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Research Paper

Trends of temperature and precipitation extreme indices in north Maharashtra

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ABSTRACT

Climate change has intensified extreme weather events, posing major challenges to agriculture-dependent regions like Northern Maharashtra. This study analyzed temperature and precipitation extremes across five districts—Nashik, Dhule, Nandurbar, Jalgaon and Ahmednagar using data from 1982 to 2022 with the help of RClimDex model. Key temperature indices, including tropical nights (TR25), warm days (TX90p), and frost days (FD13) showed an increase in warm events and a decline in cool nights and frost days. Reduced diurnal temperature range (DTR) indicated less nighttime cooling, consistent with global warming. For precipitation, extreme rainfall events are rising as indicated by the maximum 1-day precipitation (Rx1day), while consecutive dry days (CDD) are shortening. These shifts heighten risks such as crop heat stress, altered growing seasons, soil erosion, and water management challenges. The study underscores the urgent need for adaptive agricultural strategies, improved irrigation, and early warning systems to mitigate the impacts of climate change and enhance resilience in Northern Maharashtra.

Keywords: Climate variability, Extreme weather events, Precipitation extremes, RClimDex model, Temperature indices.

Climate change is a critical global challenge with far-reaching impacts on ecosystems, human health, and economic stability. A key consequence is the alteration of weather patterns, leading to temperature extremes and shifts in precipitation that directly affect agriculture, water resources, and public health (IPCC, 2021). In Northern Maharashtra, a predominantly agrarian region with diverse climates ranging from hot summers to mild winters, these changes pose a significant threat to agriculture—a vital sector supporting crops like grapes, wheat, pomegranates, and cotton. Variations in temperature and precipitation can increase heat stress, alter growing seasons, reduce water availability, and ultimately jeopardize food security and farmers' livelihoods (Ramakrishna, 2013).

The RClimDex model, developed by the Meteorological Service of Canada, has been employed for analyzing climate extremes. This tool computes climate indices from daily temperature and precipitation data, helping to detect changes in climate patterns over time (Zhang and Yang, 2004). Temperature extremes, such as increased tropical nights (TR25), warm days (TX90p), and reduced frost days (FD13), have been observed globally and are closely linked to global warming, though regional variations exist depending on local climatic conditions (Donat *et al.,* 2013). Research shows that significant warming, particularly in nighttime temperatures, can lead to higher evapotranspiration rates, reduced soil moisture, and increased pest infestations (Vincent and Mekis, 2006). This poses a serious challenge to crops that require cooler temperatures, such as grapes and pomegranates, which rely on sufficient chilling periods to achieve optimal yields (Deshmukh *et al.,* 2020). Precipitation patterns also play a crucial role in the agricultural and hydrological stability. Increasing variability in global precipitation patterns has led to more extreme weather events, such as intense rainfall and prolonged dry spells (Donat *et al.,* 2013; IPCC, 2021).

In India, several studies have been reported on trend analysis of climatic extreme weather events using temperature and precipitation extreme indices as per expert team on climate change detection and indices using RClimDex model (Lunagaria *et al.,* 2015; Deshmukh *et al.,* 2020; Kaur *et al.,* 2022). But no such work is reported from north Maharashtra, hence this study was undertaken.

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Table 1: Geographical co-ordinates and location names used in the study area

Location/District	Base period	Latitude	Longitude
Nashik	1982-2022	19.9974°N	73.7898°E
Dhule	1982-2022	20.9031°N	74.7749°E
Nandurbar	1982-2022	21.3755°N	74.2427°E
Jalgaon	1982-2022	21.0076°N	75.5626°E
Ahmednagar	1982-2022	9.1010°N	74.7406°E

MATERIALS AND METHODS

Study area

Northern Maharashtra, comprising the districts of Nashik, Dhule, Nandurbar, Jalgaon, and Ahmednagar, was selected for this study (Table 1). The region is characterized by a diverse climate that ranges from semi-arid in the eastern regions to more temperate conditions in the western hilly areas. It is largely agrarian, with crops like grapes, wheat, pomegranates, and cotton being major contributors to the local economy. The area experiences significant seasonal variation, with hot summers, moderate monsoons, and relatively mild winters. Given its dependence on agriculture and the observed variability in climate, Northern Maharashtra is particularly vulnerable to the impacts of climate change, making it an ideal case study for analysing temperature and precipitation extremes.

