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Satellite-Based Analysis and GIS Mapping of Crop Area Estimation and Distribution in Kaithal District

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Abstract
This study utilizes Sentinel-2 satellite data and GIS technology to analyze and estimate crop areas in the Kaithal district during the Rabi season of 2024. Located in the fertile Indo-Gangetic plain, this region is predominantly agricultural, with wheat being the primary crop. By employing high-resolution imagery (10 meters) and advanced techniques such as supervised classification, digitization of non-agricultural areas, and masking of agricultural zones, the study successfully identified land use patterns and crop distributions. The results indicate that wheat occupies 78.5% of the cultivated area (180,457.9 hectares), mustard makes up 5.2% (11,890.1 hectares), and other crops account for 16.4% (37,621.8 hectares) of the total 229,969.8 hectares used for cultivation.
This analysis highlights Kaithal's dependence on wheat as a key crop while also showcasing a moderate level of agricultural diversification. The combination of remote sensing and ground truthing allowed for precise land use delineation, facilitating accurate crop area estimation. The findings, illustrated through maps and tables, provide valuable insights for agricultural planning, resource management, and policy development. This method underscores the importance of advanced satellite technology and GIS in fostering sustainable agricultural growth in the region.
Keywords:- *Sentinel-2, Digital Image Processing (DIP), Rabi Crops**,** Area Estimation, GIS*

I. Introduction

Accurate crop area estimation is essential for agricultural management, food security, and market stabilization. Traditional field surveys, while effective, are often impractical in regions with limited resources or challenging terrains. Remote sensing technologies have emerged as cost-effective and efficient alternatives for estimating cropped areas, leveraging satellite imagery and geographic information systems (GIS) to provide timely and precise data for agricultural planning.

Husak et al. (2008) developed a hybrid approach combining high-resolution IKONOS images and medium-resolution Landsat ETM+ data, integrating topographic information to improve crop area estimation in Central Ethiopia. This method demonstrated high accuracy and the potential for scalability across Africa. Similarly, Khan et al. (2021) used Sentinel-2 satellite imagery and the Adaptive Maximum Likelihood Classification (AMLC) method to estimate menthol mint acreage in Uttar Pradesh, India, achieving 90.67% accuracy and highlighting the importance of remote sensing in localized crop monitoring.

Other studies have emphasized the role of advanced methodologies, such as the Random Forest classifier and optimized spatial sampling, in enhancing crop area estimation. For example, Wang et al. (2015) demonstrated how combining remote sensing data with geostatistical sampling improved winter wheat area estimates in China. In addition, Sailaja et al. (2013) and Meshram et al. (2024) explored the integration of crop models like Oryza2000 and Sentinel-1 Synthetic Aperture Radar (SAR) data to improve rice yield and acreage estimation, addressing challenges like cloud cover and data variability.

The advancements in remote sensing technologies, including the use of machine learning algorithms (Tikkiwal et al., 2013) and spatiotemporal data fusion (Sisheber et al., 2024), have further enhanced the accuracy of crop area and yield predictions. These methods have been applied globally, from the MARS project in Europe (Gallego et al., 1999) to studies in India (Goswami et al., 2012; Desai et al., 2018) and the Middle East (Hassan et al., 2001). Despite challenges such as cloud cover and data overlap between crops and urban areas, the integration of remote sensing, GIS, and advanced classification algorithms continues to drive improvements in agricultural monitoring.

This paper explores the advancements in crop area estimation through remote sensing and GIS, with a focus on the accuracy, efficiency, and scalability of various methodologies. The review highlights key studies and identifies future directions for improving crop monitoring and supporting agricultural decision-making.

STUDY AREA

Kaithal is a district and city of historical importance in northern India at latitude 27°39' N to 30°55' N and longitude 74°27' E to 77°36' E. Kaithal is a part of the Kaithal district of Haryana, and covers an area of about 2,317 square kilometers. Geographically, it is located on the southern part of Haryana and is surrounded by various neighboring districts like Karnal to the north, Kurukshetra to the northwest, Jind to the west, and Panipat to the east.

