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Spatial Distribution Of Crop Rotation Using GIS And Remote Sensing Of Mansa District, Punjab (2024–25)

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ABSTRACT

This study focused on the Kharif and Rabi crop rotation patterns in the Mansa district of Punjab for the year 2024–2025 using Sentinel-2 satellite imagery and Geographic Information System (GIS) techniques. Agriculture in Punjab, India, plays an essential role in national food security, with the region contributing important role for the country's wheat and rice production. Unsustainable crop rotation practices, groundwater depletion, and soil fertility loss have become major issues in recent years. The research focuses on mapping and assessing the spatial distribution of major crops such as cotton, paddy, wheat, and mustard, which shows the region's double-cropping system. Unsupervised classification was carried out in ERDAS Imagine, and the classified outputs were further analyzed and mapped in ArcGIS 10.8 software. The study identifies that cotton and paddy are the major Kharif crops, while wheat and mustard dominate during the Rabi season. The crop rotation analysis shows a strong dependence on irrigation infrastructure, particularly canal and tube well systems, influencing the intensity and type of crop rotation. This study demonstrates the potential of remote sensing and GIS for monitoring crop dynamics, supporting sustainable land use planning, and aiding policymakers in improving agricultural resource management and soil health in Punjab's semi-arid zones.

Keywords:-*Crop rotation, Kharif and Rabi, Mansa district, Remote sensing, GIS, Sentinel-2, agricultural monitoring*

INTRODUCTION

Punjab, known as the "Granary of India," plays an important role in India's agricultural production due to its fertile alluvial soils, assured irrigation facilities, and favorable agro-climatic conditions. Over the decades, the agricultural system in Punjab has become highly dependent on the rice-wheat cropping system, which although productive, has led to multiple ecological and economic challenges, including groundwater depletion, soil nutrient imbalance, declining soil fertility, and reduced biodiversity.In this context, spatial analysis of cropping patterns and rotations has become vital for understanding regional agricultural dynamics. Modern remote sensing and GIS technologies provide valuable tools for monitoring spatial and temporal variations in crop distribution.

This study aims to analyze the spatial distribution of crops and crop rotation patterns in Mansa District for the agricultural year 2024–25 using unsupervised classification techniques.

Agriculture in Punjab, particularly in districts like Mansa, is characterized by an intensive and highly productive cropping system where crop rotation plays central role in maintaining soil health and ensuring long-term sustainability. Crop rotation—the systematic alternation of different crops on the same land during successive seasons—enhances soil fertility, improves nutrient balance, and minimizes pest and disease incidences. The Kharif–Rabi rotation system, involving crops such as cotton, rice, wheat, and mustard, forms the backbone of Punjab's agricultural landscape, significantly influencing the region's economy and food security.

Recent advancements in remote sensing and Geographic Information System (GIS) technologies have provided powerful tools for analyzing and monitoring crop rotation patterns with high spatial and temporal accuracy. Sentinel-2 satellite imagery, with its multispectral and high-resolution capabilities, enables detailed mapping of seasonal crop transitions. Digital Image Processing (DIP) methods such as supervised and unsupervised classification, along with vegetation indices like the Normalized Difference Vegetation Index (NDVI) and False Color Composite (FCC), enhance the ability to distinguish between various crop types and land-use patterns across seasons.

Ground truth data collected through GPS surveys further validate satellite-based classifications, increasing the reliability of crop mapping and rotation analysis. By integrating remote sensing data with GIS and field observations, researchers can effectively assess spatial variations, cropping intensity, and the sustainability of existing crop rotations.

