Spatial Disparities and Performance Typologies in Crop Yields: A District-Level Comparative Analysis of Haryana, India (2006–2022)

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Abstract
This study presents a comprehensive district-wise analysis of crop yield trends in Haryana, India, over the period 2006–2022. Drawing on secondary data for six major crops—wheat, rice, bajra, mustard, cotton, and sugarcane—the research employs statistical indicators such as mean yield, coefficient of variation (CV), and linear trend slopes to assess spatial disparities and temporal changes in agricultural performance. The results reveal marked heterogeneity across districts, with northeastern regions like Karnal, Kaithal, and Kurukshetra consistently outperforming others in terms of yield and stability. In contrast, districts such as Mewat, Rewari, and Charkhi Dadri exhibit low yields, high volatility, and declining trends. Cross-crop synthesis and typological classification further underscore the existence of high-performing, vulnerable, and transition zones within the state. The study advocates for spatially differentiated agricultural policies that support sustainable intensification, climate resilience, and region-specific interventions.

Keywords:
Haryana, District-wise yield, Crop productivity, Spatial analysis, Trend slope, Typologies, Climate variability, Agricultural disparities

1. Introduction

Agriculture in India is undergoing a phase of structural transformation, driven by rising climate variability, pressure on natural resources, and the need for regional diversification of cropping systems. Within this broader context, the state of Haryana occupies a pivotal position as both a food grain surplus region and a zone of emerging agrarian stress. Although aggregate state-level indicators often suggest stable or improving trends in productivity, such representations mask significant intra-state spatial disparities in crop yields, shaped by differential access to irrigation, varying agro-ecological conditions, and diverse policy and infrastructural environments.

Haryana's agricultural landscape can broadly be divided into two agro-climatic subregions. The northeastern canal-irrigated belt, comprising districts such as Karnal, Kaithal, and Kurukshetra, is characterized by intensive cultivation of wheat and rice, backed by strong infrastructure and assured water supply. In contrast, the western and southern districts—including Fatehabad, Sirsa, Hisar, Bhiwani, and Rewari—operate largely under semi-arid and water-stressed conditions, where crops such as cotton, bajra, mustard, and sugarcane are more prominent. These structural and ecological differences create marked heterogeneity in crop performance, necessitating granular, district-level analysis to inform policy interventions.

While numerous studies have examined temporal yield trends at the state or national level, limited research exists that systematically compares district-wise yield performance across multiple crops within a single state over an extended timeframe. This paper addresses that gap by presenting a comprehensive statistical and spatial analysis of six major crops—wheat, rice, bajra, mustard, cotton, and sugarcane—across all 22 districts of Haryana from 2006 to 2022. The period under consideration coincides with key agricultural transitions in Haryana, including the spread of Minimum Support Price (MSP) regimes, changes in canal irrigation patterns, shifts toward commercial crops, and episodes of climatic extremities such as unseasonal rainfall, heatwaves, and pest outbreaks.

The analysis employs a suite of statistical indicators—mean yield, coefficient of variation (CV), and linear trend slope—along with data visualization tools such as heatmaps, bar plots, and trend rankings to assess both the central tendency and temporal dynamics of yield performance at the district level. The results are further synthesized to classify districts into yield performance typologies—including high-stable, high-volatile, moderate-improving, and low-declining zones. These typologies provide a valuable diagnostic for spatially differentiated planning, particularly in the era of climate uncertainty and input-use intensification.

By adopting a **cross-crop, cross-district lens**, this study not only highlights persistent regional inequalities but also identifies areas of emerging vulnerability and resilience. The findings have direct implications for regional targeting of subsidies, irrigation investment, crop diversification schemes, and climate adaptation policies. The district-wise evidence generated here is intended to serve as a scientific basis for **micro-regional agricultural planning**, bridging the gap between macro policy frameworks and local realities.

2. Data and Methodology

2.1 Study Area and Temporal Scope

This study is situated within the state of Haryana, located in northwestern India, encompassing 22 districts that span a range of agro-ecological conditions. Haryana exhibits stark contrasts in its agricultural systems, with the northeastern districts (e.g., Karnal, Kurukshetra, Kaithal) dominated by irrigated rice-wheat cropping systems, while the southern and western districts (e.g., Sirsa, Hisar, Bhiwani, Rewari) feature rainfed agriculture and cultivation of commercial crops such as bajra, mustard, cotton, and sugarcane. This spatial heterogeneity offers a unique context for evaluating inter-district disparities in crop performance. The temporal scope of this study spans 17 years (2006–2022), a period long enough to capture structural shifts in agricultural trends, the effects of climatic anomalies, and evolving policy landscapes.

2.2 Data Sources

This research is based entirely on secondary data obtained from reliable government sources. Specifically:

- District-wise yield data (kg/ha) for six major crops—wheat, rice, bajra, mustard, cotton, and sugarcane—were sourced from the Department of Economics and Statistics, Government of Haryana.
- The data cover annual yields from 2006 to 2022, enabling temporal trend analysis at the district level.
- Only yield data is used (excluding area and production) to isolate productivity effects and eliminate distortions due to fluctuations in cropped area.
- Supplementary context for agro-climatic and policy interpretation was drawn from the Indian Meteorological Department (IMD) and Haryana's Agro-climatic Zonal Planning literature.

2.3 Analytical Methods

To assess inter-district crop performance and temporal dynamics, the following indicators and tools were employed:

a) Statistical Indicators

For each crop in every district, the following metrics were calculated:

- **Mean Yield (kg/ha):** Represents the central tendency of productivity.
- **Standard Deviation (SD):** Captures the extent of annual fluctuations.
- **Coefficient of Variation (CV %):** A normalized measure of yield variability.
- **Trend Slope (kg/ha/year):** Estimated using simple linear regression to indicate the direction and magnitude of yield change over time.

b) Data Visualization

To supplement and communicate the quantitative findings, a set of visual tools was employed:

- **Bar Charts:** For comparing average yields across districts.
- **Heatmaps:** To visualize inter-district yield stability and volatility.
- **Trend Slope Rankings:** Identifying top and bottom performers in each crop.

2.4 District Typology Construction

In order to generate actionable insights, districts were classified into performance typologies based on:

- Mean yield levels,
- Coefficient of variation (volatility),

- Yield trend slopes.

These were categorized into five groups: high-yield stable, high-yield volatile, moderate-yield improving, low-yield declining, and emerging/volatile zones. This classification provides a robust basis for regional targeting of crop-specific interventions.

3. Results and Discussion

3.1 Wheat Yield Patterns

Wheat is a dominant Rabi crop in Haryana, extensively cultivated across all districts, particularly in the canal-irrigated northern and central regions. The district-level analysis of wheat yield trends over the period 2006–2022 reveals significant spatial disparities in average productivity, yield stability, and long-term growth trajectories.

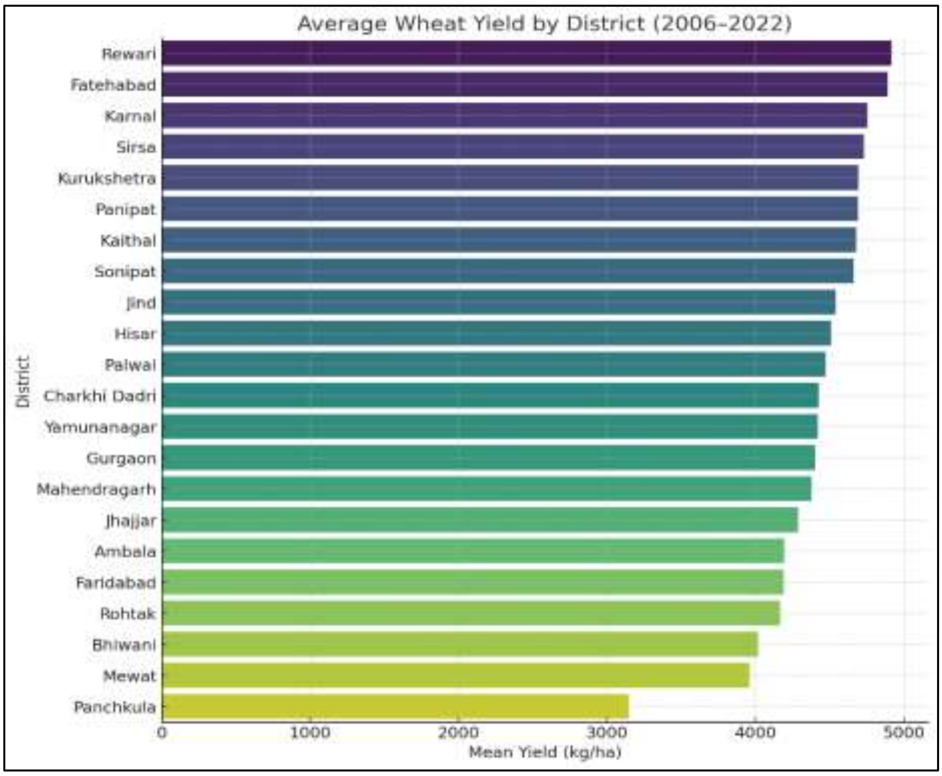


Figure 1: Average Wheat Yield by District (2006–2022)