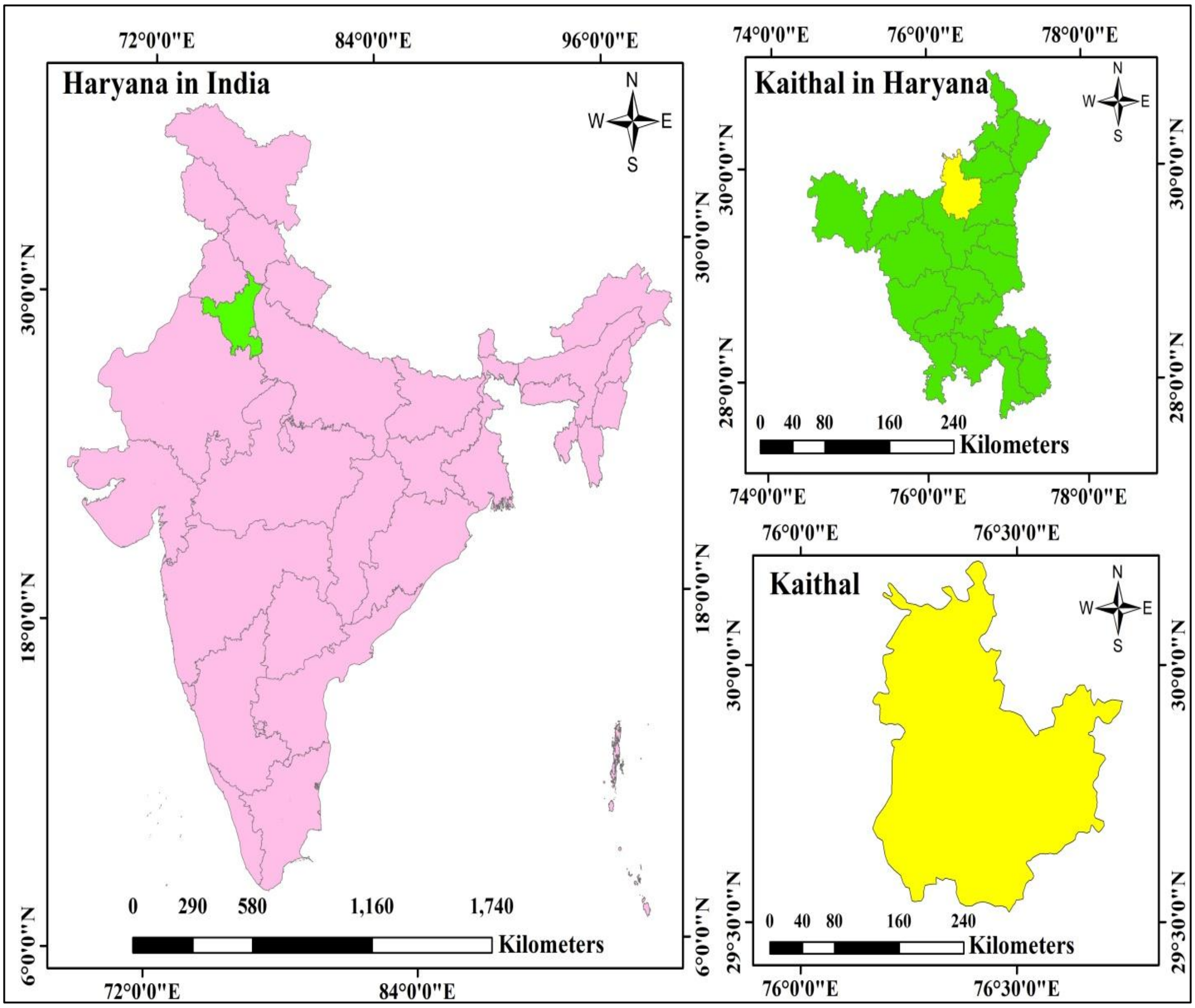


Fig.1: Location Map of the Study Area

It is a completely flat area lying in the Indo-Gangetic plain, a satellite area of rich and fertile loams which is important for agriculture. The climate of Kaithal is semi-arid with high summers and mild winters. It witnesses around average annual temperatures of 25degC to 40degC, with May- June the hottest months. The area receives the majority of its rainfall between June and September owing to the southwest monsoon winds, and averages around 400-700 mm annually.

Kaithal is at the feet of the 'Aravalli' mountain range. Although no significant topographical features such as mountains or valleys abound, there are a number of small hills and undulating terrains. The proximity to the Yamuna River on its eastern side constitutes a great factor influencing geography as well. The river, with its tributaries, contributes a great deal of fertile land to the area and the channelization to irrigated lands, which is extremely valuable for agriculture. These alluvial soils, rich in nutrients, constitute Kaithal practicing good grounds for cereals such as wheat, rice, and even sugarcane.