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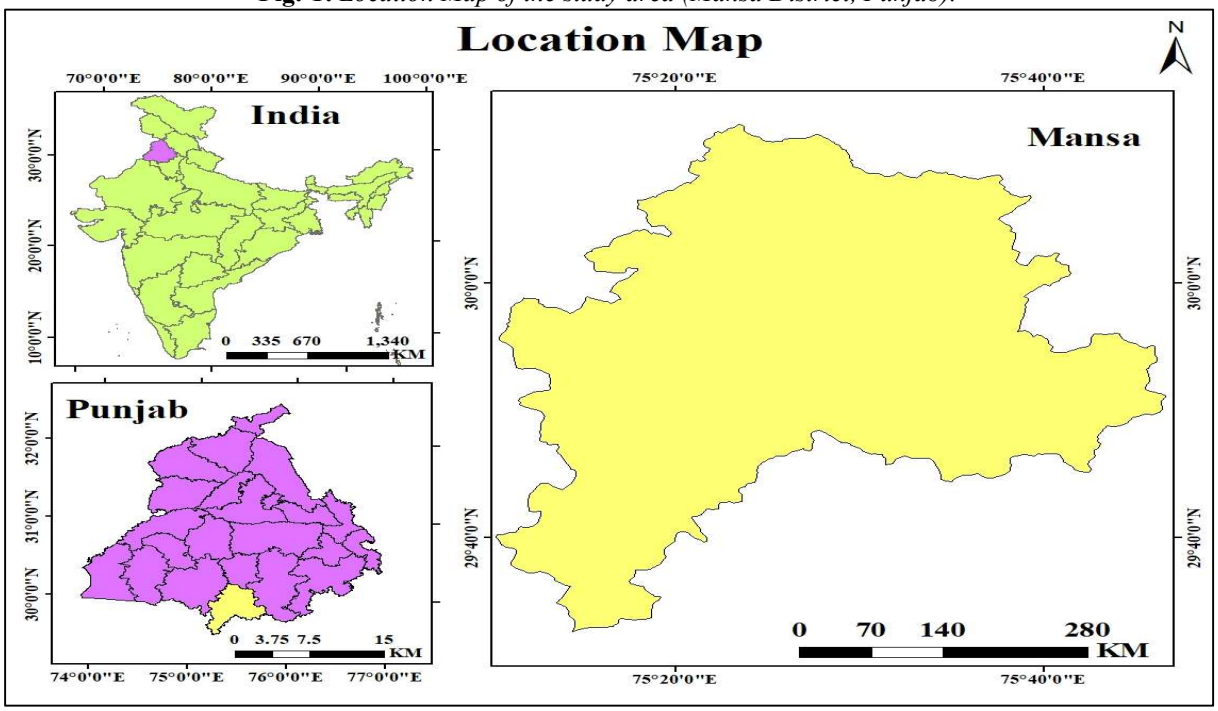
STUDY AREA

The present study was conducted in Mansa District, located in the southwestern part of Punjab, India. Geographically, Mansa lies between 29°33′ N to 30°03′ N latitude and 75°10′ E to 75°47′ E longitude. The district covers an area of approximately 2,174 square kilometers and is bordered by Bathinda District to the west, Barnala District to the northeast, and Sangrur District to the east. Administratively, Mansa comprises three main tehsils-Mansa, Budhlada, and Sardulgarh-with Mansa city serving as the district headquarters.The region experiences a semi-arid climate, with hot summers, scanty rainfall, and cold winters. The mean annual rainfall is around 400–500 mm, most of which occurs during the monsoon months (June–September).Agriculture forms the backbone of Mansa's economy, with wheat, cotton, rice, and mustard being the dominant crops.

Fig.-1: *Location Map of the study area (Mansa District, Punjab).*



Source: Prepared by the researcher with the help of QGis from the data Administrative Boundary by Survey of India (SoI).

The cropping intensity is high, and irrigation is primarily sourced from tube wells and canals. Due to excessive groundwater extraction and limited crop diversification, sustainable land-use management is a growing concern in the district.

The soils are generally alluvial to sandy loam, making them suitable for the cultivation of major crops such as wheat, paddy, cotton, and mustard. Agriculture is the predominant occupation of the population, and the district plays a vital role in Punjab's agricultural economy. The study area was selected due to its significant dependence on agriculture and its well-defined Kharif–Rabi crop rotation patterns, which make it an ideal site for spatial and temporal analysis of cropping dynamics using remote sensing and GIS techniques.

