

Investigating Variations and Trend Analysis for Temperature and Precipitation as a Result of Climate Change in Rajasthan, India

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Abstract: Climate change is a pressing issue that is affecting the lives and livelihoods of millions of people across the world. This study investigates the trend analysis and spatial-temporal variations of temperature and precipitation on a monthly, seasonal, and annual basis in Rajasthan state, India, over the past 40 years (1981-2020). The trend analysis of temperature and precipitation were analysed using the Mann-Kendall test at the confidence level of 95%. The magnitude (slope) was determined by using Theil-Sen's slope test. The results of the analysis revealed significant positive and negative trends of temperature and precipitation observed on a monthly, seasonal, and annual basis in all the 33 districts of Rajasthan state. The summer season experienced the maximum average temperature, while the winter season had the minimum. The study also found that the northern and western parts of Rajasthan experience "Mawat" rain during the winter due to cyclones happening in the Mediterranean Sea during that season. The annual average temperature and precipitation were observed to be maximum in the southern part and minimum in the northern and western parts of the state. The findings of this study provide valuable information for the future management of water resources and the likely impact of activities on the hydrologic cycle and natural resources in Rajasthan state.

Keywords: Climate change; Temperature; Precipitation; Mann-Kendall test; Sen's Slope test; ArcGIS.

Introduction

Climate change is a global issue that has become a cause for concern for nations worldwide (IPCC, 2022). It's devastating effects are being felt by millions of people around the world, and its consequences are predicted to be far-reaching and long-lasting (Trenberth, 2011; Martinez et al., 2012). The rapid rise in global temperatures and precipitation variations has put the entire planet at risk, but it is developing countries like India that are particularly vulnerable to these changes (Zhong et al., 2010; Schroer et al., 2018). India is a country that is home to over a billion people, and it is among the nations that are most likely to face the

negative impacts of climate change (Action Plan, 2022). In this context, Rajasthan, which is the largest state in India and is located in the northwest region of the country, is one of the areas that are most affected by climate change (Das et al., 2020; Dash et al., 2012).

Rajasthan is known for its arid and semi-arid climate, which makes it one of the driest and hottest states in India (Pingale et al., 2014). The impact of climate change on Rajasthan is evident in the changing trends in temperature and precipitation variations (The Royal Society, 2021). Rajasthan is experiencing a rapid rise in temperatures, with an increase of approximately 0.5°C in the last few decades. This temperature rise is accompanied by a decrease in precipitation levels, which

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has a significant impact on the state's agriculture and livestock production (Singh et al., 2018). The scarcity of water due to the decrease in precipitation levels has also led to the depletion of groundwater resources, which is a critical concern for the state (Gosling et al., 2016).

In conclusion, climate change is a significant concern for Rajasthan, which is already grappling with an arid and semi-arid climate (Gupta et al., 2017). The changing trends in temperature and precipitation variations are having a profound impact on the state's economy and the livelihoods of its people (TKIM, 2022). Therefore, it is essential to study these trends and their impact on the state's agriculture and livestock sectors to develop strategies to mitigate the negative effects of climate change on the state. The government, civil society organisations, and the private sector must work together to develop sustainable solutions that will protect Rajasthan's economy and the livelihoods of its people in the face of climate change (Weststrate et al., 2019).

Rajasthan is the biggest state in India, taking up 10.4% of the country's total land area (3.4 lakh km square). It is India's northwest state that stretches between 23°30' and 30°11' N latitudes and 69°29' and 78°17' E longitudes (India Meteorological Department, 2020). Figure 1 shows the study area of Rajasthan State

covering all the district points. The state has seven divisions—Jaipur, Jodhpur, Ajmer, Udaipur, Bikaner, Kota and Bharatpur—and 33 districts. The capital of Rajasthan, Jaipur, often known as the Pink City, was established in AD 1727 by Maharaja Sawai Jai Singh II. It serves as the state capital of Rajasthan and a key stop on the Golden Triangle tourism route, including Delhi and Agra.

