International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(12): 1123-1129
Received: 17-09-2025
Accepted: 19-10-2025

PP Patil
Department of Agricultural Meteorology, College of Agriculture, Pune, Maharashtra, India

SM Apturkar
Maharashtra Remote Sensing Application Centre, Nagpur, Maharashtra, India

SV Bagade
Department of Agricultural Meteorology, College of Agriculture, Pune, Maharashtra, India

BK Gavit
Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

SK Upadhye
Department of Agricultural Meteorology, College of Agriculture, Pune, Maharashtra, India

JD Jadhav
Agricultural Technical School, Solapur, Maharashtra, India

VA Sthool
Department of Agricultural Meteorology, College of Agriculture, Pune, Maharashtra, India

Corresponding Author:
PP Patil
Department of Agricultural Meteorology, College of Agriculture, Pune, Maharashtra, India

Climatic variability, drought vulnerability and agrometeorological constraints in Nandurbar and Dhule districts of Maharashtra

PP Patil, SM Apturkar, SV Bagade, BK Gavit, SK Upadhye, JD Jadhav and VA Sthool

DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i12p.4551

Abstract
The stability of agricultural production in the semi-arid regions of Indian peninsular is fundamentally reliant on the spatiotemporal integrity of the Southwest *monsoon*. This study investigates climatic variability, drought vulnerability and agrometeorological constraints in the Nandurbar and Dhule districts of Maharashtra using a 33-year climatic dataset (1991-2023). The research utilizes an integrated geospatial and statistical approach, employing the Mann-Kendall test and Sen's slope estimator to analyze long-term trends in rainfall and temperature, alongside the Moisture Deficit Index (MDI) to classify regional climate. Results reveal a robust regional warming signal, with a highly significant rising trend in annual minimum temperature at a rate of 0.02°C/year across both districts. While annual rainfall trends remain largely non-significant, monthly analysis shows a profound intra-seasonal shift: June rainfall is declining significantly in Nandurbar (Q = -2.43 mm/year), whereas September rainfall exhibits a significant increase in both districts (Q = 3.24 in Nandurbar; Q = 2.65 in Dhule), suggesting a prolonged *monsoon* withdrawal. Drought vulnerability analysis indicates a moderate drought frequency of 15% for Dhule and 16% for Nandurbar, with the year 2012 identified as a period of major, near-uniform *monsoon* failure. Based on MDI values ranging from -41.30 to -58.81, both districts are classified as "Arid (E)," signifying a persistent imbalance between moisture supply and atmospheric demand. Cropping pattern analysis (2003-2023) highlights a significant transition from traditional drought-tolerant staples like pearl millet and sorghum to high-value commercial crops such as cotton and maize. In Dhule, cotton area expanded by 10,598.32 ha/year, while in Nandurbar, cotton and soybean saw substantial growth. This shift, though economically driven, elevates vulnerability to thermal stress and groundwater depletion. The findings emphasize the urgent need for climate-smart planning, improved water-use efficiency and adaptive crop diversification to preserve agroecosystem sustainability in these climatically sensitive districts.

Keywords: Agrometeorology, climate change, Mann-kendall, moisture deficit index, semi-arid agriculture

Introduction
The stability and sustainability of agricultural production in the semi-arid regions of Indian peninsular are fundamentally reliant on the spatiotemporal integrity of the Southwest *monsoon*. The Nandurbar and Dhule districts, situated in the northwestern corner of Maharashtra, represent a climatically sensitive transition region. These districts fall within the Western Maharashtra Scarcity Zone and the Western Maharashtra Plain Zone, respectively. Their agricultural potential and vulnerability to climate-induced stresses are directly influenced by a complex topographical and hydrological heterogeneity: Nandurbar borders the Satpuda Range and receives drainage from the Tapi and Narmada rivers, whereas Dhule sits at a lower altitude and relies primarily on the Tapi.

The primary agricultural output of Dhule consists of Cotton, Pearl millet, Groundnut, Maize and Wheat, while Nandurbar focuses on Paddy, Sorghum, Cotton and Pulses. This regional productivity is increasingly threatened by inherent water scarcity, further exacerbated by global and regional climate change. Traditional farming practices face mounting challenges due to evidence of asymmetric diurnal warming and heightened *monsoon* volatility across Central India

(Chakraborty *et al.*, 2016; Kumar *et al.*, 2020) [3, 8]. Furthermore, previous research has established that the Coefficient of Variation (CV) of rainfall known as a key indicator of stability, is notably high in semi-arid Maharashtra, particularly during non-*monsoon* months (Mahato *et al.*, 2021) [11].

