

Remote Sensing-Based Evaluation of Seasonal Cropping Rotations in Charkhi Dadri (Haryana)

Manju¹, Dr. Dheer Singh²

¹Research Scholar, Department of Geography, Jayoti Vidyapeeth Women's University, (Jaipur)

²Assistant Professor, Department of Geography, Jayoti Vidyapeeth Women's University, (Jaipur)

Abstract:

This study utilizes Sentinel-2 satellite imagery and geospatial methods to map seasonal cropping patterns and derive crop rotations for Charkhi Dadri district, Haryana, for the agricultural year 2023–24. Supervised classification of Kharif 2023 imagery revealed that Bajra constitutes the largest share of cropped area (36.78%), followed by Cotton (23.71%) and Rice (3.59%), while 23.65% of land remained fallow and 12.24% was categorized as non-crop during the season. For the Rabi 2024 season, Mustard emerged as the dominant crop covering 52.38% of the total area, followed by Wheat at 29.95%, with 5.40% fallow and 12.24% non-crop area. Post-classification overlay was used to generate crop rotation classes, showing that Mustard–Bajra (19.4%), Wheat–Bajra (16.3%), Mustard–Fallow (16.5%), and Mustard–Cotton (15.1%) are the most prevalent crop sequences, while rice-based rotations were limited to <2% due to irrigation constraints. The results demonstrate the effectiveness of geospatial analysis in monitoring crop dynamics and provide a spatial foundation for informed agricultural planning. The findings further highlight the need for climate-resilient rotations, irrigation strengthening, and periodic remote sensing-based assessments to support sustainable agricultural decision-making in semi-arid regions.

Keywords: remote sensing, sentinel-2, supervised classification, crop rotation, seasonal cropping pattern, geospatial analysis.

I. Introduction

Agriculture in the semi-arid regions of Haryana remains a primary driver of rural livelihoods and food supply, with Charkhi Dadri district making a significant contribution to the state's crop production. The productivity and sustainability of agricultural systems in such climatic settings are strongly governed by the spatial and temporal characteristics of climate. Identifying climate–crop relationships and mapping suitability zones for major crops are therefore essential for rational crop planning, risk reduction, and long-term agricultural sustainability.

Crop distribution in any region is fundamentally determined by its climatic regime, soil characteristics, and resource availability. Climate suitability, in particular, is a critical determinant of crop growth, yield performance, and resilience under stress. In the context of increasing climate variability, a scientific understanding of current and future climatic suitability for major crops at a district scale becomes indispensable for informed decision-making.

Geospatial techniques integrated with climatic modelling now offer robust means to evaluate and map the spatial suitability of crops. By analysing historical climatic records, integrating ancillary variables such as soil texture and landform characteristics, and incorporating crop-specific thresholds, it is possible to delineate suitability zones with high spatial precision. Such evidence-based mapping supports targeted cultivation, efficient resource allocation, and adoption of climate-resilient practices.

Climate change poses emerging challenges to traditional cropping systems through rising temperatures, altered rainfall regimes, and increasing frequency of extreme weather events. These shifts threaten crop stability and necessitate anticipatory planning under future climate scenarios. Assessing the projected impacts on crop suitability can help formulate adaptation strategies, safeguard yields, and sustain food security.

