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Evaluating the Agro-Climatic Potential for Major Crops in Charkhi Dadri District, Haryana

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Abstract
This study evaluates the climatic suitability and spatial distribution of major crops in Charkhi Dadri district by analyzing seasonal variability in rainfall and land surface temperature (LST) for the year 2023. Results show distinct climatic patterns, with low and uniform rainfall during winter months and high spatial variability during the monsoon season, especially in July and August. LST analysis reveals a clear seasonal temperature gradient that significantly influences crop performance. Wheat and mustard exhibit high suitability under winter climatic conditions, whereas bajra remains the most resilient Kharif crop due to its tolerance to semi-arid environments. In contrast, cotton and rice show moderate to limited suitability in areas affected by elevated temperatures and uneven rainfall distribution. Crop area estimation and suitability mapping were strengthened using Digital Image Processing (DIP) and GIS-based interpolation methods, providing accurate spatial insights without dominating the study. Overall, the research highlights the strong relationship between climatic factors and agricultural productivity, emphasizing the need for climate-informed crop planning and adaptive strategies to support sustainable agriculture in Charkhi Dadri district.

Keywords: *Agro-climatic Analysis, Sustainable Agriculture, GIS Interpolation, Digital Image Processing, Remote Sensing*

I. Introduction

Agriculture in the Charkhi Dadri district of Haryana plays a vital role in supporting regional livelihoods and contributing significantly to the state's agricultural output. The district's agro-ecological conditions, characterized by semi-arid to sub-tropical climatic features, make it a suitable environment for growing a variety of major crops. However, the successful cultivation of these crops largely depends on understanding the agro-climatic potential of the region. Evaluating climatic suitability has therefore become a crucial component of sustainable agricultural planning, improved resource utilization, and long-term food security.

Agriculture is inherently climate-dependent, and even minor variations in temperature, rainfall, humidity, or seasonal patterns can influence crop performance. Assessing the agro-climatic potential for major crops enables better decision-making in crop selection, sowing schedules, and resource allocation. Prior studies conducted in Charkhi Dadri have already highlighted the region's dynamic agricultural landscape. For instance, **Manju and Singh (2025)** examined seasonal cropping rotations using remote sensing techniques, revealing notable spatio-temporal variations in crop behavior across the district. Similarly, **Manju et al (2023)** demonstrated decadal changes in cropping patterns through geostatistical analysis, underscoring the importance of integrating geospatial technologies for more accurate agricultural assessments.

Building on these earlier geospatially driven studies, the present research focuses on evaluating the agro-climatic potential for major crops in Charkhi Dadri by integrating climatic datasets, soil characteristics, and crop-specific environmental requirements. Through the use of advanced geospatial tools and climatic modelling, the study aims to identify the most suitable areas for crop cultivation, thereby enhancing climate-resilient planning. Historical weather records, temperature profiles, rainfall distribution, soil texture, and associated biophysical indicators serve as key inputs to assess the climatic favorability for different crops.

In the context of climate change—marked by irregular monsoons, rising temperatures, and increasing frequency of extreme weather events—the need for precise agro-climatic assessments has become even more critical. Changing climatic patterns pose significant risks to traditional cropping systems, making it essential to identify shifts in suitability zones and develop adaptive strategies for agricultural sustainability. By mapping agro-climatic suitability, this study helps determine how future climatic uncertainties may influence agricultural productivity in Charkhi Dadri.

Charkhi Dadri's diverse soil conditions—from sandy to loamy textures—and its distinct seasonal climatic variations collectively shape crop performance across the district. Evaluating agro-climatic potential not only helps identify the most suitable crops for each season but also minimizes crop failure risks, promotes efficient water and fertilizer use, and strengthens farmers' adaptive capacity. Thus, understanding spatial and seasonal suitability patterns becomes fundamental for maximizing agricultural output and fostering long-term sustainability.

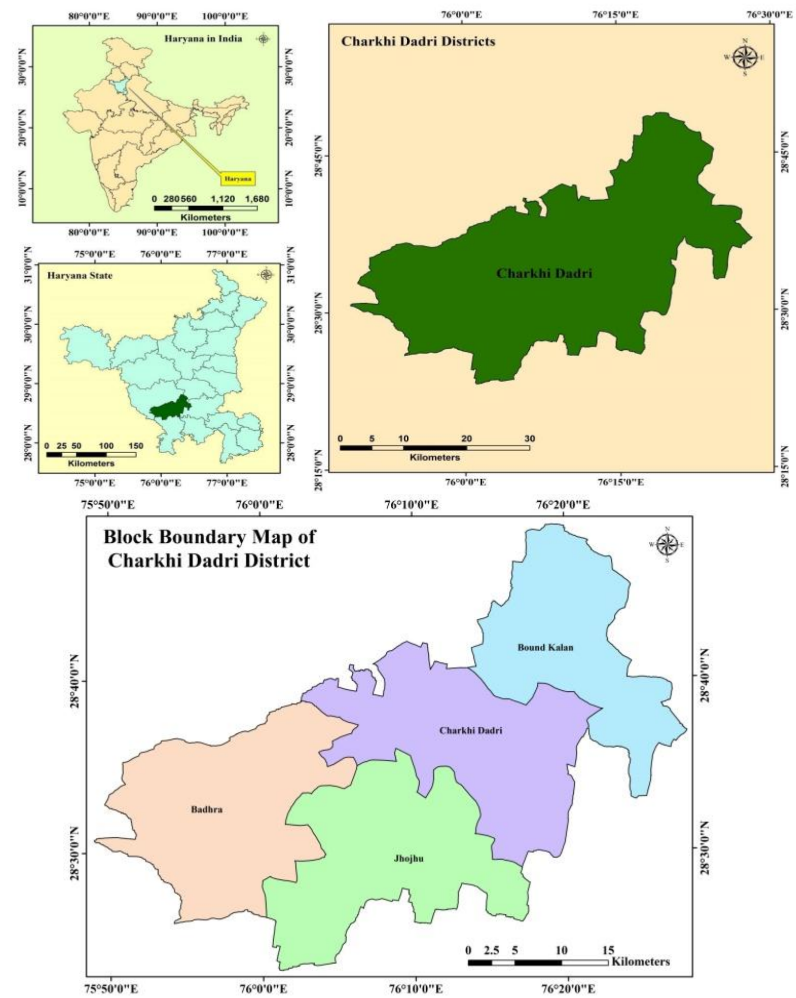
Overall, this study aims to develop a comprehensive agro-climatic suitability assessment for major crops in Charkhi Dadri district. The findings will support farmers, researchers, and policymakers in making informed decisions about crop planning, resource management, and climate-resilient agricultural strategies.

Study Area

Charkhi Dadri district, located in the northern Indian state of Haryana, represents one of the state's newest administrative units, officially declared as the 22nd district on 1 December 2016. The district is administratively structured into two sub-divisions—Charkhi Dadri and Badhra along with two tehsils bearing the same names and an additional sub-tehsil, Boundkalan. Geographically, Charkhi Dadri lies between 28.5921° N latitude and 76.2653° E longitude, occupying a strategic position approximately 112.6 km from the national capital, New Delhi, and around 295 km from the state capital, Chandigarh.