The Mansa district of Punjab, located in the semi-arid Malwa region, is one of the key agricultural zones where farmers practice intensive cultivation. Analyzing crop rotation **patterns** during the agricultural year 2024–25 is essential to understand the ongoing trends in diversification, productivity, and resource sustainability. Such assessments help identify region-specific cropping systems that balance economic returns with ecological stability. The map shows the geographical location of the study area, Mansa district, within the state of Punjab, India. The first map shows the position of Punjab within India, while the second map highlights the location of Mansa within Punjab. The main map shows the boundaries of Mansa district.

MATERIAL AND METHODS

Data Collection and Processing: The study involves two types of data: satellite data and ground truth data for crop rotation identification in the Mansa district Punjab. Both datasets are very important for the identification, classification, and validation of cropping patterns during different seasons. We used

Sentinel-2 (10 m resolution) data. The study utilized Sentinel-2 imagery for both Rabi and Kharif seasons (2024–25).

- **Satellite Data:-**All satellite data were geometrically and radiometrically corrected using ERDAS Imagine 2022. Sentinel-2 (10 m resolution) imagery was used for this study because of its high spatial and temporal resolution, which is suitable for agriculture monitoring and land cover identification.
- **Layer Stack:-** A layer stack is the process of combining multiple raster layers or spectral bands from satellite imagery into a single multi-layered dataset. Each layer or band represents data captured at a specific wavelength or time, and stacking them allows for integrated analysis of features such as vegetation, soil, water, or crop types. Layer stacking is commonly used in Remote sensing for image classification, change detection, and temporal or multi-spectral analysis. The particular bands 2,3,4 and 8 were used, corresponding to:

Band 2- Blue
Band 3- Green
Band 4- Red
Band 8- Near infrared (NIR)

These bands were stacked together to form a uniform layer stack.

- **Subset image from study area:-**A subset image is a portion of a large satellite image that corresponds specifically to the geographical boundaries of the study area. Creating a subset allows researchers to focus only on the region of interest, which reduces data volume, minimizes processing time, and enhances the accuracy of spatial analysis. This process is commonly applied in Remote sensing studies for tasks such as crop mapping, land use classification, and vegetation monitoring. Subsetting the imagery to the Mansa District boundary to focus on the agricultural region.
- **Remove Non-agriculture:-**Removing Non-agricultural area is a preprocessing step in Remote sensing . It is used for accurate crop mapping and analysis. In this process, non-agricultural areas were removed using a masking technique. Firstly, polygons of non-agricultural land cover were manually digitized based on satellite imagery. These polygons were masked and removed all pixels related to non-agricultural land using geospatial techniques in GIS or Remote Sensing software. This ensured that subsequent analysis focused only on agricultural land cover, enhancing classification accuracy and analytical reliability.
- **Process of Masking**: Masking is a process used in Remote Sensing to extract specific area of interest (AOI) from a satellite image. It helps focus analysis only on the selected area, such as a particular district or field for detailed study like crop identification or land use mapping etc.

Methods: The present study employed an integrated Remote Sensing and GIS–based approach to analyze cropping pattern and crop rotation in Mansa District, Punjab, for the agricultural year 2024–25. Multi-temporal satellite data were used to capture seasonal variations between the Kharif and Rabi seasons**.**

- **Unsupervised classification**:-Unsupervised classification is a digital image processing technique used in remote sensing where the computer automatically groups pixels into clusters based on their spectral properties like color, reflectance, etc. without any initial knowledge or training data**.**