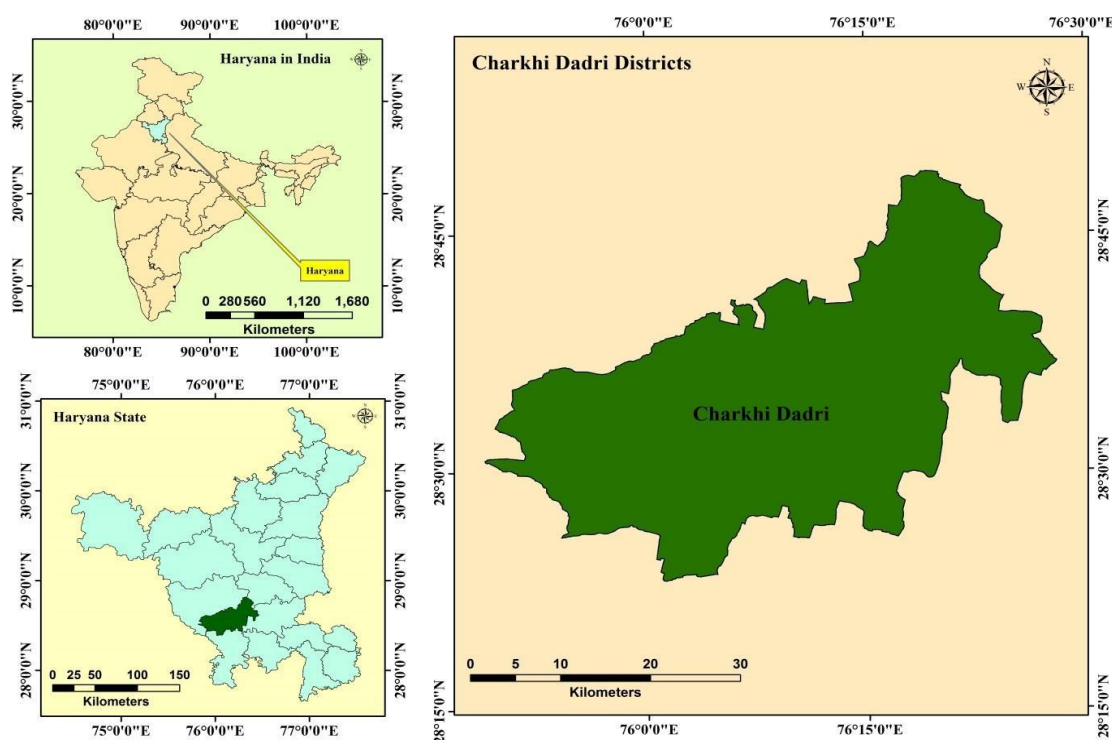
Charkhi Dadri, characterised by a subtropical climate with hot summers, monsoon-dominated rainfall, and cold winters, comprises predominantly alluvial and sandy-loam soils that influence crop choice and productivity. Mapping present and future suitability for major crops under such environmental conditions can inform both farmers and policymakers. The outcomes of this study aim to guide climate-aligned agricultural planning, reduce cultivation risks, and promote sustainable land use in Charkhi Dadri district.

Study Area:

Charkhi Dadri is the 22nd district of Haryana, created through a government notification dated 1 December 2016. Administratively, it comprises two sub-divisions (Charkhi Dadri and Badhra), two tehsils (Charkhi Dadri and Badhra), and one sub-tehsil (Bondkalan). Geographically, the district lies between 28.5921° N latitude and 76.2653° E longitude. It is located approximately 112.6 km from the national capital, New Delhi, and about 295 km from the state capital, Chandigarh.

The district experiences a wide thermal range, with temperatures varying between 2°C in winter and 45°C in summer. The average annual rainfall is around 483 mm, most of which occurs during the monsoon months of July and August. The region is characterised by the presence of minerals such as gypsum and building stones, particularly near Kaliyana village. Agricultural land use is dominated by cotton during the Kharif season and wheat and mustard during the Rabi season, with minor cultivation of paddy in select areas. The natural vegetation consists mainly of thorny and drought-resistant species such as Neem, Sheesham, Peepal, Babool, Jandi and Kair.

Location Map of Study Area



Map-1: Locational map of Study area (Charkhi Dadri District)

II. Methodology and Data Acquisition:

This study employs multispectral Sentinel-2 satellite imagery along with ground truth information to derive the seasonal cropping pattern of Charkhi Dadri district. Sentinel-2 scenes corresponding to the Kharif season of 2023 and the Rabi season of 2024 were acquired as the primary remote sensing inputs. Ground truth data collected through field verification and secondary agricultural statistics served as reference information for training and validation during classification.

