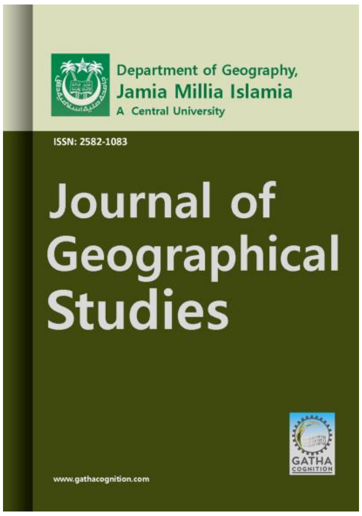



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## Evaluating Long-term Climatic Trends in Agro-climatic Zones of Satara District, Maharashtra


**Vidya Shivaji Mohite[1*], Arun Bhagwan Patil[2]**

1. Department of Geography, Sir Parashurambhau College, Pune, India.
2. Department of Geography, Arts, and Commerce College, Ashta, District- Sangli, India.



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Original Research Paper

# Evaluating Long-term Climatic Trends in Agro-climatic Zones of Satara District, Maharashtra

**Vidya Shivaji Mohite[1*], Arun Bhagwan Patil[2]**

1. Department of Geography, Sir Parashurambhau College, Pune, India.
2. Department of Geography, Arts, and Commerce College, Ashta, District- Sangli, India.

## Abstract

Climate is a natural process that influences weather patterns across different regions. The term average climate refers to the typical weather conditions observed in a specific area over a long period. In India, agriculture is largely dependent on rainfall and variations in climatic factors significantly impacting the crop production. This study analyzes climate trends in the agro-climatic zones of Satara district using data procured from NASA's Prediction of Worldwide Energy Resources (POWER) (1984-2022). The study examines key climatic parameters, including annual rainfall, maximum and minimum temperatures, relative humidity, soil wetness and soil moisture. To assess climate trends using various statistical methods such as the non-parametric Mann-Kendall test, Sen's slope estimator and linear regression were applied. The results indicate notable fluctuations in climatic factors over the past four decades. The ghat zone covering areas like Mahabaleshwar, Wai, and Patan has recorded the highest rainfall and lowest temperatures. In contrast, the scarcity zone, including Man, Khatav, and Khandala tehsils, has experienced lower rainfall and a rise in annual maximum temperatures. These findings suggest that the agro-climatic zones of Satara district are continuously influenced by changing climatic conditions. Understanding these trends is crucial for farmers, local administrators, researchers, and policymakers to develop effective agricultural and environmental management strategies.

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Soil Wetness;
Mann-Kendall Test;
Trend Analysis;
Sen's Slope.

**Editor(s)**

M. A. Siddiqui
Vijay Bhagat

## 1 INTRODUCTION

Climate is an important phenomenon that can alter the physical and cultural environment. The average climate term is commonly used to describe the typical weather patterns of a specific region. Agricultural production has been harmfully affected by rising temperatures, changes in precipitation amount and frequency, more frequent dry spells, droughts, increasing intensity of extreme weather events, rising sea levels and salinization of arable land and freshwater resources (FAO, 2016). Climate refers to the average weather conditions in a specific area over a period. This includes details about average temperatures throughout the year, rainfall, and the amount of sunshine. Every populated location on the planet is already feeling the effects of climate change with human activities contributing to the many recorded weather and climatic shifts (Allan *et al.*, 2023; Farndon *et al.*, 2020). An important task of agro-climate change research studies is to analyze long-term changes in climate change. Climate change monitoring is a significant research challenge, requiring analysis of long-term trends in climatic parameters (Goyal, *et al.*, 2014). In general, rainfall and temperature are important physical variables of climate that make changes in rainfall and its distribution useful for water resources management. With improvements and extensions to numerous datasets and more sophisticated data analyses across the globe, understanding previous and current climate change has gained considerable attention. (Kumar *et al.*, 2010; Panda and Sahu, 2019). Scientists are increasingly investigating whether there can be discernible climate change following the greenhouse effect by looking at historical observations of climatic variables (Cannarozzo *et al.*, 2006). Hence, studying climate change to understand climatic patterns in agro-

* Author's address for correspondence
Department of Geography, Sir Parashurambhau College, Tilak Road, Sadashiv Peth, Pune - 411030 (India).
Tel.: +91 9733913906
Emails: vidyamohite2012@gmail.com (*V. Mohite* -Corresponding author); arunpatil2007@gmail.com (*A. Patil*).
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climatic zones will help in decision-making. The study of extreme weather events will be more convenient, and suitable improvements can be made.

The purpose of this study is to identify variations in climatic factors for instance rainfall, maximum and minimum temperatures, relative humidity, and soil moisture. The Satara district's scarcity zone experiences limited rainfall and is considered a rain shadow region, with limited regional development. Conversely, the Ghat zone receives heavy rainfall and is characterized as a region with higher levels of rainfall. The current study examines climatic trends and variations across different agro-climatic zones in the Satara district. The study analyzed the patterns of climatic elements and examined the inter-annual trends and fluctuations, aiming to understand their impact on agriculture, livestock, irrigation, and water management in the chosen area of study.

## 2 STUDY AREA

Satara district is a historically located in the western part of Maharashtra and it lies on the western edge of the Deccan Plateau between 17° 5' N and 18° 11' N latitude and 73°33' E and 74° 54' E longitude (Figure 1). The east-west extension is 144 km and the north-south extension is about 120 km (10480 km$^2$). Satara district is situated in the basin of rivers Krishna, Neera, Manganga, Yerala, and Krishna. Crops such as millet, sorghum, maize, onion, oilseeds, pomegranate, etc. are growing in the area. Indigenous cows, buffaloes, sheeps, and goats are the major livestock of the region. India has 15 agro-climatic zones, as noted by the Indian Planning Commission. The district encompasses four of these zones: Ghat Zone, Transition Zone - I, Transition Zone - II, and Scarcity Zone. The tehsils of western Patan, Wai, and Mahabaleshwar are all part of the Ghat zone. The tehsils of eastern Jaoli, eastern Mahabaleshwar, Wai, Western Khandala, and Middle Patan are all part of Transition Zone-I. In Transition Zone-II, East Khandala, Koregaon, East Satara, Karad, and East Wai, tehsils are included while Scarcity Zone covers areas from Phaltan, Man and Khatav tehsils.

