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Spatial Analysis of Cropping Patterns Using Digital Image Processing: A Case Study of Sirsa District, Haryana

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Abstract
This research employs Sentinel-2A satellite data and GIS methodologies to examine the cropping patterns in Sirsa District, Haryana, during Kharif (2023) and Rabi (2024) seasons. With the major spectral bands (Bands 3, 4, and 8) employed for analyzing vegetation, the study detects predominant crops like cotton, rice, wheat, and mustard. Subsetting of the satellite image, classification, and digitization of non-agricultural land uses with the aid of GIS software form the method. Unsupervised classification methods were used to classify land cover, and then crop area estimation for both seasons was done. Accuracy assessment and ground truthing were conducted to test the classification outputs.
Observations indicate that Cotton-Wheat (28.9%) and Rice-Wheat (20.9%) are the major cropping patterns in the district, with Cotton-Mustard (13.5%) also occupying a substantial area. Spatial analysis of the distribution indicates the dominance of rice crop in the Ghaggar Belt for irrigation benefits, and cotton crops are clustered in the western and southwestern parts. Non-agricultural land, such as urban settlements and fallow land, is found to be in clusters in the central and southern regions of the district.
This study emphasizes the capability of remote sensing and GIS technologies to effectively monitor agriculture in a timely, accurate manner for resource management, land use regulation, and monitoring. Integration with ground truthing guarantees the utmost accuracy of crop classification for timely decision support at the level of policymakers, researchers, and agriculturalists. This research also depicts how geospatial technologies lead to better food security, optimum crop productivity, and climatic resilience by offering informed agriculture planning. The results offer a basis for sustainable agricultural management practices, facilitating effective land utilization and sustainable agriculture productivity in Sirsa District.
Keywords:- *Rabi and Kharif Crops, Crop Area Estimation, Cropping Patterns, Sentinel-2A, Digital Image Processing (DIP), GIS*

I. INTRODUCTION

Agricultural cropping patterns are a critical component of sustainable farming systems, influenced by a combination of physical, socio-economic, and environmental factors. Recent studies have employed advanced remote sensing technologies and geospatial tools to analyze and map these patterns, offering valuable insights for optimizing agricultural productivity and resource management. For instance, Nath et al. (2021) utilized Landsat satellite data and the K-means clustering algorithm to map winter crop patterns in South-eastern Bangladesh, identifying lentils and melon as dominant crops due to their low irrigation needs. Similarly, Sharma et al. (2023) highlighted the role of socio-economic factors and traditional practices in shaping cropping systems in Nepal's Humla district, emphasizing the need for technological innovation to enhance food security.

In semi-arid regions like Tumkur Taluk, Karnataka, Bharathkumar et al. (2015) demonstrated the importance of crop suitability mapping using NDVI analysis to promote water-efficient crops and mitigate groundwater depletion. Meanwhile, Mahlayeye et al. (2022, 2024) explored the potential of hyperspectral remote sensing and advanced vegetation indices to improve the mapping of complex cropping systems, particularly intercropping, which remains underexplored. In India, Gupta et al. (2018) and Gowda et al. (2024) underscored the significance of well-defined cropping patterns and systems in enhancing agricultural output and sustaining economic growth.

Regional studies, such as those by Kumari et al. (2023) in Charkhi Dadri and Reddy et al. (2022) in Andhra Pradesh, have utilized remote sensing and Markov chain analysis to evaluate dynamic cropping patterns and their implications for agricultural planning. Additionally, Chavan et al. (2020) and Satyawan et al. (2014) demonstrated the effectiveness of Sentinel-2 and IRS LISS-III data, respectively, in mapping cropping systems and identifying dominant crop rotations. Finally, Jincy et al. (2018) analyzed cropping intensity and diversity in the Kongu Uplands, providing a foundation for sustainable land-use planning. Collectively, these studies highlight the transformative potential of remote sensing and geospatial technologies in understanding and optimizing cropping patterns for sustainable agriculture.

Study Area

Sirsa District is located in the northwestern region of Haryana, India, with geographical coordinates roughly between Latitude: 29°14′ N to 29°59′ Longitude: 74°27′ E to 75°18′ E(Fig.-1). It is bordered by the states of Punjab and Rajasthan, thus a region of high climatic and agricultural diversity. The climate of the district is semi-arid, with hot summers, moderate monsoons, and cold winters. Summer (March to June) is as hot as 45°C, and winters (October to February) are as cold as 5°C, with December and January being the lowest of all. The monsoon months (July to September) are moderate in rains, averaging 300-400 mm a year, which is essential for agriculture but sometimes causes flooding.