The geographical factor makes Kaithal strategically a position in relation to connectivity with well-developed roads or railways leading to the other parts of Har.

II. Material And Methodology:-

Data:

Satellite Data: Sentinel-2 is a project underneath the European Space Agency's Copernicus program, comprising two satellites, Sentinel-2A (launched in 2015) and Sentinel-2B (launched in 2017). These satellites are equipped with a Multispectral Instrument (MSI) that captures high-decision imagery in 13 spectral bands, starting from visible to quick-wave infrared. With a spatial decision of 10 meters for visible and close to-infrared bands, and 20 to 60 meters for different bands, Sentinel-2 offers unique observations of Earth's surface. The satellites have a revisit time of five days, making sure frequent monitoring of the same areas. The statistics is used for various programs, inclusive of agriculture (crop tracking), environmental management (forest health, water best), catastrophe reaction (floods, wildfires), and weather alternate studies. Sentinel-2 facts is freely available and plays a essential role in global environmental monitoring, offering important insights for scientific studies, coverage-making, and emergency control.

METHODOLOGY:-

This flowchart describes the method for estimating crop area in District kaithal at some point of the Rabi season of 2024 using Sentinel-2A satellite statistics. Of 23 feb 2024, downloaded it from Copernicus browser, then unzipped the zip file and open in Arc 10.8 sofftware,

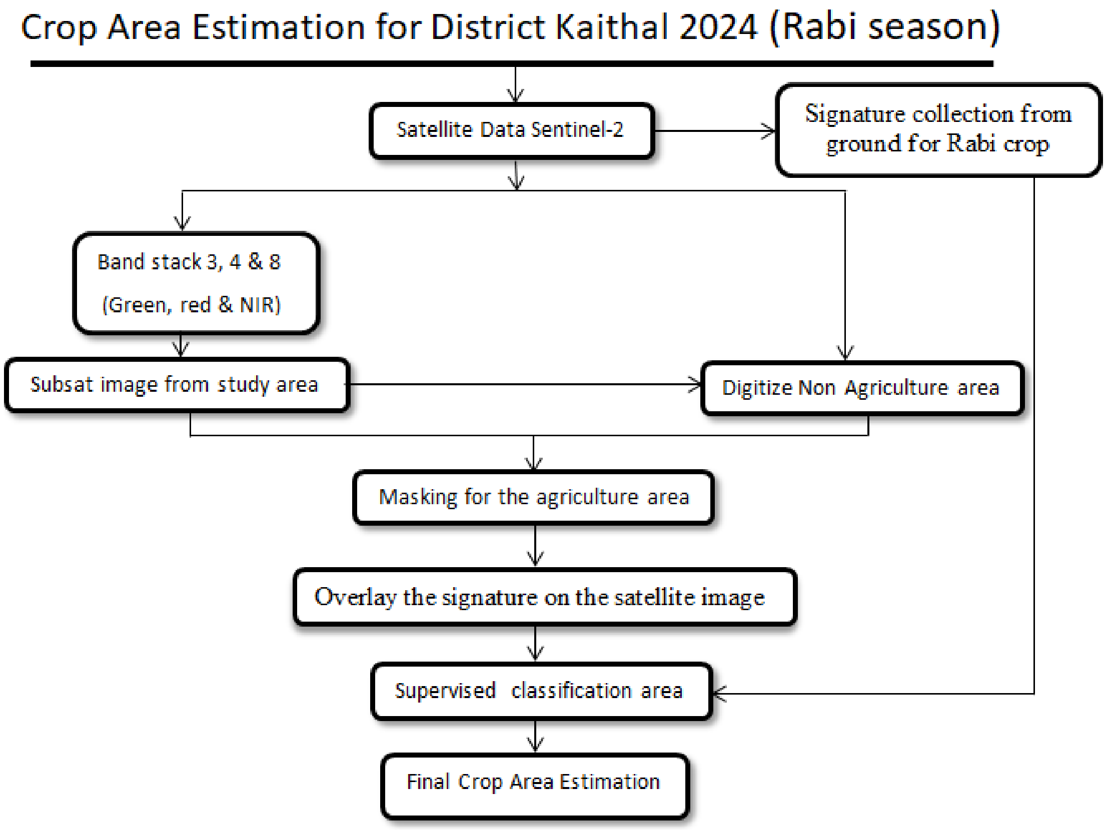


Fig.2: Methodology flow chart.