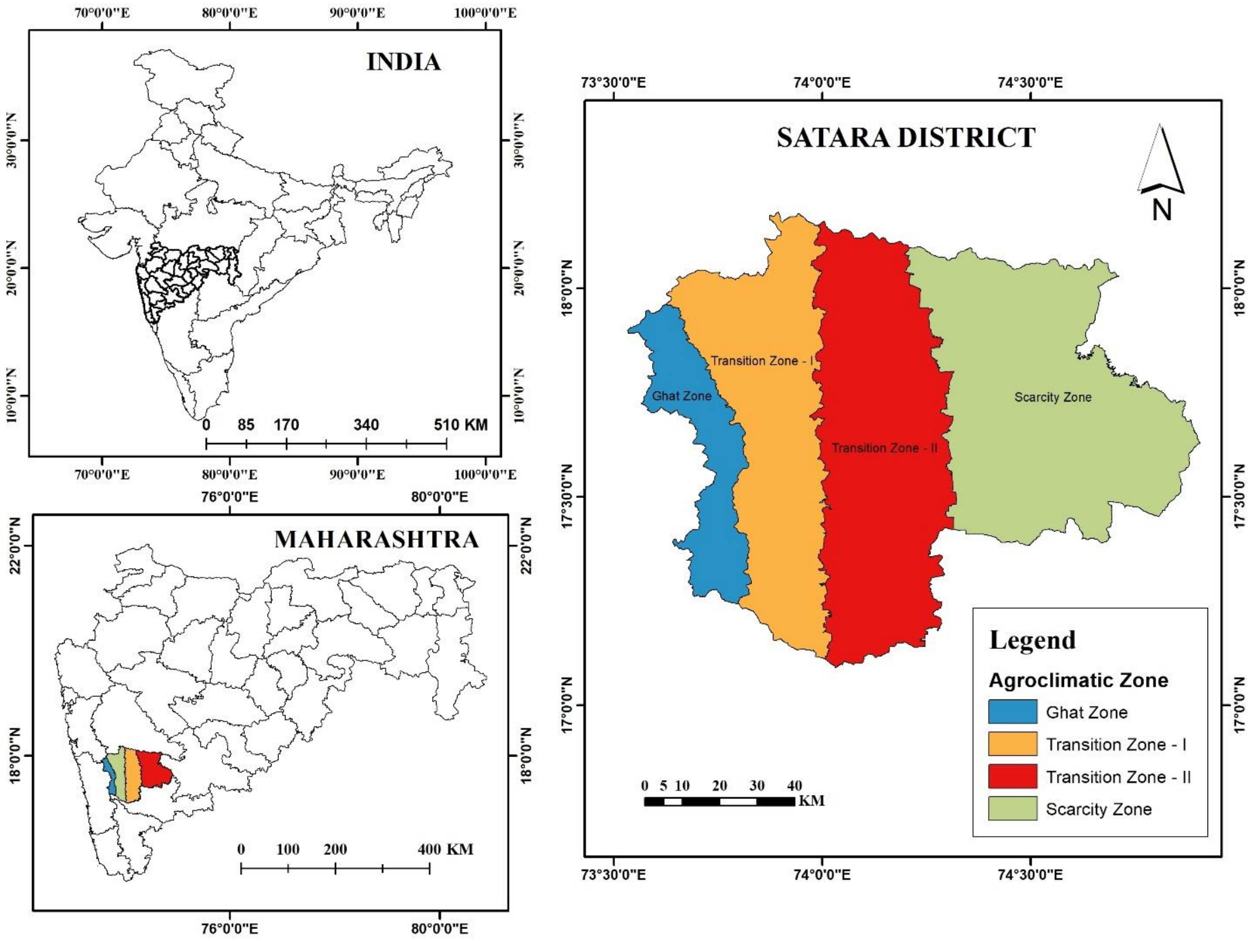


Figure 1. Study area: Satara district, Maharashtra (India)

## 3 MATERIAL AND METHODS

The non-parametric Mann-Kendall test, introduced by Mann in 1945 and further developed by Kendall in 1955, is widely used by researchers across various fields, including science, medicine and meteorological studies (Sneyers *et al*., 1990; Zhang *et al*., 2000; Yue and Hashino, 2003; Cannarozzo *et al*., 2006; Aziz and Burn, 2006; Wilks, 2006; Chandler and Scott, 2011; Kamal and Pachauri, 2018) have applied this test to detect monotonic trends in long-term time series datasets. The Mann-Kendall (MK) test developed by Mann in 1945 and Kendall in 1955 aims to statistically assess meteorological variables to identify trends, either upward or downward in a variable (Gocic and Trajkovic, 2013). The text mentions a non-parametric statistical test for detecting patterns in time series data (Kendall, 1955; Mann, 1945). Sen firstly created the Sen slope test to examine statistical linear correlations. This is used to calculate the magnitude of trends in long-term temporal data (Jiqin *et al*., 2023). In trend analysis, the null hypothesis for a trend test is $H_0$, which states no trend in the datasets. Alternative hypothesis $H_1$ shows a trend in the analyzed time series dataset. The Mann-Kendall test was applied to the annual rainfall trend (Cannarozzo *et al*., 2006). Kendall's S (Kendall, 1962) is calculated using the following formula.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \quad (1)$$

where, *n* is the data set length, and *y* denotes the data values at periods *i* and *j*.

$$sign\, \vartheta = \begin{cases} 1\ if\ \vartheta > 0 \\ 0\ if\ \vartheta = 0 \\ -1\ if\ \vartheta < 0 \end{cases} \quad (2)$$

Two parameters of the Mann-Kendall test are crucial for detecting trends. The slope magnitude estimate shows the direction and magnitude of the trend and the significance level, which indicates the test strength. Assuming that $x_i$ is independent and randomly ordered, the statistic S (equation (3)) is normally distributed when n ≥ 8 has zero mean and variance as follows:

$$var = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_t f_t(f_t - 1)(2f_t + 5)\right] \quad (3)$$

where, t varies over the set of tied ranks and ft is the number of times i.e. frequency that the rank t appears. The Mann Kendall's test uses the following test statistics:

$$Z = \begin{cases} S - 1/\sigma\ if\ \ S > 0 \\ 0 \qquad\quad if\ \ S = 0 \\ S + 1/\sigma\ if\ S < 0 \end{cases} \quad (4)$$

A 95% confidence level was considered in this research. Trend analysis is critical for understanding past and present hydrological changes, forecasting future trends and taking necessary safeguards. It is commonly used in the study of hydrological time series (Zhang *et al*., 2000). Mann-Kendall test and linear regression test association amongst a reliant on variable Y and independent variable X were used to recognize the climatic trend using XLSTAT software.