a) Yield Levels and Spatial Disparities

Districts such as Karnal (4753 kg/ha), Kaithal (4681 kg/ha), Kurukshetra (4695 kg/ha), and Fatehabad (4889 kg/ha) recorded the highest mean yields, all exceeding the 4500 kg/ha mark. These regions lie within the intensively cultivated, irrigated northeastern belt of Haryana, where wheat productivity benefits from assured canal water supply, high-yielding varieties, mechanized farming, and balanced fertilizer application.

In contrast, Mewat (3962 kg/ha), Faridabad (4193 kg/ha), and Rewari (4918 kg/ha but with extreme volatility) posted relatively lower or unstable mean yields, highlighting the challenges in regions with limited irrigation, poor soil health, or climatic exposure.

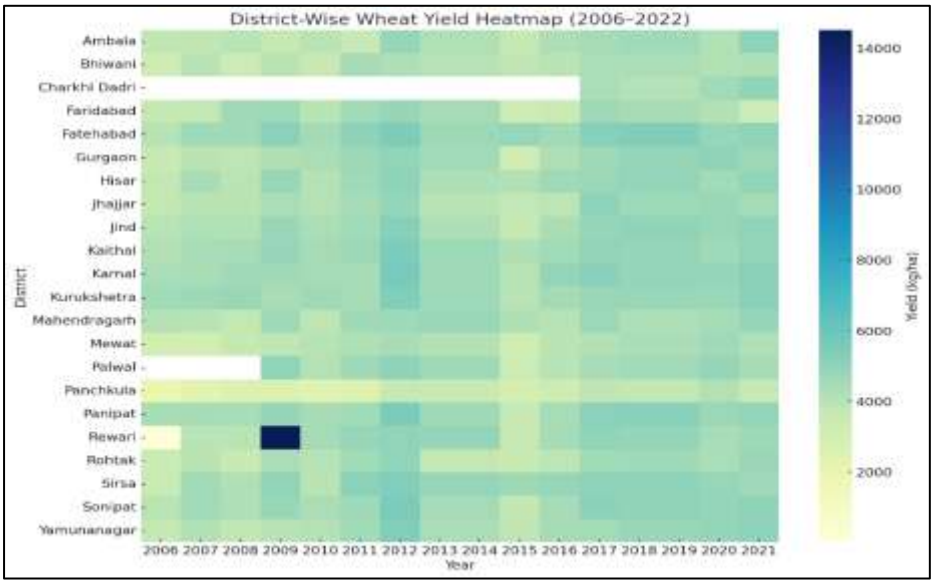


Figure 2: District-wise Wheat Yield Heatmap (2006–2022)

b) Yield Stability (Coefficient of Variation)

The Coefficient of Variation (CV%) was lowest in districts like Kaithal (6.64%) and Kurukshetra (6.51%), reflecting high yield consistency and resilience to inter-annual shocks. On the other hand, Panchkula (CV: 20.91%) and Rewari (CV: 57.61%) showed marked instability, indicating either emerging cultivation practices, data anomalies, or increased vulnerability to climatic stressors.

Table 1: Wheat Yield Statistics by District (2006–2022)

District	Mean Yield	Std Dev	CV (%)	Trend Slope (kg/ha/year)
Ambala	4194.88	449.36	10.71	64.19
Bhiwani	4016.81	346.31	8.62	46.96
Charkhi Dadri	4429.40	368.02	8.31	180.90
Faridabad	4193.12	528.70	12.61	-10.37
Fatehabad	4889.75	384.67	7.87	41.92
Gurgaon	4405.81	542.55	12.31	65.57
Hisar	4512.25	404.43	8.96	50.90
Jhajjar	4288.56	446.20	10.40	51.27
Jind	4541.44	444.84	9.80	47.49
Kaithal	4681.19	310.99	6.64	26.05
Karnal	4753.50	390.84	8.22	38.59
Kurukshetra	4694.94	305.57	6.51	16.03
Mahendragarh	4376.88	357.25	8.16	31.41
Mewat	3962.25	468.53	11.82	64.71
Palwal	4474.62	445.73	9.96	-15.45
Panchkula	3149.06	658.53	20.91	122.63
Panipat	4690.88	455.09	9.70	31.49
Rewari	4918.51	2833.66	57.61	-5.55
Rohtak	4168.62	507.49	12.17	52.36
Sirsa	4731.38	480.04	10.15	51.65
Sonipat	4660.38	456.04	9.79	43.56
Yamunanagar	4422.75	481.40	10.88	67.83

c) Yield Trend Slopes

Positive yield trends were observed in Charkhi Dadri (+180.9 kg/ha/year), Yamunanagar (+67.8), and Ambala (+64.2), suggesting sustained improvements in productivity. These may reflect the impact of improved technology diffusion or recent policy initiatives.

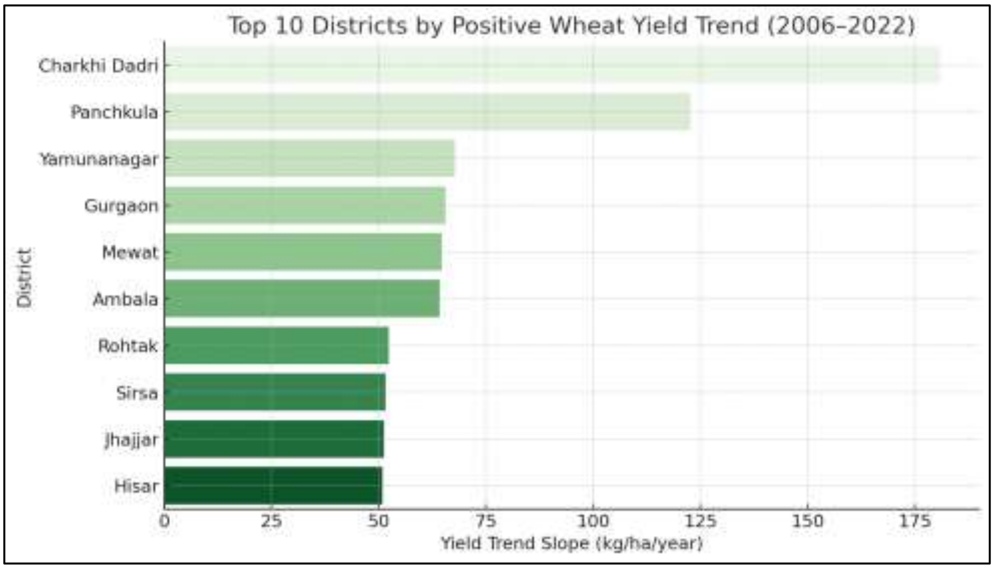


Figure 3: Top 10 Districts by Positive Wheat Yield Trend

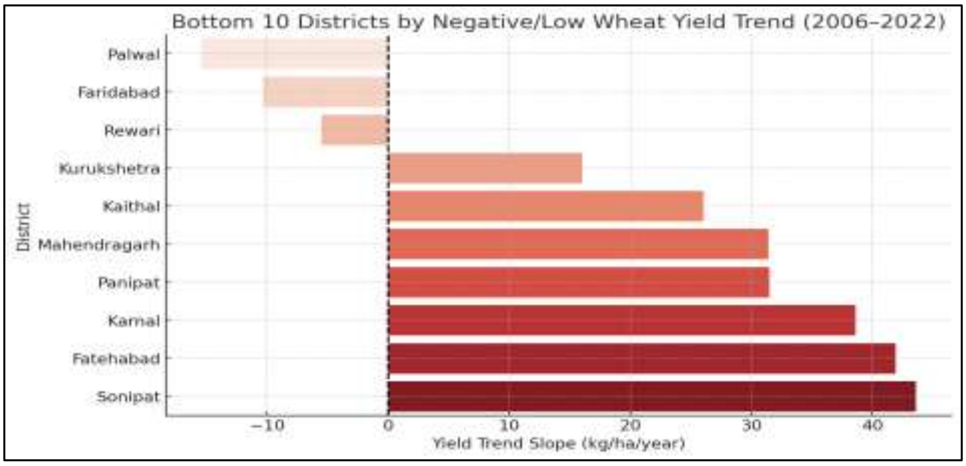


Figure 4: Bottom 10 Districts by Negative/Low Wheat Yield Trend

Conversely, districts like Faridabad (-10.4) and Palwal (-15.5) demonstrated negative slopes, indicating yield stagnation or decline despite moderate mean yields. Such trends necessitate targeted extension services, seed replacement programs, and irrigation infrastructure investments.