Most of the interior Nashik division lies within a rain-shadow zone, resulting in pervasive arid or semi-arid climatic conditions (Guhathakurta and Saji, 2013; Paramesh *et al.*, 2022) [4, 15]. Consequently, understanding the localized hydrological balance and identifying reliable growing periods are critical for developing effective agricultural risk management strategies (Jadhav *et al.*, 2018; Todmal and Kale, 2016) [5, 19]. Therefore, a detailed district-level investigation into evolving meteorological parameters, specifically the Moisture Deficit Index (MDI), is paramount for Nandurbar and Dhule.

The present research adopts an integrated geospatial and statistical approach to provide the quantitative metrics required for climate-smart planning. This study converts broad climatic data into specific, actionable agrometeorological indices to directly inform sowing decisions, crop selection and water conservation efforts. The specific objectives of this manuscript are to: (1) estimate station and year-wise meteorological drought events and MDI; (2) conduct an analysis of long-term trends in rainfall and temperature and (3) define agroclimatic constraints and provide suggested guidelines for agricultural resilience.

Materials and Methods

Study Area and Datasets

The study focuses exclusively on the Nandurbar and Dhule districts, which are part of the larger Nashik Division (Figure 1). These areas are broadly classified under the Western Plateau and Hills Region (IX) and fall within the Deccan Plateau, Hot Semi-Arid Eco-Region. Nandurbar district covers an area of 5034 km^2 with higher altitudes (550 to 675 m) compared to Dhule, which covers 7195 km^2 and has altitudes between 180 to 215 m above Mean Sea Level (MSL).

The research relied on a multi-source dataset spanning the 33-year period from 1991 to 2023. Gridded Climatic Data for daily Rainfall (0.25º × 0.25º), Maximum Temperature and Minimum Temperature (1º × 1º) were obtained from the India Meteorological Department (IMD). This IMD gridded dataset provides the foundational time-series data required for robust trend and index analysis. The district-wise annual crop Area, Production and Yield (APY) data for the period 2003 to 2023 from the Department of Agriculture, Maharashtra State, Pune and the official website of Directorate of Economics and Statistics, Government of India. Administrative boundaries for geospatial analysis were sourced from the Maharashtra Remote Sensing Application Centre (MRSAC), Nagpur. The analysis focused on four representative stations in Dhule (Dhule, Sakri, Shindkhed, Shirpur) and six stations in Nandurbar (Akkalkuwa, Akrani, Nandurbar, Navapur, Shahada, Taloda).

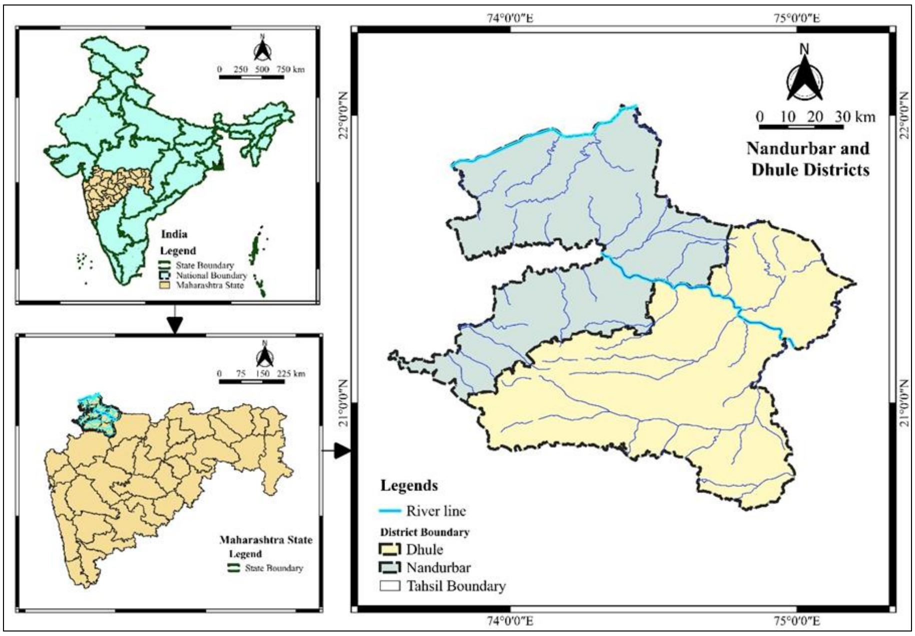

Fig 1: Study area: Nandurbar and Dhule Districts

Methodology

The methodology was structured to generate agrometeorological indices as per objectives. The methodology follows a rigorous flow of work moving from the analysis of Gridded Climatic Data to the estimation of key indices and the ultimate generation of decision-support metrics.