In the present study, the Agro-climatic base map of India published by ICAR-ATARI, Pune has been used to prepare the Agro-climatic map of Satara district using GIS technology. The Planning Commission of India has considered factors such as physiography, soil, geology, climate, cropping practices, irrigation and minerals form different agro-climatic zones. Accordingly, ICAR-ATARI, Pune has developed an agro-climatic map. The climate data for 38 years (1984-2022) was taken from NASA's Prediction of Worldwide Energy Resources POWER (DAV) agency's Agro-Climatology Field. We used Mann-Kendall's statistical test, Sen's Slope and linear regression to examine the climatic trends from 1984 to 2022.

## 4 RESULT AND DISCUSSION

The Mann-Kendall assessment is a numerical method commonly used for analyzing trends in climatic and hydrological time series (Kamal and Pachauri, 2018). The significant level (0.05%) of this test demonstrates trends in climate variables such as rainfall, temperature, relative humidity and soil moisture. The Mann-Kendall test is used to show the normal distribution of trends and data outliers in a time series of hydrometeorological data. The Mann-Kendall test is a non-parametric test that evaluates the significance of trends using the statistical p-value (Duhan and Pandey, 2013). If the p-value is (< 0.05) specifies the trend is statistically important. Additionally, Sen's slope is used to guess the magnitude of a trend with a confident value representing an increasing trend and an adverse value indicating a decreasing trend. Typically, the impacts of climate change will exacerbate the existing vulnerabilities of poor people, placing additional strain on their livelihoods and coping mechanisms (Urquhart, 2009; Davis and Vincent, 2017; Masson-Delmotte *et al*., 2021; Thornton *et al*., 2014). The statistical method used in the present study consists of linear regression analysis and coefficient of determination $R^2$, and Mann-Kendall's test is used to check the trend of climate factors. According to Mann Kendall's test study area categorized into four groups such as Ghat Zone (GH Zone), Transition Zone- I (TR I Zone), Transition Zone-II (TR II Zone), and Scarcity Zone (SC Zone). Rainfall, maximum and minimum temperature, relative humidity and soil moisture are all averaged using the spatial interpolation method, which is also used to evaluate climate trends.

Table 1. Trend Analysis

| Climatic Parameter | Agro-climatic Zones | MK Tau | p-value | Sen's Slope | $R^2$ value | Trend |
|---|---|---|---|---|---|---|
| Rainfall | GH Zone | 0.216 | 0.062** | 3.495 | 0.174 | Increasing |
| | TR - I Zone | 0.205 | 0.077** | 4.720 | 0.213 | Increasing |
| | TR - II Zone | 0.198 | 0.092** | 4.761 | 0.174 | Increasing |
| | SC Zone | 0.199 | 0.091** | 3.495 | 0.215 | Increasing |
| Max Temp. | GH Zone | -0.151 | 0.179** | -0.016 | 0.041 | Decreasing |
| | TR - I Zone | -0.186 | 0.097** | -0.020 | 0.057 | Decreasing |
| | TR - II Zone | -0.251 | 0.025* | -0.021 | 0.094 | Decreasing |
| | SC Zone | -0.251 | 0.025* | -0.018 | 0.127 | Decreasing |
| Mini Temp. | GH Zone | -0.001 | 1.000** | 0.000 | 0.003 | No Trend |
| | TR - I Zone | 0.020 | 0.866** | 0.002 | 0.003 | No Trend |
| | TR - II Zone | 0.053 | 0.648** | 0.004 | 0.008 | No Trend |
| | SC Zone | 0.004 | 0.980** | 0.000 | 0.006 | No Trend |
| RH | GH Zone | 0.212 | 0.059* | 0.058 | 0.150 | Upward |
| | TR - I Zone | 0.217 | 0.053* | 0.062 | 0.153 | Upward |
| | TR - II Zone | 0.188 | 0.095** | 0.070 | 0.139 | Upward |
| | SC Zone | 0.177 | 0.116** | 0.072 | 0.119 | Upward |
| Soil Moisture | GH Zone | 0.250 | 0.025* | 0.001 | 0.171 | Upward |
| | TR - I Zone | 0.201 | 0.073** | 0.001 | 0.155 | Upward |
| | TR - II Zone | 0.225 | 0.044* | 0.001 | 0.135 | Upward |
| | SC Zone | 0.196 | 0.081** | 0.001 | 0.100 | Upward |
| Soil Wetness | GH Zone | 0.225 | 0.044* | 0.001 | 0.189 | Upward |
| | TR - I Zone | 0.228 | 0.042* | 0.001 | 0.178 | Upward |
| | TR - II Zone | 0.174 | 0.122** | 0.001 | 0.133 | Upward |
| | SC Zone | 0.107 | 0.348** | 0.001 | 0.083 | No Trend |

*The p-value is higher than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
**The p-value is lower than the significance level alpha=0.05, one can reject the null hypothesis H0.