d) Spatial Visualization Insights

- Bar graphs show a clear north-south yield gradient, with northeastern districts outperforming southern counterparts.
- Heatmaps confirm zones of high consistency (Kaithal, Karnal) and high volatility (Rewari, Panchkula).
- Trend slope charts reinforce the divergence between improving zones (Yamunanagar, Charkhi Dadri) and declining ones (Faridabad, Palwal).

e) Interpretation

Overall, wheat productivity in Haryana shows strong spatial clustering around high-performing, irrigated districts. The relatively low CVs and positive trends in the top-yielding zones affirm the success of the rice-wheat cropping system under canal-fed conditions. However, districts in the southern and southwestern parts of the state reflect yield volatility, declining trends, or both, largely due to soil degradation, erratic winter rainfall, and uneven access to inputs. The findings call for differentiated strategies, with a focus on sustaining gains in the north and revitalizing wheat in the south through location-specific agronomic and infrastructural support.

3.2 Bajra Yield Patterns

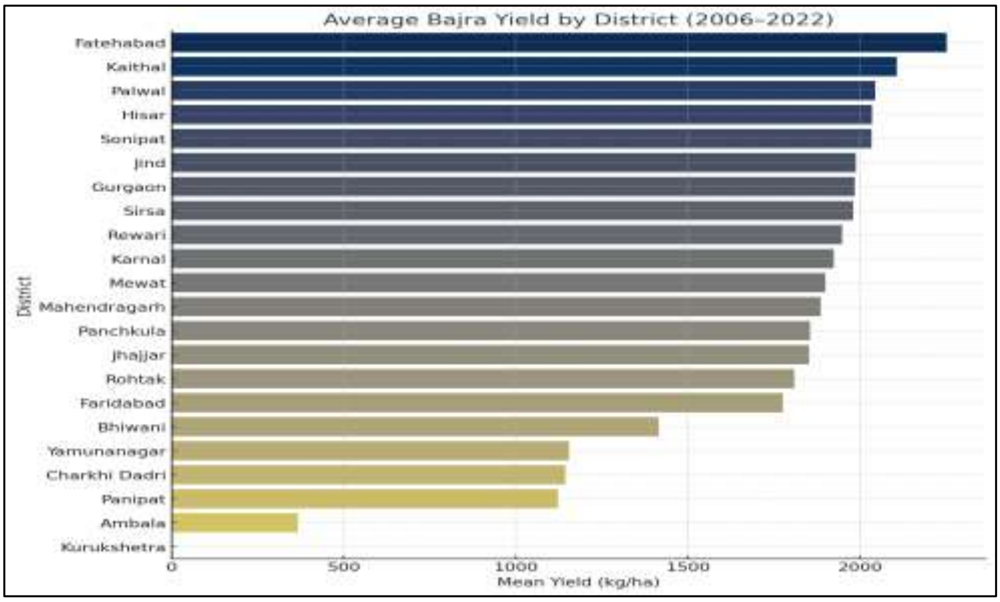
Bajra (pearl millet) is an important rainfed Kharif crop in Haryana, cultivated predominantly in the semi-arid western and southern districts. Unlike wheat or rice, its productivity is closely linked to monsoon performance, soil moisture retention, and varietal selection, making it a useful proxy for analyzing climate-sensitive agriculture in marginal environments.

a) Yield Levels and Regional Trends

Districts such as Fatehabad (2251 kg/ha), Hisar (2034 kg/ha), and Sirsa (1979 kg/ha) reported the highest mean bajra yields, reflecting favorable soil conditions and better rainfall utilization within traditional bajra-growing zones. In contrast, Ambala (367 kg/ha) and Yamunanagar (1154 kg/ha) exhibited significantly lower average yields, indicating either marginal adoption or unsuitable agro-ecological settings for bajra.

The exceptionally low yields in some eastern districts suggest that bajra has not been a crop of economic focus in these zones, likely due to the dominance of rice and lack of tradition in millet cultivation.

Figure 5.: Average Bajra Yield by District (2006–2022)



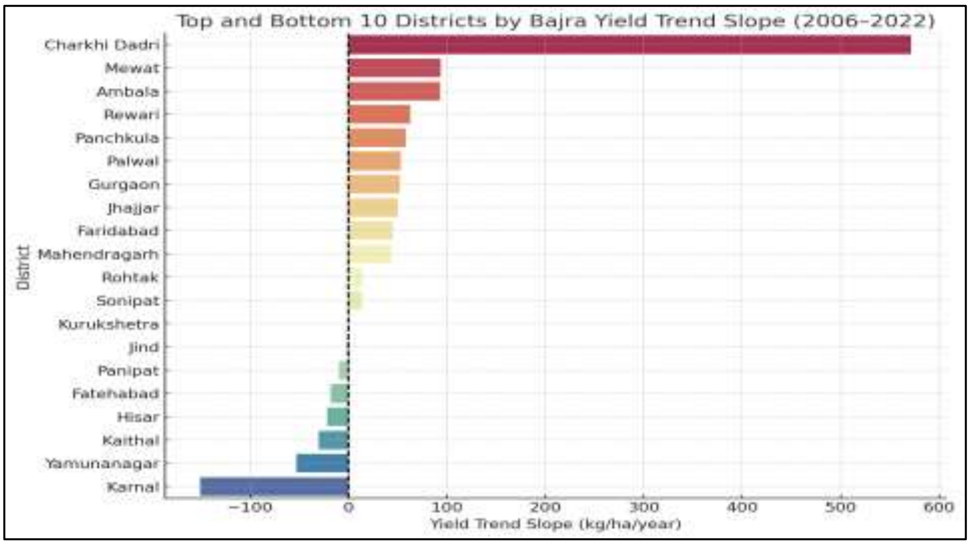


Figure 6: Top and Bottom 10 Districts by Bajra Yield Trend Slope

b) Yield Variability (CV%)

The coefficient of variation (CV) for bajra reveals extremely high inter-annual yield variability in several districts. For example, Ambala (CV: 215.9%), Charkhi Dadri (82%), and Yamunanagar (84.4%) experienced sharp year-to-year fluctuations. In contrast, Jind (CV: 10.2%) and Hisar (14.5%) displayed comparatively stable yield patterns.

Table 2: Bajra Yield Statistics by District (2006–2022)

District	Mean Yield	Std Dev	CV (%)	Trend Slope (kg/ha/year)
Ambala	367.31	792.83	215.85	92.89
Bhiwani	1414.81	291.23	20.58	28.59
Charkhi Dadri	1144.60	938.07	81.96	571.10
Faridabad	1774.56	294.85	16.62	44.92
Fatehabad	2251.25	291.45	12.95	-18.00
Gurgaon	1984.50	380.32	19.16	52.40
Hisar	2034.31	294.22	14.46	-21.39
Jhajjar	1850.94	364.03	19.67	49.89
Jind	1987.75	201.83	10.15	-1.93
Kaithal	2105.94	445.57	21.16	-30.03
Karnal	1923.19	1070.83	55.68	-150.37
Kurukshetra	0.00	0.00	nan	0.00
Mahendragarh	1884.94	428.46	22.73	43.43
Mewat	1899.12	485.13	25.54	93.60
Palwal	2042.92	361.62	17.70	53.21
Panchkula	1855.06	694.02	37.41	58.42
Panipat	1122.25	1060.23	94.47	-9.84
Rewari	1947.06	406.17	20.86	62.89
Rohtak	1808.31	275.64	15.24	14.13
Sirsa	1979.06	487.01	24.61	18.12
Sonipat	2033.06	397.38	19.55	13.97
Yamunanagar	1153.94	973.72	84.38	-53.03

Such variations may stem from **rainfall inconsistency, soil heterogeneity, and low adoption of improved hybrids**. Districts with very high CV values likely lack risk-buffering mechanisms such as drought-tolerant varieties or timely agronomic interventions.