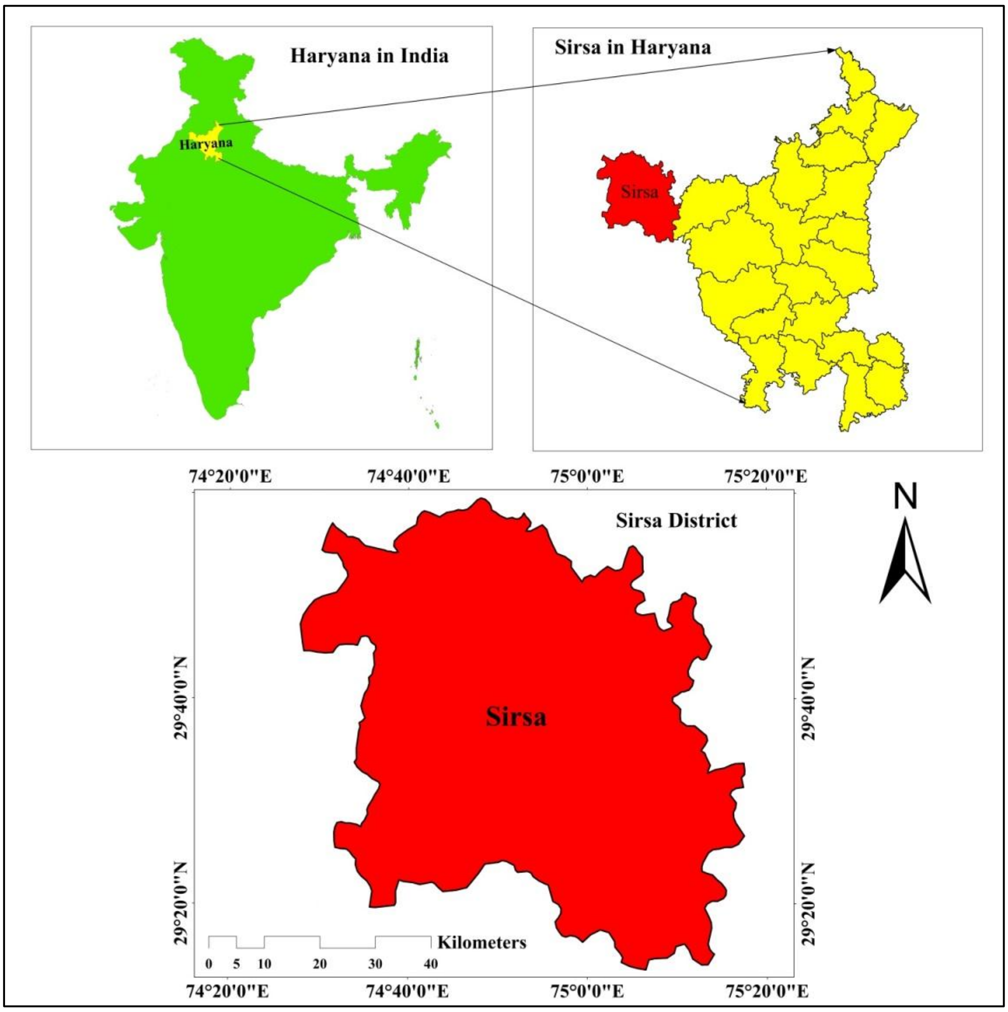

Fig.-1: Location Map of the Study Area

Climate significantly influences the crop activity in Sirsa. Kharif season (summer crops) includes crops like cotton, Rice, guar, and pearl millet, which are rain-dependent in monsoons, while the Rabi season (winter crops) includes wheat, mustard, and barley, grown during winters. Soil in Sirsa is almost alluvial, although there are certain pockets in the district where there are issues like salinity of soil, which affects the crop yield. Water sources predominantly include the Sirsa Branch of the Western Yamuna Canal and the Bhakra Canal, which are supplemented by groundwater through tube wells and wells. Deficit of water, especially during summer, is, however, a serious concern.

Geomorphologically, Sirsa lies within the Indo-Ganetic plain, which enjoys a relatively flat topography favoring intensive cultivation. The district topography is conditioned by the existence of the Thar Desert in Rajasthan, and the district is thus semi-arid. Though agriculturally affluent, Sirsa also experiences environmental issues like water shortage and soil erosion, which need to be addressed by implementing sustainable management practices to preserve long-term productivity.

II. MATERIAL AND METHODOLOGY:-

Data used/Collection

Satellite Data:-Sentinel-2A, launched on 23 June 2015, is a sun-synchronous polar orbiting high-resolution optical satellite with an altitude of 786 km. It has a Multispectral Imager (MSI) onboard that captures data in 13 spectral bands, from visible, near-infrared, red edge, to shortwave infrared wavelengths. The bands vary in spatial resolutions: 10 meters for visible and near-infrared, 20 meters for red edge and shortwave infrared, and 60 meters for atmospheric correction. With a 290 km swath width, Sentinel-2A, along with its twin satellite Sentinel-2B (launched in 2017), can provide global coverage every 5 days at the equator. The satellite offers two primary data products: Level-1C (top-of-atmosphere reflectance) and Level-2A (atmospherically corrected reflectance). The satellite applications are diverse, ranging from agriculture (crop monitoring, precision farming). Sentinel-2A data is free and accessible through portals like the Copernicus Open Access Hub, in Geo-TIFF format with XML metadata. The satellite's high-resolution imagery, revisit frequency, and open data policy render it a valuable tool for environmental monitoring, disaster response, and sustainable resource management globally.

Cropping Pattern for District Sirsa 2023-2024(Kharif & Rabi season)