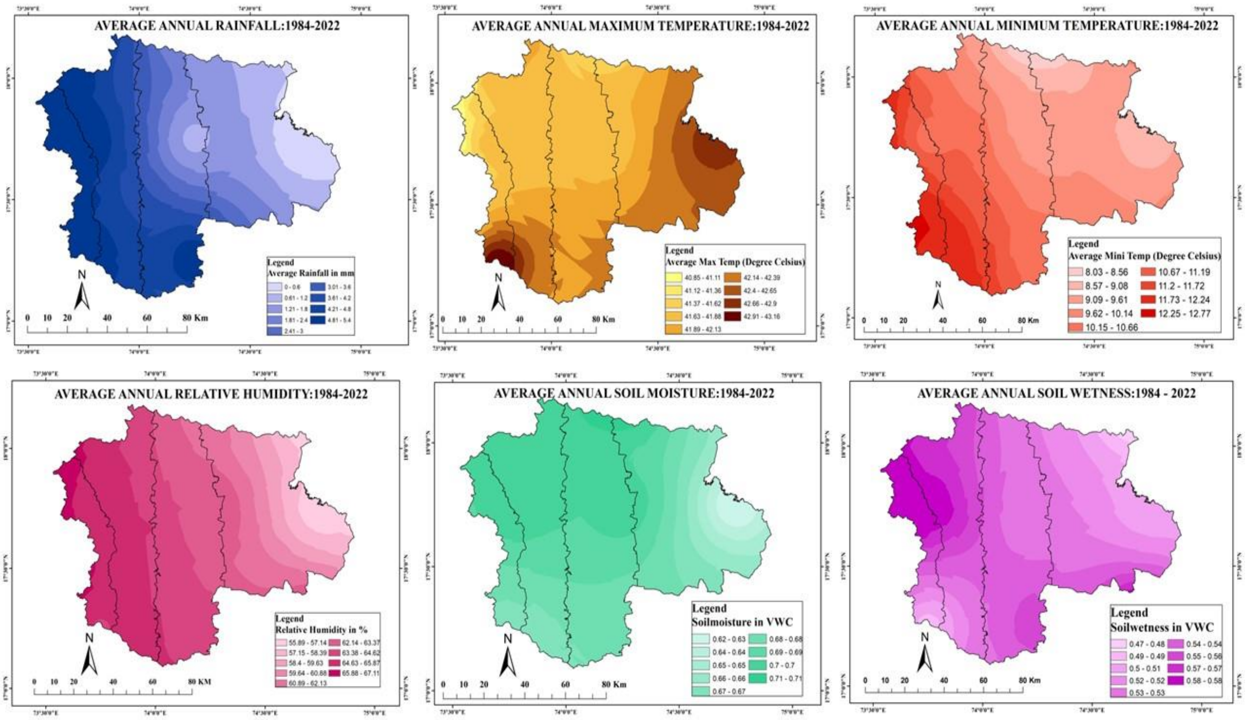


Figure 2. Average Climatic Trends and Patterns

Annual climate data from 1984 to 2022 are used to analyze the climatic trends and pattern in the study area. The annual changes in rainfall, maximum and minimum temperature, relative humidity, soil moisture and wetness have been observed from 1984 to 2022. The spatial interpolation method is used to evaluate the climate parameters, patterns, and trends. The ghat zone has higher levels of average rainfall, relative humidity, and soil moisture but the distribution decreases eastward (Figure 2).

### 4.1 Ghat Zone (GH Zone)

If the climate series indicates an upward trend, the slope coefficient should be positive and statistically significant. In contrast, a downward tendency in a variable's behavior should result in a negative slope value (Oza and Kishtawal, 2014; Gangarde *et al.*, 2023). Kendall Tau in the ghat zone is 0.216, the positive value of Sen's slope is 3.495 and the p-value is 0.062 the $R^2$ value is 0.174 which indicates a statistically upward trend of rainfall (Figure 3). However, the $R^2$ value (0.174) is relatively high, indicating a positive relationship with rainfall.

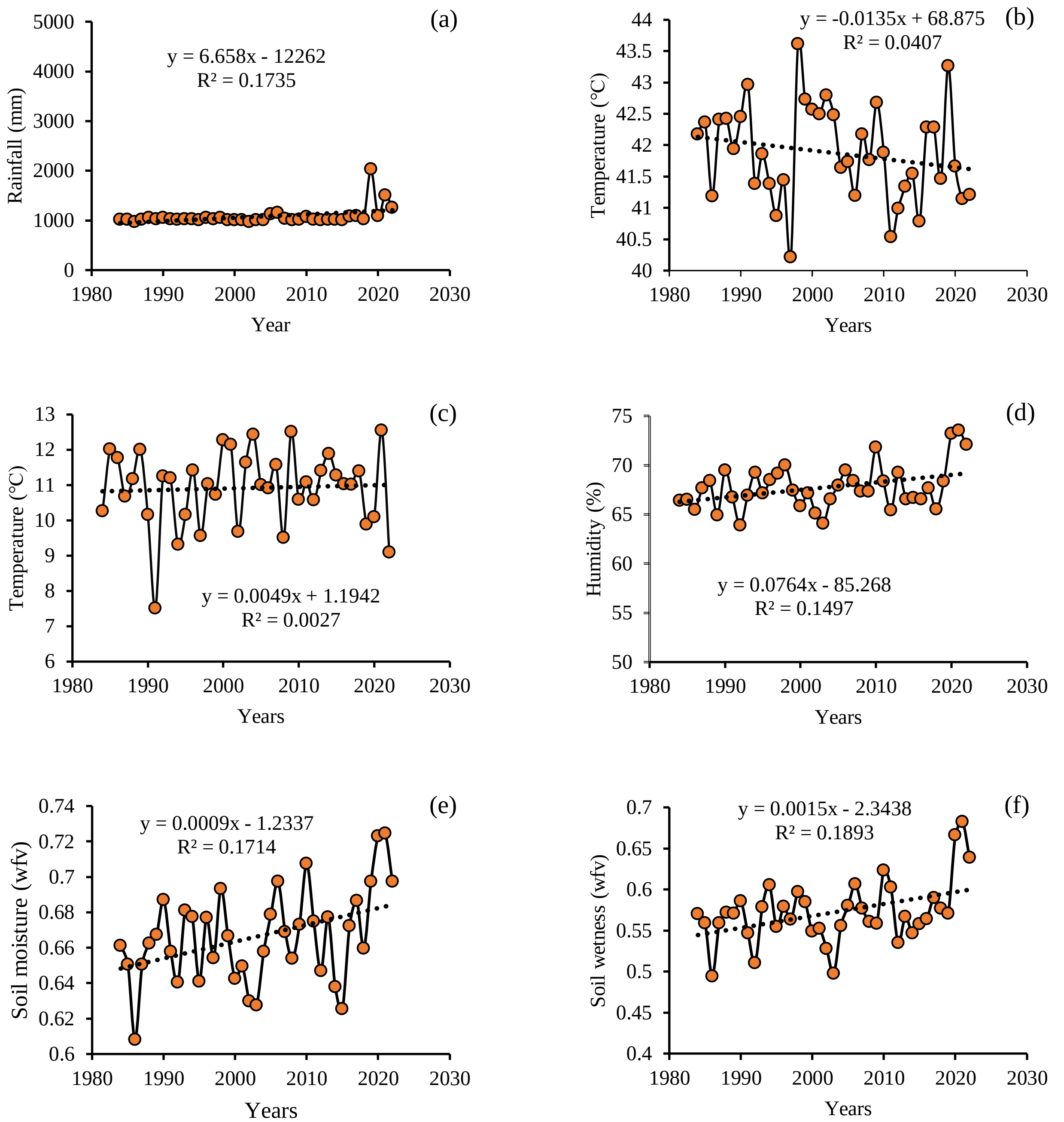


Figure 3. Climatic Trends of Ghat Zone (GH Zone): Rainfall (a), Max temperature (b), Min temperature (c), Relative humidity (d), Soil moisture (e), Soil wetness (f)