Climatic Trend Analysis

Long-term trends (1991-2023) in monthly and seasonal Rainfall, Maximum Temperature and Minimum Temperature for Nandurbar and Dhule districts were analyzed using the Mann-Kendall Z Test to determine the direction and significance of the trend and Sen's slope (Q) to quantify the magnitude of the change (Kumar *et al.*, 2020; Mahato *et al.*, 2021) [8,]. The significance levels (α) were set at 10% (+), 5% (*) and 1% (**).

Meteorological Drought Class

According to India Meteorological Department, meteorological drought over an area is defined as a situation when the seasonal rainfall received over the area is less than 75% of its long-term average value. Surplus rainfall is defined as any amount exceeding 25% above the normal value. Normal rainfall occurs when the deviation falls within a range of -25% to +25% of the long-term average. Moderate drought is characterized by rainfall between -50% and -25% of the normal amount. Finally, severe drought is identified when the seasonal rainfall received is less than -50% of the normal value.

Moisture Deficit Index (MDI)

The Moisture Deficit Index (MDI) was computed to classify the long-term climate of the stations based on Thornthwaite's approach. The MDI is calculated as the ratio of water deficit (P - PET) to Potential Evapotranspiration (PET) (Thornthwaite and Mather, 1955; Nathan and Sinha, 1996) [18,14]:

$$MDI = \frac{P - PET}{PET}$$

Climatic classification based on Thornthwaite method was determined using MDI thresholds as per given in Table 1.

Table 1: MDI based Climatic classification

Climatic Class	Moisture Deficit Index
Per-humid (A)	Over 100
Humid (B)	20 to 80
Wet sub-humid (C2)	0 to 20
Dry sub-humid (C1)	-20 to 0
Semi-arid (D)	-40 to -20
Arid (E)	-60 to -40

Analysis of Cropping Pattern Dynamics

A comprehensive time-series analysis was performed using seasonal graphs to visualize shifts between traditional and emerging crop types. The annual proportion of total cropped area was calculated to assess changes in crop dominance. The non-parametric Mann-Kendall test determined the significance and direction of these agricultural trends

Pearson’s correlation coefficient was computed to quantify the linear relationship between seasonal crop yields and concurrent climatic variables (RF, Tmax, Tmin). This analysis, supported by correlation matrices and time-series graphs, explained how climatic fluctuations directly impacted productivity. This data-driven approach facilitated the identification of vulnerable crops and districts to inform regional climate adaptation strategies.

Results and Discussion

This section presents a comprehensive analysis of the long-term climatic records, remote sensing data and seasonal agricultural statistics for the Nandurbar and Dhule districts of Maharashtra. The primary objective of this research was to quantitatively assess the effects of climate variability and extremities on regional agricultural systems, with a specific focus on evolving cropping patterns. By utilizing gridded weather data to derive agrometeorological indice such as the Moisture Deficit Index (MDI), this study provides spatially explicit evidence of how climatic shifts influence land resilience and farmer decision-making in a semi-arid environment.

Rainfall Analysis and Variability

Rainfall analysis was conducted for 10 representative stations within the study area using a 33-year long-term daily dataset spanning from 1991 to 2023. Average monthly and seasonal rainfall patterns reveal significant variations in water accessibility, largely dictated by regional topography.

Rainfall Variability (CV) Analysis

The climatic vulnerability of the region is meticulously quantified through the Coefficient of Variation (CV). While the primary *monsoon* season (June to September) remains the most statistically stable period with CV values generally below 35% (e.g., Nandurbar at 26.8% and Dhule at 24.4%), the non-*monsoon* months exhibit extreme inter-annual instability. Monthly CV values frequently exceed 200%, rendering pre- and post-*monsoon* precipitation highly unpredictable and unsuitable for long-term agricultural planning. Pre- or post-*monsoon* precipitation is highly unpredictable and unsuitable for long-term agricultural planning due to this significant instability, which is typical of semi-arid Maharashtra (Ratna, 2012) [17].

Data provided in Table 2 and Figure 2 illustrates an inverse correlation between rainfall quantity and variability; stations in the rain-shadow zones receive the least rain while experiencing the highest sensitivity to annual failures. These short SRP along with low total rainfall and a high Annual Rainfall CV (Table 2), indicate severely small growing window which led to the most severe agricultural risk. As a result, the scarcity zones of Deccan Plateau require immediate contingent crop planning and intensive water management measures (Jadhav *et al.*, 2018; Munde *et al.*, 2021; Upadhye *et al.*, 2022) [5,13,20].