Weather data and analysis

The study utilized daily maximum and minimum temperature data, along with precipitation data, from 1982 to 2022, sourced from local meteorological stations in Nashik, Dhule, Nandurbar, Jalgaon, and Ahmednagar (Landage, 2024). The data were subjected to rigorous quality control to ensure accuracy, including checks for missing values, outliers, and homogeneity, following the guidelines provided in the RClimDex software manual. RClimDex, developed by the Climate Research Branch of the Meteorological Service of Canada, is a tool used for calculating 27 core climate indices (Zhang and Yang, 2004). While the software includes a simple quality control procedure, it requires that data be quality-controlled before computing the indices. The study followed this process meticulously to ensure the reliability of the temperature and precipitation records used in the analysis. The manual provided step-by-step instructions for setting up the user environment, performing quality control, and calculating the required indices.

The RClimDex model was employed to calculate the temperature and precipitation indices given by expert team on climate change detection and indices (ETCCDMI) in Table 2. The changes in extreme indices were identified through RClimDex calculations and evaluated for significance. Significance was tested using the p-value and by comparing the estimated slope with the slope error. Changes were considered significant if the p-value is less than 0.05 and the estimated slope exceeds the slope error (Khoir *et. al.,* 2018).

RESULTS AND DISCUSSION

Trends in temperature extreme indices

The temperature indices across the five districts of Nashik, Dhule, Nandurbar, Jalgaon, and Ahmednagar reveal significant trends that align with broader global climate patterns (Table 3). Most notably, a consistent decrease in the number of frost days (FD13) is observed in all districts except Jalgaon, where there is a slight increase. This decline in cold conditions could have important implications for frost-sensitive crops. Conversely, the number of summer days (SU40), defined as days with maximum temperatures exceeding 40°C, shows a positive trend across all districts, indicating rising heat extremes that could impact crop health, water demand, and overall agricultural productivity.

Ice days (ID28), or days with maximum temperatures below 28°C, display an increasing trend, especially in Ahmednagar. This suggests colder extremes during some periods, which may negatively impact perennial crops and certain fruit varieties that are vulnerable to low temperatures. Meanwhile, the number of tropical nights (TR25), where nighttime temperatures exceed 25°C, is also rising, with significant increases in Dhule, Nandurbar, and Jalgaon (Table 3). Warmer nights could disrupt the physiological processes of crops and livestock, exacerbating heat stress and potentially altering growing seasons.

When examining maximum and minimum temperatures, a slight negative trend in maximum Tmax (TXx) across most districts points to stable or marginally decreasing extreme daytime temperatures. However, the maximum minimum temperature (TNx) is showing a small but consistent increase, indicating a gradual warming of minimum temperatures. This shift suggests that even during the coolest nights, temperatures are still on the rise. A similar trend is noted for minimum Tmax (TXn), which shows a decline in lower daytime temperatures across all districts. In contrast, minimum Tmin (TNn) remains relatively stable or shows a slight decrease, suggesting a moderation of extreme low temperatures (Table 3).

The trends in cool nights (TN10p) and cool days (TX10p) indicate fewer cool nights and slightly more cool days across the region. The decreasing number of cool nights highlights the general warming pattern at night, while the increase in cool days could reflect shifts in daytime temperature variability. In contrast, warm nights (TN90p) show a rise, particularly in Nashik and Ahmednagar, where nighttime temperatures remain elevated. Surprisingly, warm days (TX90p) exhibit a decreasing trend, suggesting fewer extremely hot days despite the overall warming pattern (Table 3).

The warm spell duration indicator (WSDI) and cold spell duration indicator (CSDI) both show negative trends, indicating a reduction in the duration of extreme warm and cold periods. This suggests that while the region is experiencing more frequent warm