Study Area

Methodology

The purpose of this study is to analyse the trends in temperature and precipitation variations in Rajasthan state, India, for the past 40 years. To achieve this, temperature and precipitation data were collected from NASA's Power Access Climate Data website. The Mann-Kendall (MK) test was used to determine the trend analysis in temperature and precipitation. The MK test is a non-parametric statistical test used to detect trends in time-series data, particularly when the data do not follow a normal distribution (Meena et al., 2019). This test is widely used in climate change studies to identify trends in climate data. In this study, the test was applied to the temperature and precipitation data

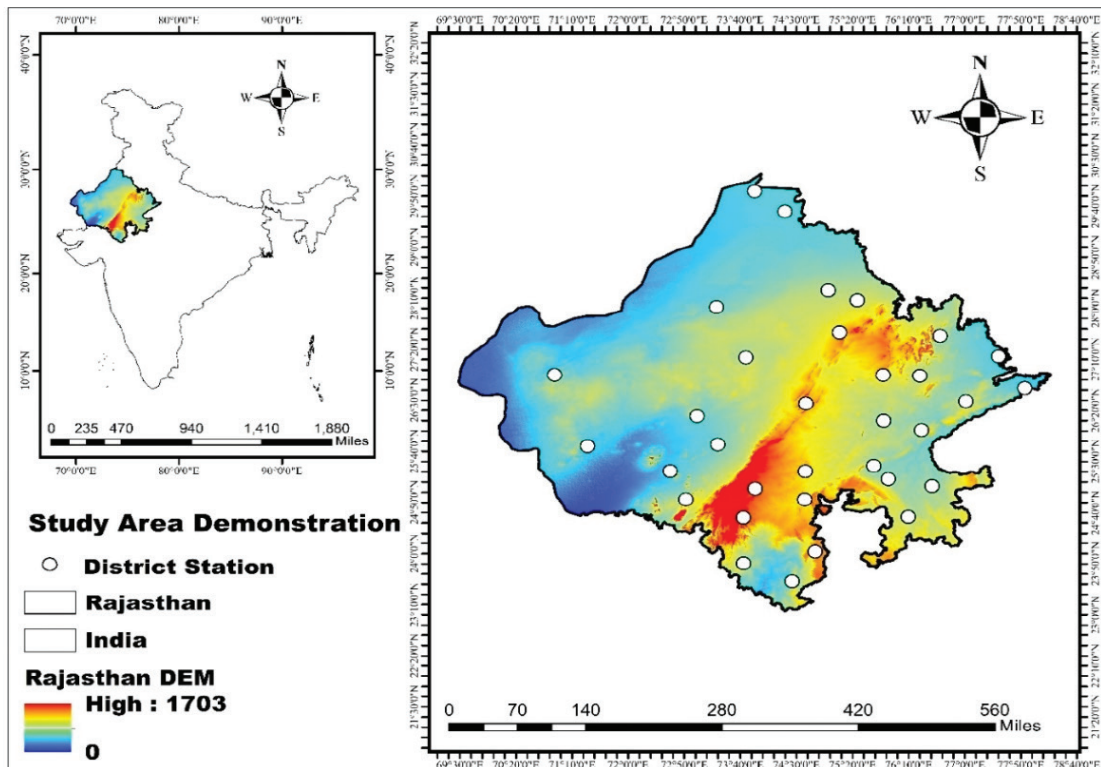


Figure 1: Rajasthan state, including all the districts.

for the years 1981-2020. It is based on the test statistic S defined as (Meshram et al., 2017):

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

where, $x_1, x_2, x_3, \dots, x_n$ represent n data points where x_j represents the data point at time $j > i$. A very high positive value of S indicates an increasing trend and a very low negative value indicates a decreasing trend (Devi et al., 2017).

$$\text{sgn}(x_j - x_i) = \begin{cases} +1, & \text{if } (x_j - x_i) > 0 \\ 0, & \text{if } (x_j - x_i) = 0 \\ -1, & \text{if } (x_j - x_i) < 0 \end{cases} \quad (2)$$

It has been documented that when $n \geq 10$, the statistic S is approximately normally distributed with the mean $E(S) = 0$,

And its variance is (Malik, 2020),

$$\text{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and t is the number of data points in the i^{th} group. The standard test statistic Z is computed as follows (Kumar et al., 2020):

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}}, & \text{if } S < 0 \end{cases} \quad (4)$$

The Z (standard normal distribution cumulative) value was determined from the test to decide the upward or downward trend line. This value provides information on the direction and magnitude of the trend. Positive values of Z indicate increasing trends, while negative Z values show decreasing trends. The null hypothesis, H_0 , meaning that no significant trend is present, is accepted if the test statistic Z is not statistically significant, i.e., $-Z\alpha/2 < Z < Z\alpha/2$, where $Z\alpha/2$ is the standard normal deviate. Testing trends is done at the specific α significance level. The Mann-Kendall test is essentially limited to testing the null hypothesis that the data are independent and identically distributed.

