International Journal of Engineering and Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 14 Issue 8 August 2025 || PP 57-65

Geospatial Assessment of Kharif–Rabi Cropping Patterns and Rotational Sequences Using Multispectral Satellite Data: A Case Study of Fatehabad Block, Haryana

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ABSTRACT
Spatiotemporal surveillance of agricultural land use provides fundamental spatial intelligence required for evaluating cropping intensity, resource efficiency, and agrarian sustainability across distinct agro-climatic cycles. This study investigates seasonal crop allocation dynamics and dual-season rotation systems across Fatehabad Block (Fatehabad District, Haryana), encompassing a geographic extent of 66,922.2 hectares during the 2024–25 agricultural year. High-resolution Sentinel-2 multispectral imagery captured during peak phenological windows for Kharif and Rabi seasons was processed within a GIS environment. To eliminate spectral confusion, an empirical non-agricultural spatial mask was constructed, successfully isolating pure cultivated surfaces from artificial built-up zones, transportation networks, and surface water bodies. Independent digital image classification procedures revealed that Wheat constitutes the primary winter cover, spanning 38,786.5 hectares (57.9%), whereas Rice leads summer cultivation at 25,453.0 hectares (38.0%). To delineate cross-seasonal land utilization, a vector-based topological Spatial Union operation intersected the classified Kharif and Rabi layers. The resulting rotation matrix established Wheat–Rice as the dominant sequence, occupying 21,719.4 hectares (32.45%), followed by Wheat–Cotton covering 8,333.9 hectares (12.45%), alongside localized Mustard-based rotations. These empirical findings underscore the utility of multi-temporal satellite observations and spatial overlay modeling in generating field-level agricultural insights for optimized land management.

Keywords: *Cropping Pattern, Crop Rotation Dynamics, Sentinel-2 Multispectral Imagery, Spatial Union, Remote Sensing & GIS, Crop Acreage Estimation, Fatehabad Block.*

I. INTRODUCTION

Agriculture plays a central role in sustaining food security, rural livelihoods, and ecological balance across semi-arid regions. Tracking seasonal land-use shifts and continuous cropping sequences is fundamental for assessing agricultural intensity, soil health, and regional water resource allocation. Over recent decades, traditional field-survey methods for crop monitoring have proven resource-intensive and spatially limited. Space-borne remote sensing technology, combined with Geographic Information Systems (GIS), offers an efficient, non-destructive, and high-resolution framework for multi-temporal surveillance of agricultural dynamics across broad geographical extents.

In the state of Haryana, agricultural productivity is heavily driven by dual-season cultivation cycles comprising Kharif (summer-monsoon) and Rabi (winter) seasons. Fatehabad Block, spanning a total geographical area of 66,922.2 hectares, represents an agrarian landscape reliant on intensive crop sequences like Wheat–Rice and Wheat–Cotton. Continuous monoculture and high-intensity rotation systems present significant challenges to long-term sustainability, including groundwater depletion and soil nutrient degradation. Therefore, generating high-precision spatial metrics of seasonal crop footprints and year-round rotational patterns is essential for evidence-based land administration.

Several researchers have utilized satellite remote sensing and GIS techniques to monitor regional cropping patterns, seasonal rotations, and land-use dynamics. They evaluated multi-temporal Sentinel-2A/B observations across Nathusari Chopta Block in Sirsa District, applying an ISODATA unsupervised classification framework to delineate seasonal crop boundaries. *(Kumar and Kumar, 2020)* They mapped dual-season cropping intensity in Sampla Block, Rohtak, utilizing IRS-P6 LISS-III satellite data. *(Savitpal et al., 2015)* To evaluate multi-decadal vegetation trends, leveraged long-term MODIS Normalized Difference Vegetation Index (NDVI) time-series data from 2000 to 2023 across Punjab, Pakistan. (*Nathaniel Blessing ,2025)* Furthering temporal crop assessment in North-Western Haryana,Tracked long-term agricultural shifts from 1990–1991 to 2021–2022 by comparing archived Landsat-5 imagery with contemporary Sentinel-2 datasets. *(Dr. Parveen ,2024)*