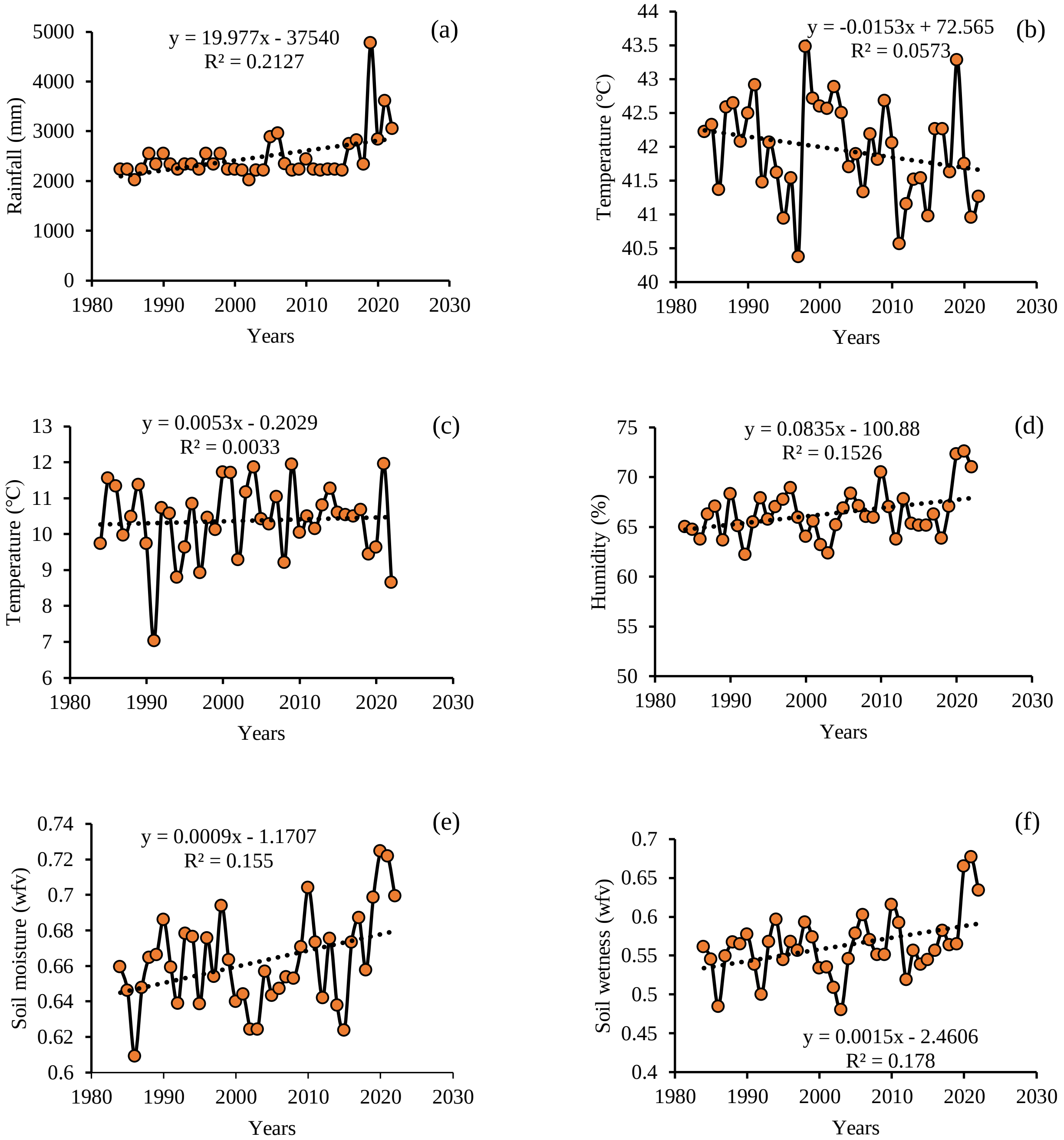


Figure 4. Climatic Trends of Transition Zone - I (TR- I Zone): Rainfall (a), Max temperature (b), Min temperature (c), Relative humidity (d), Soil moisture (e), Soil wetness (f)

This means that the data points show significant scatter around the fitted line and significant fluctuations in rainfall from year to year. Kendall tau of the ghat zone is -0.151, Sen's negative slope is -0.016 and the p-value is 0.179 besides $R^2$ value is 0.174 which indicates the statistically downward trend of maximum temperature. However, the $R^2$ value (0.041) is relatively low, indicating a negative relationship with maximum temperature. According to Kendall tau, Sen's slope, p-value and $R^2$ value, there is no trend in minimum temperature (Table 1). Relative humidity in this zone has a Kendall tau of 0.212, a positive value of Sen's slope stands at 0.058, and a p-value of 0.059 besides an $R^2$ value of 0.150 indicating a statistically significant upward trend. The p-values of soil moisture and soil wetness in this zone are 0.025 and 0.044, respectively representing that there is a statistically significant upward trend.