The magnitude (slope) of the rainfall trend was determined using Sen's Slope test at a 95% confidence

interval. Sen's Slope test is a non-parametric method used to calculate the slope of a linear trend in a time series. The slope of n pairs of data points was estimated using Theil-Sen's estimator, which is given by the following relation:

$$\beta = \text{median} \left(\frac{x_j - x_i}{j - i} \right) \quad (5)$$

$1 < i < j < n$ and β is the robust estimate of the trend magnitude. A positive value of β indicates an "upward trend", and a negative value of β indicates a "downward trend". The test is particularly useful when the data contain outliers or are not normally distributed. In this study, the Sen's Slope test was applied to the precipitation data for the years 1981-2020.

The ArcGIS software was used to observe the spatial-temporal variations of temperature and precipitation for all the monitoring points in Rajasthan state, covering the state's 33 districts. ArcGIS is a geographic information system software that is widely used in climate change studies to analyse spatial-temporal data (Gunawat et al., 2017). In this study, the software was used to visualise the spatial distribution of temperature and precipitation variations in Rajasthan state. In this study, the IDW method was used to estimate the temperature and precipitation values for each district in Rajasthan state. The Inverse Distance Weighted (IDW) method was used to interpolate the data for each district. It estimates values at unsampled locations based on the values of neighbouring sampled locations, using an inverse distance weighting scheme.

IDW is a direct deterministic interpolation method broadly applied in spatial interpolation applications. It was developed based on the assumption that the interpolated points are the most affected by the nearest points and the least affected by the most distant points. IDW is a local, exact, and deterministic method (Hadi et al., 2018).

The general equation of IDW is as follows:

$$\hat{Z}(s_0) = \sum_{i=0}^N \lambda_i Z(s_i) \quad (6)$$

where $\hat{Z}(s_0)$ is the estimated values at location s_0 , N is the number of points located around the point to be calculated used in the calculation, $Z(s_i)$ is the value of the known points measured at s_i , and λ_i is the weight corresponding to each known issue, which is inversely proportional to the distance between the known points and the estimated point.

The weights are calculated as follows:

$$\lambda_i = \frac{d_{i0}^{-p}}{\sum_{i=1}^N d_{i0}^{-p}} \quad (7)$$

where p is the power, which controls the influence of the distance between the points on the estimation value; N is the number of points used in the estimation; and d_i is the distance between the point to be estimated s_0 and the known point s_i .

The study analysed temperature and precipitation data for the past 40 years, from 1981 to 2020. The data were collected from NASA's Power Access Climate Data website, which provides reliable and high-quality climate data. The Mann-Kendall (MK) test was used to detect temporal trends in temperature and precipitation, and Sen's Slope test was used to calculate the magnitude of the rainfall trend. The ArcGIS software was used to visualise the spatial distribution of temperature and precipitation variations, and the Inverse Distance Weighted (IDW) method was used to interpolate the data for each district in the Rajasthan state.

In conclusion, the methodology used in this study is appropriate for analysing trends in temperature and precipitation variations in the Rajasthan state. The use

of non-parametric statistical tests such as the Mann-Kendall (MK) test and Sen's Slope test is particularly useful when dealing with non-normal data. The ArcGIS software and the Inverse Distance Weighted (IDW) method are powerful tools for visualizing and interpolating spatial data. The findings of this study can help policymakers and stakeholders in Rajasthan state to develop strategies to mitigate the negative effects of climate change on the state's economy and the livelihoods of its people.

Results

The study investigated the trend analysis and spatial-temporal variations of temperature and precipitation in the Rajasthan state and its 33 districts using data collected from NASA's "Power Access Climate Data" website. Table 1 shows the resultant values of the Mann-Kendall test performed for Temperature and precipitation which gives the values of τ (Kendall Rank correlation coefficient, which measures the monotony of the slope), p (signifies the evidence against the null hypothesis), slope (identifies the magnitude of the trend in a data series) and Z (standard normal distribution cumulative).

Table 1: Temperature and Precipitation value of τ , p , slope and Z on monthly, seasonal and annual basis