Fig.-2: *Methodology Flow Chart.*

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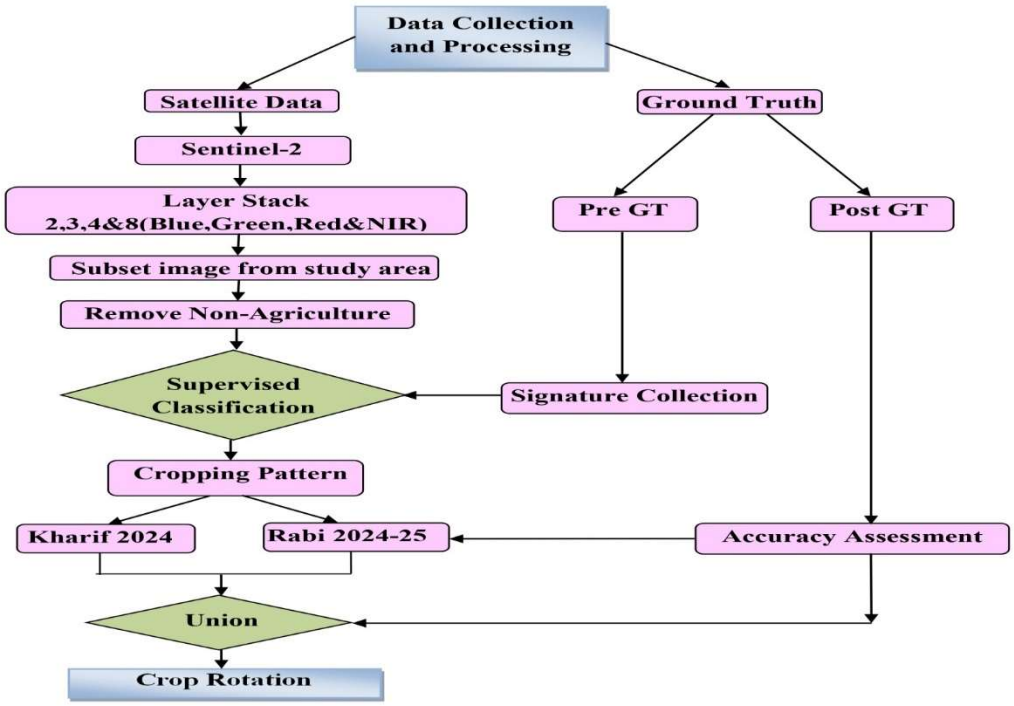

Common methods include ISODATA and K-means clustering**.** We used Unsupervised classification technique on the pre-processed Sentinel-2 imagery. In this method, the software groups pixels into clusters based on their spectral similarity without prior knowledge of crop types. The clusters were later interpreted and labeled using ground truth data to identify crop classes. An unsupervised classification technique was applied using k mean algorithm in ERDAS Imagine. The classification mainly generated 36 spectral clusters, which were merged into major crop classes based on field knowledge and GT. The final classes were identified as:

Wheat, Mustard, Rice, Cotton and Other crops.

Cropping Pattern:- Separate classified maps were created for the Kharif and Rabi seasons. The identified crop classes were analyzed to determine the cropping pattern during each season Kharif and Rabi. The classified images were analyzed two major agricultural seasons:

- Kharif 2024
- Rabi 2024–25

Each season's cropping pattern was identified separately based on the classified
imagery and verified through ground observations.

Union:- The union process is a GIS operation that combines multiple spatial layers into a single layer, retaining all information from the input layers (Jensen, 2015). In agricultural studies, it is used to merge Kharif and Rabi crop maps to analyze crop distribution, rotation, and overlap within a study area.

RESULT AND DISCUSSION:

The crop rotation map illustrates the spatial transitions between Rabi and Kharif crops. The overlay analysis indicates that approximately 65–70% of the agricultural land follows a double-cropping system (Kharif–Rabi), predominantly Rice–Wheat or Cotton–Wheat rotations. Around 15% of the land remains single-cropped, often due to water scarcity or poor soil fertility, while fallow and built-up areas constitute the remainder.

Cropping Pattern of Kharif Season:

The Kharif cropping pattern of Mansa District is strongly dominated by **rice**, which occupies about **74.23%** of the total cropped area. This reflects the district's high dependence on water-intensive paddy cultivation, supported by canal irrigation and widespread groundwater extraction. Rice fields are spatially extensive and form a nearly continuous agricultural cover across most parts of the district during the Kharif season.

The table clearly corresponds with the spatial pattern shown in the Kharif crops distribution map of Mansa District. **Rice** is the dominant Kharif crop, occupying **160,995.65 hectares (74.23%)** of the total area. This dominance is visually evident on the map, where green colour extensively covers almost the entire district, indicating widespread rice cultivation due to assured irrigation and suitable agro-climatic conditions.