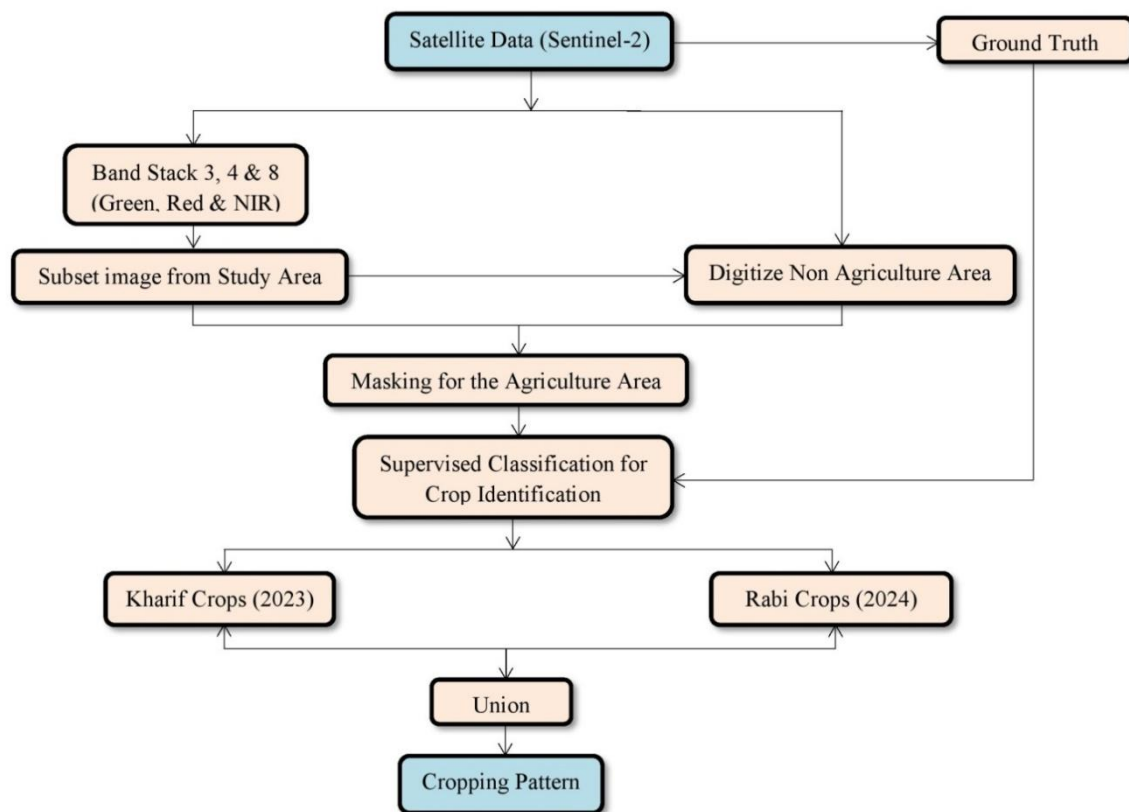


Figure-1: Flow Diagram of data and Methodology.

From the Sentinel-2 imagery, the bands most relevant for vegetation discrimination—Band 3 (Green), Band 4 (Red) and Band 8 (NIR)—were stacked to generate a composite image. The imagery was then subset to the administrative boundary of the Charkhi Dadri district to restrict processing within the study area. Parallel to this, non-agricultural features such as urban settlements, roads, scrubland and water bodies were manually digitized using GIS tools. These areas were masked out to isolate agricultural land pixels for further analysis.