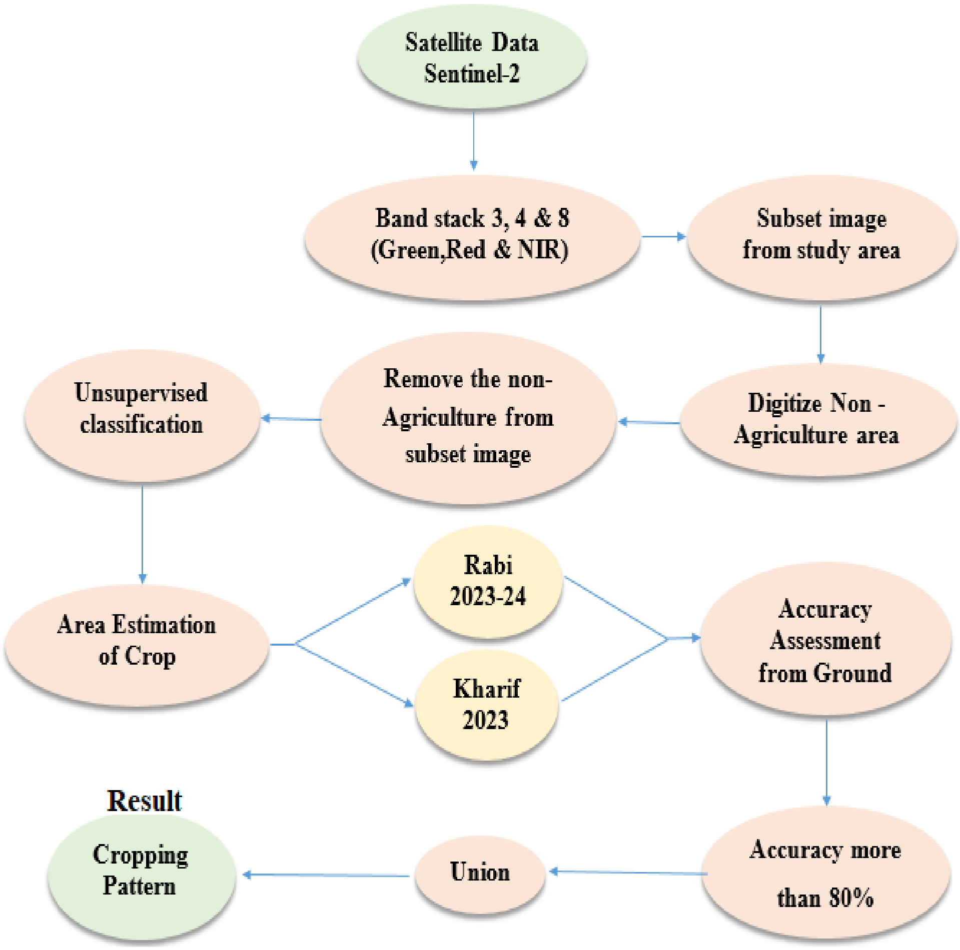

Fig.-2: Methodology flow chart.

Band stack:- The band stack of Band 3 (Green - 560 nm), Band 4 (Red - 665 nm), and Band 8 (NIR - 842 nm) of Sentinel-2 is very common for vegetation analysis and land cover mapping. Band 3 is a green light measurement, an indicator of chlorophyll concentration, and can be used to measure the health of the plant. Band 4, as it is chlorophyll-absorbed, is valuable for vegetation analysis, particularly in combination with NIR. Band 8 (NIR) reflects heavily from green vegetation due to plant cellular structure and can be used to estimate density, health, and biomass. All three bands combined are used to make a false-color composite suitable for vegetation analysis and crop monitoring.

Subset image from study area:-
Subsetting an image from a study area involves extracting a specific portion of an image that matches the geographic extent of the area of interest. This is done by defining the study area using coordinates or a shapefile and clipping the image using GIS software or tools like Python's rasterio and geopandas. The process ensures the subset image retains geographic metadata and focuses only on the relevant region, making it easier to analyze. Proper alignment of coordinate systems between the image and study area is crucial to avoid errors.

Digitize Non -Agriculture area:-
To digitize non-agricultural areas as polygons in ArcGIS, load the base image and create a new polygon attribute table and save your edits. This process is useful for land use mapping and analysis.

Remove the non-Agriculture from subset image:-Removing non-agricultural areas from a subset image in GIS involves isolating and retaining only the agricultural land cover while excluding other land use types (e.g., urban areas, forests, water bodies, etc.). This process typically involves classification, reclassification, and extraction techniques. Below is a detailed description of the process:

Unsupervised Classification:-Unsupervised classification is a machine learning approach used to categorize or group data without relying on pre-labeled examples. Unlike supervised classification, where the algorithm learns from labeled datasets, unsupervised classification works with raw, unlabeled data to identify patterns, structures, or relationships. The algorithm analyzes the inherent structure of the data and groups similar instances together based on their characteristics. Common techniques include clustering, such as K-means or hierarchical clustering, which organizes data into distinct groups, and dimensionality reduction methods like Principal Component Analysis (PCA), which simplifies data while preserving its essential structure. Unsupervised classification is particularly valuable when labeled data is unavailable or when exploring unknown patterns in datasets. It is widely used in applications such as customer segmentation, anomaly detection, and organizing large datasets for further analysis.

Area Estimation of Crops: Rabi and Kharif
Area estimation of Rabi and Kharif crops is an essential agricultural practice for assessing crop production, planning resource allocation, and making policy decisions. The estimation is done using traditional field surveys, remote sensing technology, and GIS-based mapping**.**

Understanding Rabi and Kharif Crops

- **Rabi Crops**: Grown in the winter season, sown from October to December, and harvested between March and May. Examples: Wheat, Barley, Mustard, Peas, Gram.
- **Kharif Crops**: Grown in the monsoon season, sown from June to July, and harvested between September and October. Examples: Rice, Maize, Millet, Cotton, Sugarcane.

Accuracy assessment:-Accuracy assessment from the ground, often referred to as **ground truthing**, is a crucial step in evaluating the reliability of remotely sensed data, GIS models, and classification results. It involves comparing classified or predicted data with real-world observations collected from the ground. This process is widely used in remote sensing, monitoring for area estimation of crop. That's why After our area estimation, we conducted accuracy assessment from the ground using GT to determine the accuracy of the results.

Union:-To determine the union of Rabi and Kharif areas, we first estimated the area of Rabi crops, which included major crops like wheat and mustard. Similarly, we then estimated the area for the Kharif season, where major crops included rice, cotton, and bajra. After estimating the areas for both seasons, we applied the union command to find their union. This helped us understand the crop pattern followed in different areas. In this way, the union is useful for identifying cropping patterns.

cropping pattern:-A cropping pattern refers to the way crops are cultivated in a specific area over a given period, influenced by factors such as climate, soil type, water availability, and agricultural practices. It determines land utilization for agriculture and plays a crucial role in optimizing yield, maintaining soil health, and ensuring sustainable farming.
feature class. Use the **Polygon** tool in the **Edit** tab to create vertices around the boundaries of non-agricultural areas (e.g., urban, forest, water bodies). Add land use types in the

RESULT AND DISCUSSION: The study used Sentinel-2A data to analyze Rabi and Kharif crop patterns by subsetting the study area and applying a band stack (Bands 3, 4, 8) for vegetation analysis. Non-agricultural areas were digitized and removed using GIS tools, and unsupervised classification categorized land cover. Area estimation for Rabi (e.g.,wheat, mustard) and Kharif crops (e.g.,cotton, rice) was conducted, with their union revealing cropping patterns. Ground truthing validated results, demonstrating Sentinel-2A's potential for sustainable agricultural planning and resource management.