Table 2: Station-wise average amount of rainfall and ranfall CV in Nandurbar and Dhule Districts

DIST	STN	Summer		*Monsoon*		Winter		Annual	
		Avg. RF	RF CV	Avg. RF	RF CV	Avg. RF	RF CV	Avg. RF	RF CV
Nandurbar	AKW	6.4	138.5	938.6	27.5	15.9	147.6	960.9	27.2
	AKN	6.5	127.3	844.6	29.0	16.2	146.8	867.3	28.2
	NDB	8.6	115.1	782.2	25.1	19.7	141.6	810.6	24.6
	NWP	8.1	110.6	899.3	23.4	20.1	149.4	927.5	22.7
	SHD	7.8	113.3	765.1	27.9	19.5	143.5	792.4	27.2
	TLD	7.1	120.3	839.1	27.7	17.4	144.8	863.6	27.1
	NDB District	7.4	120.8	844.8	26.8	18.1	145.6	870.4	26.2
Dhule	DHL	13.0	106.5	705.5	23.5	24.4	143.6	742.9	23.3
	SKR	11.5	113.0	711.7	22.1	23.4	143.2	746.5	21.9
	SDK	11.2	112.3	717.6	25.6	22.9	138.0	751.7	25.2
	SRP	10.6	117.9	749.5	26.4	22.4	152.8	782.5	25.8
	DHL District	11.5	112.4	721.1	24.4	23.3	144.4	755.9	24.0

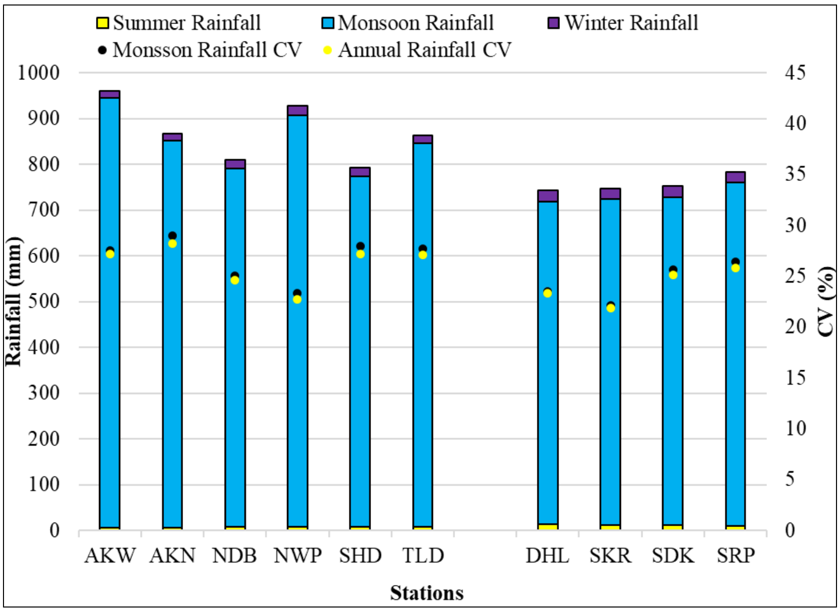

Fig 2: Rainfall distribution and C.V. (%) of annual and seasonal rainfall in Nandurabar and Dhule districts

Climatic Trend Analysis

Long-term trends from 1991 to 2023 reveal a complex pattern of atmospheric warming and critical intra-seasonal shifts in precipitation, aligning with broader findings for Central India. The details about the montly and sasonal trends of primary weather parameters is given in Table 3.

Trends in Rainfall and Temperature

While annual and *kharif* rainfall trends were largely non-significant at a district level, monthly scales revealed profound shifts. This aligns with general findings for central India, where *monsoon* variability is prominent over steady linear trends (Mondal *et al.*, 2015) [12]. Nandurbar showed a statistically significant decline in June rainfall (Q = -2.43 mm/year, alpha = 0.1), indicating a weakening early *monsoon* phase that increases water stress during the crucial sowing period (Bhagat *et al.*, 2021) [2]. Conversely, September rainfall exhibited significant increasing trends in both Nandurbar (Q = 3.24, alpha = 0.05) and Dhule (Q = 2.65, alpha = 0.05). This shift toward heavier late-*monsoon* rain suggests a prolonged withdrawal, which can disrupt traditional harvest calendars (Guhathakurta and Saji, 2013) [4].

Temperature analysis confirms a robust regional warming signal. Annual minimum temperature (Tmin) showed a highly significant rising trend across both districts at a rate of 0.02°C/year (alpha = 0.001). Most notably, December Tmin in Dhule increased by 0.08°C/year (alpha = 0.001), suggesting that winters are becoming considerably warmer. This sustained warming in nocturnal and winter temperatures is a clear sign of a robust regional warming signal and confirms observations of asymmetric diurnal patterns across north Maharashtra (Landage *et al.*, 2024; Rao *et al.*, 2014) [9,16].