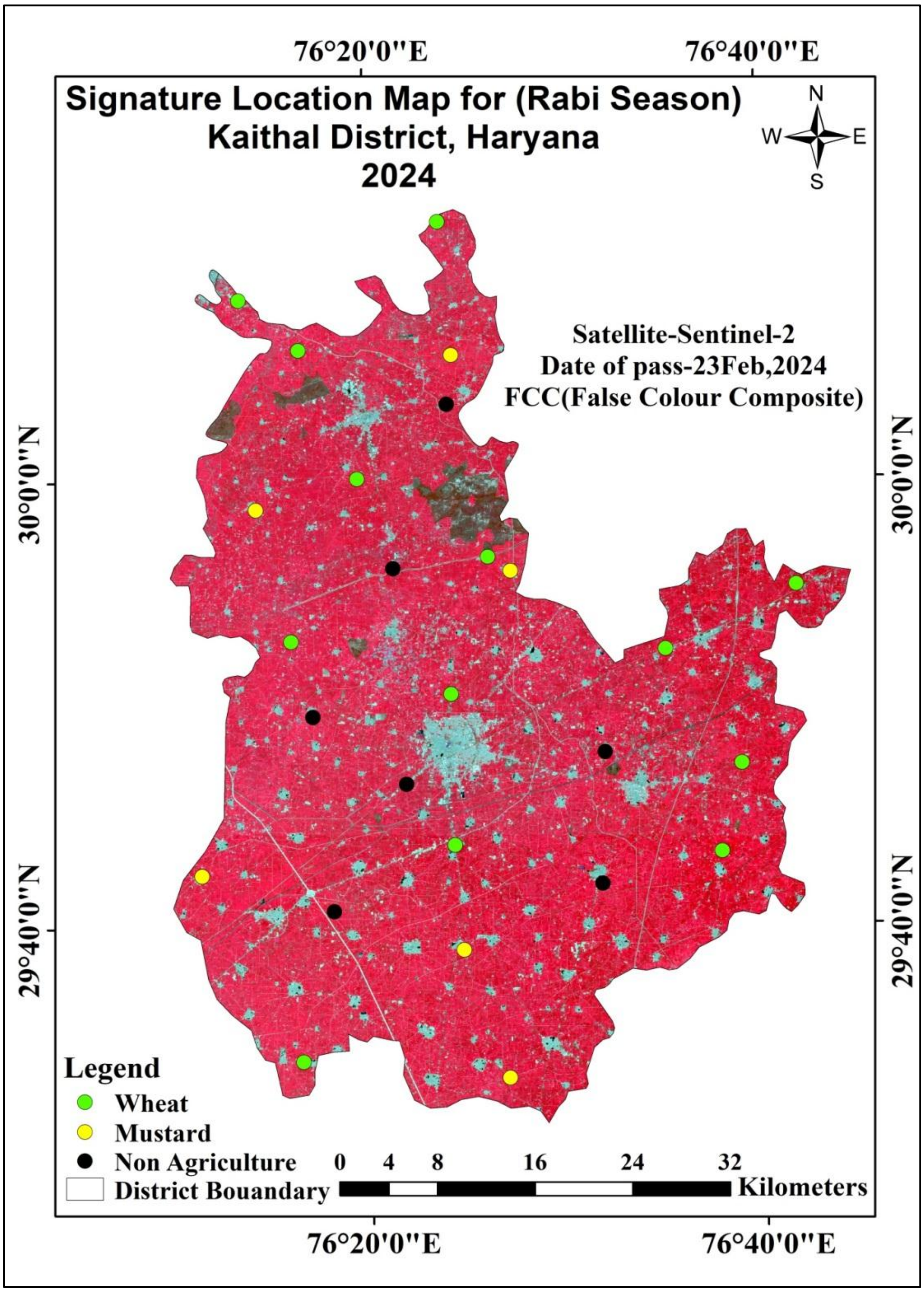