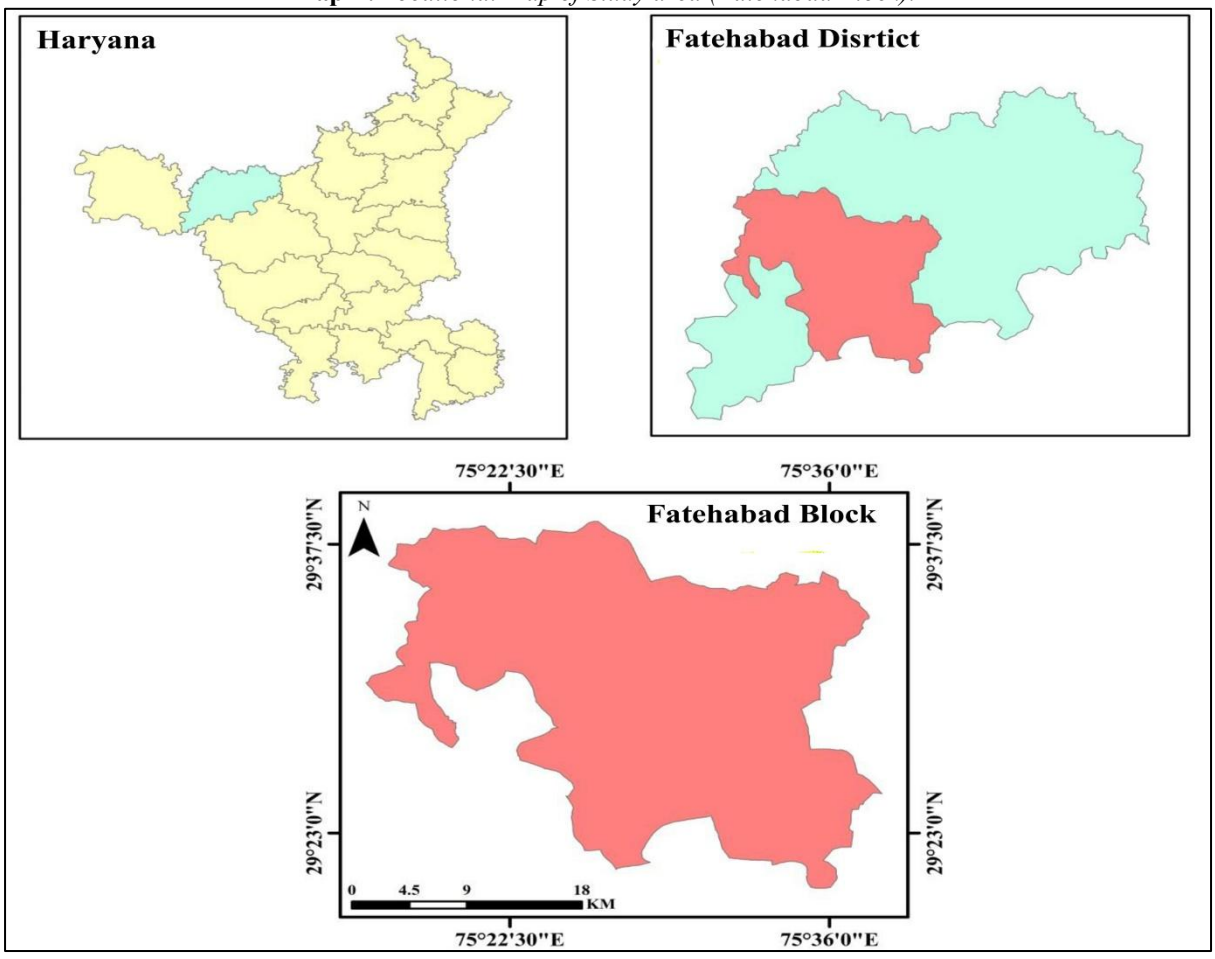
The research deployed high-resolution Sentinel-2B data for the 2020–2021 agricultural year in Rohtak District to evaluate field-level cropping intensity and seasonal land utilization. Extending this focus to resource degradation. *(Punia et al., 2021)* The study highlighted how intensive reliance on water-demanding Wheat–Rice rotations in Haryana has accelerated groundwater depletion, demonstrating that geoinformatics provides vital spatial intelligence for sustainable land-use planning and agricultural conservation.*(Devi J. et al. 2022, 2023)*

While previous studies have mapped individual seasonal extents, there remains a need for fine-resolution, object-level spatial integration of cross-seasonal boundaries. This research addresses this gap by utilizing high-resolution Sentinel-2 multispectral imagery from the 2024–25 agricultural year. By applying non-agricultural spatial masking alongside vector-based topological Spatial Union modeling, this study quantifies discrete crop acreages and derives dual-season rotation dynamics across Fatehabad Block to support sustainable regional agricultural planning.

II. STUDY AREA

The study was carried out in Fatehabad Block, north-western Haryana, India (between 29°20' N - 29° 35' N latitudes and 75°15' E - 75°35' E longitudes). Topographically, it features flat alluvial plains of the Ghaggar basin with localized sandy patches, operating under a semi-arid climate of extreme seasons and localized monsoons. Bordering Punjab, Sirsa, and Hisar, the block forms a dynamic linguistic transit corridor shaped by native agrarian groups and post-Partition resettlements.