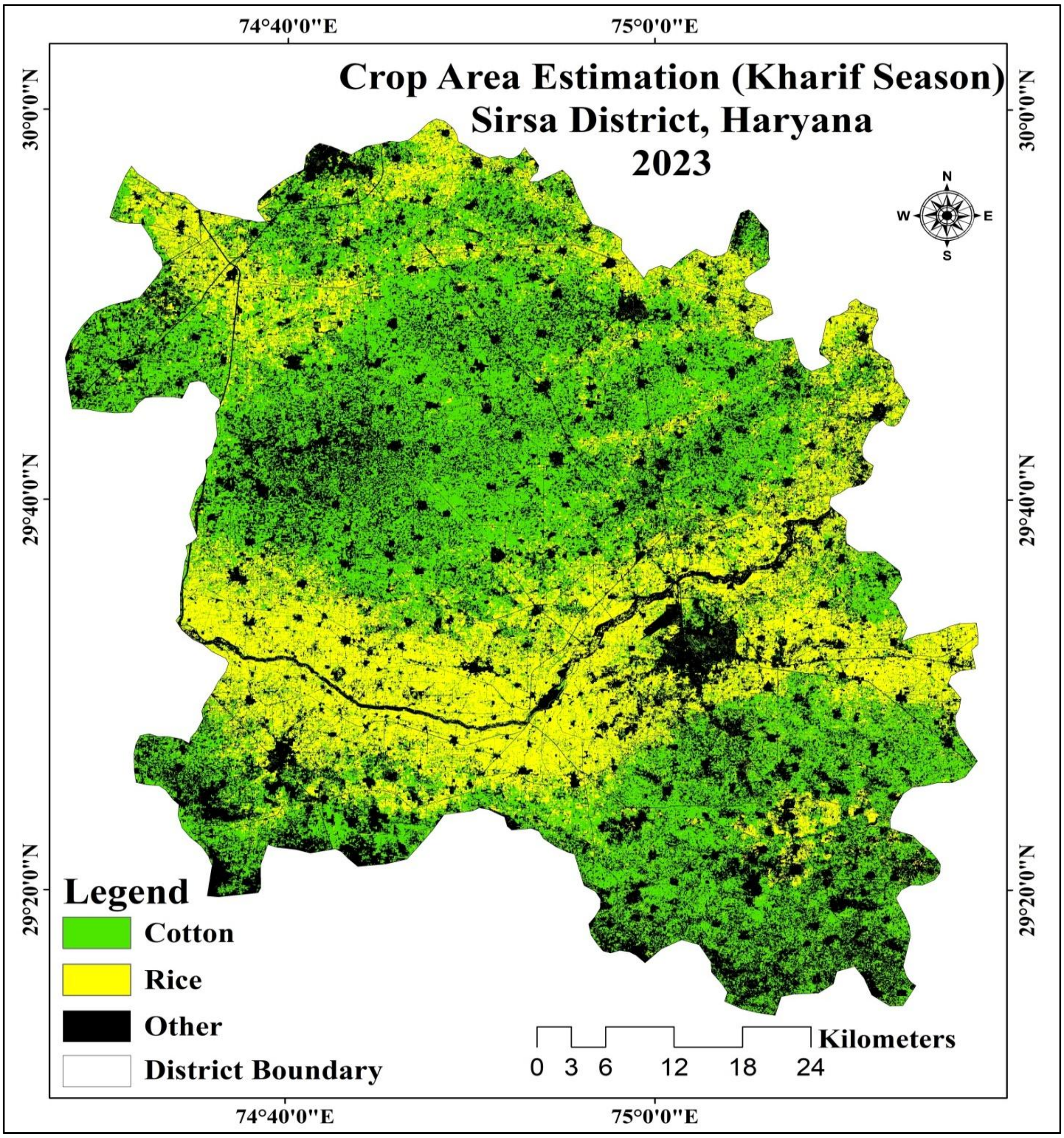

Fig.-3: Crop Area Estimation Map of Kharif Season Sirsa District Haryana 2023.

This Sirsa District, Haryana, Kharif Season 2023 Crop Area Estimation map shows the spread of major crops like cotton (green) and rice (yellow), with non-agricultural land (black) representing urban settlements, fallow land, and water bodies (Showing in **Fig**.-3). Cotton is cultivated mainly in the western, central, and southwestern regions, and rice is seen to be more clustered in the eastern and southeastern (Ghagger Belt) regions, suggesting potential irrigation benefits. Non-agricultural lands are densely grouped in the central and southern regions, likely showing urban settlements. The western boundary controlled by cotton fields, while the eastern boundary has higher rice cultivation

Table-1: Estimated Area of Kharif Crops 2023 of Sirsa District Haryana

Crop area Estimation of Sirsa 2023(Kharif season)			
Sr.No.	**Crop name**	**Area in Hac.**	**Area in %**
1	Cotton	186245.4	44.0
2	Rice	104355.8	24.7
3	Other	132372.2	31.3
Total		**422973.4**	**100.0**

The table-1 lists the crop area estimation of Sirsa for the Kharif season of 2023. It categorizes different crops on the basis of their respective areas covered in hectares and the portion of the total cultivated area occupied. The dominant crops are Cotton, covering an area of 186,245.4 hectares (44.03%), and Rice, covering an area of 104,355.8 hectares (24.67%). The rest of the area covers 132,372.2 hectares (31.29%). The total area is 422,973.4 hectares, equating to 100% of the reported land. The data is meaningful to give us insights into the distribution of crops in Sirsa for the Kharif season, with the dominant crop being cotton.