Period	Temperature				Precipitation			
	τ	p	Sen's slope	Z	τ	p	Sen's slope	Z
January	-0.04	0.75	-0.01	-0.30	-0.06	0.66	0.00	-0.43
February	0.04	0.74	0.01	0.31	-0.09	0.49	0.00	-0.67
March	0.11	0.35	0.03	0.93	0.10	0.43	0.00	0.77
April	0.23	0.04	0.04	2.04	0.10	0.41	0.00	0.81
May	0.17	0.14	0.03	1.48	0.10	0.38	0.00	0.86
June	0.04	0.72	0.01	0.36	0.29	0.01	0.98	2.49
July	-0.04	0.75	0.00	-0.30	0.13	0.26	0.96	1.11
August	-0.12	0.30	-0.02	-1.04	0.03	0.79	0.18	0.25
September	-0.05	0.67	-0.01	-0.44	0.13	0.27	0.53	1.09
October	-0.02	0.87	-0.01	-0.16	-0.14	0.24	0.00	-1.16
November	0.08	0.49	0.01	0.70	0.05	0.68	0.00	0.39
December	-0.02	0.85	0.00	-0.18	0.01	0.96	0.00	0.03
Annual	0.01	0.94	0.00	0.07	0.16	0.17	2.97	1.37
Summer	0.19	0.10	0.01	1.67	0.24	0.04	0.26	2.07
Rainy	-0.12	0.31	0.03	-1.02	0.11	0.34	0.44	0.94
Winter	0.05	0.65	-0.01	0.45	-0.09	0.45	0.00	-0.74

The maximum and minimum temperature values of Z are observed in April (2.04) and August (-1.04), respectively, as they give the upward or downward trendline. The maximum and minimum precipitation values of Z are observed in June (2.49) and October (-1.16), respectively. The positive value denotes the increasing trend day by day, and the negative value represents the decreasing trend of the temperature and precipitation, i.e. the value decreases in a particular month for the given period.

Figures 2 and 3 show the trend analysis of average temperature and, precipitation of the past 40 years in Rajasthan state respectively.

The study found that the annual average temperature in Rajasthan state has increased significantly in the past 40 years, with the maximum increase observed in 1988, 2009, and 2016, and the minimum in 2008 and 2013. The average annual temperature in the state has been almost 24.5°C. The summer season experienced the maximum average temperature, i.e., 33°C in 2016, while the average temperature in winter decreased to 17°C in 2012. The average temperature during the rainy season fluctuated between 29 and 31°C as the number of water bodies in an area affects the rainfall pattern.

The study also found that the annual precipitation in Rajasthan state has increased significantly in the

past 40 years, with the maximum increase observed in 2019 and the minimum in 2002. The average value of precipitation lies between 350 and 450 mm, showing an increasing trend line in the state. During winters, Rajasthan's northern and western parts experience "Mawat" rain due to cyclones in the Mediterranean Sea. The average precipitation value in the summer season is observed in the year 1986, which nearly equals 14 mm. The rainy season shows the maximum value of average precipitation in 2019, i.e., 140 mm, and the minimum value of average precipitation in 2002, i.e., 7 mm.

The study also identified spatial-temporal variations in temperature and precipitation across Rajasthan's 33 districts. The annual average temperature of Rajasthan state is shown in Figure 4. The annual average temperature was maximum at 26°C, observed in the Sriganganagar, Jaisalmer, Dholarpur, Banswara, and Dungarpur districts. The minimum value was 23°C in the Ajmer, Bhilwara, Chittorgarh and Rajsamand districts. The annual average precipitation of Rajasthan state is shown in Figure 5 as the maximum value is observed in the southeast part covering a region of Bharatpur, Dausa, Jhalawar, Baran, Banswara and Pratapgarh. The minimum value observed in the western part consists of Barmer, Jaisalmer, and Bikaner in the last 40 years.

The study findings can be useful in identifying the likely impact of activities on the hydrologic cycle, natural resources and future management of water resources in the state of Rajasthan. Further research may explore the specific causes of the observed trends and variations and investigate their potential consequences for human societies and ecosystems in the region. Overall, the present study contributes to the growing knowledge on climate change and its implications for vulnerable regions worldwide.

Conclusion

Based on the detailed trend analysis and spatiotemporal variations of temperature and precipitation in Rajasthan state and its districts over the past 40 years, several key conclusions can be drawn.

1. There is an upward trend line in temperature in February, March, April, May, June, and November, while there is an increasing trend of precipitation in March, April, May, June, July, August, September, November, and December.
2. The average annual temperature value has been almost 24.5°C, with a maximum observed in 1988,

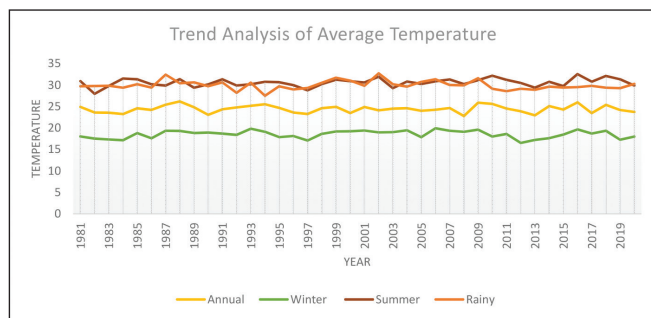


Figure 2: Trend analysis of average temperature on monthly and seasonal basis.