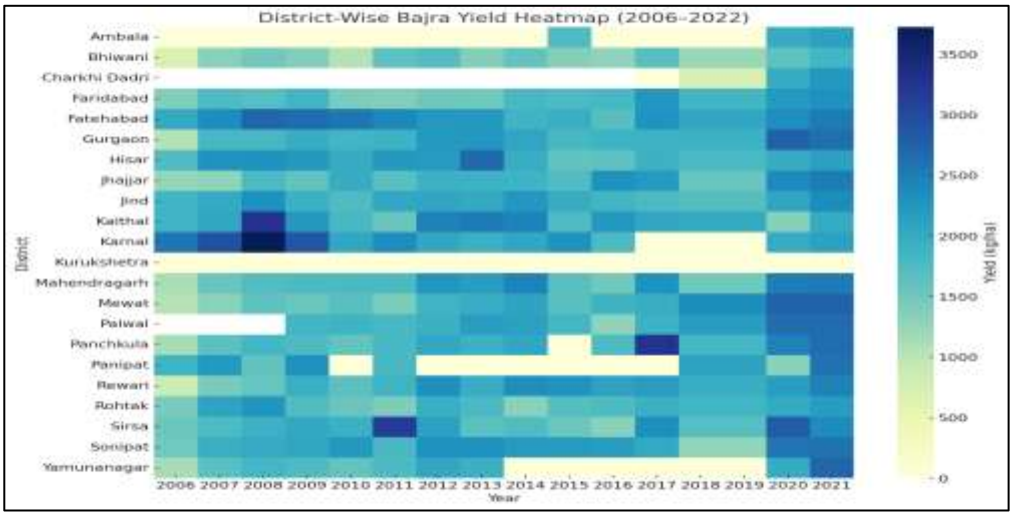


Figure 7: District-wise Bajra Yield Heatmap (2006–2022)

c) Trend Slope Analysis

The linear trend slope analysis showed that Charkhi Dadri (+571 kg/ha/year), Mewat (+93.6), and Rewari (+62.9) had the steepest positive growth in yield. However, in the case of Charkhi Dadri, the unusually high slope is likely a statistical artifact caused by near-zero yields in early years—suggesting data distortion or recent expansion of bajra cultivation.

Conversely, Karnal (-150.37), Kaithal (-30.03), and Hisar (-21.39) recorded negative trends, indicating a gradual decline in bajra productivity. This could be due to land-use shifts, declining rainfall reliability, or replacement by more remunerative crops.

d) Interpretation

The bajra yield analysis reveals a dual narrative. In traditional bajra belts like Fatehabad and Sirsa, the crop has maintained relatively high and stable productivity, suggesting untapped potential for millet-based climate resilience strategies. On the other hand, several eastern and northern districts show either minimal cultivation or erratic trends, pointing to ecological unsuitability or policy neglect.

Given the national-level push for millet promotion under initiatives like the International Year of Millets (2023), these findings support the case for reviving bajra in western Haryana through improved seed systems, watershed development, and agro-climatic targeting.

3.3 Cotton Yield Patterns

Cotton is a commercially significant Kharif crop cultivated predominantly in the western and southwestern districts of Haryana such as Sirsa, Fatehabad, Hisar, and Bhiwani. The crop's performance, however, has become increasingly erratic due to its high sensitivity to pest infestations, monsoon variability, and rising input costs. The district-level yield analysis for the period 2006–2022 reveals a concerning pattern of low average yields, high volatility, and widespread declining trends.

Districts such as Fatehabad (405.5 kg/ha), Hisar (344.2 kg/ha), and Sirsa (395.9 kg/ha) reported the highest mean cotton yields in the state. However, these values remain modest in comparison to national benchmarks, and their interpretation is tempered by the extremely high levels of variability recorded across all cultivating districts. For instance, coefficient of variation (CV%) ranged from 84% in Bhiwani to over 110% in Sonipat, indicating persistent inter-annual instability. In some districts, such as Gurgaon, Mewat, and Palwal, extremely high CVs above 200% reflect emergent or marginal adoption, often from negligible baseline levels.

What is especially striking is the uniformly negative yield trend slopes observed across all major cotton-growing districts. Fatehabad (-52.87 kg/ha/year), Hisar (-42.24), and Kaithal (-44.03) recorded steep downward trajectories, signaling a structural decline in cotton productivity over the 17-year period. The absence of any significant district with a consistently positive slope highlights the systemic nature of the problem. These findings correlate with the 2015–2016 whitefly outbreak, rising cost of Bt seed technology, and growing climate-induced stress.

Heatmap visualizations and slope charts reinforce these conclusions, showing widespread yield collapses in key years and a spatial clustering of vulnerability in the cotton belt. Even in districts with relatively high mean yields, such as Fatehabad and Sirsa, the consistent downward slopes emphasize that current cotton cultivation systems are increasingly unsustainable under existing practices.

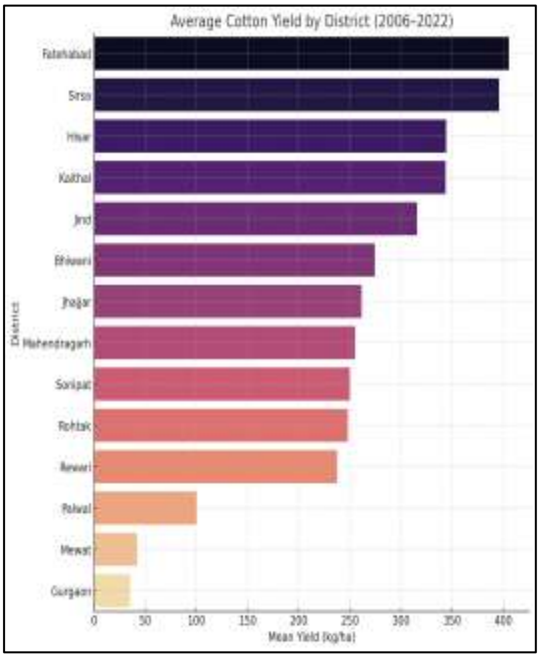


Figure 8: Average Cotton Yield by District (2006–2022)

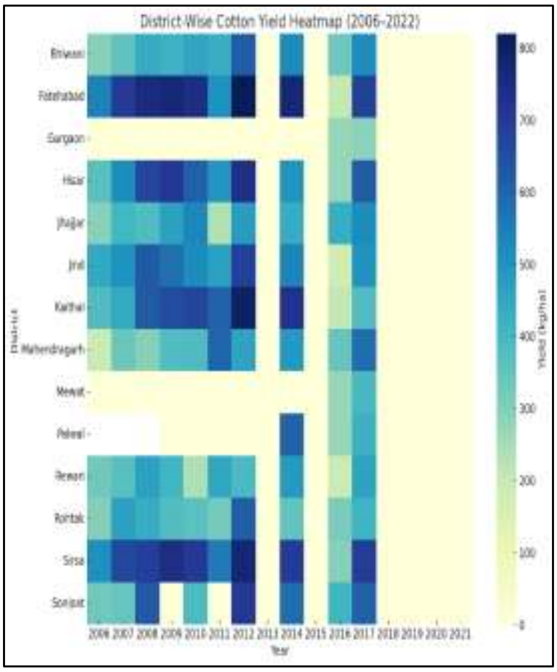


Figure 9: District-wise Cotton Yield Heatmap (2006–2022)