Charkhi Dadri district comprises four administrative blocks **-**Charkhi Dadri, Badhra, Bond Kalan (Bound Kalan), and Jhojhu**-**each contributing uniquely to the district's agricultural and developmental landscape. Charkhi Dadri block serves as the central and semi-urban hub with diverse cropping practices, while Badhra block is predominantly rural and known for large-scale cultivation of cotton in Kharif and wheat–mustard in Rabi. Bond Kalan block represents a traditional farming region where agriculture depends largely on seasonal rainfall, with major crops including cotton, bajra, wheat, and mustard. Jhojhu block is characterized by scattered rural settlements and dryland agriculture, supporting crops such as cotton, wheat, and mustard alongside typical semi-arid vegetation. Together, these blocks reflect the district's mixed agro-climatic conditions and agricultural diversity.

Location Map of Study Area



Map-1: Locational Map of District Charkhi Dadri and Block Boundary map of Study area.

The district is characterized by a semi-arid climate with considerable seasonal variability. Temperatures range widely from 2°C during winter to 45°C in peak summer, reflecting the typical climatic conditions of southwestern Haryana. Rainfall is relatively scarce, averaging 483 mm annually, with the majority received during the monsoon months of July and August. This limited and irregular precipitation significantly influences the district's agricultural practices and water availability.

Agriculture remains the dominant land use, with cropping patterns shaped by climatic and soil conditions. Cotton serves as the major Kharif crop, while wheat and mustard dominate during the Rabi season. A smaller extent of paddy is also cultivated where irrigation facilities permit. The region is also known for mineral resources, particularly gypsum and various types of building stones, notably the flexible stone found in Kaliyana village.

Natural vegetation in Charkhi Dadri is sparse and adapted to its dry environment. Common tree species include Neem, Sheesham, Peepal, Babool, Jandi, and Kair, representing typical flora of semi-arid ecosystems.

Methodology:

The methodology integrates climatic data and satellite-derived parameters to generate spatial maps and assess agro-climatic suitability. Two major components-rainfall analysis and land surface temperature (LST) estimation-form the core of the workflow.

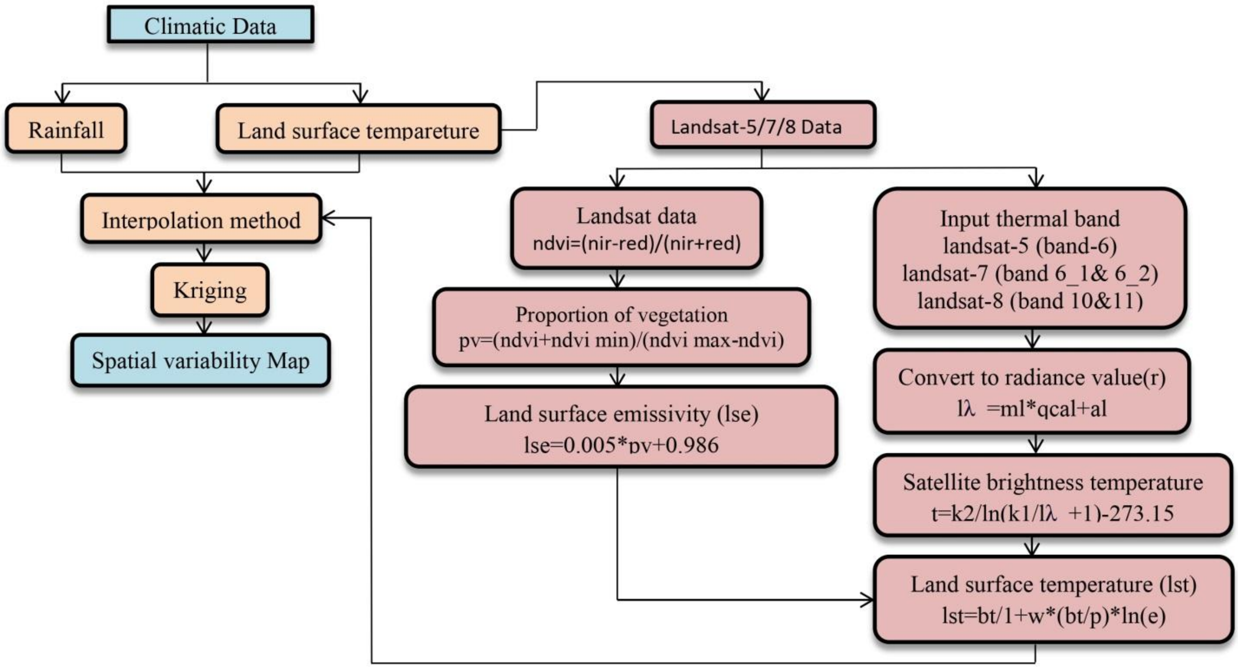


Figure-1: Methodology for Spatial Distribution of Climatic Variables of Charkhi Dadri District.

The methodology integrates climatic variables and satellite-derived parameters to assess agro-climatic conditions in Charkhi Dadri district. Rainfall data obtained from meteorological stations were processed using spatial interpolation, where the Kriging technique was applied to generate a continuous rainfall variability map. Land Surface Temperature (LST) was derived from Landsat-5, 7, and 8 thermal bands by calculating NDVI, estimating the proportion of vegetation, and computing land surface emissivity. Thermal digital numbers were converted to radiance, followed by retrieval of brightness temperature and final LST using emissivity correction. The resulting rainfall and LST layers were used to map spatial climatic variability and support the assessment of agro-climatic potential for major crops.

A. Land Surface Temperature (LST):

LST is defined as the surface radiometric temperature corresponding to the instantaneous field of view of the sensor. Information about land surface temperature is obtained using Landsat data from the following formula (Eq. 2). These data are being used as input for the TCI and VHI computation, an advanced and optimized model of agricultural drought monitoring.

LST=BT/1+w*(BT/p)*In(e) (F.W. Badeck et al)

where BT = At satellite temperature, W = wavelength if emitted radiance, P = h*c/s (1.438*10^-23 m k), h = Plank's constant (1.38*10^-23 j/k), s = Boltzmann constant and c = velocity of type (2.998*10^8 m/s).

- **NDVI Calculation**:

NDVI (Normalized Difference Vegetation Index) is calculated using the formula:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

This step uses near-infrared (NIR) and red bands from satellite data to estimate vegetation cover.

- **Proportion of Vegetation (PV)**:

The proportion of vegetation is calculated as:

$$PV = \frac{\text{NDVI} + \text{NDVI min}}{\text{NDVI max} - \text{NDVI}}$$

This helps in determining areas with varying vegetation density.

- **Land Surface Emissivity (LSE)**:

Land surface emissivity is derived using the formula:

$$LSE = 0.005 \times PV + 0.986$$

- **Radiance Conversion**:

Thermal Bands from Landsat data are converted to **radiance values (r)** using the formula:

$$\lambda = ml \times qcal + al$$

Here, ml and al are coefficients, and qcal is the calibrated digital number from the satellite imagery.

- **Satellite Brightness Temperature (BT)**:
  Using radiance values, the **brightness temperature (BT)** is calculated with the formula:

$$T = \frac{k2}{\ln\ \frac{k1}{\lambda} + 1} - 273.15$$

Here, k1 and k2 are calibration constants, and the result is converted to Celsius by subtracting 273.15.