Fig.-3: *Spatial Distribution of Kharif crops Mansa District Punjab 2024.*

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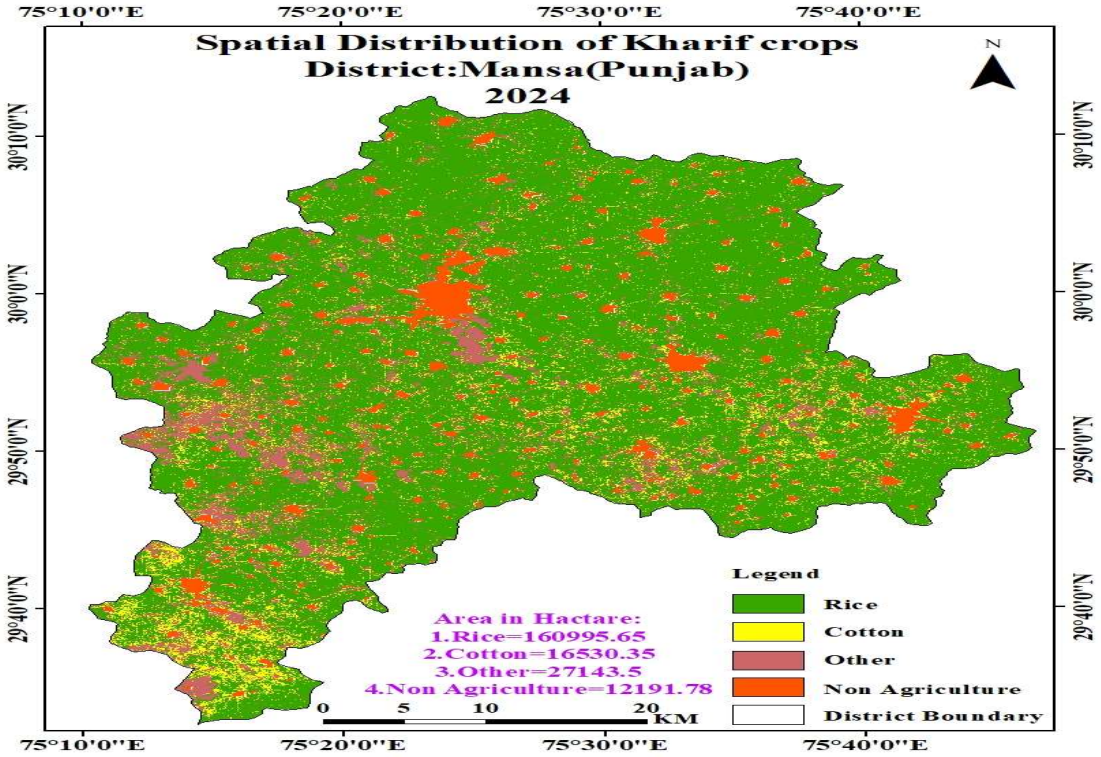

Source: Prepared by the researcher with the help of QGis from Satellite data (Sentinel-2).

Cotton covers **16,530.35 hectares (7.62%)** and is represented by yellow patches on the map. These areas are mainly concentrated in the southern and south-western parts of the district, where soil texture and relatively lower water availability favour cotton cultivation over rice.

Table-1: Spatial Distribution of Kharif crops Mansa District Punjab 2024

Sr.No.	Crop/LULC	Area in Hectare	Area in %
1	Rice	160995.6	74.23
2	Cotton	16530.3	7.62
3	Non-Agriculture	12191.7	5.62
4	Others	27143.5	12.51
Total		**216861.2**	**100**

The **'Others'** category accounts for **27,143.50 hectares (12.51%)**, shown in light brown color. These scattered patches represent minor Kharif crops such as fodder, pulses, and oilseeds, distributed intermittently across the district, often mixed with rice and cotton fields.

Non-agricultural land, covering **12,191.78 hectares (5.62%)**, is depicted in orange on the map. These areas correspond to built-up land, roads, settlements, water bodies, and other non-cultivated surfaces, which appear as dispersed clusters throughout the district with slightly higher concentration near urban centres.

Cropping Pattern of Rabi Season:

The Rabi cropping pattern of Mansa District is primarily dominated by **wheat**, which occupies the largest share of cultivated land during the winter season. Wheat is extensively grown across almost the entire district due to its suitability to the region's semi-arid climate, availability of canal and groundwater irrigation, and well-developed procurement and support systems. As a result, the landscape during the Rabi season is largely characterized by continuous wheat fields.