Table 3: Trend analysis of Rainfall, Maximum and Minimum Temperature in Nandurbar and Dhule Districts

	Rainfall						Maximum Temperature						Minimum Temperature					
	Nandurbar			Dhule			Nandurbar			Dhule			Nandurbar			Dhule		
Time series	Z Test	α	Q	Z Test	α	Q	Z Test	α	Q	Z Test	α	Q	Z Test	α	Q	Z Test	α	Q
JAN	0.19		0	0.06		0	-1.44		-0.03	-1.19		-0.03	0.82		0.02	0.95		0.02
FEB	-0.03		0	-0.37		0	1.5		0.03	1.44		0.03	1.87	+	0.04	1.72	+	0.03
MAR	2.51	*	0.04	2.57	*	0.09	0.11		0	0.02		0	1.13		0.02	0.79		0.01
APR	0.02		0	0		0	1.66	+	0.03	1.81	+	0.03	2.56	*	0.03	2.31	*	0.03
MAY	-1.07		-0.02	-0.6		-0.02	0.98		0.02	1.19		0.02	1.19		0.02	1.04		0.01
JUN	-1.75	+	-2.43	-1.5		-2	0.02			0.11		0	-0.2		0	-0.05		0
JUL	0.29		0.41	0.57		0.92	0.09		0	0.03		0	-0.39		0	-0.42		0
AUG	0.73		1.62	0.98		1.92	0.67		0.01	1.13		0.02	0.76		0.01	0.82		0.01
SEP	2.22	*	3.24	2.06	*	2.65	0.6		0.01	0.6		0.01	2.56	*	0.02	2.4	*	0.02
OCT	-0.23		-0.07	-0.45		-0.16	0.11		0	0.26		0.01	1.87	+	0.04	1.5		0.03
NOV	0.16		0.01	0.16		0	-0.23		-0.01	0		0	1.6		0.03	1.47		0.03
DEC	1.87	+	0.01	1.83	+	0.01	-1.38		-0.03	-0.88		-0.02	3.24	**	0.07	3.36	***	0.08
Kharif	0.91		3.8	1.29		3.29	0.51		0	0.85		0.01	0.85		0.01	0.79		0.01
Rabi	0.86		0.62	0.44		0.29	-0.37		0	0.11		0	2.6	**	0.04	2.38	*	0.02
Summer	0.44		0.04	1.05		0.16	0.83		0.01	0.99		0.02	2.29	*	0.03	2.06	*	0.02
Annual	1.01		4.14	1.22		4.56	0.39		0	0.79		0.01	3.42	***	0.02	3.21	**	0.02

First year	1991	Z Test	Positive and Negative trend	Level of Significance (α)	+	10%	0.1	**	1%	0.01
Last Year	2023	Q	Sen's slope		*	5%	0.05	***	0. 01%	0.001
Years (n)	33									

Drought Vulnerability Analysis

The frequency of drought events from 1991 to 2023 reveals a distinct pattern of climatic vulnerability across the Nandurbar and Dhule districts. This vulnerability is intrinsically linked to the regional topography, particularly the rain-shadow effects observed in the northwestern corner of Maharashtra.

The probability of occurrence for various rainfall classes shows significant inter-annual variation across the stations in these two districts (Table 4). Nandurbar district exhibits a district-wide drought frequency of 16%, while Dhule district shows a frequency of 15%. Within Nandurbar, stations such as Akrani (SNR), Trimbakeshwar (TBK) and Yaval (YVL) recorded the highest drought frequency at 18.2%. In Dhule district, the Shirpur (SRP) station stands out as particularly vulnerable, with a 21.2% probability of moderate drought years. Despite their geographical distribution, these areas have a common feature of high inter-annual rainfall variability (as quantified by the CV in Table 2), which leads directly to a higher risk of meteorological drought, which has been well documented in semi-arid regions of Madhya Maharashtra (Adamson and Nash, 2013) [1]. On the other hand, the Jalgaon district has the lowest district-wide drought frequency (11%), indicating comparatively better rainfall stability. The significant temporal variation between drought and surplus emphasizes the growing *monsoon* volatility in the region, which pushes traditional farming methods to challenge and requires comprehensive water security solutions (Kale *et al.*, 2014) [6].