- **Land Surface Temperature (LST)**:
  Finally, the **land surface temperature (LST)** is derived by adjusting brightness temperature based on emissivity:

$$LST = \frac{BT}{1 + w \times \frac{BT}{p} \times \ln(e)}$$

Here, w, p, and e are constants or emissivity values.

This methodology combines climatic data, interpolation, and satellite-derived indices to analyze and map the spatial distribution of climatic variables, particularly focusing on rainfall and temperature across the land surface.

Methodology For Crops Area Estimation:

The flowchart outlines a remote sensing and GIS-based methodology for analyzing cropping patterns in Charkhi Dadri District. Here's a breakdown of each step:

1. **Satellite Data (Sentinel-2)**: Use Sentinel-2 satellite imagery, which provides high-resolution multispectral data essential for vegetation and crop analysis.
2. **Ground Truth**: Gather ground truth data to validate the accuracy of satellite image classification. Ground truthing involves field visits or collecting data from reliable local sources to ensure that the classification corresponds with actual land features.
3. **Band Stack (Green, Red, and NIR)**: Utilize specific spectral bands (3, 4, and 8) of Sentinel-2 data—Green, Red, and Near-Infrared (NIR). These bands are particularly useful for vegetation and crop health analysis since plants reflect strongly in NIR and Green and absorb in the Red band.
4. **Subset Image from Study Area**: Extract or subset the image data specific to Charkhi Dadri District to limit the analysis to the area of interest.
5. **Digitize Non-Agriculture Area**: Identify and digitize areas that are non-agricultural (e.g., urban regions, water bodies, and barren land) to exclude them from crop analysis.
6. **Masking for the Agriculture Area**: Apply a mask over the image to isolate agricultural areas. This step removes non-agricultural areas and focuses on fields and croplands.
7. **Supervised Classification for Crop Identification**: Perform supervised classification, where known crop types (based on ground truth data) are used to train the classification model. The model then identifies and classifies crops across the district.

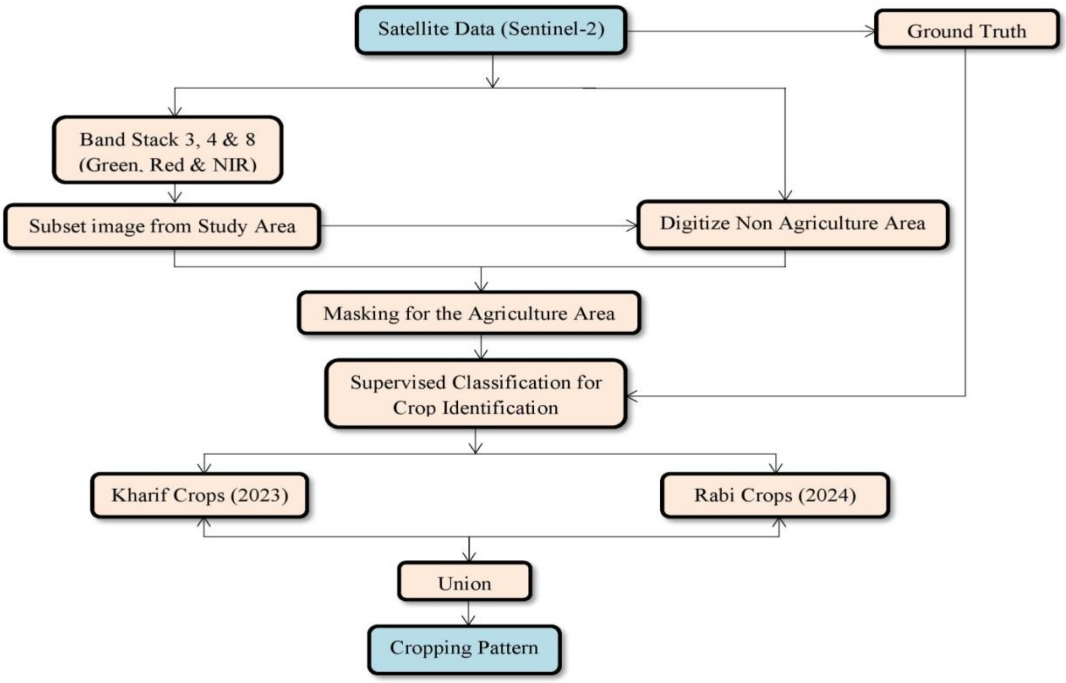


Figure-2: Methodology flow chart for Crops Area estimation of Rabi and Kharif season and Cropping pattern of Charkhi Dadri District.

The study used Sentinel-2 satellite imagery along with ground-truth data to identify major crops and derive cropping patterns for Charkhi Dadri district. Bands 3, 4, and 8 (Green, Red, and NIR) were stacked and subsetted for the study area, while non-agricultural features such as settlements, water bodies, and barren land were digitized to create a mask for isolating agricultural land. Supervised classification was then performed for crop identification using field-verified training samples. Separate classifications were generated for Kharif crops (2023) and Rabi crops (2024), and the outputs were combined through a union operation to produce a comprehensive cropping pattern map. This integrated approach enabled accurate spatial delineation of seasonal crops and agricultural land use across the district.

II. Result and Discussion:

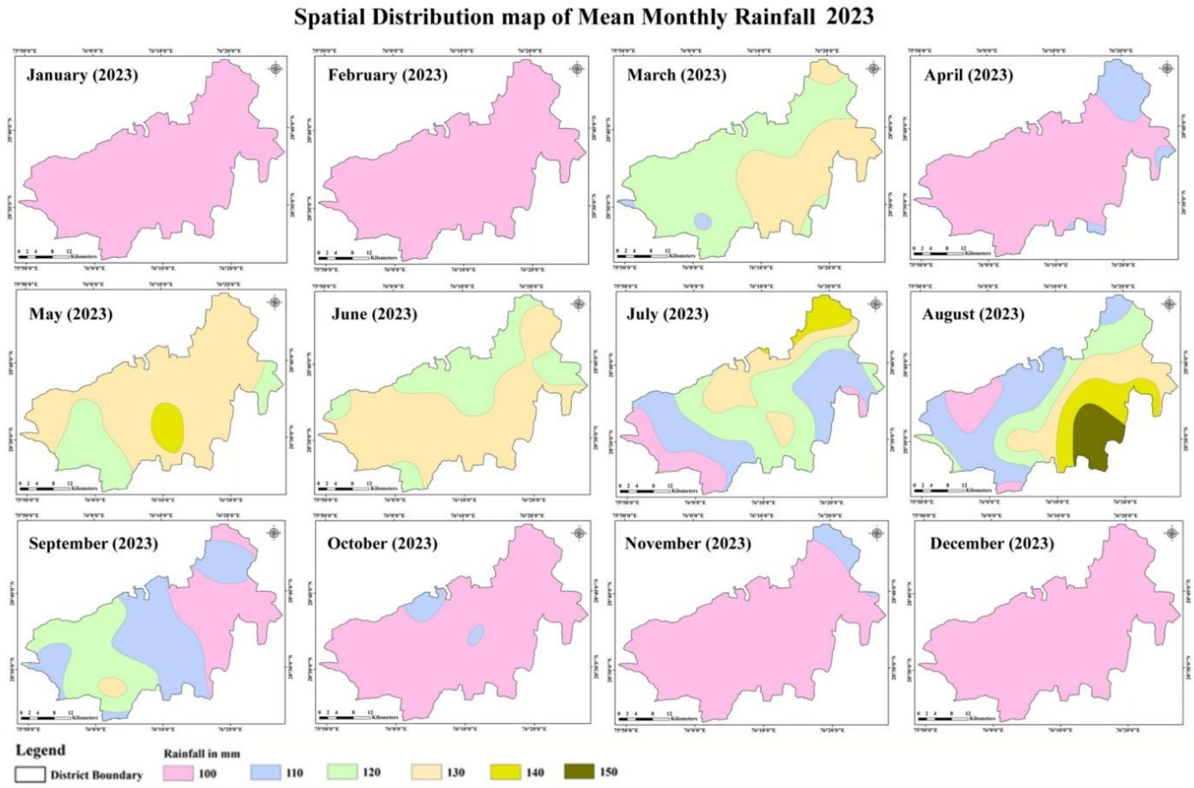
The results show that rainfall and temperature patterns in Charkhi Dadri vary significantly across seasons, directly influencing crop distribution and suitability. Monsoon months exhibit high rainfall variability supporting Bajra, Cotton, and Rice, while winter months provide favorable conditions for Wheat and Mustard. Suitability maps derived from LST and rainfall reveal distinct zones of suitable, moderate, and unsuitable areas for each crop, aligning well with observed cropping patterns. Overall, the findings highlight that climatic factors play a crucial role in determining crop performance and spatial distribution in Charkhi Dadri district.