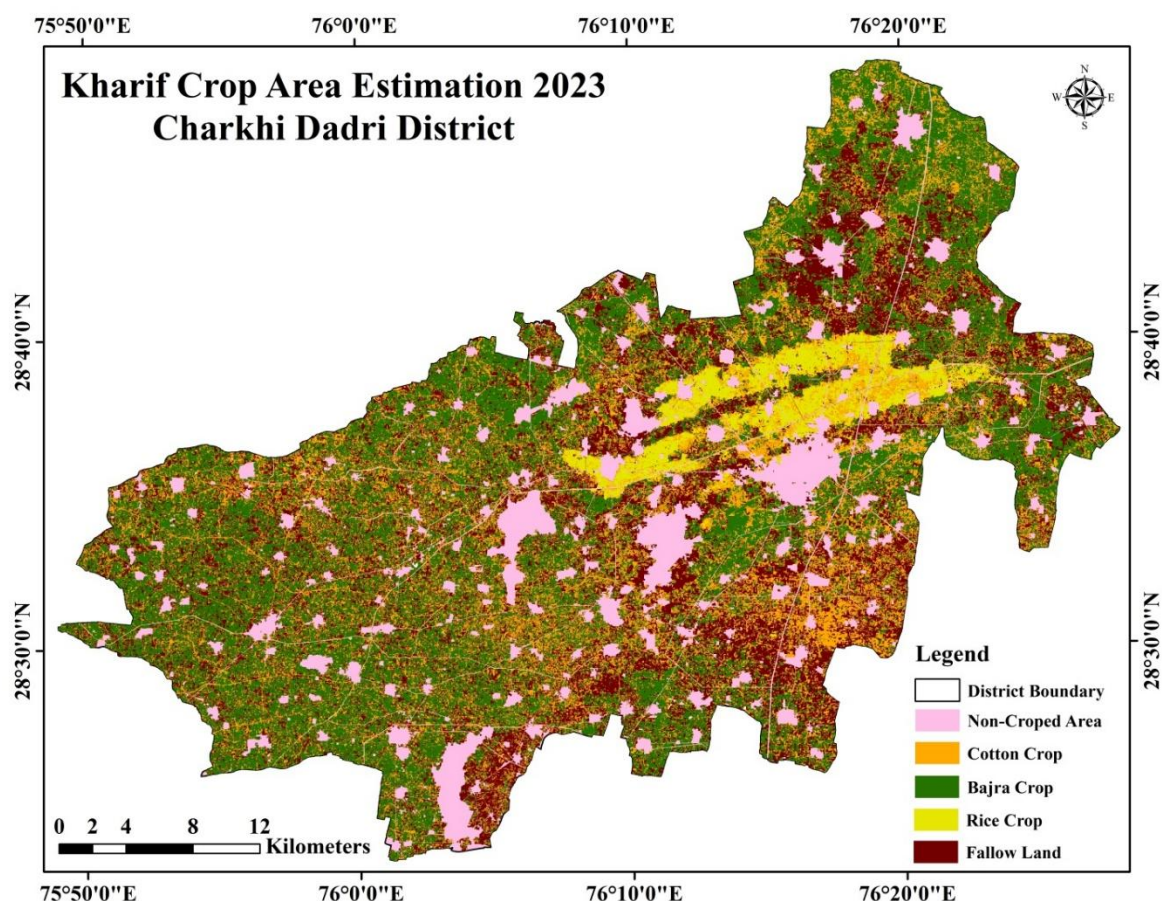
The supervised classification approach was used to identify crop types. Training samples for major crops were generated using field observations and ancillary crop reports. Two separate classification models were executed—one for Kharif 2023 and the other for Rabi 2024—to generate season-wise crop distribution maps. The classified outputs were then subjected to a union overlay operation to derive pixel-wise crop rotation classes. This post-classification analysis enabled the identification of crop sequence transitions such as Cotton–Wheat, Fallow–Mustard, Paddy–Wheat, and other rotation combinations.

The final cropping pattern map provides insight into the spatial distribution of crop rotations, supporting the evaluation of seasonal crop dynamics in the district. This geospatial methodology ensures reliable delineation of agricultural land use transitions, which can further serve as an analytical foundation for agricultural planning and policy interventions.

III. Result and Discussion:

Crop area Estimation of Charkhi Dadri District: Estimating crop area in Charkhi District using supervised classification with Sentinel-2 optical data is a robust method for agricultural monitoring and land management. Estimating the entire area of land used for agricultural production in a given geographic area—a field, farm, region, or district is known as crop area estimation. Planning for agriculture, allocating resources, developing policies, and making decisions at all levels—from municipal to national—all depend on this calculation. Use spectral signatures from satellite photos, together with agricultural data and specialized knowledge, to categorize the discovered agricultural area into several crop varieties. The area in the district allotted to each crop can be estimated with the aid of this classification.