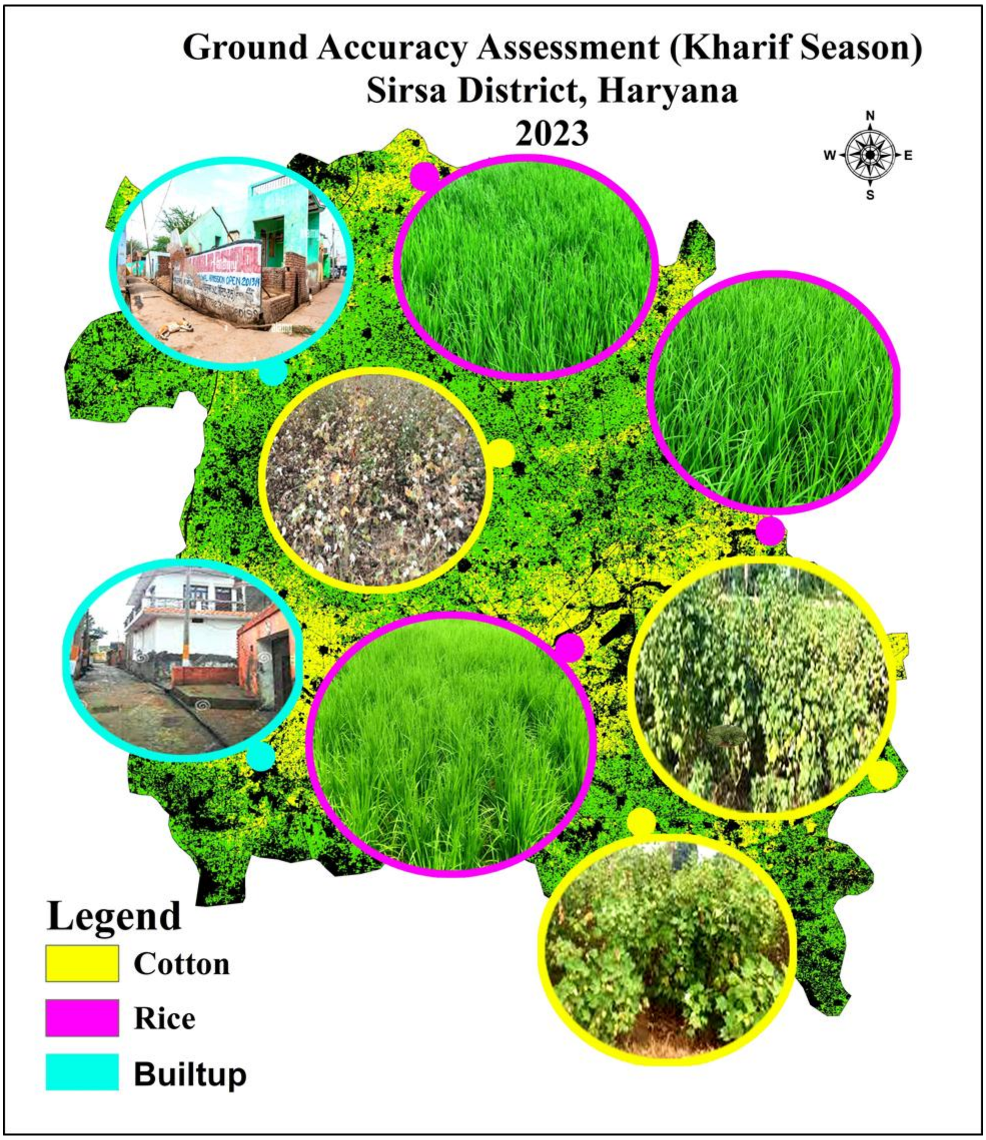

Fig.-4: Ground Accuracy Assessment Map of Kharif Season Sirsa District Haryana 2023.

Accuracy evaluation of this map includes checking the classification of various land covers—cotton, rice, and urban—against ground truth data. The evaluation confirms that remotely sensed classification accurately depicts the land use at Sirsa District, Haryana, for the Kharif season of 2023. The map shows field survey points superimposed on a classified land cover image, which is justified by ground photographs for each class. The process of accuracy assessment usually involves computing measures like total accuracy, producer's accuracy, and user's accuracy by employing an error matrix to identify reliability in classification. The incorporation of field data increases confidence in the accuracy of the map for agricultural and urban planning purposes (**Fig**.-4)