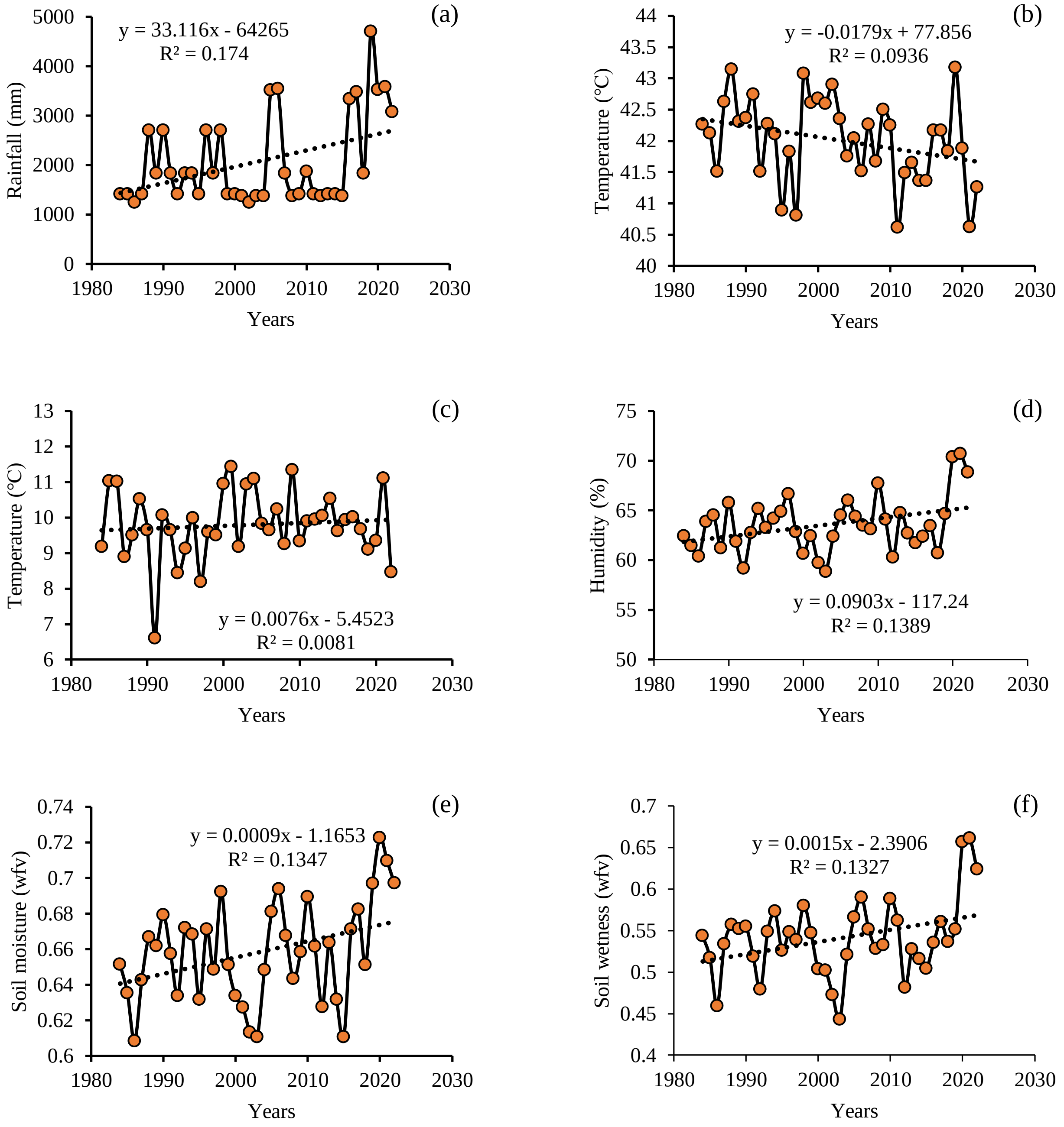


Figure 5. Climatic Trends of Transition Zone - II (TR- II Zone): Rainfall (a), Max temperature (b), Min temperature (c), Relative humidity (d), Soil moisture (e), Soil wetness (f)

## 4.2 Transition Zone – I (TR I Zone)

In transition zone - I (Table 1 and Figure 2), Kendall tau is 0.205, the positive value of Sen's slope is 4.720 the p-value is 0.077 and besides $R^2$ value is 0.213 which indicates a statistically upward trend of rainfall.

The rainfall in the transition zone- I increased during the period 1984 to 2022. However, the $R^2$ value (0.213) is relatively high, indicating a positive relationship with rainfall. The negative value of Kendall tau in the transition zone- I position is -0.186, Sen's negative slope is -0.020 and the p-value is 0.097 besides the $R^2$ value is 0.057 which indicates the statistical downward trend of maximum temperature (Figure 4). According to Kendall tau, Sen's slope, p-value and $R^2$ value, minimum temperature shows no trend. The relative humidity in this zone has a Kendall tau of 0.217, a positive value of Sen's slope of 0.062, and a p-value of 0.053 indicating a statistically significant upward trend. The p-values for soil moisture and soil wetness in this zone are 0.073 and 0.042, respectively, indicating a statistically slightly upward trend.