Spatial Distribution of Kharif Crops: The map-2 “Kharif Crop Area Estimation 2023 (Charkhi Dadri District)” represents the spatial distribution of major Kharif season crops across the district using Sentinel-2 satellite imagery and supervised classification techniques.



Map-2: Kharif Crop Area Estimation 2023 map of Charkhi Dadri District.

The pink patches represent non-cropped areas such as settlements, barren land and other non-agricultural surfaces. Among the cropped areas, cotton (displayed in brownish-red) appears as the most dominant Kharif crop across the district, indicating its prominence in the region's agricultural system. Bajra (millet) shown in green is largely distributed across scattered patches, particularly in western and southern parts. Rice cultivation, depicted in yellow, is concentrated in a continuous band-like zone running east-west across the central part of the district, reflecting canal irrigation influence in that belt. Areas shown in dark maroon denote fallow land left uncultivated during the Kharif season.

Table-1: Kharif Crop estimated area of Charkhi Dardi District, 2023.

Sr. No.	Kharif Crops	Area in Hectares
1	Bajra	50540.75
2	Cotton	32568.46
3	Rice	4932.11
4	Fallow Land	32487.31
5	Non Crop Area	16820.97
Total		137349.60

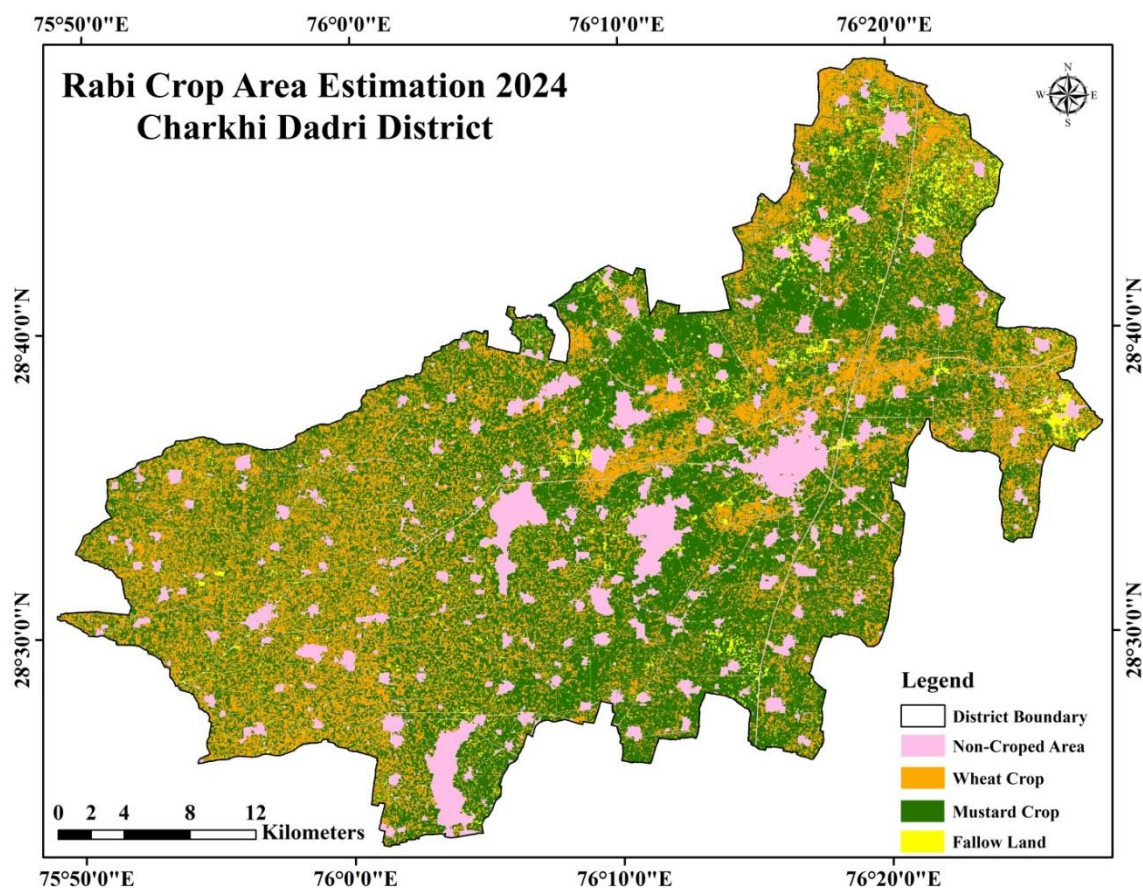
The table-1 presents the estimated area under different land-use classes during the Kharif season in Charkhi Dadri district. The total mapped area considered for the analysis is 137,349.60 hectares.