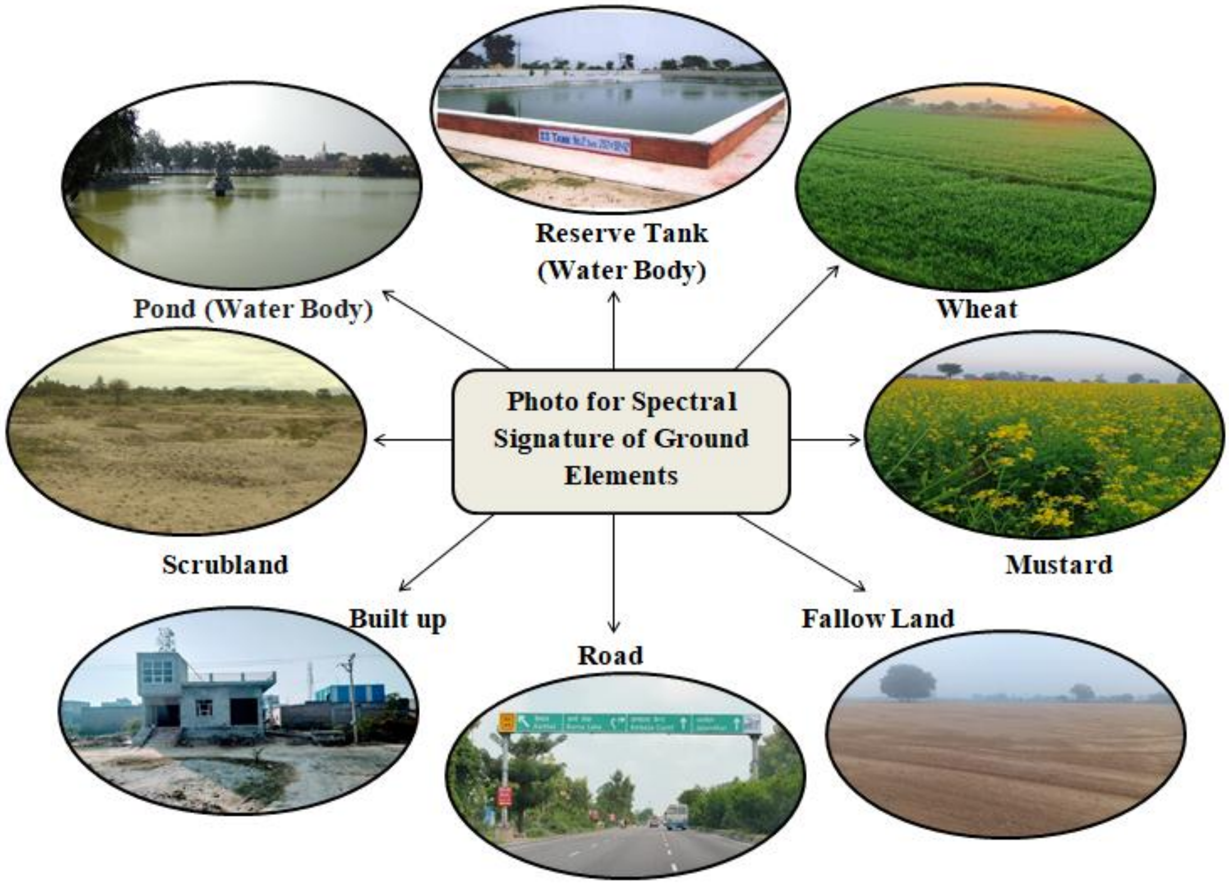