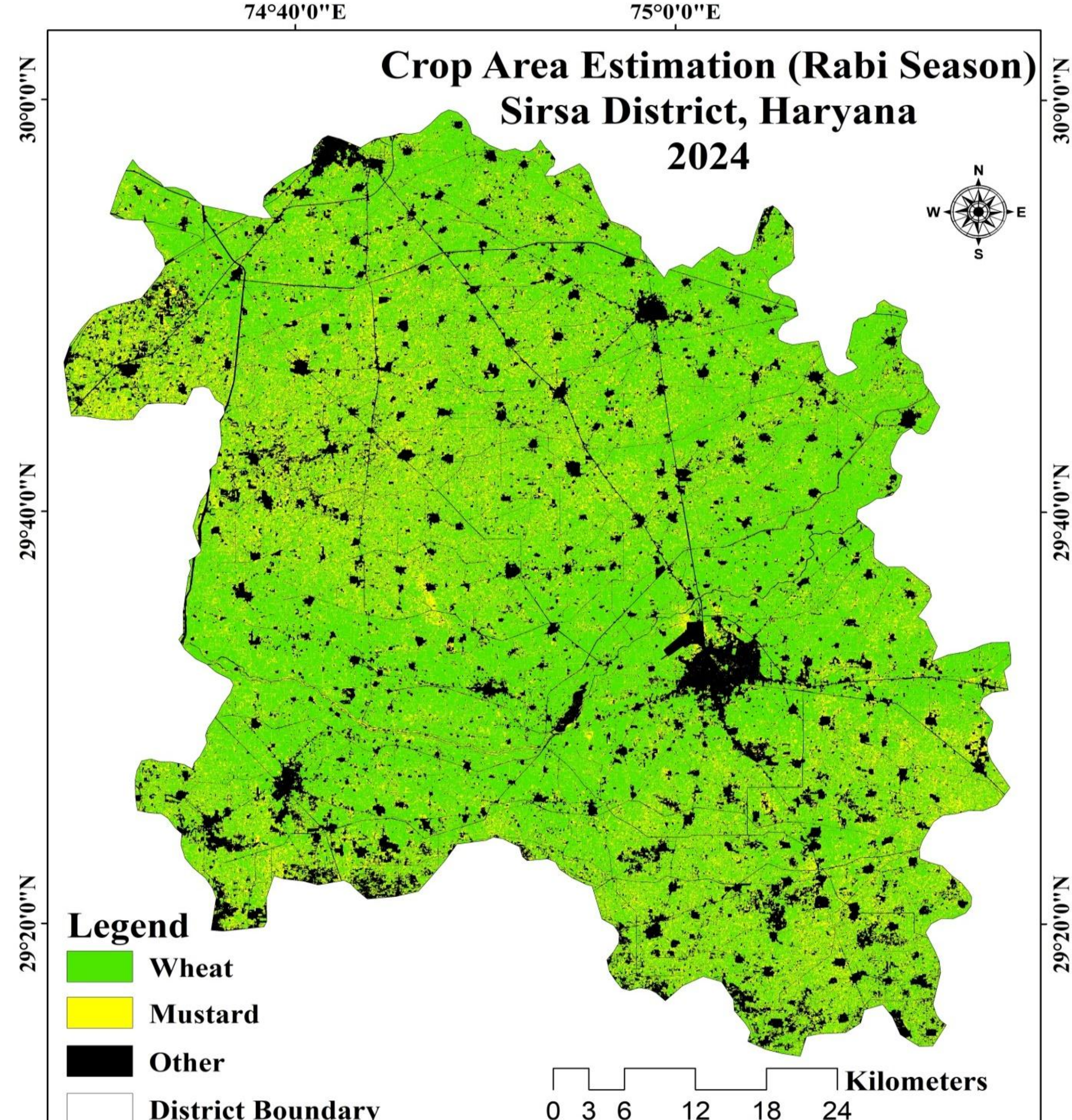

Fig.-5: Crop Area Estimation Map of Rabi Season Sirsa District Haryana 2024.

This Crop Area Estimation map of Rabi Season 2024, Sirsa District, Haryana, indicates the spatial distribution of the major crops, wheat (green) and mustard (yellow), and non-agricultural land (black) such as urban areas, water bodies, and barren land. Wheat is the dominant crop across the district with extensive areas covering the north, west, center, and the southern regions of the district indicating its importance as the major Rabi crop. Mustard fields are scattered in nature, located primarily in the southeastern and south-western region of the district, indicating smaller but notable concentration. Non-agricultural land (black) is located surrounding the urban areas with high-density aggregations in the center, the north, and the south-west, perhaps indicating cities, roads, the north and west where wheat prevails while the east and the southeast are more covered by mustard fields and some wheat plantations. This map is an essential tool for farmers, scientists, and planners to realize the crop distribution, plan resource mobilization, and make decisions on agricultural development for the area.(Fig.-5)

Table-2: Estimated Area of Rabi Crops 2024 of Sirsa District Haryana.

Crop area Estimation of Sirsa 2024 (Rabi season)			
Sr.No.	**Crop name**	**Area in hac.**	**Area in %**
1	Wheat	253379.8	60.9
2	Mustard	107431.0	26.1
3	Other	62162.6	13.0
Total		**422973.4**	**100.0**

The table-2 shows crop area estimation figures for Sirsa for the 2024 Rabi season. It shows various crops based on the area of land they are grown on in hectares and the percentage of the total cultivated land. The prominent crops are Wheat, taking up 253,379.76 hectares (60.88%), and Mustard, which covers 107,431 hectares (26.14%). Other area is 62,162.6 hectares (12.98%). The total area is 422,973.36 hectares, adding up to 100%. These data point towards wheat as the largest crop in Rabi season at Sirsa.