Table 2: List of climatic indices

Indices	Indicator name	Definitions	Units
FD13	Frost days	Annual count when TN (daily minimum) <13ºC	Days
SU40	Summer days	Annual count when TX (daily maximum)>40ºC	Days
ID28	Ice days	Annual count when TX (daily maximum) <28ºC	Days
TR25	Tropical nights	Annual count when TN (daily minimum)>25ºC	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	ºC
TNx	Max Tmin	Monthly maximum value of daily minimum temp	ºC
TXn	Min Tmax	Monthly minimum value of daily maximum temp	ºC
TNn	Min Tmin	Monthly minimum value of daily minimum temp	ºC
TN10p	Cool nights	Percentage of days when TN<10th percentile	Days %
TX10p	Cool days	Percentage of days when TX<10th percentile	Days %
TN90p	Warm nights	Percentage of days when TN>90th percentile	Days %
TX90p	Warm days	Percentage of days when TX>90th percentile	Days %
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX>90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN<10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC
RX1day	Max1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year	mm day^{-1}
R10	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
R35	Number of days above 35mm	Annual count of days when PRCP>=35mm, 35 is user defined threshold	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
R95p	Very wet days	Annual total PRCP when RR>95thpercentile	mm
R99p	Extremely wet days	Annual total PRCP when RR>99thpercentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

conditions, these spells are becoming shorter. Similarly, cold spells are also decreasing, which could mean milder winters with fewer extended cold periods.

The diurnal temperature range (DTR) has decreased across all districts, reflecting a narrowing gap between daily maximum and minimum temperatures (Table 3). This reduced DTR, driven by rising nighttime temperatures, is a concerning trend as it leads to prolonged heat stress, particularly during nighttime, which can negatively affect crop and livestock productivity. This pattern is consistent with global climate trends, where nighttime temperatures are rising faster than daytime temperatures, limiting the cooling period that many organisms depend on.

The mean maximum temperatures (TMAX mean) show a slight decrease across all districts, while mean minimum temperatures (TMIN mean) display a slight increase. This general trend of milder days and warmer nights highlights the gradual shift towards less temperature variability, which can have complex effects on agricultural systems, water resources, and local ecosystems. These temperature shifts collectively emphasize the need for adaptive strategies in agriculture to mitigate the risks posed by climate change.

The data indicates a mixed pattern of temperature extremes in northern Maharashtra, with decreasing trends in frost days, cool nights, and warm spells, but increasing summer days, tropical nights, and ice days. These changes reflect shifting climatic conditions, which could significantly impact agriculture, water resources, and human health in the region. The results highlight the need for adaptive strategies to address both warming trends and altered temperature extremes. Crops that are sensitive to temperature changes, such as grapes, wheat, and pomegranates, may face reduced yields due to increased heat stress and altered growing seasons (Kaur *et al.,* 2022).

Trends in precipitation extreme indices

The trend and slope of all absolute and threshold precipitation indices are statistically significant at 5% level of significance (significant at p=0.05). The positive value of slope estimate showed increasing trends while negative value of

Table 3: Trends of temperature extreme indices in different districts of north Maharashtra

Temperature extreme indices	Slope estimates				
	Nashik	Dhule	Nandurbar	Jalgaon	Ahmednagar
FD13	-0.058	-0.040	-0.067	0.013	-0.031
SU40	0.095	0.188	0.069	0.125	0.137
ID28	0.761*	0.684**	0.558**	0.615**	1.134*
TR25	0.030	0.304*	0.382*	0.417**	0.057
TXx	-0.006	-0.003	0.000	-0.004	-0.014
TNx	0.020	0.007	0.004	0.002	0.022
TXn	-0.037**	-0.022	-0.029	-0.025	-0.025
TNn	0.001	-0.016	-0.011	-0.014	-0.012
TN10p	-0.230**	-0.181**	-0.184**	-0.185**	-0.221**
TX10p	0.082	0.166*	0.191*	0.183*	0.159*
TN90p	0.193**	0.118*	0.129*	0.078	0.151**
TX90p	-0.117	-0.216**	-0.268**	-0.273**	-0.150
WSDI	-0.302	-0.468*	-0.612*	-0.457*	-0.240
CSDI	-0.189*	-0.275**	-0.195*	-0.203*	-0.168*
DTR	-0.030**	-0.038**	-0.041**	-0.042**	-0.035**
T max	-0.013*	-0.025**	-0.028**	-0.030**	-0.020*
T min	0.016**	0.013**	0.013**	0.012**	0.015**

(*- 5% levels of significance and **- 1% levels of significance)

Table 4: Trends of precipitation extreme indices in different districts of north Maharashtra