The table-2 and the spatial distribution map together depict the Rabi cropping pattern of Mansa District for the agricultural year 2024–25, clearly highlighting crop dominance, spatial spread, and land-use structure.

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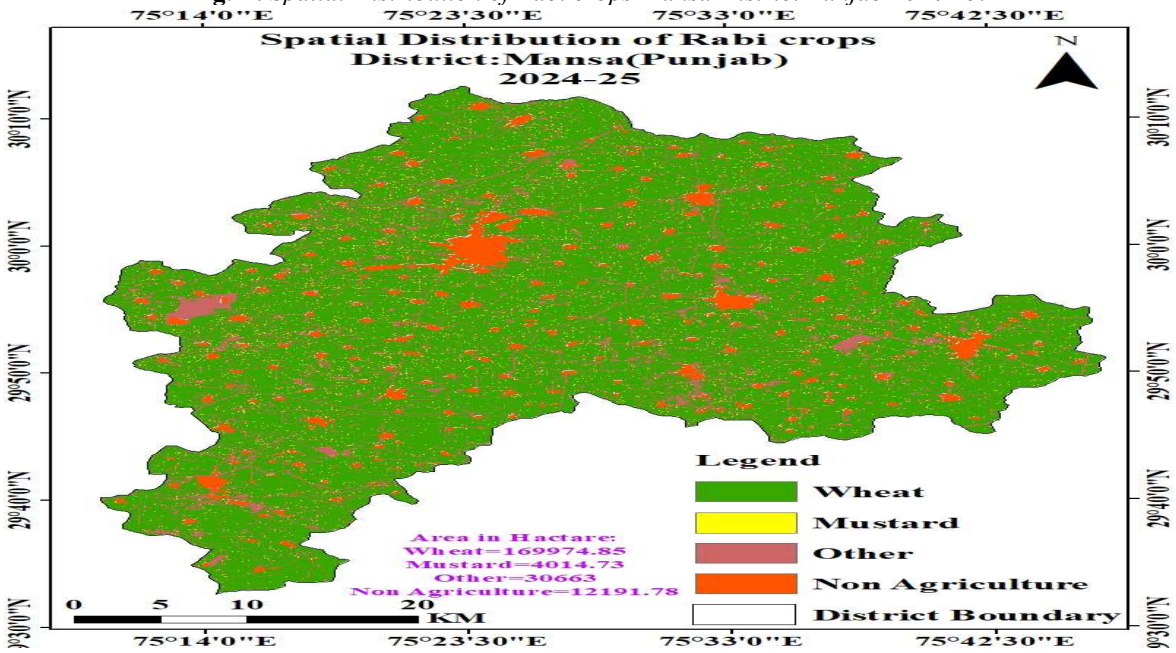
Wheat is the principal Rabi crop, occupying 169,974.85 hectares, which accounts for 78.39% of the total geographical area. This dominance is clearly visible on the map, where green colour extensively covers almost the entire district. The widespread distribution of wheat reflects favorable winter climatic conditions, well-developed irrigation infrastructure, and strong procurement support, making wheat the backbone of Rabi agriculture in Mansa.

Fig.-4: *Spatial Distribution of Rabi crops Mansa District Punjab 2024-25.*



Source: Prepared by the researcher with the help of QGis from Satellite data (Sentinel-2).

Mustard occupies a relatively small area of 4,014.73 hectares (1.85%) and is represented by yellow patches on the map. These areas appear as scattered pockets, mainly in regions with lighter soils and comparatively lower irrigation availability, where mustard is preferred due to its low water requirement and short growing period.

Table-2: *Spatial Distribution of Rabi crops Mansa District Punjab 2024-25.*

Sr.No.	Name	Area in Hectare	Area in %
1	Wheat	169974.85	78.39
2	Mustard	4014.73	1.85
3	Other	30663	14.14
4	Non Agriculture	12191.78	5.62
Total		**216844.36**	**100.00**

The 'Other crops' category covers 30,663 hectares (14.14%), shown in light brown colour. This group includes crops such as gram, barley, fodder crops, and vegetables. Their spatial distribution is dispersed across the district, often intermixed with wheat fields, indicating limited but essential crop diversification driven by local consumption needs and livestock fodder demand.