Map-1: *Locational Map of Study area (Fatehabad Block).*

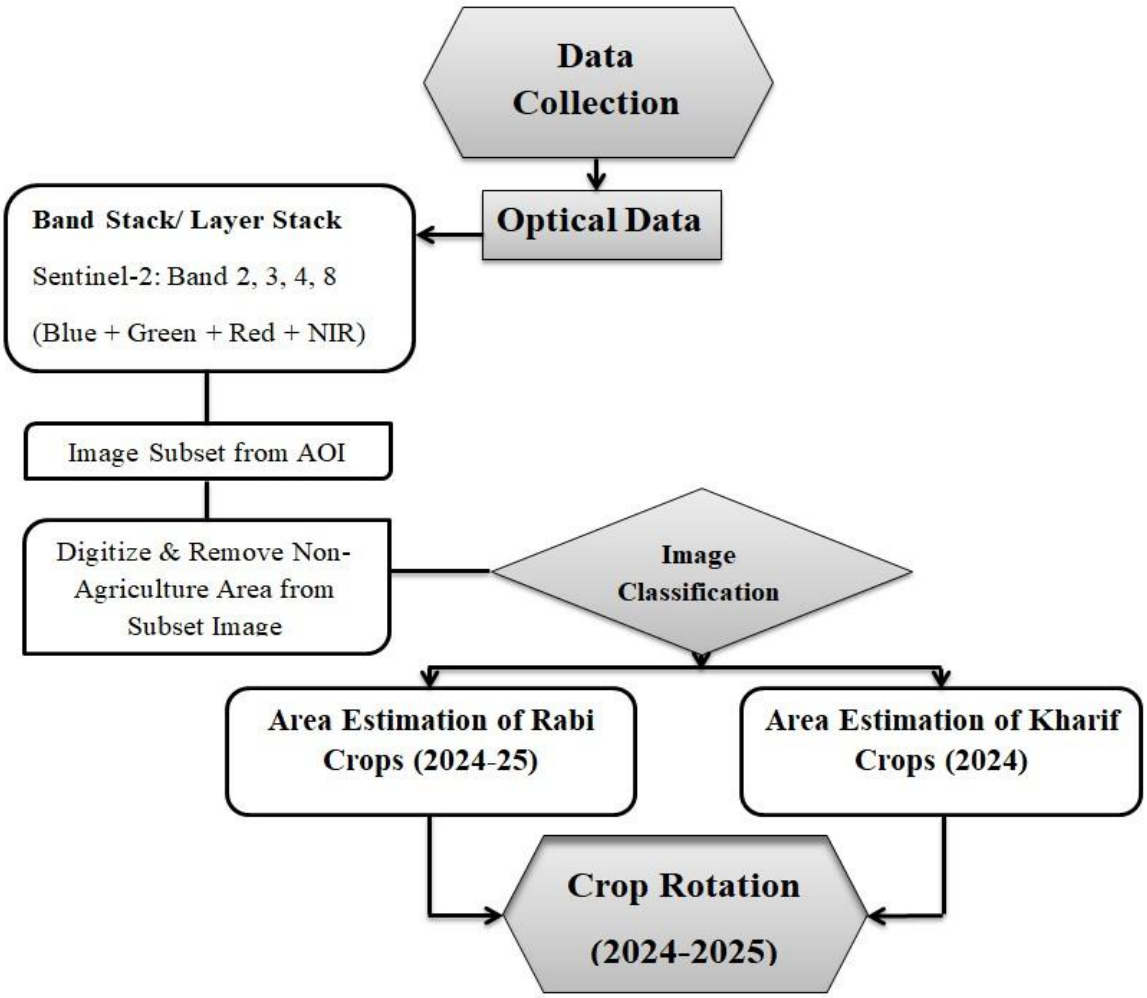


The local speech environment is defined by the active convergence of Bagri, and Malwai Punjabi, resulting in distinct phonological adaptations, lexical blending, and on-going code-mixing. Complemented by formal Hindi and English in official domains, Fatehabad block provides an ideal empirical setting for examining dialect contact and language variation.

III. DATASET & METHODOLOGY

i. **Data Acquisition & Spectral Layer Stacking:** Cloud-free multispectral Sentinel-2 imagery capturing peak crop vigor across both Kharif and Rabi seasons was acquired. The high-resolution optical bands—Band 2 (Blue), Band 3 (Green), Band 4 (Red), and Band 8 (Near-Infrared)—were extracted and layer-stacked to construct multi-band composite rasters for each season.