Climatic Condition & Estimation of Major Crop in Charkhi Dadri District:

The climatic conditions of Charkhi Dadri district show clear seasonal variability, ranging from extremely dry winter months to intense monsoonal rainfall during July and August. These fluctuations in temperature, rainfall, and land surface characteristics significantly influence agricultural productivity and crop suitability in the region. By analyzing climatic parameters such as rainfall distribution, land surface temperature, and seasonal patterns, the estimation of major crops—including Bajra, Cotton, Rice, Wheat, and Mustard—becomes more accurate and spatially representative. Understanding these climate–crop relationships is essential for assessing crop performance, identifying suitable cultivation zones, and developing climate-resilient agricultural strategies for Charkhi Dadri district.

Spatial Distribution and Variability of Mean Monthly Rainfall (2023)

The spatial distribution and variability of mean monthly rainfall (Map:1) in Charkhi Dadri during 2023 reveal clear seasonal contrasts across the district. The winter and post-monsoon months show uniformly low rainfall, with most of the district receiving minimal precipitation. In contrast, the monsoon period, particularly July and August, exhibits high spatial variability, marked by multiple rainfall classes ranging from moderate to very high intensities. This uneven distribution reflects the influence of localized convective activity and the district's semi-arid climatic setting. Overall, the rainfall patterns highlight significant spatial heterogeneity, which directly affects soil moisture availability, cropping decisions, and agricultural productivity in Charkhi Dadri district.



Map-2: Spatial Distribution map of Mean Monthly Rainfall of 2023.

The table-1 presents the **spatial distribution of monthly rainfall classes** and their corresponding **area coverage** across Charkhi Dadri district for the year 2023. Each month is categorized into rainfall intensity classes (in millimeters), and the area (in hectares) falling under each rainfall class is quantified. The results show that rainfall distribution in the district varies significantly throughout the year, both in intensity and spatial extent.

During the **winter months (January–February)**, the district received very low rainfall, with only a single rainfall class (9–10 mm) covering the entire area of approximately 137,349 ha, indicating uniform and minimal precipitation. In **March**, rainfall intensity increased, and the district experienced three distinct rainfall classes (20, 30, and 40 mm), reflecting spatial variability as the pre-monsoon transition began.

Table-1: Month-wise Rainfall Classes and Area (ha), Charkhi Dadri District - 2023

Month	Rainfall Classes (mm) & Area (ha)
January	10 mm → 137349.6 ha
February	9 mm → 137349.6 ha
March	20 mm → 1791.0 ha; 30 mm → 83817.5 ha; 40 mm → 51741.2 ha
April	10 mm → 121909.1 ha; 20 mm → 15440.5 ha
May	30 mm → 26706.8 ha; 40 mm → 103210.5 ha; 50 mm → 7432.4 ha
June	30 mm → 45706.8 ha; 41 mm → 91642.8 ha
July	170 mm → 16098.4 ha; 180 mm → 42559.0 ha; 190 mm → 47662.4 ha; 200 mm → 23283.7 ha; 215 mm → 7746.1 ha

August	100 mm → 11492.5 ha; 110 mm → 41234.1 ha; 120 mm → 26762.2 ha; 130 mm → 26223.2 ha; 140 mm → 18281.6 ha; 152 mm → 13356.0 ha
September	10 mm → 38238.1 ha; 20 mm → 57251.9 ha; 30 mm → 39302.7 ha; 40 mm → 2557.0 ha
October	10 mm → 131586.4 ha; 20 mm → 5763.2 ha
November	10 mm → 131094.0 ha; 20 mm → 6255.6 ha
December	2 mm → 137349.6 ha

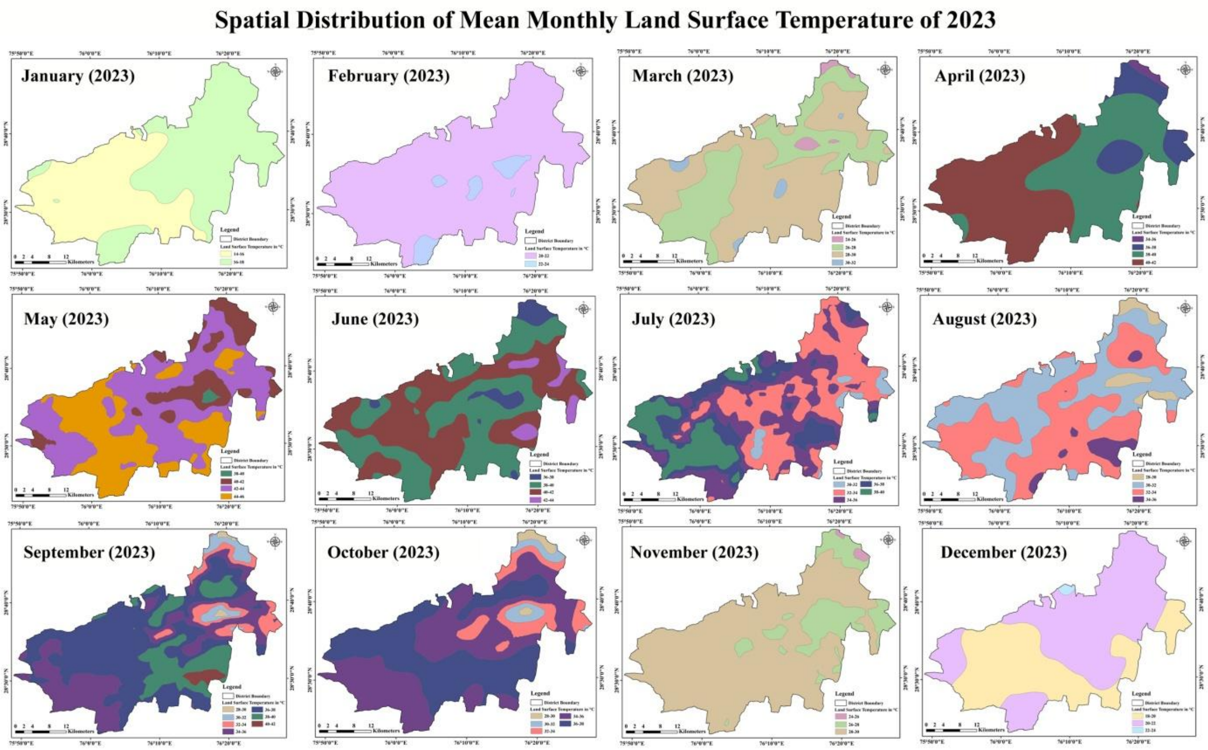
April, May, and June continue this variability pattern, with multiple rainfall classes present in each month. May shows the introduction of higher rainfall classes (30–50 mm), while June exhibits moderate rainfall intensities ranging between 30–41 mm. These shifts reveal the transition toward monsoon activity.