Non-agricultural land, accounting for 12,191.78 hectares (5.62%), is depicted in orange on the map. These areas represent settlements, roads, water bodies, and other built-up surfaces. They are spatially clustered around urban centers and along transport corridors, remaining largely constant across seasons.

Accuracy Assessment for Both Season (Rabi and Kharif):

The accuracy assessment of the classified crop maps for Kharif 2024 and Rabi 2024–25 was carried out to evaluate the reliability of crop identification in Mansa District using Sentinel-2 imagery. Since the classification was performed using an unsupervised approach, validation was conducted through visual interpretation, seasonal crop characteristics, and reference information from field observations and agricultural knowledge of the region.

Table-3: *Accuracy Assessment for Both Season (Rabi and Kharif)*

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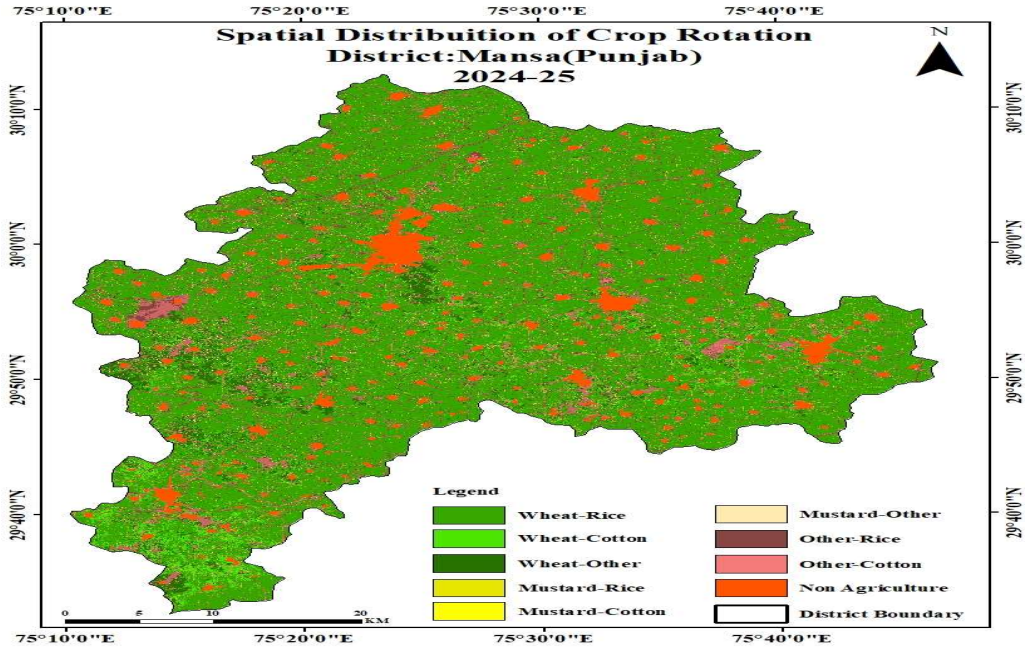
Crop Class	Producer's Accuracy (%)	User's Accuracy (%)
Rice	88–92	85–90
Cotton	78–84	76–82
Wheat	90–94	88–92
Mustard	75–82	73–80
Other Crops	70–78	68–76
Non-Agriculture	92–96	90–95

The crop rotation map was generated through GIS union analysis of the validated Kharif and Rabi crop maps. As both seasonal classifications exhibited high accuracy, the derived crop rotation patterns particularly Rice–Wheat and Cotton–Wheat rotations—are considered reliable for spatial analysis and interpretation. The overall accuracy of the crop rotation mapping is therefore estimated to be above 84%, which is acceptable for regional crop rotation studies.

Crop Rotation of Mansa District:

Crop rotation in Mansa District is largely characterized by a rice–wheat dominant system, which is the most prevalent agricultural practice across the district. During the Kharif season, rice occupies the maximum area, followed by cotton and minor crops, while in the Rabi season, wheat overwhelmingly dominates the cropped area.