Figure 1.1: *Flow Chart of Methodology Spatial Sub-setting & Non-Agricultural*



ii. **Feature Masking:** The layer-stacked optical composites were spatially clipped to the boundary of the Area of Interest (AOI). To eliminate spectral interference, non-agricultural land use classes—including built-up urban/rural settlements, canal networks, roads, railway lines, and surface water bodies—were digitized and extracted via vector masking, isolating pure agricultural pixels.

iii. **Digital Image Classification:** Image classification procedures were independently applied to the refined Kharif and Rabi agricultural composites to categorize land cover into seasonal target crop types based on their distinct spectral signatures.

iv. **Seasonal Acreage Estimation:** Pixel-based spatial metrics were calculated by multiplying total classified pixel counts by the spatial resolution of the satellite sensor, generating precise geographical footprint estimations (in hectares and percentages) for individual Kharif and Rabi crops.

v. **Spatial Union & Crop Rotation Modeling:** To map year-round cropping sequences, the thematic classified layers of both seasons underwent a vector-based Spatial Union operation. This topological recombination intersected Kharif crop boundaries with corresponding Rabi footprints, populating a dual-season matrix (e.g., Rice–Wheat, Cotton–Wheat) to accurately quantify spatio-temporal crop rotation dynamics across the study region.

IV. RESULT & DISCUSSION

The multi-temporal remote sensing analysis captures seasonal agricultural dynamics across Fatehabad Block, highlighting spatial variations in land utilization during Kharif, Rabi, and continuous dual-season rotation cycles.

Rabi Crops (2024-25):

The Rabi cropping season in Fatehabad Block, Haryana, extends from November to April, with sowing during November-December and harvesting in March-April. The region is characterized by fertile alluvial soils and a well-developed canal and tube-well irrigation network, making it one of the important agricultural areas of western Haryana. Wheat is the dominant Rabi crop, covering the largest share of cultivated land, followed by mustard, gram (chickpea), barley, and berseem grown for fodder. The prevalence of irrigated agriculture supports high cropping intensity and makes wheat-mustard and wheat fodder systems the most common cropping patterns in the block.

The quantitative spatial statistics for the Rabi season across Fatehabad Block are presented in Table-1. Wheat emerges as the primary staple crop, dominating the landscape with an estimated acreage of 38,786.5 hectares (57.9%).

Table-1: *Area Estimation of Rabi Crop in Fatehabad Block (2024-25).*

Sr. No.	Class	Area in Hec.	Area in %
1	Wheat	38786.5	57.9
2	Mustard	4564.8	6.8
3	Others	19144.6	28.6
4	Non-Agriculture Area	4426.3	6.61
Total		**66922.2**	**100**

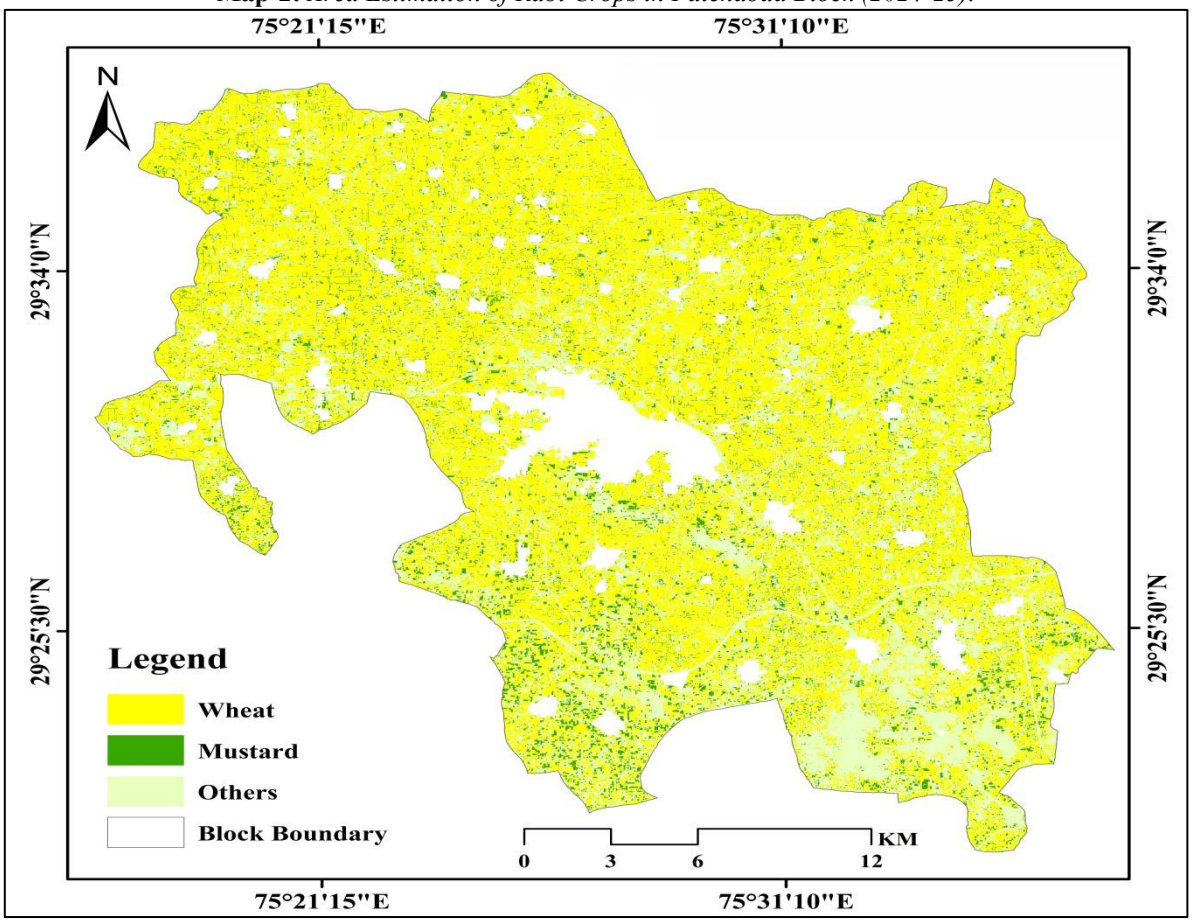
Mustard occupies a secondary footprint of 4,564.8 hectares (6.8%), serving as the principal oilseed crop of the region. The Others category, comprising fallow fields and minor agricultural patches, accounts for 19,144.6 hectares (28.6%), while Non-Agricultural Area constitutes 4,426.3 hectares (6.61%) of the total 66,922.2 hectares geographical area. Overall, these metrics highlight the overwhelming prevalence of wheat cultivation and provide a baseline for spatial land-use allocation across the block.