Among the cultivated crops, Bajra (Pearl millet) occupies the largest area, covering 50,540.75 hectares, indicating its dominance as the primary Kharif crop in the district. Cotton is the second major Kharif crop with an area of 32,568.46 hectares, signifying its substantial share in the agricultural land use. Rice cultivation is limited in extent, covering only 4,932.11 hectares, reflecting its spatial concentration mainly in canal-irrigated belts.

In addition to cultivated areas, a large portion of land 32,487.31 hectares remained as fallow, indicating that a significant area was left uncultivated during the Kharif season. The non-crop area, which includes built-up land, barren land, roads, water bodies, etc., accounts for 16,820.97 hectares.

Spatial Distribution of Rabi Crops:

The map-3 “Rabi Crop Area Estimation 2024 (Charkhi Dadri District)” shows the spatial distribution of major Rabi season crops in the district based on classified Sentinel-2 satellite imagery. The district boundary is outlined in black, and the classified land cover categories are symbolized using the colors shown in the legend.



Map-3: Rabi Crop Area Estimation 2024 map of Charkhi Dadri District.

Among the cultivated areas, wheat (represented in dark green) is the dominant Rabi crop, widely distributed across almost all parts of the district. Mustard, depicted in yellow-orange, appears in fragmented pockets, especially in the northern and central locations. Fallow land, colored yellow-light, indicates areas left uncultivated during the Rabi season, likely reserved for Kharif cultivation or left idle due to moisture constraints. The non-crop areas, shown in pink, represent settlements, water bodies, barren land, or other non-agricultural surfaces.

Table-2: Rabi Crop estimated area of Charkhi Dardi District, 2023-24.

Sr. No.	Rabi Crops	Area in Hectares
1	Mustard	71950.28
2	Wheat	41156.55
3	Fallow Land	7421.80
4	Non Crop Area	16820.97
Total		137349.60

The table-2 presents the estimated area under different land-use classes during the Rabi season of 2024 in Charkhi Dadri district, covering a total mapped area of 137,349.60 hectares.