The **monsoon months (July and August)** display the widest rainfall variation and highest intensities. July features rainfall classes ranging from 170 mm to 215 mm, while August displays several distinct classes between 100 mm and 152 mm. These months collectively represent the period of **peak monsoon rainfall**, with substantial spatial differences across the district.

In **September**, the monsoon begins to weaken, yet multiple rainfall classes (10–40 mm) persist, suggesting uneven withdrawal. By **October and November**, rainfall again becomes minimal and is dominated by low-intensity classes (10–20 mm), indicating the return to dry post-monsoon conditions. In **December**, extremely low rainfall (2 mm) uniformly covers the entire district, consistent with the typical dry winter season.

Spatial Distribution and Variability of Mean Monthly (LST) Land Surface Temperature (2023):

The spatial distribution and variability of mean monthly LST (show in Map:) in Charkhi Dadri during 2023 reveal a distinct seasonal temperature pattern across the district. Cooler temperatures dominate the winter months, while progressively higher LST values appear from March to June, reflecting the transition into peak summer conditions. The monsoon period shows moderate LST variability due to increased cloud cover and rainfall, whereas September exhibits the widest spatial temperature variation during monsoon withdrawal. Overall, the district experiences strong spatial and temporal fluctuations in LST, influencing soil moisture availability, crop suitability, and seasonal agricultural activities.



Map-3: Spatial Distribution of Mean Monthly Land Surface Temperature of 2023.

The table-2 illustrates the monthly distribution of Land Surface Temperature (LST) classes across Charkhi Dadri district, highlighting how surface temperature varies spatially throughout the year. During the winter months (December–February), the district records lower LST values ranging from 14°C to 24°C, covering most of the agricultural area, indicating cool conditions favourable for Rabi crops such as wheat and mustard. As temperatures begin to rise in March and April, moderate LST classes between 24°C and 40°C become dominant, reflecting the transition toward the summer season.

Table-2: Month-wise Land Surface Temperature (°C) Classes and Area (ha) - Charkhi Dadri District, 2023.

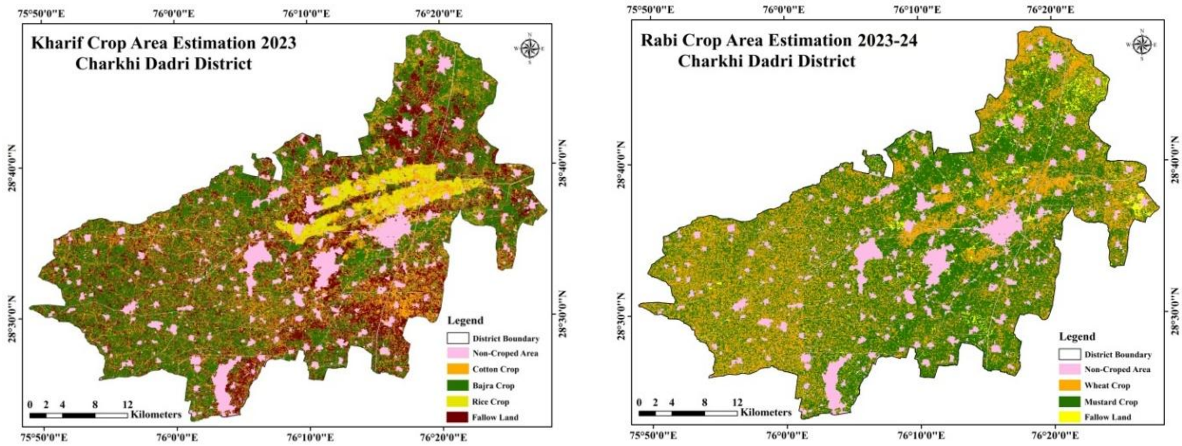
Month	Land Surface Temperature Classes (°C) & Area (ha)
January	14–16 (62843.0 ha), 16–18 (74506.6 ha)
February	20–22 (129688.3 ha), 22–24 (7661.3 ha)
March	24–26 (2436.0 ha), 26–28 (49772.7 ha), 28–30 (82673.0 ha), 30–32 (2467.9 ha)
April	34–36 (1583.7 ha), 36–38 (16851.2 ha), 38–40 (55972.0 ha), 40–42 (62942.7 ha)
May	38–40 (859.8 ha), 40–42 (21844.8 ha), 42–44 (67805.9 ha), 44–46 (46839.1 ha)
June	36–38 (7497.3 ha), 38–40 (61511.1 ha), 40–42 (62606.7 ha), 42–44 (5734.5 ha)
July	30–32 (4643.5 ha), 32–34 (47136.0 ha), 34–36 (38601.5 ha), 36–38 (25413.1 ha), 38–40 (21555.6 ha)
August	28–30 (6619.4 ha), 30–32 (58285.2 ha), 32–34 (66130.7 ha), 34–36 (6314.3 ha)
September	28–30 (799.3 ha), 30–32 (5045.6 ha), 32–34 (9422.8 ha), 34–36 (35325.1 ha), 36–38 (63048.5 ha), 38–40 (21407.8 ha), 40–42 (2300.5 ha)
October	28–30 (2333.0 ha), 30–32 (5143.6 ha), 32–34 (13447.6 ha), 34–36 (62259.2 ha), 36–38 (54166.2 ha)
November	24–26 (954.7 ha), 26–28 (23654.8 ha), 28–30 (112740.2 ha)
December	18–20 (56640.9 ha), 20–22 (79978.8 ha), 22–24 (729.9 ha)

The peak summer months (May and June) show the highest temperature ranges, extending from 38°C to 46°C, covering large portions of the district. These elevated LST values correspond to strong heating, low soil moisture, and greater evapotranspiration, influencing the early monsoon crop environment. During the monsoon months of July, August, and September, temperature values decrease slightly but remain within moderate to high ranges (28°C–40°C), indicating a mix of cloud cover, rainfall influence, and seasonal humidity. Notably, September displays the widest range of temperature classes, suggesting strong spatial variability during monsoon withdrawal.

By October and November, LST values continue to moderate, returning to cooler ranges as the district moves into post-monsoon and winter conditions. Overall, the table demonstrates clear seasonal fluctuations and spatial variability in surface temperature, which directly influence vegetation health, crop suitability, and agricultural decision-making in Charkhi Dadri district.