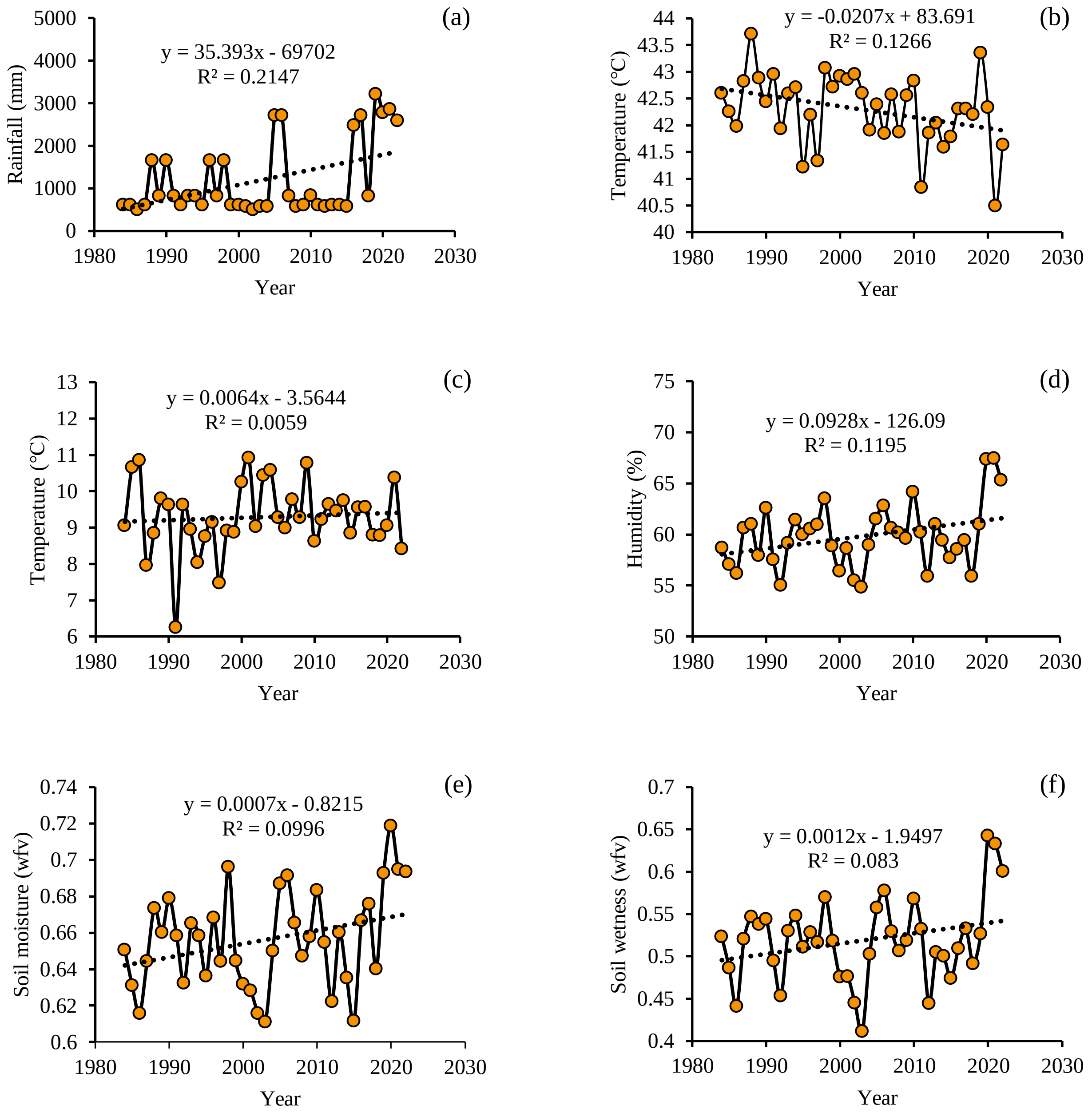


Figure 6. Climatic Trends of Scarcity Zone (SC Zone): Rainfall (a), Max temperature (b), Min temperature (c), Relative humidity (d), Soil moisture (e), Soil wetness (f)

### 4.3 Transition Zone – II (TR II Zone)

In transition zone- II, Kendall tau is 0.198, the positive value of Sen's slope is 4.761, and the p-value stands at 0.092, which indicates a statistically upward trend of rainfall. From this, rainfall in transition zone-II, is increasing during the period 1984 to 2022. However, the $R^2$ value (0.213) is relatively high, indicating a positive relationship with rainfall. The negative value of Kendall tau in transition zone- II is -0.251, and Sen's negative slope is -0.021, which specifies the statistically downward trend of maximum temperature. In this zone, no statistically significant trend is observed in minimum temperature (Figure 2). The relative humidity in this zone, Kendall tau is 0.188 and the positive value of Sen's slope is 0.070 which indicates a statistically significant upward trend. The p-values for soil moisture and soil wetness in this zone are 0.044 and 0.122, respectively, indicating a statistically slightly upward trend (Figure 5).

### 4.4 Scarcity Zone (SC Zone)

In the scarcity zone, Kendall tau is 0.199, and the positive value of Sen's slope is 3.495, which indicates a statistically slight upward trend of rainfall (Table 1 and Figure 2). The negative value of Kendall tau in the scarcity zone is -0.251, and Sen's negative slope is -0.018, which indicates a statistically decreasing trend of maximum temperature. In this zone, no statistically significant trend shows in minimum temperature. The relative humidity in this zone, p-value is 0.116, and $R^2$ value (0.119) which indicates a statistically slightly upward trend. The p-values for soil moisture and soil wetness in this zone are 0.081 and 0.348, respectively, indicating a statistically slightly upward trend (Figure 6).

## 5 CONCLUSIONS

This study examined long-term climatic trends and spatial variations across the agro-climatic zones of Satara district using data from 1984 to 2022. Key climatic parameters, including rainfall, maximum temperature, minimum temperature, relative humidity, soil moisture, and soil wetness, were analyzed using statistical methods such as Mann-Kendall's tau and Sen's slope to determine trends and their significance. The results indicate a steady increase in rainfall across all four agro-climatic zones (GH, TR-I, TR-II, and SC), with statistically significant p-values (<0.5), confirming the presence of a notable trend. The ghat region showed the most significant increase in rainfall, with a Sen's slope of 3.495. However, transition zone II and the scarcity zone exhibited more pronounced variations due to differences in topography and rainfall distribution. In the last decades of rainfall analysis, the graph shows the pressure of extreme events as the peak values are more than the mean normal. These areas, experiencing inconsistent rainfall, require reliance on artificial irrigation for stable agricultural production.

Regarding temperature trends, all zones showed a decline in maximum temperature with statistically significant p-values (<0.05). The SC and TR-II zones, in particular showed a declining trend as indicated by a negative Sen's slope (-0.021). Despite the overall decrease, temperature variations were observed in annual climatic patterns. Relative humidity exhibited an increasing trend across all zones with statistically significant p-values (<0.5). This rise in humidity was accompanied by an increase in soil moisture and wetness both showing significant upward trends ($p < 0.05$). These findings suggest that higher rainfall and humidity contribute to lower temperatures and improved soil moisture conditions, which are essential for agricultural productivity.

Understanding these climatic changes is crucial for long-term planning in agriculture and water resource management. To address these shifts, it is necessary to implement climate-resilient farming strategies such as improved water management techniques, integrated pest control and the cultivation of drought-resistant crops. Moreover, enhancing community awareness through training and accessible information can strengthen adaptive capacity. Sustainable land management practices, including soil conservation, afforestation, and watershed management, should be promoted to mitigate the adverse effects of climate change on agriculture.

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## ABBREVIATIONS

**WHO:** World Health Organization, **SOI:** Survey of India, **GIS:** Geographical Information System, **MK:** Mann Kendall, **GH Zone:** Ghat Zone, **TR - I Zone:** Transition Zone - I**, TR - II Zone:** Transition Zone - II, **SC Zone:** Scarcity Zone, **Mini. Temp.:** Minimum Temperature, **Max. Temp.:** Maximum Temperature, **SM:** Soil Moisture, **SW:** Soil Wetness, **RH:** Relative Humidity.

## CONFLICT OF INTEREST

The authors confirm no conflicts of interest.

## REFERENCES

Allan, R. P., Arias P. A., Berger S., Canadell J. G., Cassou C., Chen D., Cherchi A., Connors S. L., Coppola E., Cruz F. A., Niang A. D., Doblas-Reyes F. J., Douville H., Driouech F., Edwards T. L., Engelbrecht F., Eyring V., Fischer E., Flato G. M., Forster P., Kemper B. F., Fuglestvedt J. S., Fyfe J. C., Gillett N. P., Gomis M. I, Gulev S. K., Gutiérrez J. M., Hamdi R., Harold J., Hauser M., Ed Hawkins, Hewitt H. T., Johansen T. G., Jones C., Jones R. G., Kaufman D. S., Klimont Z., Kopp R. E., Koven C., Krinner G., Lee J. Y., Lorenzoni I., Marotzke J., Masson-Delmotte V., Maycock T. K. , Meinshausen M., Monteiro P. M.S., Morelli A., Naik V., Notz D., Otto F., Palmer M. D., Pinto I., Pirani A., Plattner G. K., Raghavan K., Ranasinghe R., Rogelj J., Rojas M., Ruane A. C., Sallée J.B., Samset B.H., Seneviratne S. I., Sillmann J., Sörensson A. A., Stephenson T. S., Storelvmo T., Szopa S.,Thorne P. W., Trewin B., Vautard R., Vera C., Yassaa N., Zaehle S., Zhai P., X. Zhang X., Zickfeld K., 2023. Intergovernmental Panel on Climate Change (IPCC). Summary for Policymakers. In *Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change* (3-32). Cambridge University Press. DOI: https://doi.org/10.1017/9781009157896.001