Spatial Distribution of Rabi Crop (2024-25):

The spatial distribution of Rabi crops in Fatehabad Block for the 2024–25 seasons was mapped using classified Sentinel-2 satellite imagery (10 m spatial resolution). The classification identified three major land-use classes: Wheat, Mustard, and Others. Wheat is the dominant crop and occupies the largest proportion of cultivated land across the block, while mustard is distributed in scattered agricultural fields, particularly in suitable irrigated and light-textured soils. The Others class includes minor Rabi crops, fallow land, fodder crops, and non-agricultural areas, providing a comprehensive representation of the seasonal agricultural landscape.

Wheat (yellow) is the dominant Rabi crop and is uniformly distributed across almost the entire block, indicating its extensive cultivation under irrigated conditions. Mustard (green) occurs in scattered patches, with a higher concentration in the southern and south-western parts of the block, where it is grown alongside wheat in suitable agricultural fields. The Others class (light green) represents minor Rabi crops, fodder fields, fallow land, and non-agricultural areas, which are mainly observed around settlements and localized agricultural patches.

Map-2: *Area Estimation of Rabi Crops in Fatehabad Block (2024-25).*



As depicted in Map-2, digital classification of high-resolution Sentinel-2 imagery delineates spatial allocations across the agricultural surface. Wheat forms the predominant crop blanket (yellow), occupying contiguous arable belts throughout the northern, central, and eastern agricultural tracts due to favourable irrigation infrastructure and fertile soils. Conversely, Mustard (dark green patches) exhibits localized spatial clustering in central-western and southern parcels.

Kharif Crops (2024):

The Kharif cropping season in Fatehabad Block, Haryana, extends from June to October, with sowing during the monsoon (June–July) and harvesting in September–October. The region's fertile alluvial soils and extensive canal and tube-well irrigation support diverse Kharif agriculture. Cotton is the principal Kharif crop and occupies the largest cultivated area, followed by paddy (rice), pearl millet (bajra), guar (cluster bean), and fodder crops such as sorghum and maize. Cotton–wheat and paddy–wheat are the predominant cropping systems, contributing significantly to the agricultural economy of Fatehabad Block.

Table-2: Area Estimation of Kharif Crop in Fatehabad Block (2024)

Sr.No.	Class	Area in Hec.	Area in %
1	Rice	25453.0	38
2	Cotton	13711.0	20.4
3	Others	23331.9	34.8
4	Non-Agriculture Area	4426.3	6.6
Total		**66922.2**	**100**

The classified spatial metrics for the Kharif season across Fatehabad Block are structured in Table 4.2. Rice serves as the primary Kharif crop, occupying an estimated footprint of 25,453.0 hectares (38.0%) of the total geographical area. Cotton acts as the key commercial cash crop, covering 13,711.0 hectares (20.4%), while the Others class (fallow fields and minor crops) accounts for 23,331.9 hectares (34.8%). Non-agricultural

infrastructure covers 4,426.3 hectares (6.6%), bringing the total evaluated spatial extent of the block to 66,922.2 hectares.