Fig.5: Spatial Distribuition of Crop Rotation Mansa District Punjab 2024-25.



Source: Prepared by the researcher with the help of QGis from Satellite data (Sentinel-2).

The crop rotation pattern of Mansa District during 2024–25 is predominantly governed by the Wheat–Rice system, which occupies 147,389.61 hectares (67.96%) of the total area and appears as the most extensive and continuous class on the map, indicating strong dependence on irrigation-intensive cereal cultivation. The Wheat–Cotton rotation, covering 9,659.04 hectares (4.45%), is mainly confined to the southern and south-western parts of the district, where lighter soils and relatively lower water availability favor cotton during the Kharif season followed by wheat in Rabi.

Table-4: Spatial Distribution of Crop Rotation Mansa District Punjab 2024-25

Sr.No.	Crop Rotation	Area in Hectare	Area in %
1	Wheat-Rice	147389.61	67.96
2	Wheat-Cotton	9659.04	4.45

3	Wheat-Other	12926.2	5.96
4	Mustard-Rice	2602.67	1.2
5	Mustard-Cotton	681.75	0.31
6	Mustard-Other	730.32	0.34
7	Other-Rice	10990.08	5.07
8	Other-Cotton	6188.19	2.85
9	Non Agriculture	25724.73	11.86
Total		**216892.59**	**100**

The Wheat–Other rotation accounts for 12,926.20 hectares (5.96%) and represents areas where wheat is combined with fodder crops, pulses, or minor cereals, appearing as scattered patches across the district. Mustard-based rotations, including Mustard–Rice (1.20%), Mustard–Cotton (0.31%), and Mustard–Other (0.34%), together form a very small share of the total area and are limited to marginal zones, reflecting mustard's role as a low-water alternative crop. The Other–Rice (5.07%) and Other–Cotton (2.85%) rotations indicate limited diversification with minor crops and are spatially discontinuous on the map. Non-agricultural land, covering 25,724.73 hectares (11.86%), is concentrated around urban settlements and infrastructure. Overall, the table and map together reveal a highly cereal-dominated and less diversified crop rotation system, highlighting increasing pressure on groundwater resources and the need for sustainable crop diversification in Mansa District.

CONCLUSION

This study demonstrates the effective use of Sentinel-2 imagery, unsupervised classification, and GIS spatial analysis in evaluating crop distribution and rotation patterns in Mansa District, Punjab. The results highlight the predominance of wheat during the Rabi season and the persistence of traditional double-cropping systems. Limited crop diversification continues to challenge the sustainability of the region's agriculture.

The present study provides a comprehensive spatio-temporal assessment of cropping pattern and crop rotation in Mansa District, Punjab, using geospatial techniques. The analysis of Kharif, Rabi, and crop-rotation maps clearly reveals a highly cereal-dominated agricultural system, with rice in the Kharif season and wheat in the Rabi season forming the backbone of regional agriculture. The Wheat–Rice rotation alone accounts for nearly two-thirds of the total cultivated area, indicating strong dependence on irrigation-intensive crops supported by favorable policies, assured irrigation, and established procurement mechanisms.

Cotton-based and mustard-based rotations occupy relatively smaller areas and are spatially confined to specific agro-ecological zones, particularly in the southern and south-western parts of the district where soil and water conditions are comparatively marginal. Although minor crops, fodder, and pulses are present under "other" categories, their spatial extent remains limited and fragmented, reflecting low crop diversification across the district.

The dominance of the Rice–Wheat system, as highlighted by both the statistical tables and spatial maps, raises serious concerns regarding groundwater depletion, soil health degradation, and long-term agricultural sustainability. The non-agricultural land share further indicates gradual pressure on cultivable land due to urbanization and infrastructure development.

Overall, the study demonstrates the effectiveness of remote sensing and GIS in accurately mapping cropping patterns and crop rotations at the district level. The findings emphasize the urgent need to promote diversified and resource-efficient crop rotations, such as pulses, oilseeds, and less water-intensive crops, to reduce environmental stress and ensure sustainable agricultural development in Mansa District.

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