Aziz, O. I. A. and Burn, D. H., 2006. Trends and variability in the hydrological regime of the Mackenzie River Basin. *Journal of hydrology*, 319(1-4), 282-294. DOI: https://doi.org/10.1016/j.jhydrol.2005.06.039

Cannarozzo, M., Noto, L. V. and Viola, F., 2006. Spatial distribution of rainfall trends in Sicily (1921-2000). *Physics and Chemistry of the Earth, Parts* a/b/c, 31(18), 1201-1211. DOI: https://doi.org/10.1016/j.pce.2006.03.022

Chakravarty, P. and Kumar, M., 2020. Trend Analysis and ARIMA Modeling to Assess Meteorological and Surface Parameters in Ranchi, India During Pre-Monsoon Months. *GIS Business*, 15(2), 69-87.

Chandler, R. and Scott, M., 2011. *Statistical methods for trend detection and analysis in the environmental sciences*. John Wiley and Sons. DOI: https://doi.org/10.1002/9781119991571

Davis, C. L. and Vincent, K., 2017. Climate risk and vulnerability: A handbook for Southern Africa.

Duhan, D. and Pandey, A., 2013. Statistical analysis of long term spatial and temporal trends of precipitation during 1901–2002 at Madhya Pradesh, India. *Atmospheric Research*, 122, 136-149. DOI: https://doi.org/10.1016/j.atmosres.2012.10.010

FAO [Food and Agriculture Organization of the United Nations], 2016. The State of Food and Agriculture; FAO (Ed.) FAO: Rome, Italy.

Farndon, J., Callery, S., and Smith, M., 2020. *Weather*. Scholastic Inc.

Gangarde, A., Dauji, S. and Londhe, S., 2023. Comparison of long-term and short-term trends of annual rainfall in India: A case study. *ISH Journal of Hydraulic Engineering*, 29(3), 411-424. DOI: https://doi.org/10.1080/09715010.2022.2084351

Gocic, M. and Trajkovic, S., 2013 Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. *Global and planetary change*, 100, 172-182. DOI: https://doi.org/10.1016/j.gloplacha.2012.10.014

Goyal, M. K., 2014. Statistical analysis of long-term trends of rainfall during 1901-2002 at Assam, India. *Water resources management*, 28, 1501-1515. DOI: https://doi.org/10.1007/s11269-014-0529-y

ICAR [Indian Council of Agricultural Research], 2019. ICAR-Indian Agricultural Statistics Research Institute, Technical report, New Delhi, India.

Jiqin, H., Gelata, F. T. and Chaka Gemeda, S., 2023. Application of MK trend and test of Sen's slope estimator to measure impact of climate change on the adoption of conservation agriculture in Ethiopia. *Journal of Water and Climate Change*, 14(3), 977-988. DOI: https://doi.org/10.2166/wcc.2023.508

Kamal, N. and Pachauri, S., 2018. Mann-Kendall test-A novel approach for statistical trend analysis. *Int. J. Comput. Trends Technol*, 63, 18-21. DOI: https://doi.org/10.14445/22312803/IJCTT-V63P104

Kendall, M. G., 1955. Further contributions to the theory of paired comparisons. *Biometrics*, 11(1), 43-62. DOI: https://doi.org/10.2307/3001479

Kendall, M. G., 1962. Rank correlation methods, 3rd Ed., Hafner Publishing Company, New York.

Kumar, V., Jain, S. K. and Singh, Y., 2010. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal–Journal des Sciences Hydrologiques*, 55(4), 484-496. DOI: https://doi.org/10.1080/02626667.2010.481373

Mann, H. B., 1945. Nonparametric tests against trend. *Econometrica: Journal of the econometric society*, 245-259. DOI: https://doi.org/10.2307/1907187

Masson-Delmotte, V., Zhai P., Pirani A., Connors S. L., Péan C., Berger S., Caud N., Chen Y., Goldfarb L., Gomis M. I., Huang M., Leitzell K., Lonnoy E., Matthews J.B.R., Maycock T.K., Waterfield T., Yelekçi O., Yu R. and B. Zhou B., 2021. Climate change 2021: The physical science basis. *Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change*, 2(1), 2391. DOI: https://doi.org/10.1017/9781009157896

Oza, M. and Kishtawal, C. M., 2014. Trends in rainfall and temperature patterns over North East India. *Earth Science India*, 7(4). DOI: https://doi.org/10.12691/aees-10-6-6

Panda, A. and Sahu, N., 2019. Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmospheric Science Letters*, 20(10), e932. DOI: https://doi.org/10.1002/asl.932

Sneyers, R., Vandiepenbeeck, M., Vanilierde, R. and Demarée, G. R., 1990. Climatic changes in Belgium as appearing from the homogenized series of observations made in Brussels-Uccle (1933-1988) In: SCHIETECAT, GD. *Contributions à l'etude des changements de climat. Bruxelles: Institut Royal Meteorologique de Belgique, Publications Série*, 124, 17-20.

Thornton, P. K., Ericksen, P. J., Herrero, M. and Challinor, A. J., 2014. Climate variability and vulnerability to climate change: A review. *Global change biology*, 20(11), 3313-3328. DOI: https://doi.org/10.1111/gcb.12581

Urquhart, P., 2009. IFAD's response to climate change through support to adaptation and related actions. *Comprehensive report: Final version, International Fund for Agricultural Development (IFAD), Rome, Italy*.

Wilks, D. S., 2006. On "field significance" and the false discovery rate. *Journal of applied meteorology and climatology*, 45(9), 1181-1189. DOI: https://doi.org/10.1175/JAM2404.1

Yue, S. and Hashino, M., 2003. Long term trends of annual and monthly precipitation in Japan 1. *JAWRA Journal of the American Water Resources Association*, 39(3), 587-596. DOI: https://doi.org/10.1111/j.1752-1688.2003.tb03677.x

Zhang, X., Vincent, L. A., Hogg, W. D. and Niitsoo, A., 2000. Temperature and precipitation trends in Canada during the 20th century. *Atmosphere-ocean*, 38(3), 395-429. DOI: https://doi.org/10.1080/07055900.2000.964965

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