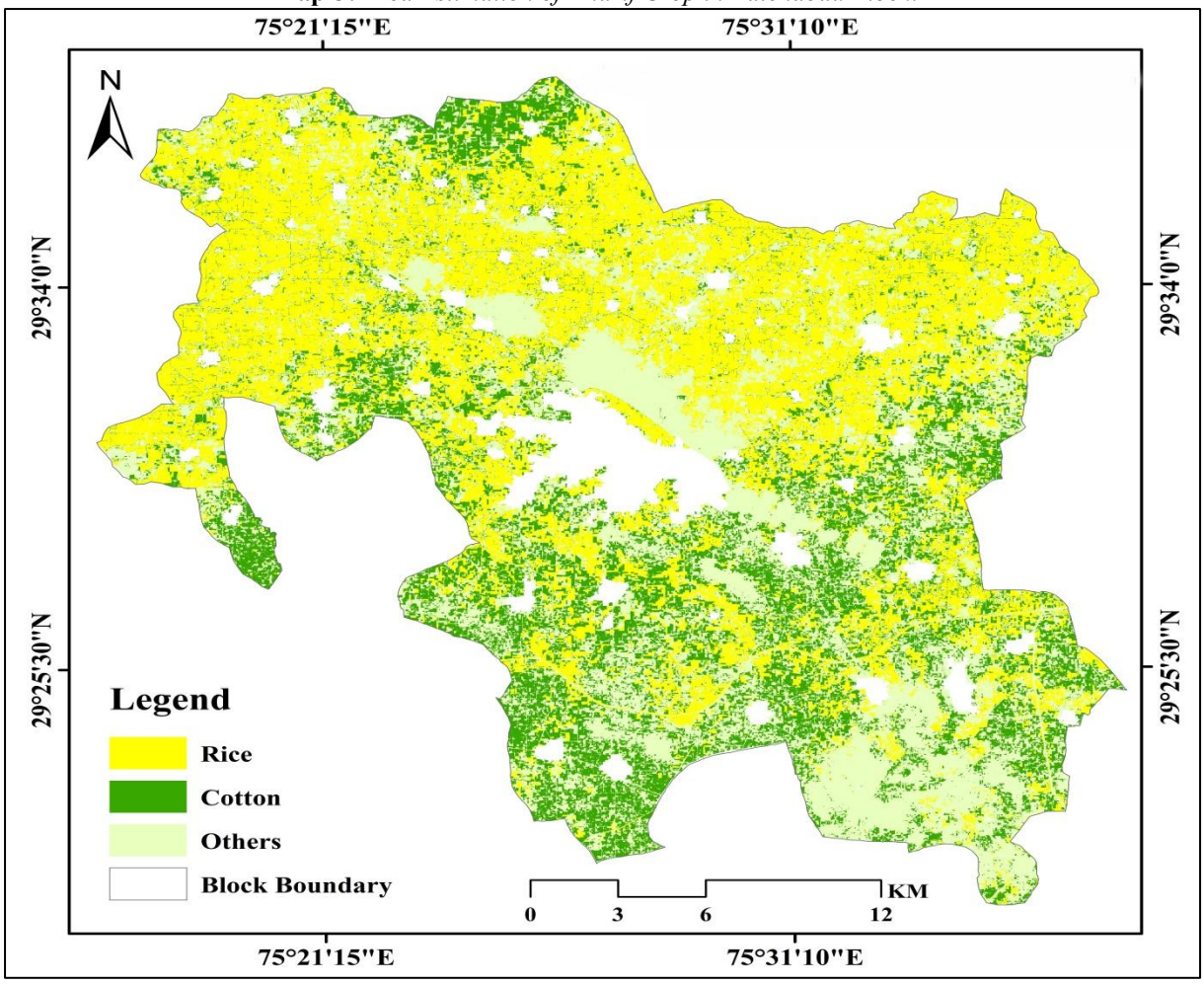
Spatial Distribution of Kharif Crop (2024):

The spatial distribution of Kharif crops in Fatehabad Block for the 2024 season was mapped using classified Sentinel-2 satellite imagery (10 m spatial resolution). The classification identified three major classes: Cotton, Paddy, and Others. Cotton is the dominant Kharif crop, occupying the largest share of cultivated land across the block, while paddy is concentrated in well-irrigated agricultural areas. The others class includes pearl millet (bajra), guar, fodder crops, fallow land, and non-agricultural areas, providing a comprehensive representation of the Kharif agricultural landscape.