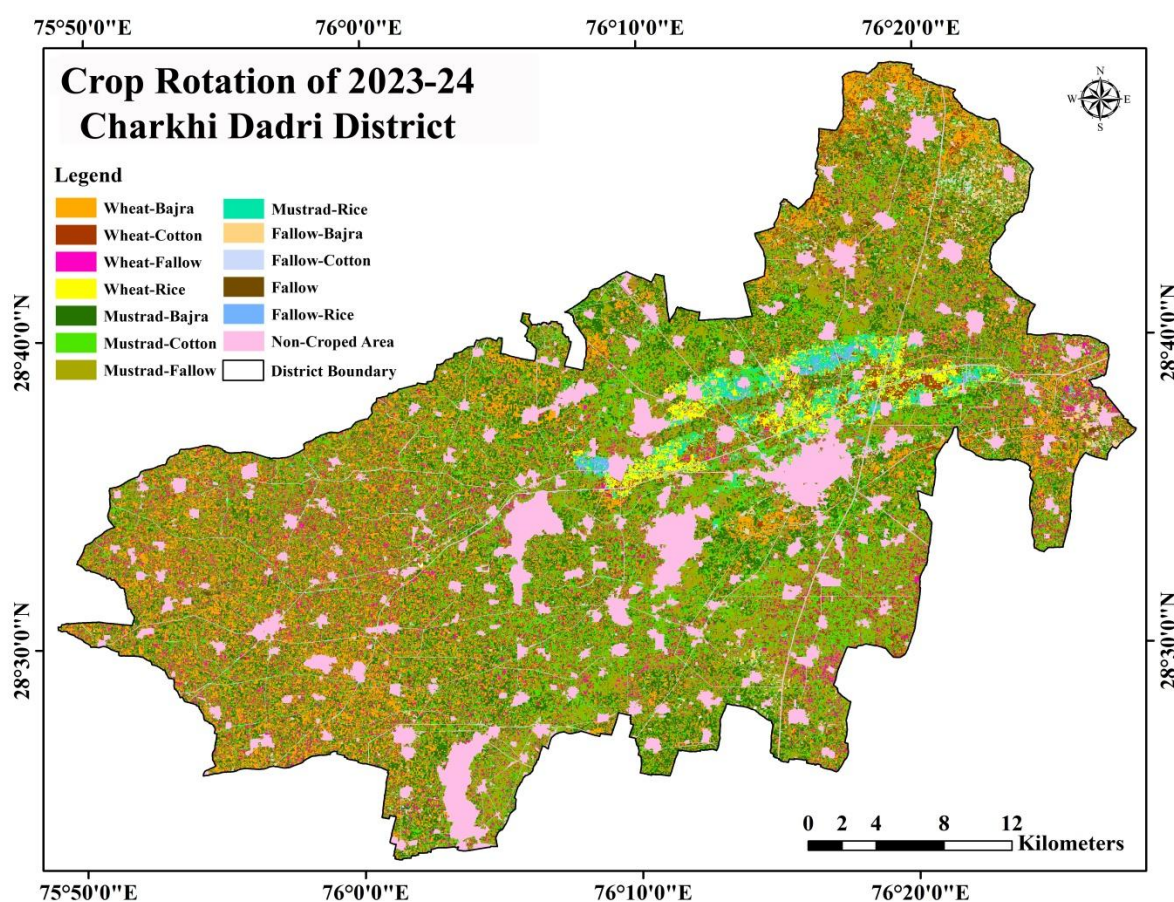
Among the cultivated crops, mustard occupies the largest share with 71,950.28 hectares, indicating that mustard is the dominant Rabi crop in the district. Wheat is the second major crop with 41,156.55 hectares, reflecting its substantial role in winter agriculture, though less dominant than mustard.

A significant portion of land, 7,421.80 hectares, remained fallow, meaning it was not cultivated in the Rabi season. This might be due to soil moisture limitations, irrigation constraints, or preparation for the next cropping cycle. The non-crop area, which includes built-up land, barren land, roads, and other non-agricultural surfaces, accounts for 16,820.97 hectares and remains constant as it does not change seasonally.

Crop Rotation of Charkhi Dadri District (2023-24):

The map-4 “Crop Rotation of 2023–24 (Charkhi Dadri District)” illustrates the spatial distribution of cropping sequences derived by combining Kharif (2023) and Rabi (2024) classified crop maps. Using post-classification overlay, pixel-wise transitions between the two agricultural seasons were identified and categorized into various crop rotation classes.

Each color in the map represents a distinct crop rotation combination such as Wheat–Bajra, Wheat–Cotton, Mustard–Bajra, Fallow–Cotton, Mustard–Fallow, etc., as shown in the legend. These rotations reflect the actual crop succession practiced by farmers between the Kharif and Rabi seasons. The presence of Mustard–Bajra and Wheat–Bajra combinations indicates dominant rotational patterns across many parts of the district, while Rice-related rotations (e.g., Fallow–Rice or Mustard–Rice) are concentrated in the canal-irrigated central belt of the district. Areas marked Fallow–Fallow or Non-cropped area represent either uncultivated agricultural land or permanent non-agricultural classes such as built-up area, water bodies, etc.



Map-4: Crop Rotation 2023-24 map of Charkhi Dadri District.