Crop Area estimation on Charkhi Dadri:

Crop area estimation in Charkhi Dadri district was carried out using digital image processing techniques applied to satellite imagery. Through supervised classification, spectral signatures of major crops such as Bajra, Cotton, Rice, Wheat, and Mustard were accurately identified and mapped. The use of DIP enabled precise delineation of crop boundaries, differentiation between seasonal crops, and quantification of fallow and non-crop areas. Overall, digital image processing provided a reliable and efficient approach to assess spatial patterns of agricultural land use and estimate crop areas across the district.



Map-4: Spatial Distribution of Rabi and Kharif crops in Charkhi Dadri district.

The table-3 presents the seasonal distribution of major land use and crop categories in Charkhi Dadri district, showing clear differences between Kharif and Rabi cultivation patterns. During the Kharif season, Bajra (50,540.75 ha) and Cotton (32,568.46 ha) dominate the agricultural landscape, followed by a smaller area under Rice (4,932.11 ha). In contrast, the Rabi season is primarily characterized by Mustard (71,950.28 ha) and Wheat (41,156.55 ha), reflecting the district's reliance on winter crops.

Table-3: Seasonal Cropping Pattern and Land Use (Kharif & Rabi), Charkhi Dadri District.

Sr. No.	Land Use / Crop Category	Kharif Area (ha)	Rabi Area (ha)
1	Bajra	50540.75	–
2	Cotton	32568.46	–
3	Rice	4932.11	–
4	Mustard	–	71950.28
5	Wheat	–	41156.55
6	Fallow Land	32487.31	7421.8
7	Non-Crop Area	16820.97	16820.97
Total		**137349.6**	**137349.6**

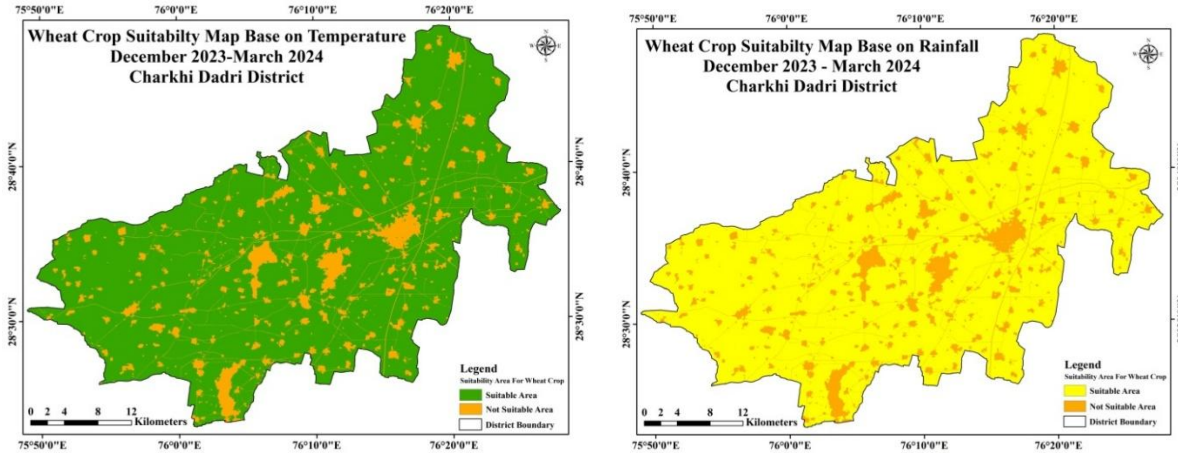
Fallow land appears in both seasons, with a larger share during Kharif (32,487.31 ha) compared to Rabi (7,421.8 ha), indicating seasonal crop rotation or temporary non-cultivation. The non-crop area remains constant across both seasons (16,820.97 ha), representing settlements, infrastructure, and uncultivable land. Overall, the table highlights a distinct seasonal shift in cropping patterns driven by climatic and water availability conditions in Charkhi Dadri district.

Climatic Suitability Areas for Crops of Charkhi Dadri District

Climatic suitability analysis in Charkhi Dadri district identifies areas that are most favorable for major crops based on temperature and rainfall conditions. Wheat and mustard show high suitability in winter-dominant zones, while bajra, cotton, and rice align with regions receiving higher monsoon rainfall. Overall, the spatial variation in LST and rainfall creates distinct suitability zones that guide efficient and climate-responsive crop planning in the district.

Climatic suitability for Wheat Crop:

Climatic suitability analysis for wheat in Charkhi Dadri district shows that most of the area is highly favorable for wheat cultivation due to low winter temperatures and moderate moisture availability. Both LST- and rainfall-based assessments indicate that a large portion of the district falls under the suitable category, making wheat one of the most climatically supported Rabi crops in the region.



Map-5: Wheat crop suitability maps base on mean monthly Temperature and Rainfall (2023).

The table-4 compares wheat crop suitability in Charkhi Dadri district based on Land Surface Temperature (LST) and rainfall conditions. Both indicators show identical suitability patterns, with 120,537.7 ha (87.8%) of the total agricultural area classified as *suitable* for wheat cultivation. Only 16,811.9 ha (12.2%) fall under the *not suitable* category, indicating limited climatic constraints. The total assessed area remains consistent at 137,349.6 ha for both datasets.

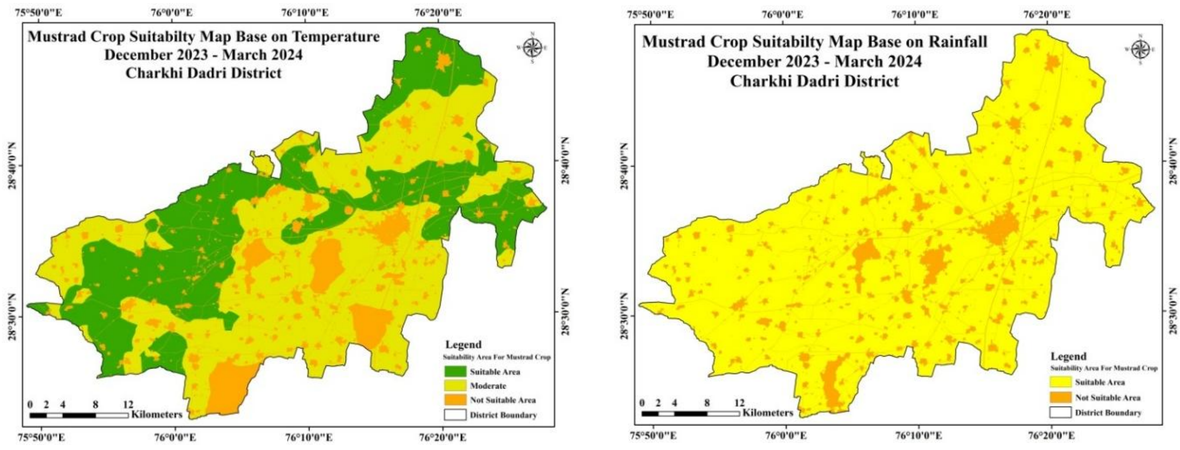
Table-4: Wheat Crop Suitability Assessment Based on LST and Rainfall, Charkhi Dadri District.