The classified map shows that rice (yellow) is the dominant Kharif crop and occupies the largest proportion of cultivated land, particularly across the northern, central, and north-eastern parts of Fatehabad Block. Its continuous and widespread distribution indicates the prevalence of well-irrigated agricultural fields suitable for paddy cultivation.

Cotton (green) is the second major Kharif crop and is mainly concentrated in the southern, south-western, and south-eastern regions of the block. These areas exhibit dense clusters of cotton fields, reflecting the preference for relatively well-drained soils and the widespread adoption of the cotton-based farming system.

Map-3: *Area Estimation of Kharif Crop in Fatehabad Block.*



The Others (light green) category includes minor Kharif crops, fodder crops, fallow land, orchards, settlements, and other non-agricultural land uses. These patches are primarily observed around village settlements and in localized agricultural areas throughout the block.

Interspersed fallow lands and minor crop patches are represented under others (beige areas), while non-agricultural built-up zones and infrastructure are shown as masked void spaces (white patches) throughout the block.

Crop Rotation of Rabi & Kharif Crop (2024-25):

Crop rotation is a widely practiced agricultural system in Fatehabad Block, Haryana, to maintain soil fertility, improve productivity, and reduce pest and disease incidence. The most common rotation is Cotton-Wheat, followed by Paddy-Wheat. This seasonal alternation between Kharif and Rabi crops enhances efficient use of irrigation resources, nutrients, and land, contributing to sustainable agricultural production in the region.

The quantitative evaluation in Table 4.3 details the spatio-temporal dynamics of dual-season crop sequences across Fatehabad Block during the 2024–25 agricultural cycle. The Wheat–Rice sequence dominates as the primary rotation system, covering 21,719.4 hectares (32.45%) of the total land area.

Table-3: *Crop Rotation of Rabi and Kharif Crops (2024–25).*

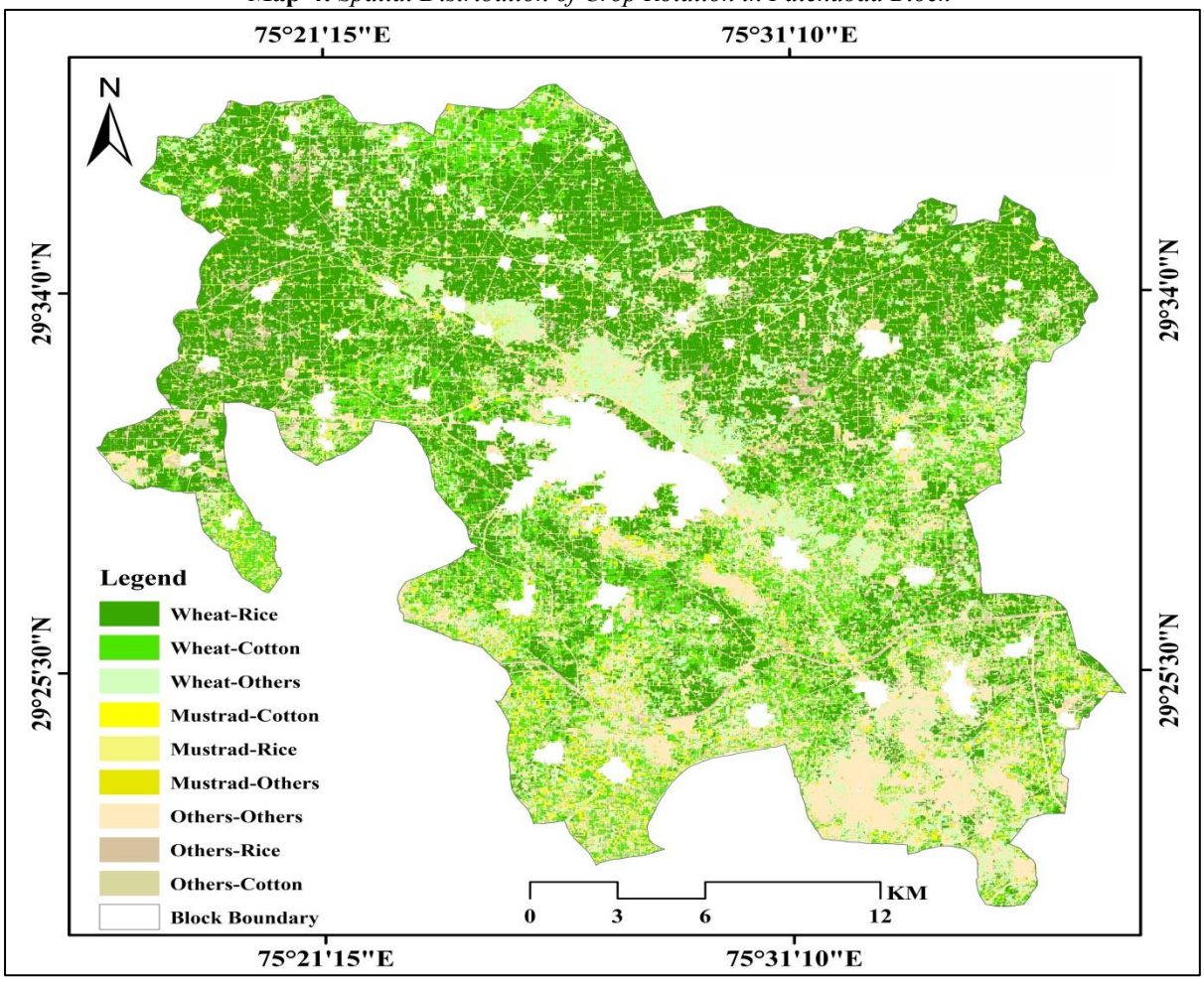
Sr. No.	Class	Area in Hec.	Area in %
1	Wheat-Rice	21719.4	32.45
2	Wheat-Cotton	8333.9	12.45
3	Wheat-Others	8710.4	13
4	Mustard-Rice	927.7	1.39
5	Mustard-Cotton	1673.6	2.5
6	Mustard-Others	1902.0	2.8
7	Others-Rice	2773.2	4.1
8	Others-Cotton	3698.5	5.5
9	Others-Others	12757.1	19
10	Non-Agriculture Area	4426.3	6.61
Total		**66922.2**	**100**