Table 4: Station-wise distribution of drought prone years and percent of occurrence in Nandurbar and Dhule Districts

		Number of Years (1991-2023)			Percent		
DIST	**Stations**	**Moderate Drought Years**	**Normal Years**	**Above Normal Years**	**Drought Year**	**Normal Year**	**Surplus Year**
NANDURBAR	NPD	4	14	15	12.1	42.4	45.5
	PNT	5	14	14	15.2	42.4	42.4
	SNR	6	14	13	18.2	42.4	39.4
	SRG	5	10	18	15.2	30.3	54.5
	TBK	6	15	12	18.2	45.5	36.4
	YVL	6	14	13	18.2	42.4	39.4
	NDB Dist	5	14	14	16	41	43
DHULE	DHL	4	13	16	12.1	39.4	48.5
	SDK	5	13	15	15.2	39.4	45.5
	SKR	4	12	17	12.1	36.4	51.5
	SRP	7	10	16	21.2	30.3	48.5
	DHL Dist	5	12	16	15	36	48

Moisture Deficit Index (MDI) and Climatic Classification

The Moisture Deficit Index (MDI), computed as the ratio of water deficit to potential evapotranspiration. It is a reliable, quantitative indicator for defining long-term climate in the Nashik division using the Thornthwaite method. The MDI is important because it directly measures the imbalance between moisture supply (precipitation) and atmospheric water demand (PET), enabling precision agroclimatic zoning (Paramesh *et al.*, 2022) [15].

The Moisture Deficit Index (MDI) provides a quantitative measure of the imbalance between moisture supply and atmospheric demand. As shown in Table 5, the majority of stations in Nandurbar and Dhule are classified as Arid (E). The provided table details the Moisture Deficit Index (MDI) for various stations in the Nandurbar and Dhule districts, classifying the entire region as Arid (E). It highlights significant annual water deficits, with MDI values ranging from -41.30 to -58.81 and a lower Coefficient of Variation (CV) in Dhule compared to Nandurbar, indicating a persistently stable but severe moisture-deficient climate.

Table 5: Station-wise Moisture Deficit Index (MDI) in Nandurbar and Dhule Districts

DIST	Station	Average MDI	MDI Class	CV
Dhule	DHL	-58.23	Arid (E)	22.22
	SKR	-57.94	Arid (E)	21.42
	SDK	-58.00	Arid (E)	24.55
	SRP	-56.88	Arid (E)	24.65
Nandurbar	AKW	-58.81	Arid (E)	22.28
	AKN	-44.08	Arid (E)	38.58
	NDB	-43.81	Arid (E)	40.82
	NWP	-41.30	Arid (E)	47.79
	SHD	-57.63	Arid (E)	23.33
	TLD	-57.63	Arid (E)	23.86

Cropping pattern variability

During the *Kharif* season, both Nandurbar and Dhule districts demonstrate a significant shift from traditional food staples to commercial cultivation, driven by market incentives and intensifying environmental pressures. Temporal correlation of *kharif* crop yields with concurrent seasonal climatic factors as given in Table 6 and 8 for Nandurbar and Dhule Districts, whereas Table 7 and Table 9 shows Mann-Kendall test and Sen's slope estimation for cropping area.

Nandurbar district is experiencing statistically significant shifts toward commercial crops prompted by market incentives, which has increased the region's vulnerability to soil degradation. Agriculture in this district is marked by complex and often weak interactions with meteorological factors, suggesting that crop performance may be dominated by non-climatic issues like poor water retention and localized management practices. While *Kharif* cotton and pigeon pea show mild positive correlations with temperature, most crop yields exhibit non-significant relationships with concurrent seasonal climatic characteristics. Despite this, Nandurbar has seen a sharp increase in high-demand crops, specifically cotton (+5,321.26 ha/year), maize (+1,720.44 ha/year) and soybean (+1,076.29 ha/year). As these high-value alternatives expand, there is a corresponding significant loss of drought-tolerant *Kharif* staples, including green gram, pearl millet and black gram. Notable area of millets reductions points to their susceptibility to unpredictable rainfall and increasing temperatures, which is consistent with expected yield decreases under warming scenarios (Lobell *et al.*, 2011) [10]. This transition elevates the district's vulnerability to climate-related risks, such as thermal stress and unpredictable precipitation, while the loss of staple-growing land indicates a decline in agroecosystem diversity and an increased risk of land degradation due to water depletion.

Similarly, in Dhule district, the agricultural landscape is characterized by high sensitivity to climate variability and a resulting risk of land degradation. The yields of *Kharif* crops in this district have become highly reliant on moisture availability, with pigeon pea showing a strong positive correlation with rainfall (r = 0.46) and sunflower exhibiting an even higher association (r = 0.59). While *Kharif* cotton appears more adaptable to climatic fluctuations with a negligible correlation to rainfall (r = -0.01), other staples are highly susceptible to heat stress, indicating that it is more adaptable or less sensitive to current climate fluctuation (Khedikar *et al.*, 2023) [7]. Statistical analysis through Sen's slope and Mann-Kendall tests confirms a massive expansion of high-value commercial crops in Dhule, with cotton area increasing by 10,598.32 ha/year and maize by 3,169.19 ha/year. This expansion occurs at the direct expense of traditional dryland staples; pearl millet, *Kharif* sorghum and sesamum are being replaced at significant annual rates, reflecting a regional retreat from food grains due to market and climatic constraints.