Fig.4: Signature Location Map For Rabi Season 2024 of Kaithal District Haryana

Signature collection from ground for Rabi crop: The process typically involves collecting specific data or signatures directly from the field concerning Rabi crops. This can include various activities aimed at gathering crucial ground-level information about crops planted during the Rabi season. The Rabi season, which generally runs from October to March, features crops such as wheat, mustard, barley, and gram, depending on the region.



Data Collection Field Surveys: Teams visit agricultural fields to collect information about crop types, sowing patterns, and health conditions. GPS and Geotagging: Geographic coordinates are recorded to pinpoint the exact locations of the fields for precise data mapping. Signature Collection in Remote Sensing: In the context of remote sensing or satellite imagery, "signature" refers to the unique spectral reflectance pattern of a crop. Ground truthing is performed to validate these patterns by physically gathering data from the field. Calibration of Satellite Data: Ground signatures assist in correlating and calibrating satellite data to ensure accurate monitoring of crop health, acreage, and yield.

Band stack: A **band stack:** in GIS and remote sensing refers to the combination of multiple spectral bands from satellite or aerial imagery into a single multi-layer dataset. Each band represents a different wavelength of light, capturing specific environmental features (e.g., visible light, infrared, etc.). By stacking these bands, you get a more comprehensive view of the Earth's surface. A false color composite can be created by assigning specific bands to different colors (e.g., Red = NIR, Green = Green, Blue = Red). This kind of display is often used to highlight vegetation and make it stand out in imagery, where healthy vegetation appears in bright red.

Subset Image: Subset Image: In this case, tools such as “Clip” or “Extract by Mask” are used to cut out an area of interest from a bigger satellite photo or GIS image. It zooms in on the analysis for a certain spatial extent, such as administrative district, which is useful in enhancing efficiency since it decreases the area of interest and concentrate the analysis on important aspects.

Digitizing Non-Agricultural Areas: The processes first entail marking and mapping out non- agricultural areas such as water bodies and forests within high resolution satellite data like Sentinel – 2A. These areas are manually digitized in GIS by firstly tracing polygons around them. The digitized features are stored in a shapefile to create a non-agricultural layer, which can be used in agricultural studies to mask out areas that do not relate to agriculture.

Supervised classification: Supervised classification is a key technique in GIS for analyzing spatial data, especially satellite imagery. It involves training a model using labeled examples (training data) to classify features like "forest," "water," or "urban" based on pixel characteristics such as color, texture, and spectral bands (e.g., RGB, Near-Infrared). Algorithms like Maximum Likelihood Classification (MLC), Support Vector Machines (SVM), and Random Forests are commonly used. The trained model assigns each pixel to a class, and results are refined through post-processing and validated against ground truth data. While effective for tasks like land cover mapping and environmental management, supervised classification requires accurate, labor-intensive training data and is sensitive to its quality.

III. RESULT AND DISCUSSION:

The area under wheat, mustard, and some other important Rabi crops in Kaithal district was found using Sentinel-2 satellite data and GIS technology. The study discussed the prominent Rabi crops with especial emphasis on wheat and mustard. Satellite imagery covered with spatial resolution of 10 meters proves beneficial in collecting detailed and accurate information for mapping and classifying crop areas. The outputs of the work are shown in maps and tables. The data are visual at this point through maps, easy to comprehend in spatial relationships; and tables provide detailed information in a more structured and comprehensive presentation.