Suitability Class	LST-Based Suitability (Area ha)	LST (%)	Rainfall-Based Suitability (Area ha)	Rainfall (%)
Suitable	120537.7	87.8	120537.7	87.8
Not Suitable	16811.9	12.2	16811.9	12.2
Total Area	**137349.6**	**100**	**137349.6**	**100**

The close agreement between LST-based and rainfall-based suitability suggests that wheat production in Charkhi Dadri is strongly supported by both temperature and rainfall conditions, making it one of the most climatically favorable crops in the district.

Climatic suitability for Mustrad Crop:

The suitability analysis for mustard in Charkhi Dadri district shows that temperature and rainfall influence the crop differently. Based on LST, a large part of the district falls under moderately suitable conditions, while only about one-third is highly suitable. However, rainfall-based suitability indicates that most of the district provides highly favorable moisture conditions for mustard, making it a well-supported Rabi crop in the region.



Map-6: Mustrad crop suitability maps base on mean monthly Temperature and Rainfall (2023).

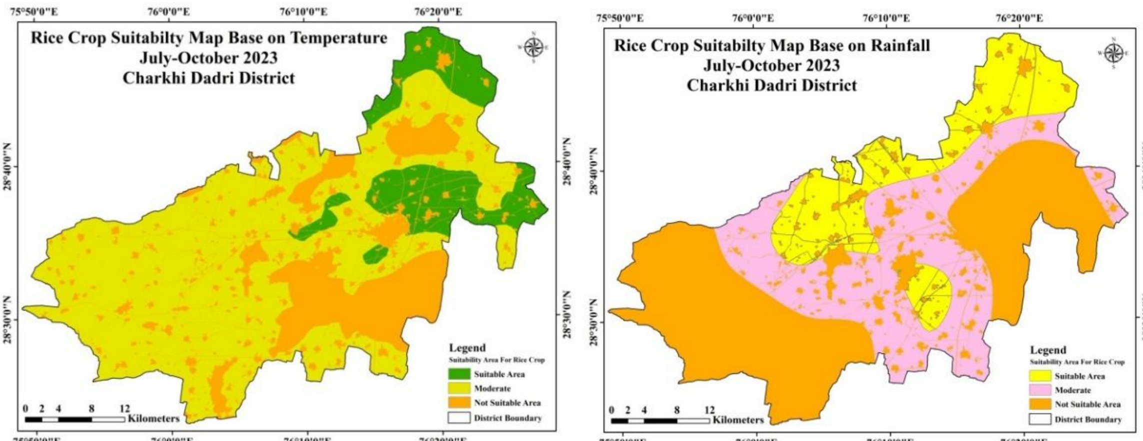
The table-5 compares mustard crop suitability in Charkhi Dadri district based on two key climatic factors: Land Surface Temperature (LST) and rainfall. The LST-based assessment shows that 36.8% (50,606.9 ha) of the district is classified as *suitable* for mustard, while the largest share, 47.6% (65,346 ha), falls in the *moderately suitable* category, indicating that temperature conditions are generally favorable but vary across the district. A smaller portion, 15.6% (21,396.7 ha), is considered *not suitable* due to thermal stress or higher temperature values.

Table-5: Mustard Crop Suitability Assessment Based on LST and Rainfall, Charkhi Dadri District

Suitability Class	LST-Based Suitability (Area ha)	LST (%)	Rainfall-Based Suitability (Area ha)	Rainfall (%)
Suitable	50606.9	36.8	120537.7	87.8
Moderate	65346	47.6	–	–
Not Suitable	21396.7	15.6	16811.9	12.2
Total Area	**137349.6**	**100**	**137349.6**	**100**

In contrast, rainfall-based suitability shows a much higher proportion-87.8% (120,537.7 ha)-as *suitable*, reflecting the district's adequate winter rainfall conditions for mustard growth. Only 12.2% (16,811.9 ha) is categorized as *not suitable* due to insufficient rainfall. The total assessment area remains constant at 137,349.6 ha for both parameters.

Climatic suitability for Rice Crop:
The suitability analysis for rice in Charkhi Dadri shows that climatic conditions vary in their support for the crop. Temperature-based suitability indicates that a majority of the district falls under moderately suitable zones, with only a small portion being highly suitable. However, rainfall-based analysis reveals stronger limitations, with half of the district classified as not suitable due to inadequate or uneven monsoon rainfall.



Map-7: Rice crop suitability maps base on mean monthly Temperature and Rainfall (2023).

The table-6 presents a comparative assessment of rice crop suitability in Charkhi Dadri district based on Land Surface Temperature (LST) and rainfall. The LST-based analysis shows that only 13.7% (18,777.9 ha) of the district is highly suitable for rice, while the majority of the area-60.8% (83,470.6 ha)-falls under the moderately suitable category, indicating that thermal conditions are generally acceptable but not optimal across much of the region. A significant portion, 25.6% (35,101.1 ha), is classified as not suitable due to higher temperature ranges that may limit rice growth.

Table-6: Rice Crop Suitability Assessment Based on LST and Rainfall, Charkhi Dadri District

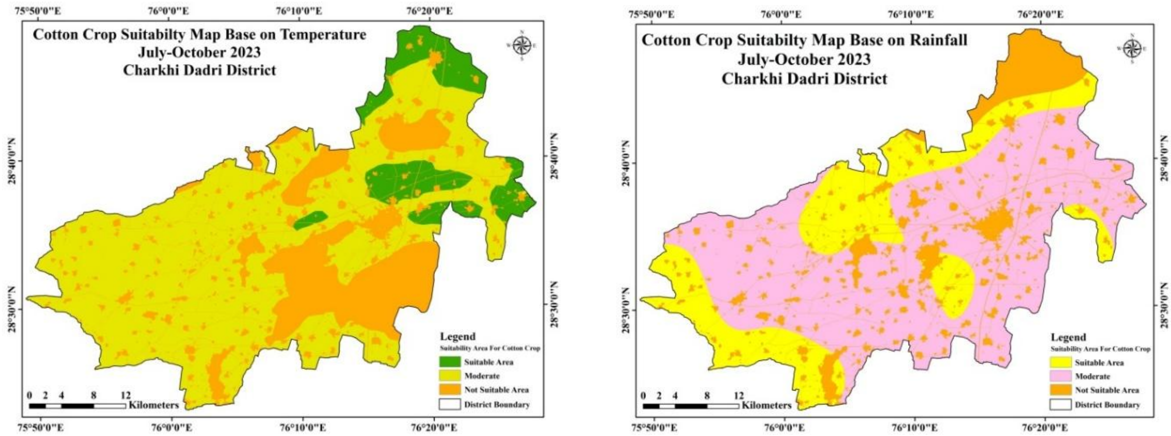
Suitability Class	LST-Based Suitability (Area ha)	LST (%)	Rainfall-Based Suitability (Area ha)	Rainfall (%)
Suitable	18,777.90	13.7	27,687.90	20.2
Moderate	83,470.60	60.8	41,051.90	29.9

Not Suitable	35,101.10	25.6	68,609.80	50
Total Area	**137,349.60**	**100**	**137,349.60**	**100**

In contrast, rainfall-based suitability shows a different pattern, with 20.2% (27,687.9 ha) suitable and 29.9% (41,051.9 ha) moderately suitable. Notably, half of the district, 50% (68,609.8 ha), is considered not suitable for rice based on rainfall, reflecting insufficient or uneven monsoon precipitation in many areas.