Table 6: Temporal correlation of *kharif* crop yields with concurrent seasonal climatic factors in Nandurbar district

		K-Rainfall	K-Tmax	K-Tmin
Kharif	Pigeon Pea	-0.28	0.25	0.11
	Cotton	0.10	0.25	0.30
	K-Sorghum	-0.16	-0.09	-0.03
	Green gram	-0.06	-0.11	-0.05
	Paddy	0.28	-0.16	0.18
	Black gram	-0.12	-0.09	0.06
	K-Groundnut	0.25	-0.43	0.33
	Soybean	-0.16	-0.02	-0.07
	Sunflower	0.40	-0.34	0.11

(K- *kharif*, Level of significance(α): + for 10%, * for 5%, ** for 1%)

Table 7: Mann-Kendall test and Sen's slope estimation for cropping area in Nandurbar district

Crops	Z Test	α	Q	Crops	Z Test	α	Q
Kharif							
Paddy	1.98	*	337.50	Horse Gram	-2.60	**	-52.10
K-Sorghum	1.01		179.42	Cotton	4.57	**	5321.26
Pearl Millet	-3.15	**	-631.60	K-Groundnut	-3.99	**	-425.26
Foxtail Millet	-1.67	+	-10.28	Sesamum	-3.13	**	-35.13
Maize	4.90	**	1720.44	Niger	-0.77		0.00
Pigeon pea	-0.88		-213.90	Sunflower	-2.44	*	-24.05
Green Gram	-4.44	**	-650.76	Soybean	2.69	**	1076.29
Black Gram	-4.74	**	-476.16	Sugarcane	3.57	**	744.98

(K- *kharif*, Level of significance

Table 8: Temporal correlation of *kharif* crop yields with concurrent seasonal climatic factors in Dhule district

		K-Rainfall	K-Tmax	K-Tmin
Kharif	Pigeon Pea	0.46*	-0.13	0.16
	Pearl Millet	0.11	0.25	0.19
	Cotton	-0.01	-0.14	-0.20
	K-Sorghum	0.05	-0.34	-0.46
	Green gram	0.12	-0.12	-0.20
	Paddy	-0.11	-0.17	0.22
	Black gram	0.18	-0.37	-0.21
	K-Groundnut	0.33	-0.11	-0.16
	Soybean	-0.30	-0.09	-0.32
	Sunflower	0.59**	-0.39	0.53*

(K- *kharif*, Level of significance(α): + for 10%, * for 5%, ** for 1%)

Table 9: Mann-Kendall test and Sen's slope estimation for cropping area in Dhule district

Crops	Z Test	α	Q	Crops	Z Test	α	Q
Kharif							
Paddy	0.91		107.16	Horse Gram	-4.73	**	-665.43
K-Sorghum	-4.19	**	-1146.04	Moth bean	-0.39		-19.00
Pearl Millet	-3.99	**	-4743.46	Cotton	5.68	**	10598.32
Foxtail Millet	-2.86	**	-165.39	K-Groundnut	-2.82	**	-835.62
K-Maize	3.34	**	3169.19	Sesamum	-4.06	**	-510.63
Pigeon pea	2.04	*	229.72	Sunflower	-4.19	**	-7.90
Green Gram	0.49		150.95	Soybean	4.44	**	1186.71
Black Gram	1.14		159.34	Sugarcane	-2.83	**	-329.91

(K- *kharif*, Level of significance(α): + for 10%, * for 5%, ** for 1%)

Summary and Conclusion

The climatic analysis of Nandurbar and Dhule districts (1991-2023) reveals a region facing significant agrometeorological challenges, characterized by an Arid (E) classification and chronic moisture deficits. While *monsoon* rainfall remains relatively stable, notable intra-seasonal shifts include declining June rainfall and increasing September precipitation, which disrupts traditional planting and harvest calendars. Concurrently, a robust regional warming signal is evident through a highly significant rise in minimum temperatures, particularly during winter. These climatic extremities, alongside market incentives, have driven a transition from drought-tolerant staples like pearl millet to water-intensive commercial crops such as cotton and maize. This shift increases vulnerability to thermal stress and groundwater depletion, necessitating climate-resilient agronomic practices and intensive water management to ensure long-term agricultural sustainability.