Wheat–Cotton forms the secondary major agricultural sequence at 8,333.9 hectares (12.45%), closely followed by Wheat–Others at 8,710.4 hectares (13%). Secondary oilseed-based sequences including Mustard–Cotton (2.5%), Mustard–Rice (1.39%), and Mustard–Others (2.8%) represent localized crop choices across the region. Fields categorized under Others–Others account for 12,757.1 hectares (19%), while Non-Agriculture Area comprises 4,426.3 hectares (6.61%) of the block's overall 66,922.2 hectares geographical extent.

Spatial Distribution of Crop Rotation (2024-25):

The spatial distribution of crop rotation in Fatehabad Block for 2024–25 was derived using classified Sentinel-2 satellite imagery of both Kharif 2024 and Rabi 2024–25 seasons. The analysis identified the major crop rotation classes, including Cotton–Wheat, Paddy–Wheat, and Others. Cotton–Wheat is the predominant rotation across the block, while Paddy–Wheat is mainly concentrated in well-irrigated areas. The Others class represents minor crop rotations, fodder-based systems, fallow land, and non-agricultural areas, providing a comprehensive view of seasonal agricultural land use.

Map-4: *Spatial Distribution of Crop Rotation in Fatehabad Block*



The spatial distribution Map 1.4 illustrates the dual-season cropping sequences derived from topological union analysis across Fatehabad Block. The Wheat–Rice system (dark green) forms a dense, contiguous spatial blanket dominant across northern and central agricultural belts with assured canal irrigation. The Wheat–Cotton sequence (light green) is heavily concentrated in the central-western and southern parcels, reflecting regional crop adaptability to lighter soil profiles. Minor rotations involving Mustard–Cotton and Mustard–Rice (yellow and olive tones) display localized clusters, while multi-seasonal fallow and secondary crop combinations (Others–Others) are distributed as fragmented patches throughout the block.

V. CONCLUSION

This study successfully integrated multi-temporal Sentinel-2 satellite imagery and GIS-based spatial overlay operations to map and quantify seasonal crop dynamics and rotation patterns across Fatehabad Block for the 2024–25 agricultural years. By executing a dedicated non-agricultural spatial masking process, pure cultivated land pixels were isolated, enabling precise digital classification of Kharif and Rabi season crops. The analytical findings indicate that Wheat dominates the Rabi cycle, covering 38,786.5 hectares (57.9%), while Rice leads the Kharif season, occupying 25,453.0 hectares (38.0%) of the total geographical area. The topological spatial union of seasonal layers revealed that the Wheat–Rice crop rotation system forms the primary agricultural backbone of the region, encompassing 21,719.4 hectares (32.45%), followed by the Wheat–Cotton sequence at 8,333.9 hectares (12.45%). Minor rotations, such as Mustard-based cycles, highlight localized crop diversification within the block. Overall, the multi-sensor Geoinformatics approach demonstrated high efficiency in capturing field-level spatio-temporal cropping shifts. The spatial metrics generated in this research offer a reliable empirical foundation for regional agricultural planning, water resource management, and promoting sustainable land-use practices.

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