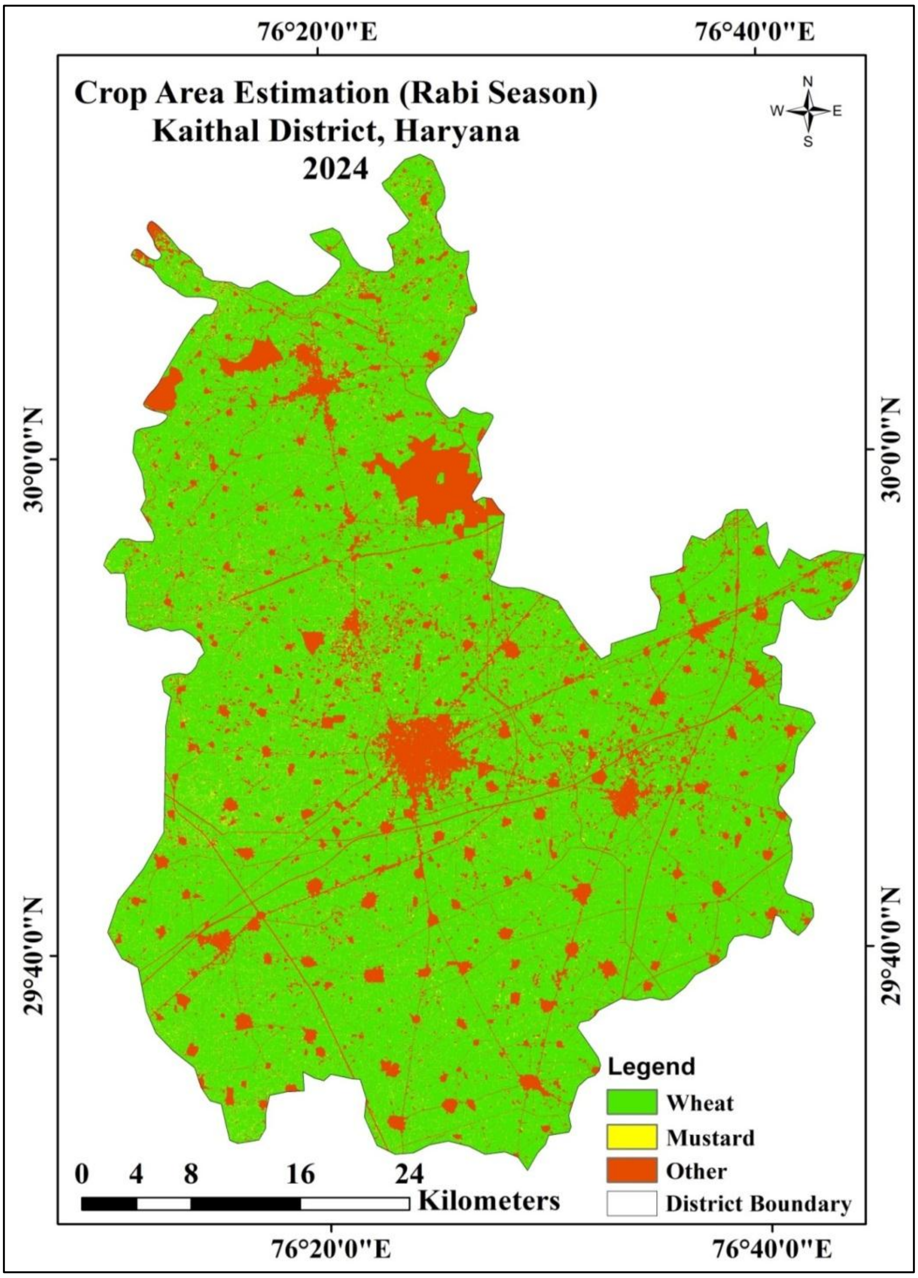


Fig.4: Crop Area Estimation Map of Rabi Season Sirsa District Haryana 2024.

The table provides an overview of crop area estimation for Kaithal district during the Rabi season of 2024. It shows the total land utilized for cultivation, which amounts to 229,969.8 hectares.

Table-1: Estimated Area of Rabi Crops 2024 of Kaithal District Haryana.

Crop area Estimation of Kaithal 2024 (Rabi season)			
Sr.No.	crop name	Area in Hac.	Area in %
1	Wheat	180457.9	78.5
2	Mustard	11890.1	5.2
3	Other	37621.8	16.4
Total		**229969.8**	**100**

The data highlights three main crop categories: Wheat, Mustard, and Other crops. Wheat dominates the cultivated area, covering 180,457.9 hectares, which accounts for 78.5% of the total. This indicates a strong preference for wheat during the Rabi season. Mustard, on the other hand, is cultivated on 11,890.1 hectares, making up only 5.2% of the total area, showing its relatively minor presence. The remaining 37,621.8 hectares, or 16.4%, are allocated to other crops, which could include a variety of grains, pulses, or vegetables. This data underscores the dominance of wheat in Kaithal's agricultural practices, while also reflecting the presence of diversification through other crops, albeit to a smaller extent. Such insights are crucial for agricultural planning, resource management, and decision-making for the upcoming seasons.

IV. Conclusion

The study effectively used Sentinel-2 satellite data and GIS technology to analyze and estimate the crop area during the Rabi season of 2024 in Kaithal district. The findings showed that wheat is the primary crop, covering about 78.5% of the cultivated area, with mustard following at 5.2%, and the remaining 16.4% allocated to other crops. This underscores the region's heavy dependence on wheat as a staple while also indicating a moderate level of agricultural diversification. Utilizing high-resolution satellite imagery (10 meters) was extremely beneficial for detailed mapping, accurate classification, and analysis of crop areas. Methods like supervised classification, digitization of non-agricultural areas, and masking of agricultural zones improved the study's accuracy, allowing for precise land use delineation. The insights from this research are crucial for agricultural planning, resource allocation, and policymaking. They facilitate targeted interventions to enhance crop production, manage resources effectively, and inform future agricultural strategies. The combination of advanced remote sensing tools with ground truthing ensures reliable data, contributing to the sustainable development of agriculture in Kaithal district.

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