergarh and Nuh, report zero hectares for rice cultivation, highlighting regional agricultural variations. This detailed data assists in understanding the distribution of rice cultivation across the state.

he analysis of methane emissions during wheat and rice crop seasons in Haryana provides crucial insights into the spatial distribution and intensity of methane release, contributing to our understanding of agricultural greenhouse gas emissions in the region. The data highlights several key patterns in methane emissions over the course of a year.

7.3 Wheat based methane emission*s:*

Methane emissions from wheat cultivation show a clear gradient, with the majority of the area falling under the "Very Low" concentration category (1890 ppb), covering a significant 2,845,764.2 hectares. This suggests that the wheat fields in Haryana generally emit lower levels of methane.

Smaller areas with higher concentrations of methane, particularly in the "Very High" category (1968 ppb) over 117,642.4 hectares, point to localized regions with greater emissions. These regions, though limited in area, may require focused attention for methane mitigation strategies.

7.4 Rice based methane emissions*:*

In contrast to wheat, rice cultivation in Haryana shows much larger areas with higher methane emissions. The "Very High" category (1968 ppb) covers a vast 3,354,135.8 hectares, suggesting that rice fields contribute significantly to methane emissions in the region.

The absence of areas in the "Low" and "Very Low" methane categories for rice indicates that the methane emissions are consistently moderate to high across most of the rice-growing areas, highlighting rice as a major source of methane in Haryana.

7.5 Seasonal Variations*:*

Across different months, methane emissions from wheat and rice show distinct seasonal trends. For instance, in January, the majority of emissions fall into the "Very Low" and

"Low" categories, while in later months like July and September, there is a marked increase in the area classified under "High" and "Very High" methane concentrations.

These seasonal patterns suggest that certain months, possibly linked to crop growth stages, contribute more significantly to methane emissions. Understanding these temporal variations can help in the development of targeted mitigation measures.

7.6 Implications for Climate Policy:

Given the significant areas covered by high methane emissions, particularly in rice cultivation, it is crucial for policymakers to focus on reducing methane emissions through improved water management techniques (e.g., alternate wetting and drying for rice fields), soil health management, and adoption of less methane-intensive cultivation methods.

The data underscores the need for region-specific strategies, as different crops and regions within Haryana contribute differently to methane emissions.

.This comprehensive analysis of methane emissions from wheat and rice cultivation across Haryana reveals the environmental impact of agricultural practices. The clear differences in methane emissions between wheat and rice fields highlight the need for crop-specific strategies to mitigate emissions. By adopting improved agricultural techniques and policies focused on emission reduction, Haryana can contribute to the broader goal of reducing agricultural greenhouse gas emissions and combating climate change.

7.7 Justification of methane emission from rice and wheat field

The justification for why rice crops produce methane (CH_4) while wheat crops do not lies in their growing environments and physiological processes:

Rice is typically grown in flooded paddy fields, creating anaerobic (oxygen-free) conditions in the soil. These conditions are ideal for methanogenic bacteria, which thrive in the absence of oxygen and decompose organic matter to produce methane gas as a byproduct. This biological process, known as methanogenesis, occurs extensively in waterlogged rice paddies where oxygen does not penetrate deeply into the soil.

In contrast, wheat is cultivated in aerobic (well-drained and oxygen-rich) soil conditions, where aerobic decomposition takes place. In the presence of oxygen, organic matter breaks down through oxidative processes that do not produce methane. As a result, wheat fields do not support the activity of methanogenic bacteria, and therefore, do not emit significant amounts of methane.

Thus, the presence or absence of standing water and oxygen in the soil during cultivation is the key environmental factor that explains methane emissions from rice but not from wheat.

7.8 Evaluate the role of agriculture practices responsible for methane emission:

Demonstrated that agricultural practices, particularly rice cultivation, are the dominant source of methane emissions in Haryana, with flooded paddy fields, stubble burning, and organic fertilizer use creating anaerobic conditions highly conducive to methane production. Wheat cultivation was found to contribute relatively lower emissions, though localized hotspots were identified where soil and water management practices intensified methane release. The chapter also emphasized the environmental implications of these emissions, showing how methane—being 28–34 times more potent than CO_2—significantly amplifies Haryana’s greenhouse gas profile and climate vulnerability. It concluded that effective mitigation strategies such as alternate wetting and drying, fertilizer optimization, stubble management, crop diversification, and adoption of improved rice varieties are essential to reduce methane emissions from agriculture.

7.9 Determinant of Methane Mixing Ration:

Building upon this, Chapter 6 analyzed the determinants of methane mixing ratio (MMR) and established that methane emissions are shaped by multiple factors, including crop type, water management, soil organic matter, fertilizer use, temperature and seasonal variations, tillage and residue management, land use patterns, and groundwater conditions. Rice-dominated districts like Karnal, Kurukshetra, Kaithal, and Fatehabad emerged as methane hotspots due to their intensive paddy cultivation and poor water management. The chapter also outlined a comprehensive set of mitigation strategies, ranging from technological solutions (AWD, low-methane varieties, biogas plants) to agronomic practices (crop rotation, conservation agriculture), supported by policy interventions and continuous monitoring using GIS and remote sensing tools.

Together, these chapters highlight that methane emissions in Haryana are both practice-driven and condition-dependent, with rice agriculture as the primary driver. Reducing emissions will require a multi-pronged, location-specific approach integrating improved water and nutrient management, sustainable residue handling, technological innovation, and targeted policy support. Such an integrated strategy will not only lower methane emissions but also enhance Haryana’s progress toward climate-smart agriculture and environmental sustainability.

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LIST OF PUBLICATION AND CONFERENCES

Type of Paper (Journal Paper/Conference proceeding/Book Chapter)	Name of the Journal/Conference/Book	Journal indexing (Scopus/UGC/ Web of Science)	Title of the Paper	Published Date (Date/Month/Year)	Volume & Issue Number
Journal	Educational Administration: Theory and Practice	Scopus	Winter Wheat Acreage Estimation Using Sentinel-2 Data: A Case Study of Haryana State.	2024	30(5)
Journal	African Journal of Bio Medical research	Scopus	Rice and wheat area estimation using remote sensing and GIS	2024	27 (4S)
Paper Presented in National Conference	National Conference on Natural Resources Sustainability and Geospatial Technology	Paper Presented	Winter Wheat Acreage Estimation Using Sentinel-2 Data: A Case Study of Haryana State.	21-22 April 2023	
Paper Presented in National Seminar	One Day National Seminar on Environment Conservation and Sustainable Development: A Pragmatic Perspective	Paper Presented	Impact of methane emission on environment	18-Mar-23	

Paper Presented in International Conference	International Conference on Global Synergy Summit-Bridging the Discipline in Management, Research, Science, Engineering, Education and Humanities	Paper Presented	Area Estimation of Rice Crop using Remote Sensing and GIS	26-Feb-24	
Paper Presented in International Conference	International Conference on Clean Water, Good Health, Sustainable Cities & Communities (CWGHSCC)	Paper Presented	Analysis of Methane Emission Mixing Ratios in Haryana of Rice Crop using Geo-informatics Techniques	18,19 Oct 2023	
Paper Presented in International Conference	International Conference on Clean Water, Good Health, Sustainable Cities & Communities (CWGHSCC)	Paper Presented	Determining of Methane Emission Mixing Ratios of Wheat Crop of Using Sentinel - 5P: A Case Study of Haryana	18,19 Oct 2023	