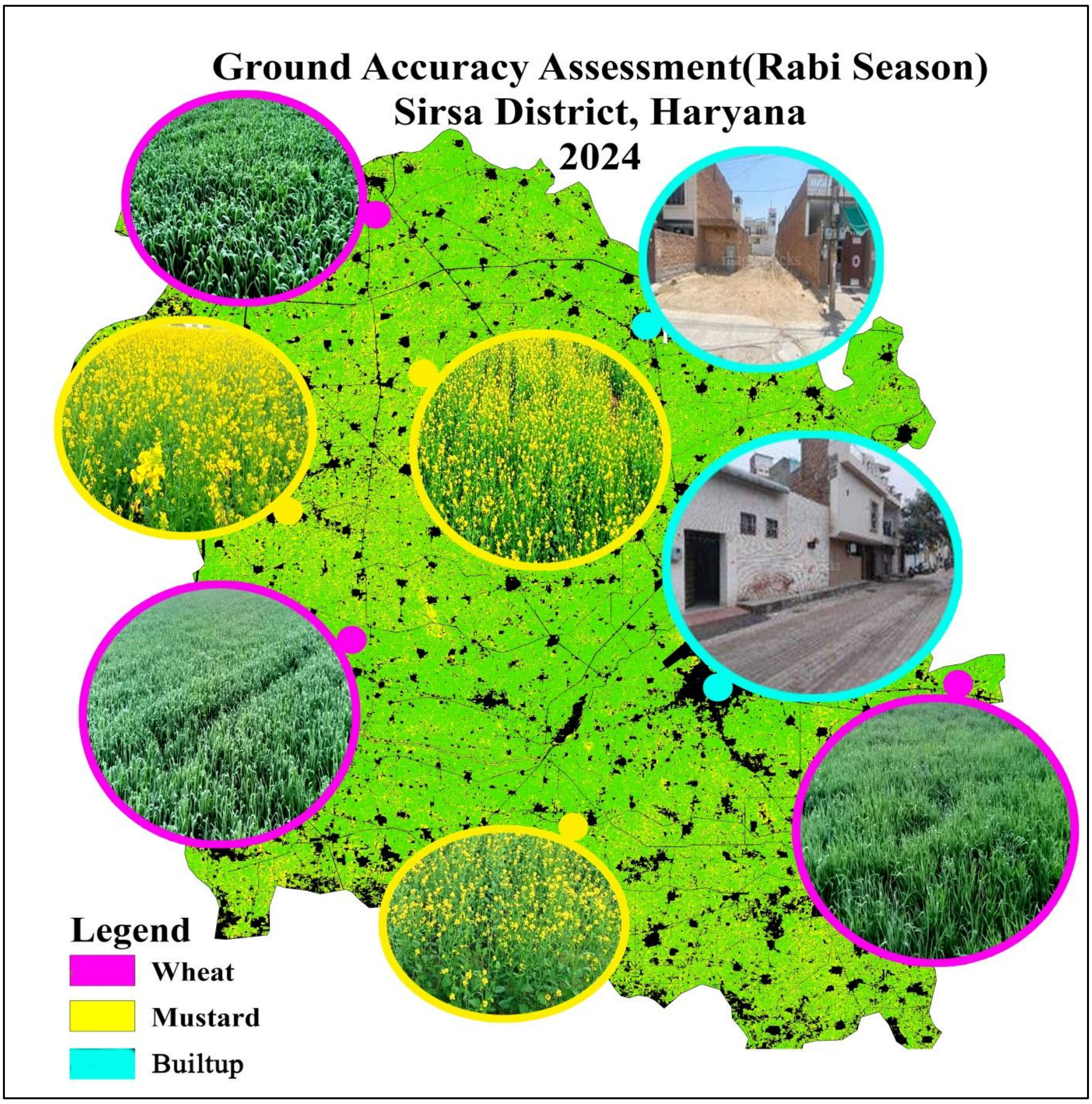

Fig.-6: Ground Accuracy Assessment Map of Rabi Season Sirsa District Haryana 2024.

Verifying the identified land cover types—wheat, mustard, and built-up areas—against real field data gathered from Sirsa District, Haryana, during the Rabi season of 2024 is part of the accuracy evaluation process for this map. The evaluation guarantees that the remote sensing categorization faithfully captures the actual distribution of crops and land use. To confirm the classification, field photos are used as reference points, and an error matrix is usually employed to compute statistical measures including overall accuracy, producer accuracy, and user accuracy. This procedure increases trust in the map's use for land management and agricultural planning while also assisting in assessing the classification's dependability.(Fig.-6)