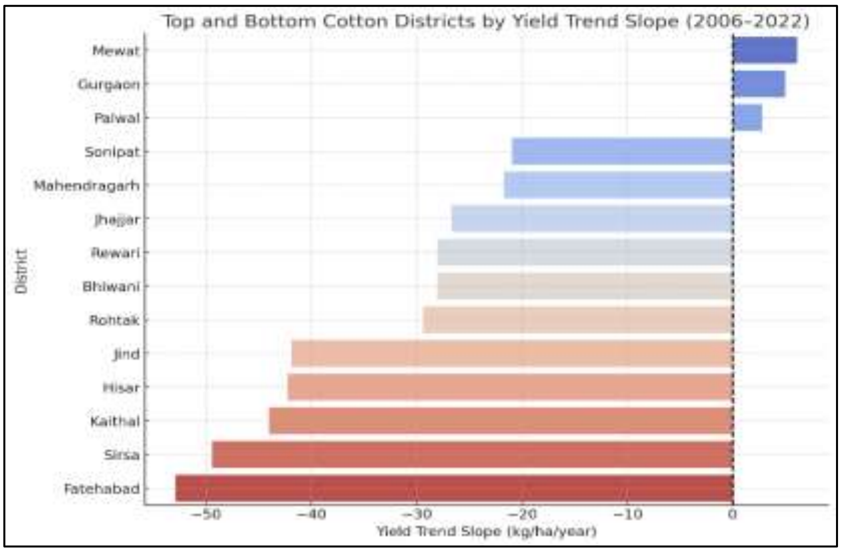


Figure 10: Top and Bottom Cotton Districts by Yield Trend Slope

Table 3: Cotton Yield Statistics by District (2006–2022)

District	Mean Yield	Std Dev	CV (%)	Trend Slope (kg/ha/year)
Ambala	0.00	0.00	nan	0.00
Bhiwani	274.44	231.67	84.42	-28.08
Charkhi Dadri	0.00	0.00	nan	0.00
Faridabad	0.00	0.00	nan	0.00
Fatehabad	405.50	354.53	87.43	-52.87
Gurgaon	35.19	96.19	273.36	4.99
Hisar	344.19	298.46	86.71	-42.24
Jhajjar	261.56	221.80	84.80	-26.70
Jind	315.69	273.61	86.67	-41.87

Kaithal	343.69	310.21	90.26	-44.03
Karnal	0.00	0.00	nan	0.00
Kurukshetra	0.00	0.00	nan	0.00
Mahendragarh	255.25	226.97	88.92	-21.73
Mewat	41.94	116.77	278.45	6.10
Palwal	100.23	202.36	201.89	2.79
Panchkula	0.00	0.00	nan	0.00
Panipat	0.00	0.00	nan	0.00
Rewari	237.62	205.21	86.36	-28.02
Rohtak	248.19	211.65	85.28	-29.39
Sirsa	395.88	335.45	84.74	-49.47
Sonipat	249.88	276.57	110.68	-20.96
Yamunanagar	0.00	0.00	nan	0.00

The implications are serious: cotton appears to be the most vulnerable and declining crop in Haryana's agricultural portfolio. Without urgent interventions in integrated pest management (IPM), climate-resilient varietal development, and price risk mitigation, cotton cultivation in Haryana may continue to shrink in both productivity and area. The trends observed in this analysis warrant a policy reorientation, possibly toward crop diversification, reduced pesticide reliance, and support for alternative high-value, low-risk crops in affected districts.

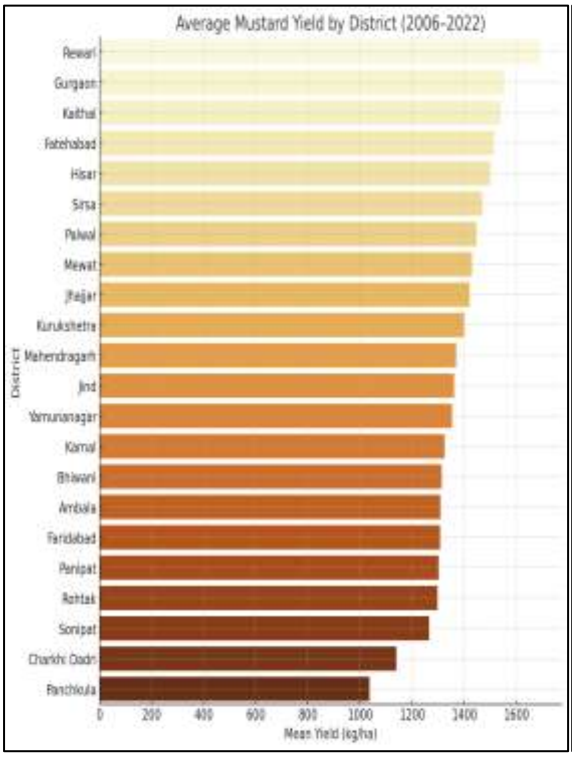
3.4 Mustard Yield Patterns

Mustard is a key rabi oilseed crop in Haryana, widely cultivated across both irrigated and semi-arid zones. Its significance lies in its relatively short growing season and suitability for residual moisture conditions. However, the crop's yield performance over the period 2006–2022 indicates increasing instability and a widespread decline across districts, highlighting its growing vulnerability to climatic stress and soil moisture deficits, especially during sensitive reproductive stages.

Among the districts, Rewari (1689 kg/ha), Gurgaon (1554 kg/ha), Kaithal (1539 kg/ha), and Fatehabad (1513 kg/ha) recorded the highest average mustard yields. These values suggest strong productivity potential in the southern and western districts, where mustard is an important component of the wheat-mustard or bajra-mustard cropping systems. However, despite high means in some areas, yield volatility remains a pervasive issue. Coefficient of variation (CV%) values exceed 40% in nearly all districts, with Charkhi Dadri (CV: 91.29%), Palwal (60.07%), and Panchkula (62.61%) indicating extreme inter-annual fluctuations. These patterns reflect the mustard crop's sensitivity to terminal heat during pod formation, coupled with inconsistent winter rainfall and deteriorating soil health.

The trend slope analysis reveals an even more concerning pattern. Nearly all districts show negative yield trends, with the steepest declines observed in Charkhi Dadri (-569.1 kg/ha/year), Faridabad (-68.8), and Fatehabad (-57.16). Even high-performing districts like Rewari (-40.94) and Sirsa (-36.35) experienced declining trajectories. This widespread pattern suggests a systemic decline in mustard productivity, possibly driven by increased weather variability, depletion of organic matter in soils, and rising cost of cultivation.

Spatial representations confirm these findings. While western districts show pockets of relatively higher average productivity, the accompanying high variability and negative slopes highlight growing uncertainty. In eastern and peri-urban districts like Faridabad and Panchkula, mustard appears increasingly marginalized, with low yields and limited resilience to climatic shocks.



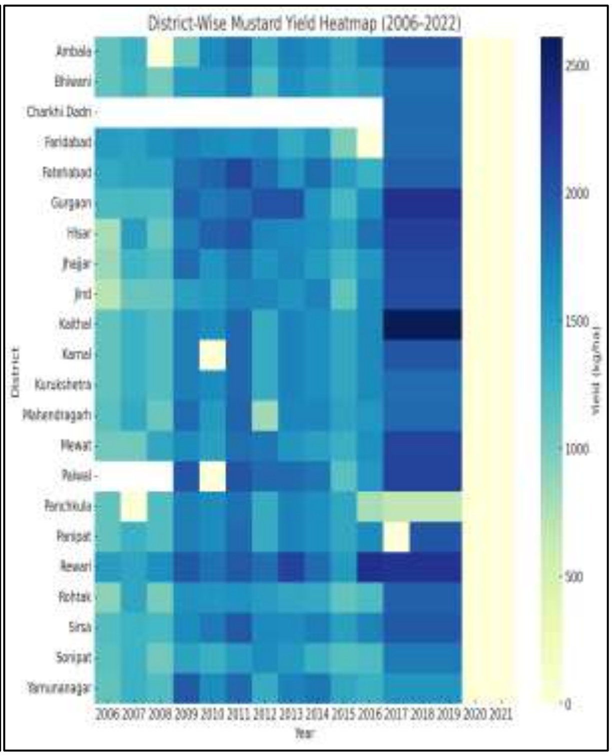


Figure 11: Average Mustard Yield by District (2006–2022) **Figure 12: District-wise Mustard Yield Heatmap (2006–2022)**