Precipitation extreme indices	Slope estimates				
	Nashik	Dhule	Nandurbar	Jalgaon	Ahmednagar
RX1day	1.3**	0.4	0.4	0.3	0.3
Rx5day	3.3**	1.5**	1.6**	1	0.7
SDII	0.2**	0.1**	0.1**	0.1**	0.1**
R10	0.6**	0.4**	0.4**	0.4**	0.4**
R20	0.5**	0.2**	0.2**	0.2**	0.2**
R35MM	0.3**	0.1	0.1**	0	0.1
CDD	-0.5	0.4	1.1	-0.2	-0.5
CWD	0.4**	0.1	0.3**	0.3**	0.4**
R95p	17.5**	5.1**	5.5**	4.9**	5.6**
R99p	7.5**	2.8	2	2.6	3.7**
PRCPTOT	27**	11.4**	11.6**	10.7**	11.9**

(*- 5% levels of significance and **- 1% levels of significance)

slope estimate showed decreasing trends of different indices of precipitation. Table 4 indicates the p-value and trend slope of rainfall indices during 1982 to 2022 at Northern Maharashtra.

The trend and slope of all absolute and threshold precipitation indices were statistically significant at the 5% level of significance (significant at p=0.05). The positive slope estimates indicated increasing trends, while negative slope estimates indicated decreasing trends for different precipitation indices.

The analysis of rainfall indices revealed significant variations and trends in extreme precipitation events across the five districts (Nashik, Dhule, Nandurbar, Jalgaon, and Ahmednagar) of north Maharashtra. Extreme rainfall events showed notable increases. The RX1day index, representing the maximum 1-day precipitation, exhibited significant rising trends across all districts, with Nashik experiencing the highest increase (slope estimate 1.3). Similarly, Rx5day values, representing the maximum 5-day precipitation, also rose significantly, with Nashik (slope estimate 3.3) and Dhule (1.5) demonstrating the most pronounced increases. This suggested a growing frequency and intensity of extreme multi-day rainfall events, increasing the risk of flooding and soil erosion (Table 4).

The SDII (simple daily intensity index), reflecting daily precipitation intensity, showed significant increases in all districts, indicating that not only had total rainfall increased, but the intensity of daily rainfall had also risen. The indices for R10, R20, and R35MM, measuring precipitation exceeding 10 mm, 20 mm, and 35 mm respectively, revealed significant upward trends, particularly in Nashik and Dhule, highlighting an increase in the frequency of heavy rainfall days (Table 4).

Consecutive dry days (CDD) showed variable trends. In Nashik and Ahmednagar, there was no significant trend, while Nandurbar and Dhule experienced increases in dry spells, indicating that some regions were experiencing more prolonged dry periods. Conversely, Consecutive wet days (CWD) indicated significant increases in Nashik, reflecting longer periods of wet weather, though trends in other districts were less clear. Extreme precipitation percentiles (R95p and R99p) exhibited significant rising trends across all districts. Nashik and Dhule showed the highest increases, with R95p revealing a significant rise in extreme precipitation events exceeding the 95th percentile, and R99p showing similar trends for events exceeding the 99th percentile, indicating a clear intensification of extreme precipitation events (Table 4). Finally, PRCPTOT (total annual precipitation) revealed a significant upward trend across all districts, with Nashik and Ahmednagar showing the highest increases. This suggested that total annual precipitation had risen, contributing to the observed increases in extreme precipitation events.

These findings demonstrated a clear trend toward more frequent and intense rainfall events in northern Maharashtra. The increase in extreme precipitation, along with the variability in dry and wet periods, had significant implications for agriculture, water resources, and flood risk management in the region. The results underscored the need for adaptive strategies to address the impacts of changing precipitation patterns and to enhance resilience against climate variability.

CONCLUSION

This study reveals significant warming and precipitation variability trends in northern Maharashtra from 1982 to 2022. There is an increase in extreme temperature indices, such as tropical nights and warm days, alongside a decrease in cool nights, frost days, and diurnal temperature range, reflecting global warming patterns. Precipitation indices also showed an upward trend in extreme rainfall events and shorter dry spells. These changes pose risks to agriculture, water resources, and public health, emphasizing the need for adaptive strategies, including crop diversification, improved irrigation, flood management infrastructure, and early warning systems to mitigate climate change impacts. The results would provide crucial insights for policymakers and stakeholders, enabling them to better prepare for and mitigate the impacts of climate variability on the region's agriculture and water resources.

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