The table presents the area distribution of different cropping patterns practiced in Charkhi Dadri district between the Kharif season of 2023 and the Rabi season of 2024. The total study area considered is 137,349.60 hectares, which is further divided into different crop rotation classes along with their corresponding area in hectares and percentage share.

The most dominant cropping pattern is Mustard–Bajra, covering 26,597.17 hectares (19.4%), indicating that a large portion of land cultivated with bajra during Kharif was followed by mustard in Rabi. The second major rotation is Mustard–Fallow (16.5%), showing that many bajra-growing areas in Kharif are left

uncultivated in Rabi after mustard. Mustard–Cotton (15.1%) and Wheat–Bajra (16.3%) are also widely practiced, reflecting the prominence of bajra in Kharif and mustard/wheat in Rabi.

Table-3: Cropping Pattern Estimated Area of Charkhi Dardi District, 2023-24.

Sr. No.	Cropping Pattern	Area in Hectares	Area in %
1	Mustard-Bajra	26597.17	19.4
2	Mustard-Cotton	20801.29	15.1
3	Mustard-Fallow	22688.62	16.5
4	Mustard-Rice	2005.69	1.5
5	Wheat-Bajra	22396.75	16.3
6	Wheat-Cotton	9556.65	7.0
7	Wheat-Fallow	6639.43	4.8
8	Wheat-Rice	2531.58	1.8
9	Fallow-Bajra	1836.48	1.3
10	Fallow-Cotton	2048.44	1.5
11	Fallow-Other	3041.95	2.2
12	Fallow-Rice	384.58	0.3
13	Non Crop Area	16820.97	12.2
Total		137349.60	100

Less prevalent rotations such as Mustard–Rice (1.5%), Wheat–Rice (1.8%), and Fallow–Rice (0.3%) suggest that paddy-based rotations are restricted to limited irrigated belts. Rotations involving fallow both in Kharif and/or Rabi (Fallow–Bajra, Fallow–Cotton, Fallow–Other) together account for a smaller fraction, indicating partial cultivation or moisture constraints. The Non-Crop Area occupies 12.2%, representing built-up, barren or other permanent non-agricultural land categories.

IV. Conclusion and Suggestion:

This study demonstrated the potential of geospatial techniques and multi-temporal Sentinel-2 satellite data to accurately map seasonal cropping patterns and derive crop rotations for Charkhi Dadri district. The Kharif crop distribution showed a dominance of Bajra and Cotton, whereas the Rabi season was primarily governed by Mustard and Wheat cultivation. The post-classification overlay revealed that Mustard–Bajra, Wheat–Bajra, and Mustard–Fallow are the most prevalent crop rotations practiced in the district, reflecting the agro-climatic suitability, irrigation availability, and farmer preference. Rice-based rotations were restricted to canal-irrigated belts, indicating localized irrigation dependency.

The spatial differentiation of crop rotation classes provides a realistic picture of land-use dynamics and helps understand the cropping behavior at a granular scale. The substantial share of fallow land in either season highlights seasonal water stress, soil constraints, or purposeful planning for subsequent crops. Overall, the methodology proved effective for agricultural monitoring, supporting strategic decision making in climate-sensitive and resource-restricted regions.

V. Suggestions / Recommendations:

It is recommended to promote sustainable crop rotations by encouraging diversification with pulses and oilseeds in fallow-dominated areas to enhance soil fertility and farm income. Water-efficient irrigation systems such as drip, sprinkler or micro-irrigation should be expanded, particularly in bajra-dominant and fallow-prone zones, to reduce seasonal idle land. Climate-resilient planning is essential, including the introduction of stress-tolerant crop varieties in drought-prone regions and adjustments in sowing calendars in response to climate variability. Policy interventions are needed to support the cotton–mustard belt through strengthened procurement, subsidies, and pest management. In water-deficient areas, substitution of rice with low-water crops like millets or pulses should be encouraged. Finally, periodic geospatial monitoring of seasonal crops every 2–3 years is suggested to detect shifts in cropping dynamics, support adaptive decision-making, and enable evidence-based agricultural policy planning.

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