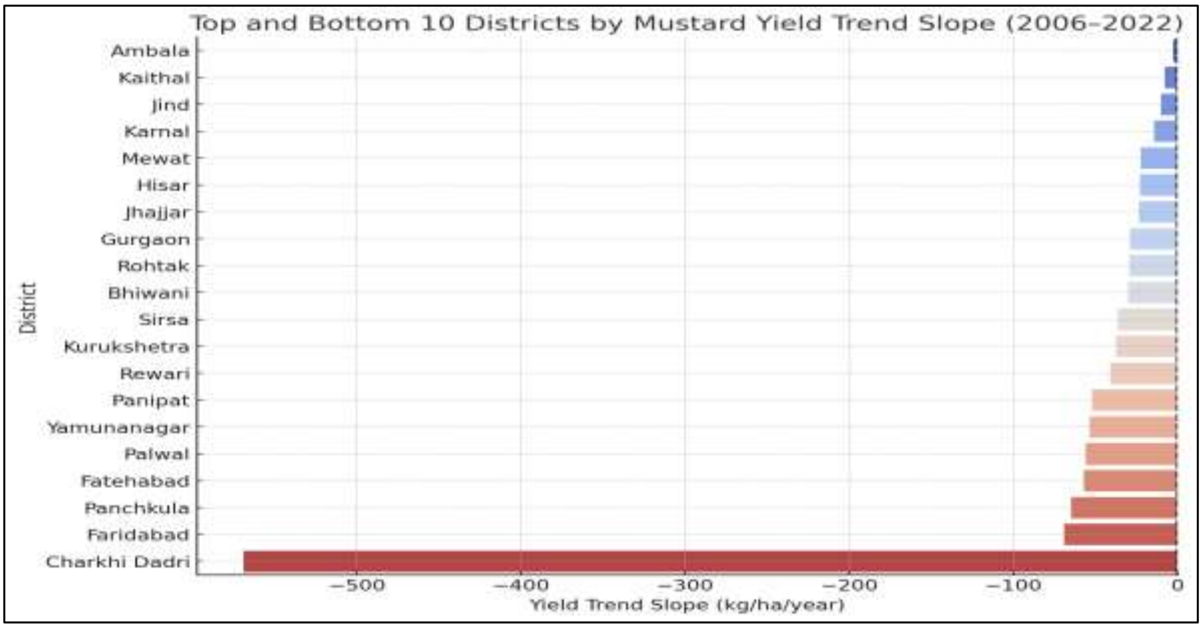


Figure 13: Top and Bottom 10 Districts by Mustard Yield Trend Slope

Table 4: Mustard Yield Statistics by District (2006–2022)

District	Mean Yield	Std Dev	CV (%)	Trend Slope (kg/ha/year)
Ambala	1308.38	711.08	54.35	-2.55
Bhiwani	1312.19	570.29	43.46	-30.07
Charkhi Dadri	1138.20	1039.03	91.29	-569.10
Faridabad	1306.81	682.64	52.24	-68.80

Fatehabad	1513.38	633.27	41.84	-57.16
Gurgaon	1553.94	715.82	46.06	-28.82
Hisar	1498.81	698.16	46.58	-22.57
Jhajjar	1420.31	654.19	46.06	-23.59
Jind	1360.00	658.87	48.45	-9.90
Kaithal	1538.62	764.64	49.70	-7.62
Karnal	1323.75	712.91	53.86	-14.09
Kurukshetra	1397.94	595.26	42.58	-37.39
Mahendragarh	1368.56	621.37	45.40	-35.23
Mewat	1428.81	650.81	45.55	-22.37
Palwal	1446.17	868.75	60.07	-55.80
Panchkula	1035.25	648.21	62.61	-64.62
Panipat	1301.31	695.04	53.41	-51.94
Rewari	1689.00	720.74	42.67	-40.94
Rohtak	1296.00	591.26	45.62	-29.17
Sirsa	1467.50	625.60	42.63	-36.35
Sonipat	1264.56	541.48	42.82	-36.03
Yamunanagar	1352.94	577.19	42.66	-53.60

In summary, mustard cultivation in Haryana is facing structural constraints. The simultaneous occurrence of high yield potential and steep declines suggests that without adaptive interventions, mustard could become economically unviable in many regions. The findings call for immediate focus on improved seed systems, climate-smart agronomy, early sowing strategies, and better access to contingency irrigation, especially in climate-exposed southern districts. These measures will be critical if Haryana is to reverse the trajectory of declining mustard yields and ensure oilseed self-reliance under changing climatic regimes.

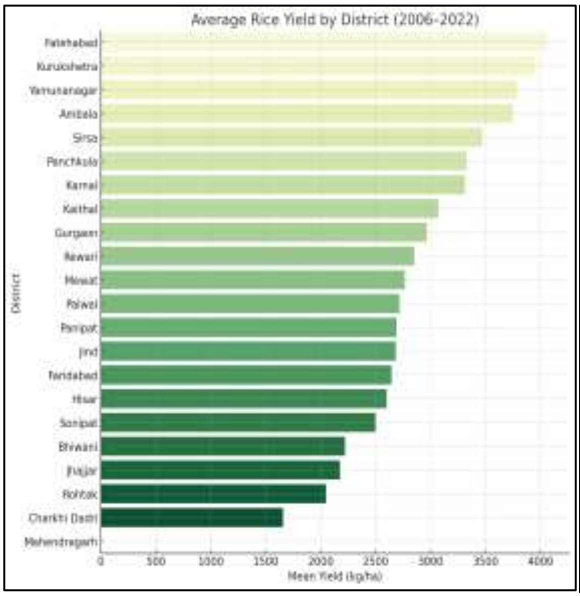
3.5 Rice Yield Patterns

Rice is a major kharif season cereal crop in Haryana, predominantly cultivated in the northeastern canal-irrigated districts. As part of the rice-wheat rotation system, rice has benefitted from intensive input use, policy support through procurement under the Minimum Support Price (MSP) regime, and consistent water availability. The district-wise analysis from 2006 to 2022 reveals relatively high productivity and yield stability in traditional rice-growing zones, but also identifies signs of stagnation and emerging stress in several peripheral districts.

The highest average rice yields were recorded in Fatehabad (4057.6 kg/ha), Kurukshetra (3958.8 kg/ha), Yamunanagar (3787.4 kg/ha), and Ambala (3748.8 kg/ha). These districts form the rice-intensive northeastern belt of Haryana, supported by well-developed irrigation infrastructure, assured canal water from the Western Yamuna Canal system, and widespread adoption of high-yielding rice varieties. Their coefficient of variation (CV%) values remained below 10%—Fatehabad (6.93%), Palwal (6.15%), and Hisar (7.16%)—indicating a high degree of yield consistency over the 17-year period.

In contrast, Charkhi Dadri (1658.6 kg/ha), Bhiwani (2220.8 kg/ha), and Rewari (2850.8 kg/ha) recorded significantly lower yields, reflecting limitations in irrigation availability and suitability of agro-ecological conditions. Mahendragarh reported zero values throughout, confirming the absence of rice cultivation. Interestingly, Charkhi Dadri reported a very high positive yield trend slope (+523 kg/ha/year), which, similar to bajra in this district, is likely a data distortion artifact stemming from near-zero early-year values and recent adoption. Such outliers should be interpreted cautiously and not considered evidence of sustainable yield improvement.

The trend slope analysis further supports the observed regional divide. Districts like Yamunanagar (+60.5), Jhajjar (+67.0), and Kaithal (+57.1) posted positive trends, confirming gradual but steady improvements in yield over time. Conversely, districts such as Sirsa (-24.9), Faridabad (-12.3), and Rewari (-44.9) witnessed negative slopes, indicative of stagnation or decline in rice productivity, possibly due to groundwater depletion, delayed transplanting, or increasing heat stress during the grain-filling stage.