Climatic suitability for Cotton Crop:

The suitability assessment for cotton in Charkhi Dadri shows that most of the district falls under moderately suitable conditions for cotton cultivation based on both temperature and rainfall. Only a small portion of the area is highly suitable, while certain zones remain unsuitable due to thermal stress or inadequate rainfall.



Map-8: Cotton crop suitability maps base on mean monthly Temperature and Rainfall (2023).

The table-7 compares the suitability of Charkhi Dadri district for cotton cultivation based on Land Surface Temperature (LST) and rainfall conditions. The LST-based assessment shows that only 10.1% (13,919.8 ha) of the district is highly suitable for cotton, while the majority-62.4% (85,726.9 ha) falls in the moderately suitable class, indicating that temperature conditions generally support cotton but are not optimal everywhere. About 27.5% (37,702.8 ha) is categorized as not suitable due to thermal stress or higher temperature ranges.

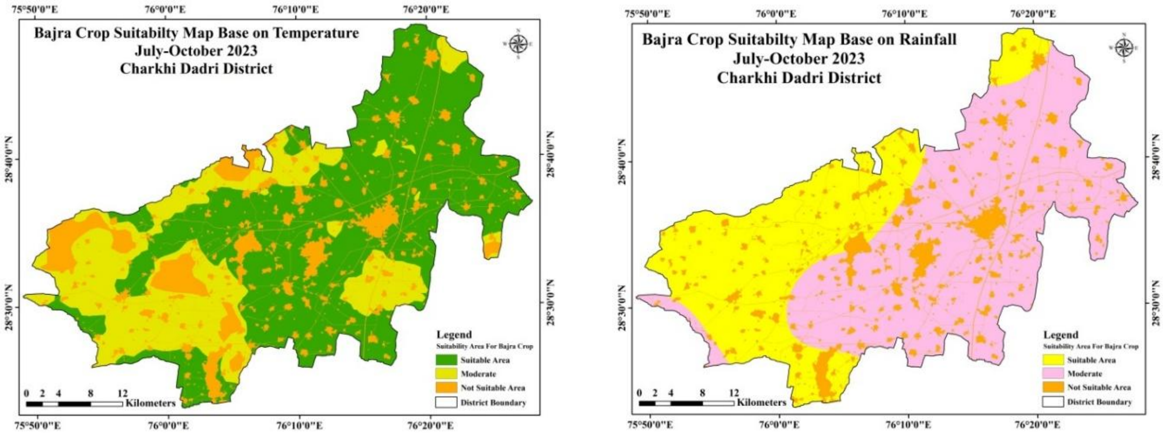
Table-7: Cotton Crop Suitability Assessment Based on LST and Rainfall, Charkhi Dadri District

Suitability Class	LST-Based Suitability (Area ha)	LST (%)	Rainfall-Based Suitability (Area ha)	Rainfall (%)
Suitable	13,919.80	10.1	34,392.90	25
Moderate	85,726.90	62.4	78,934.90	57.5
Not Suitable	37,702.80	27.5	24,021.80	17.5
Total Area	**137,349.60**	**100**	**137,349.60**	**100**

Rainfall-based suitability shows a slightly more favorable pattern, with 25% (34,392.9 ha) of the area classified as suitable and 57.5% (78,934.9 ha) as moderately suitable, reflecting the dependence of cotton on monsoon rainfall. Only 17.5% (24,021.8 ha) is considered not suitable in terms of rainfall.

Climatic suitability for Bajra Crop:

The suitability analysis for Bajra in Charkhi Dadri shows that the crop is strongly supported by the district's temperature conditions, with more than half of the area falling under the suitable category based on LST. Rainfall suitability is slightly lower due to the region's semi-arid monsoon variability, but most areas still remain moderately suitable.



Map-9: Bajra crop suitability maps base on mean monthly Temperature and Rainfall (2023).

The table-8 presents the suitability of Charkhi Dadri district for Bajra cultivation based on Land Surface Temperature (LST) and rainfall. According to LST-based analysis, Bajra performs well under the district's thermal conditions, with 55.7% (76,535.4 ha) categorized as suitable and 26.3% (36,101.6 ha) as moderately suitable. Only 18% (24,712.6 ha) falls under the not suitable category, indicating that temperature is largely favorable for this crop.

Table-8: Bajra Crop Suitability Assessment Based on LST and Rainfall, Charkhi Dadri District

Suitability Class	LST-Based Suitability (Area ha)	LST (%)	Rainfall-Based Suitability (Area ha)	Rainfall (%)
Suitable	76,535.40	55.7	46,901.00	34.1
Moderate	36,101.60	26.3	73,634.70	53.6
Not Suitable	24,712.60	18	16,813.90	12.2
Total Area	**137,349.60**	**100**	**137,349.60**	**100**

Rainfall-based suitability, however, shows a different pattern. Only 34.1% (46,901 ha) of the area is highly suitable in terms of rainfall, while the majority-53.6% (73,634.7 ha) is classified as moderately suitable. A smaller portion, 12.2% (16,813.9 ha), remains unsuitable due to low or inconsistent monsoon rainfall.

Future Climate Scenarios of Charkhi Dadri District:

Future climate scenarios for Charkhi Dadri district indicate increasing variability in both temperature and rainfall, which may significantly influence agricultural sustainability. Rising land surface temperatures, particularly during the pre-monsoon and summer months, suggest a shift toward more frequent heat stress conditions, potentially affecting sensitive crops such as rice and cotton. Rainfall projections point toward greater spatial and temporal irregularities, with intensified monsoon bursts but longer dry spells, which may challenge water availability and reduce the reliability of traditional Kharif cropping systems. In contrast, climate-resilient crops such as Bajra and Mustard are expected to remain more adaptable under these changing conditions due to their tolerance to heat and low moisture. Overall, future scenarios highlight the need for adaptive crop planning, improved water-management strategies, and climate-resilient agricultural practices to sustain crop productivity in Charkhi Dadri district.

III. Conclusion:

The study highlights the strong influence of climatic factors on agricultural patterns in Charkhi Dadri district. Seasonal variations in rainfall and land surface temperature clearly shape the spatial distribution and suitability of major crops. Wheat and mustard emerge as the most favorable Rabi crops due to cooler winter temperatures and adequate moisture availability, while bajra performs well as a climate-resilient Kharif crop in semi-arid conditions. In contrast, cotton and rice show more limited suitability, mainly because of temperature stress and uneven monsoon rainfall. These findings reinforce the important role of climate in determining crop performance, spatial suitability zones, and long-term agricultural sustainability in the district.

The application of Digital Image Processing (DIP) techniques enabled accurate classification and estimation of crop areas, while GIS-based interpolation methods, particularly Kriging, effectively captured the spatial variability of rainfall across the district. The combined use of DIP and GIS technologies provided reliable spatial datasets for identifying suitability zones and understanding crop–climate interactions. Future climate scenarios indicate increasing temperature extremes and irregular rainfall patterns, which may challenge existing cropping systems. Therefore, climate-resilient crops, efficient water management, and geospatial monitoring are essential for sustaining agricultural productivity.

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