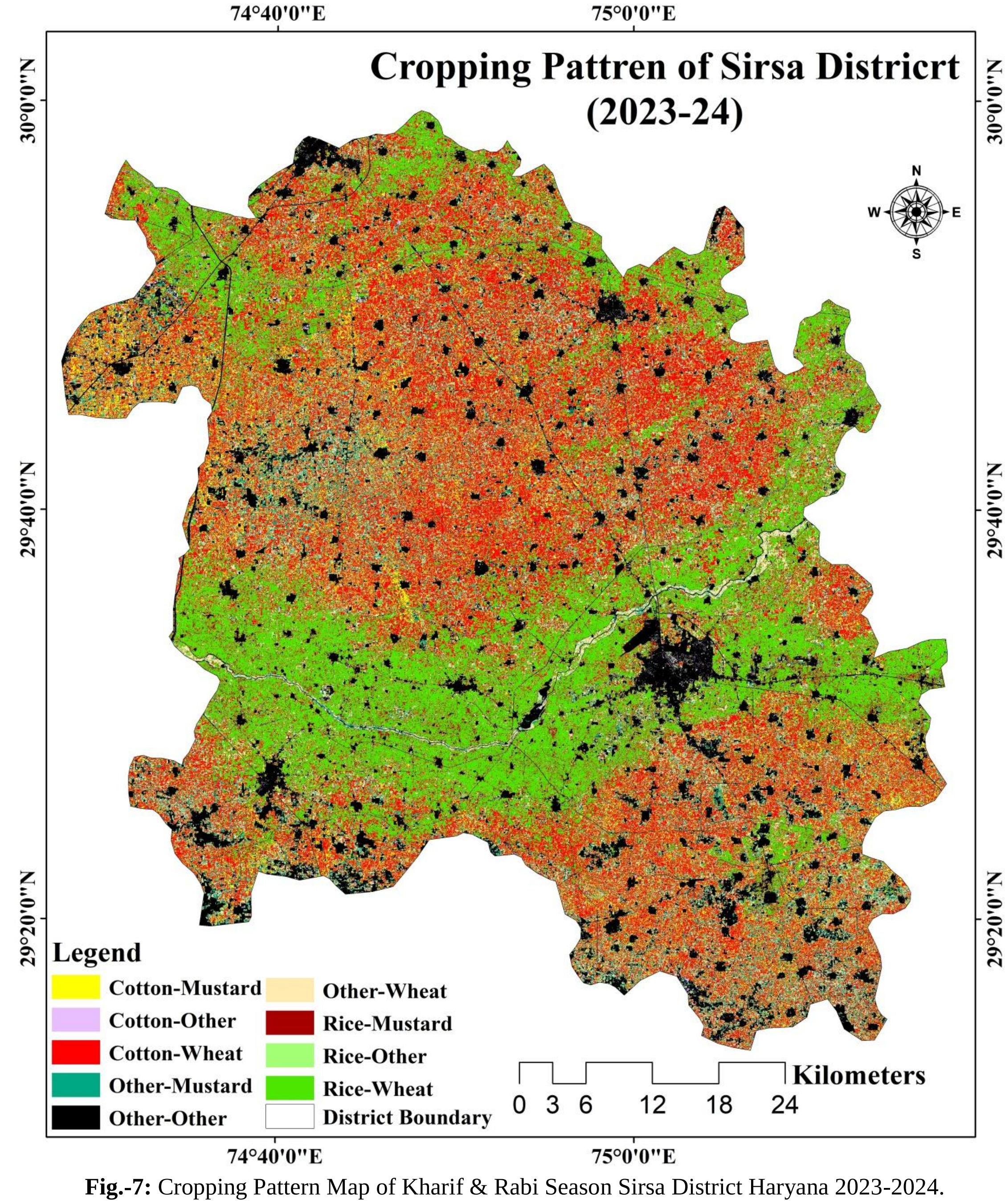

Fig.-7: Cropping Pattern Map of Kharif & Rabi Season Sirsa District Haryana 2023-2024.

This map shows Sirsa District cropping pattern for the year 2023-24, depicting different crop combinations with different colors.

Spatially, Ghagger Belt’s areas of the district are a mix of Rice-Wheat (green) and Cotton-Wheat (red) patterns of cultivation, the former being comparatively more prevalent towards the northeast. The western edge of the district is a tightly mixed blend of Cotton-Mustard (yellow) and Other-Wheat (orange). Southern and

southwestern districts are a mix of Rice-Mustard (dark red) and Cotton-Wheat, partly consisting of Other-Other (black) land use, which may be non-agricultural or fallow land.
Settlement and built-up land, marked black, occur dispersed but more intensely in the eastern and central part of the district, which might be the places of big towns or cities. The river network, represented by thin white lines, runs across the district and determines the cropping pattern.
Overall, the map provides good insights into the prevailing cropping patterns, and it reflects that Cotton-Wheat and Rice-Wheat are the dominant crop rotations with others in smaller proportions based on local soil, climate, and irrigation.(Fig.-7)

Table-3: Estimated Area of Cropping Pattern of Kharif & Rabi Season 2023-2024 of Sirsa District Haryana

Cropping Pattern of Sirsa (2023-2024)			
Sr. No.	**Cropping Pattern**	**Area in hac.**	**Area In %**
1	Cotton-Wheat	122245.6	28.9
2	Cotton-Mustard	57114.1	13.5
3	Cotton-Other	6887.0	1.6
4	Rice-Wheat	88366.9	20.9
5	Rice-Mustard	13899.8	3.3
6	Rice-Other	2089.1	0.5
7	Other-Wheat	42849.3	10.1
8	Other-Mustard	36371.4	8.6
9	Other-Other	53150.2	12.6
Total		**422973.4**	**100**

The table-3 provides cropping pattern statistics for Sirsa during the 2023-2024 cropping year. The table categorizes different cropping patterns based on the area they cover in hectares and the percentage of the total cropped area. The major cropping patterns are:

- Cotton-Wheat, covering 122,245.6 hectares (28.90%), is the most common cropping system.
- Rice-Wheat at 88,366.94 hectares (20.89%) is the second prominent trend.
- Cotton-Mustard, on 57,114.12 hectares (13.50%), is also practiced.

Cotton-Other crops take up 6,887.04 hectares (1.63%). This data reveals that Cotton-Wheat is the most common cropping pattern of Sirsa, followed by Rice-Wheat and Cotton-Mustard, showing the reliance of the area on these crops for farming.

III. CONCLUSION

The research effectively utilized Sentinel-2A satellite data and GIS methods to examine and map the cropping patterns of Sirsa District, Haryana, for the Kharif (2023) and Rabi (2024) seasons. Through the use of important spectral bands and classification methods, the study presented a comprehensive spatial distribution of prominent crops like cotton, rice, wheat, and mustard. The research successfully eliminated non-agricultural land and classified land cover types, allowing accurate crop area estimation. Ground truthing and accuracy checks further confirmed the classification outcome, validating the reliability of remote sensing for agricultural analysis. Evidence points to the predominance of cotton-wheat and rice-wheat cropping patterns highlighting the dependency of the region on these crop sequences because of the suitability of soils, climatic conditions, and irrigation facilities. The information further shows mustard production is concentrated within certain regions bringing about crop diversification. The spatial analysis showcases the role played by the Ghaggar Belt in sustaining the cultivation of rice, while the western edges of the district have cotton fields prevalent.

The research highlights the significance of GIS and remote sensing for sustainable farm management, which helps policymakers, scientists, and farmers with crucial information for strategic planning and optimizing resources.

Satellite data coupled with ground truthing guarantees correct land use evaluation, which helps in making better decisions for enhancing crop yields, water management, and sustainable agriculture in Sirsa District. This study illustrates that sophisticated geospatial technologies have the potential to be an important tool for improving food security, land use efficiency, and climate variability and resource constraint risk reduction.

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