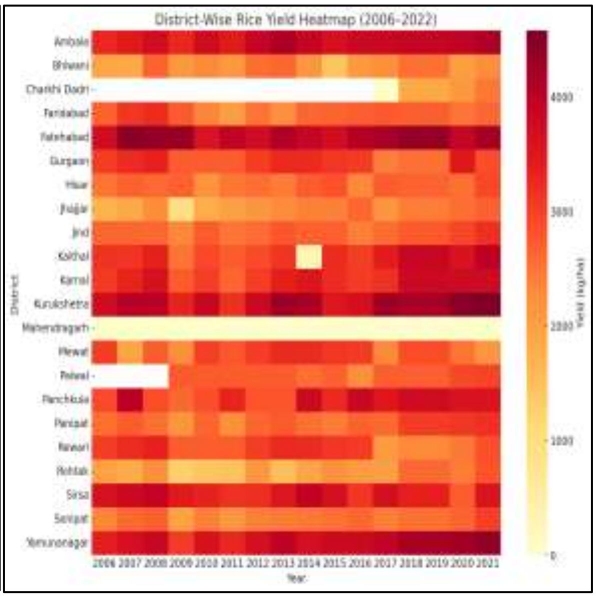


Figure 14: Average Rice Yield by District (2006–2022) Figure 15: District-wise Rice Yield Heatmap (2006–2022)

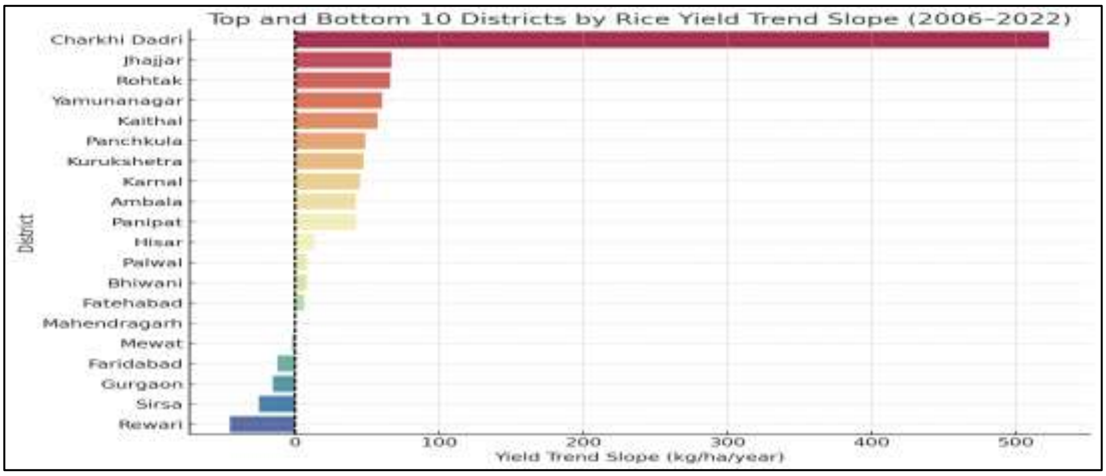


Figure 16: Top and Bottom 10 Districts by Rice Yield Trend Slope

Table 5: Rice Yield Statistics by District (2006–2022)

District	Mean Yield	Std Dev	CV (%)	Trend Slope (kg/ha/year)
Ambala	3748.75	267.28	7.13	42.41
Bhiwani	2220.75	327.61	14.75	7.91
Charkhi Dadri	1658.60	962.45	58.03	523.00
Faridabad	2643.00	285.93	10.82	-12.25
Fatehabad	4057.56	280.99	6.93	6.58
Gurgaon	2964.62	318.33	10.74	-15.23
Hisar	2600.88	186.25	7.16	13.89
Jhajjar	2173.12	432.45	19.90	67.03
Jind	2683.25	203.23	7.57	24.14
Kaithal	3071.31	850.27	27.68	57.08
Karnal	3312.25	369.06	11.14	45.17
Kurukshetra	3958.75	395.82	10.00	47.53
Mahendragarh	0.00	0.00	nan	0.00

Mewat	2764.06	414.71	15.00	-2.08
Palwal	2715.92	166.96	6.15	8.06
Panchkula	3328.50	449.36	13.50	48.89
Panipat	2689.38	290.48	10.80	42.36
Rewari	2850.81	389.62	13.67	-44.94
Rohtak	2046.62	458.73	22.41	66.00
Sirsa	3470.62	310.88	8.96	-24.94
Sonipat	2498.56	229.23	9.17	24.34
Yamunanagar	3787.44	355.09	9.38	60.54

Spatially, the yield heatmaps and slope charts illustrate a clear east-west divide. The northeast continues to dominate in both yield level and stability, while southwestern and southern districts show signs of agro-ecological unsuitability or policy-induced withdrawal from rice cultivation. These patterns align with state-level initiatives such as the "Mera Pani Meri Virasat" scheme, which encourages crop diversification away from water-intensive rice in vulnerable zones.

In conclusion, while rice remains a high-performing and stable crop in northeastern Haryana, its expansion into less suitable regions is not economically or ecologically sustainable. The results underscore the need for region-specific rice policies—including promotion of direct-seeded rice (DSR) in water-stressed districts, incentives for crop diversification, and technological interventions to enhance water-use efficiency in intensive zones. Balancing productivity with sustainability will be key to managing the future of rice cultivation in Haryana.

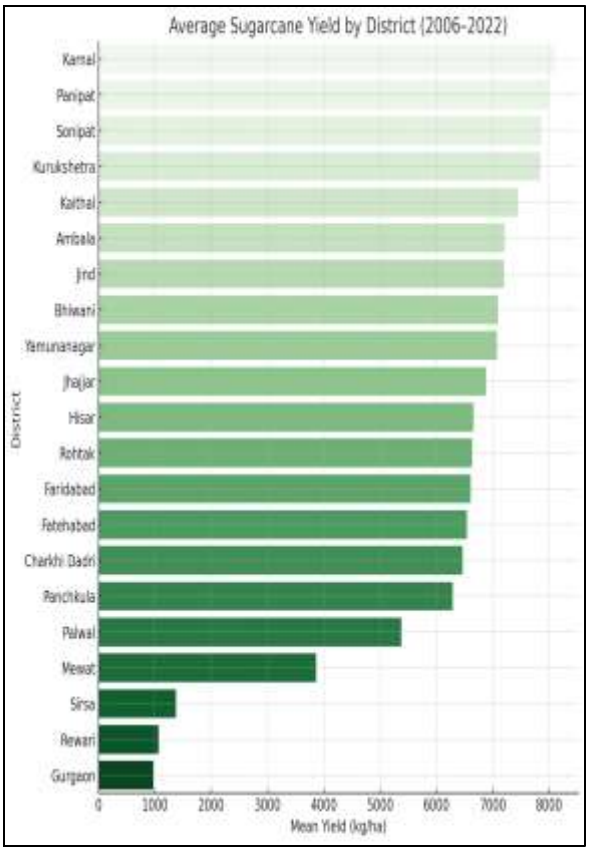
3.6 Sugarcane Yield Patterns

Sugarcane, a high-water-demand and long-duration cash crop, occupies a relatively smaller area in Haryana compared to cereals and oilseeds but plays a significant role in the cropping systems of central and eastern districts with established sugar mill infrastructure. Unlike cotton and mustard, sugarcane shows encouraging trends in both yield stability and long-term productivity, making it one of the more resilient crops during the 2006–2022 period.

The highest average yields were recorded in Karnal (8115.1 kg/ha), Panipat (7996.7 kg/ha), Kurukshetra (7845.1 kg/ha), and Kaithal (7451.8 kg/ha). These districts lie within Haryana's central canal-irrigated zone and benefit from better irrigation, proximity to sugar mills, and institutional support for crop processing and procurement. Their coefficient of variation values remained below 13% in most cases, indicating stable and consistent yield performance over time.

By contrast, southern and western districts such as Rewari (1064 kg/ha), Sirsa (1374.1 kg/ha), and Gurgaon (975.6 kg/ha) reported very low yields, alongside extremely high CVs (>200%), pointing to either marginal cultivation or inconsistent adoption. Similarly, Charkhi Dadri (CV: 56.2%) and Faridabad (CV: 18.9%) displayed volatile yield patterns, possibly reflecting experimental cultivation or data anomalies in early years.

The trend slope analysis shows a generally positive trajectory across most districts. The most dramatic increases were seen in Charkhi Dadri (+1761.1 kg/ha/year) and Fatehabad (+286.2), although such extreme slopes are likely inflated due to low baseline values and recent adoption. More reliable growth trends were observed in Karnal (+190.3), Ambala (+113.9), and Yamunanagar (+146.4), which combine both high mean yields and moderate, consistent gains over time.