References

1. Adamson GC, Nash DJ. Long-term variability in the date of monsoon onset over western India. Clim Dyn. 2013;40(11):2589-2603. https://doi.org/10.1007/s00382-012-1494-x
2. Bhagat AA, Bhoge RS, Jadhav DS. Trend and variability of rainfall in Jalgaon district of Maharashtra. Int J Farm Sci. 2021;11(4):18-20.
3. Chakraborty A, Seshasai MVR, Rao SK, Dadhwal VK. Geo-spatial analysis of temporal trends of temperature and its extremes over India using daily gridded (1×1) temperature data of 1969-2005. Theor Appl Climatol. 2017;130:133-149. https://doi.org/10.1007/s00704-016-1869-8
4. Guhathakurta P, Saji E. Detecting changes in rainfall pattern and seasonality index vis-à-vis increasing water scarcity in Maharashtra. J Earth Syst Sci. 2013;122(3):639-649.
5. Jadhav BT, Jadhav JD, Shinde VA, Pawar PB, Londhe VM, Amrutsagar VM. Agro advisories a boon for crop planning. Contemp Res India. 2018:105-110.
6. Kale VS, Todmal RS, Kulkarni P. The monsoon-fed rivers of Maharashtra: their hydro-geomorphic characteristics and management. J Geol Soc India. 2014;(Spl.) 3:26-34.
7. Khedikar SY, Panchabhai SN, Mandal TK. Study on effect of rainfall variability on crop productivity of Tur (Arhar) and Cotton crops for various districts of Maharashtra, India. Int J Environ Clim Change. 2023;13(9):2347-2357. https://doi.org/10.9734/ijecc/2023/v13i92468

8. Kumar S, Chanda K, Pasupuleti S. Spatiotemporal analysis of extreme indices derived from daily precipitation and temperature for climate change detection over India. Theor Appl Climatol. 2020;140:343-357. https://doi.org/10.1007/s00704-020-03088-5
9. Landage RS, Jadhav VT, Patil P. Trends of temperature and precipitation extreme indices in north Maharashtra. J Agrometeorol. 2024;26(4):442-446. https://doi.org/10.54386/jam.v26i4.2735
10. Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. Science. 2011;333(6042):616-620.
11. Mahato LL, Kumar M, Suryavanshi S, Singh SK, Lal D. Statistical investigation of long-term meteorological data to understand the variability in climate: A case study of Jharkhand, India. Environ Dev Sustain. 2021;23(11):16981-17002. https://doi.org/10.1007/s10668-021-01374-4
12. Mondal A, Khare D, Kundu S. Spatial and temporal analysis of rainfall and temperature trend of India. Theor Appl Climatol. 2015;122(1):143-158. https://doi.org/10.1007/s00704-014-1283-z
13. Munde PS, Upadhye SK, Wale VD, Jadhav JD, Sthool VA, Bhagat AA. Weekly rainfall and rainy days trend analysis for crop planning in Baramati Tehsil of Pune District. Int J Curr Microbiol Appl Sci. 2021;10(2):589-598. https://doi.org/10.20546/ijcmas.2021.1002.070
14. Nathan KK, Sinha SK. Moisture deficit index evaluated for dry regions of India. 1996.
15. Paramesh V, Kumar P, Shamim M, Ravisankar N, Arunachalam V, Nath AJ, *et al*. Integrated farming systems as an adaptation strategy to climate change: case studies from diverse agroclimatic zones of India. Sustainability. 2022;14(18):11629. https://doi.org/10.3390/su141811629
16. Rao BB, Chowdary PS, Sandeep VM, Rao VUM, Venkateswarlu B. Rising minimum temperature trends over India in recent decades: implications for agricultural production. Glob Planet Change. 2014;117:1-8. https://doi.org/10.1016/j.gloplacha.2014.03.001
17. Ratna SB. Summer monsoon rainfall variability over Maharashtra, India. Pure Appl Geophys. 2012;169(1):259-273. https://doi.org/10.1007/s00024-011-0276-4
18. Thornthwaite CW, Mather JR. The water balance. Publ Climatol. 1955;VIII(1). Drexel Institute of Climatology, Centeron, New Jersey.
19. Todmal RS, Kale VS. Monsoon rainfall variability and rainfed agriculture in the water-scarce Karha Basin, western India. Mausam. 2016;67(4):927-938.
20. Upadhye SK, Sthool VA, Munde PS, Jadhav JD, Bagade SV. Trend analysis of annual rainfall and rainy days over Pune District of Maharashtra. J Agric Res Technol. 2022;47:145-152.