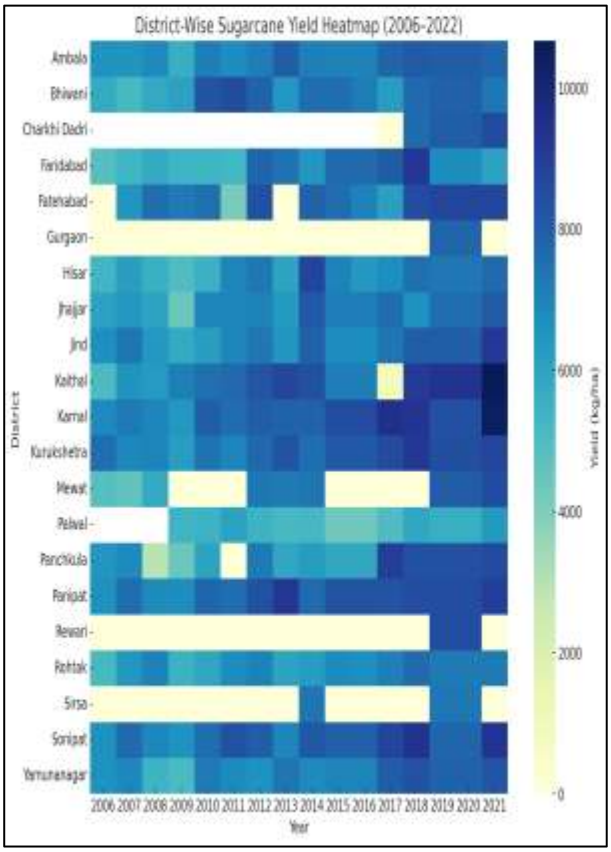


Figure 17: Average Sugarcane Yield by District (2006–2022) **Figure 18: District-wise Sugarcane Yield Heatmap (2006-2022)**

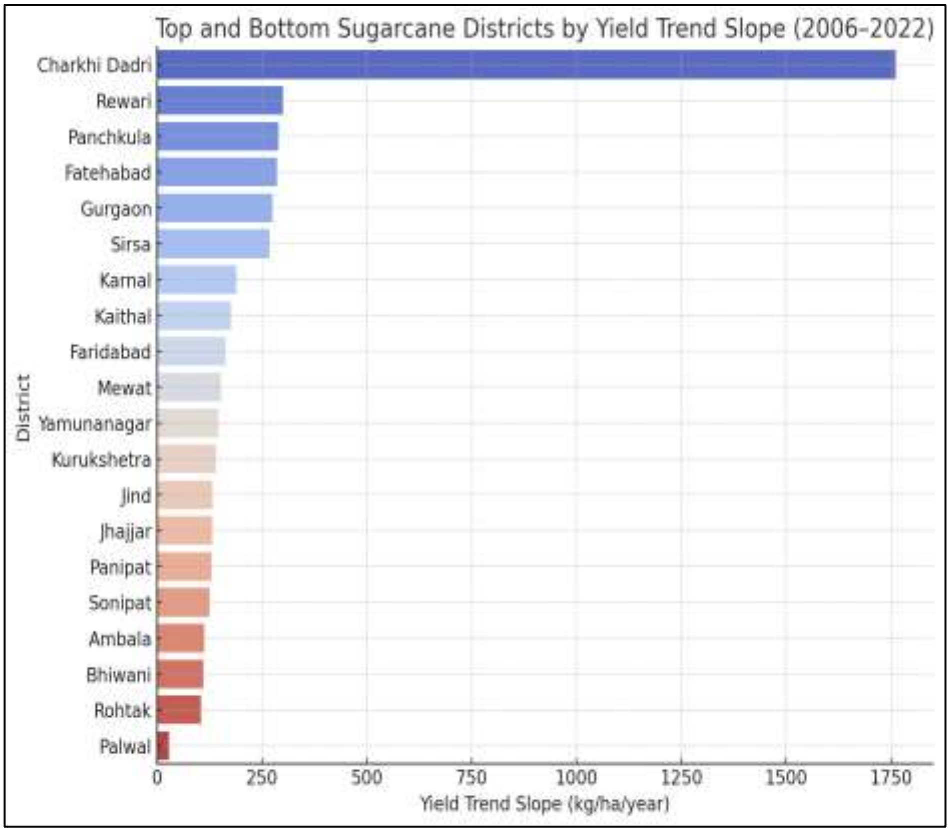


Figure 19: Top and Bottom Sugarcane Districts by Yield Trend Slope

Table 6: Sugarcane Yield Statistics by District (2006–2022)

District	Mean Yield	Std Dev	CV (%)	Trend Slope (kg/ha/year)
Ambala	7212.88	692.04	9.59	113.87
Bhiwani	7089.94	1022.12	14.42	110.76
Charkhi Dadri	6464.80	3630.44	56.16	1761.10
Faridabad	6609.56	1251.76	18.94	163.81
Fatehabad	6542.88	2819.01	43.09	286.17
Gurgaon	975.62	2665.92	273.25	275.47
Hisar	6660.19	1016.89	15.27	146.73
Jhajjar	6884.44	927.19	13.47	132.53
Jind	7200.31	871.83	12.11	133.00
Kaithal	7451.81	2221.34	29.81	176.52
Karnal	8115.12	1053.80	12.99	190.26
Kurukshetra	7845.12	807.37	10.29	140.50
Mahendragarh	0.00	0.00	nan	0.00
Mewat	3863.44	3673.16	95.07	152.34
Palwal	5377.69	577.50	10.74	28.83
Panchkula	6289.19	2351.88	37.40	289.51
Panipat	7996.69	782.01	9.78	129.86
Rewari	1064.00	2907.40	273.25	300.42
Rohtak	6638.00	697.90	10.51	105.47
Sirsa	1374.06	2954.16	214.99	269.02
Sonipat	7862.69	850.59	10.82	124.87
Yamunanagar	7077.50	906.69	12.81	146.36

These results suggest that sugarcane, unlike cotton or mustard, has maintained and even expanded its productive capacity in many districts. This is likely due to a combination of irrigation availability, favorable climate, and the presence of procurement and processing infrastructure which reduces market uncertainty. Additionally, since sugarcane is a less pest-prone crop and responds well to intensive input systems, it appears better positioned to withstand climatic and market-related shocks.

However, the analysis also highlights important caveats. In emerging or marginal districts such as Rewari and Gurgaon, the high volatility and low yield base indicate that sugarcane expansion without sufficient water management and market linkages would be ecologically unsustainable. Furthermore, the positive trends seen in districts with previously negligible cultivation (e.g., Charkhi Dadri) must be interpreted cautiously, as they may reflect data anomalies rather than agronomic success.

In sum, sugarcane emerges as a relatively stable and improving crop in Haryana's agricultural landscape. While not universally suitable across the state, it shows strong potential in select agro-climatic zones, particularly where mill linkages and water availability are adequate. Its continued performance, however, will depend on addressing emerging concerns around water-use efficiency, cane pricing delays, and the long-term viability of intensive input use. Tailored policies to support sustainable sugarcane intensification in the core districts, while preventing unplanned expansion in fragile zones, will be essential.

4. Conclusion

This study has revealed deep and persistent spatial disparities in crop yield performance across Haryana's 22 districts over a 17-year period, highlighting the uneven outcomes of agricultural development in the state. While aggregate trends often present a picture of stability, disaggregated, district-wise analysis across six major crops—wheat, rice, bajra, mustard, cotton, and sugarcane—demonstrates that not all regions have benefitted equally from technological advancement and policy support.

Districts in the northeastern canal-irrigated belt, such as Karnal, Kaithal, and Kurukshetra, emerged as consistently high-yielding and stable across multiple crops. These regions represent zones of intensive input use, assured irrigation, and infrastructure-driven productivity. In contrast, districts such as Mewat, Rewari, Faridabad, and Charkhi Dadri consistently recorded low mean yields, high variability, and negative yield trends, underscoring systemic structural and ecological constraints.

The findings point to crop-specific vulnerabilities as well. Cotton and mustard displayed the most widespread yield declines, signaling a need for urgent interventions in pest resistance, heat stress tolerance, and input cost management. Bajra, despite being rainfed, showed resilience in western districts, while sugarcane exhibited relatively stable and improving trends, especially in central and eastern districts with established mill linkages. Rice and **wheat**, though high-yielding, showed signs of stagnation in some peripheral regions, suggesting the limits of current intensification models.

Overall, the results affirm the need for spatially differentiated policy frameworks that reflect Haryana's internal agro-ecological diversity. High-performing zones should shift toward sustainable intensification, while vulnerable regions require climate-resilient technologies, diversification support, and infrastructural investments. The typological classification developed through this analysis offers a valuable tool for targeted planning, ensuring that interventions are aligned with localized challenges and opportunities.

By offering a cross-crop, district-level diagnostic of yield patterns, this study contributes not only to the academic understanding of regional agrarian dynamics but also provides practical insights for adaptive agricultural governance in an era of climate uncertainty.

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