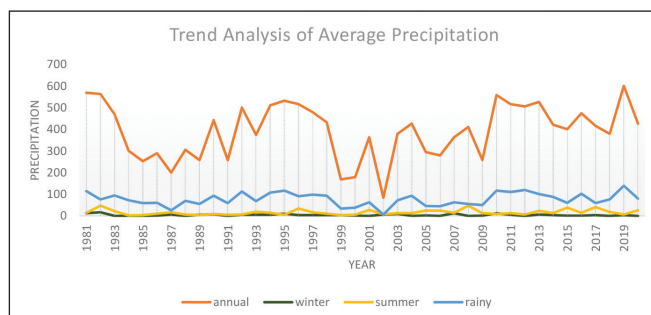


Figure 3: Trend analysis of average precipitation on monthly and seasonal basis.

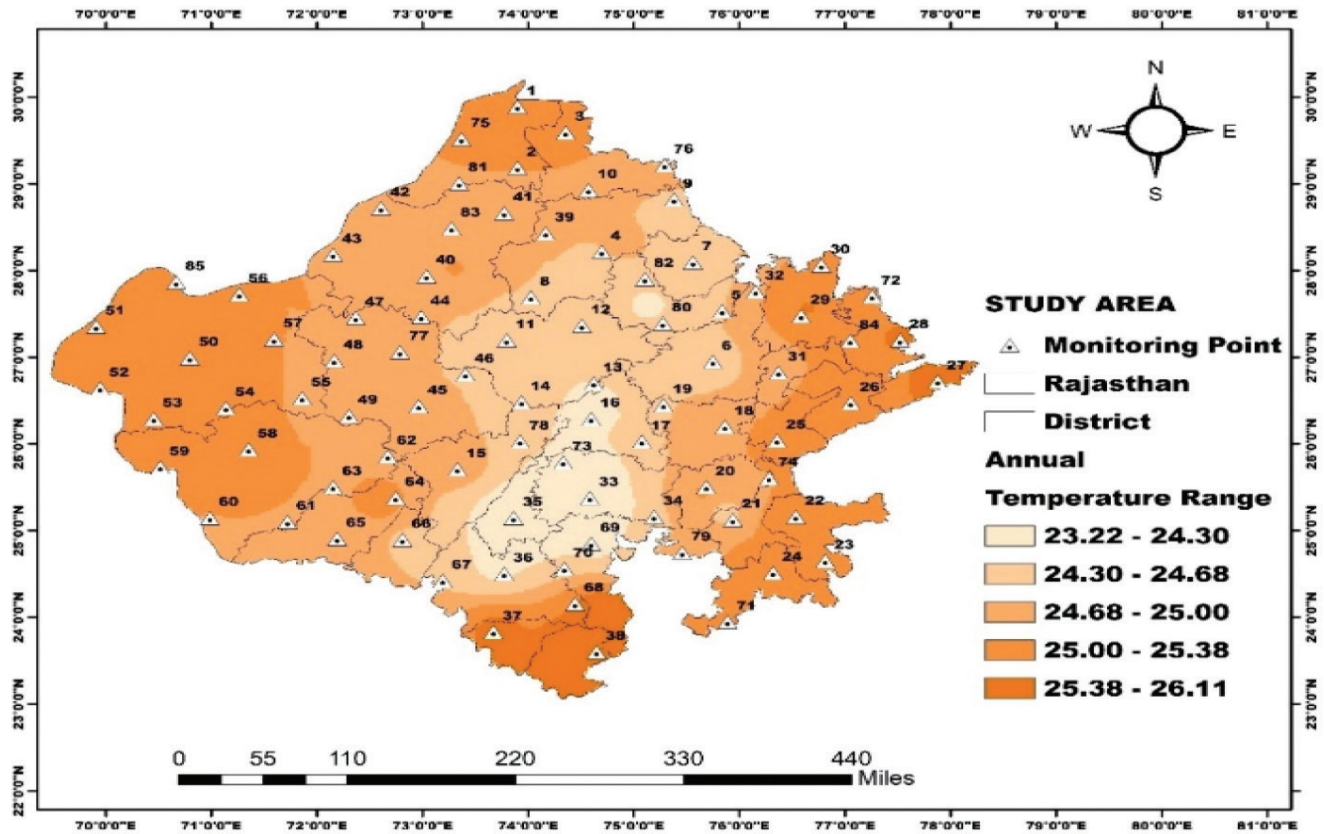


Figure 4: Variation of average temperature on the annual basis.

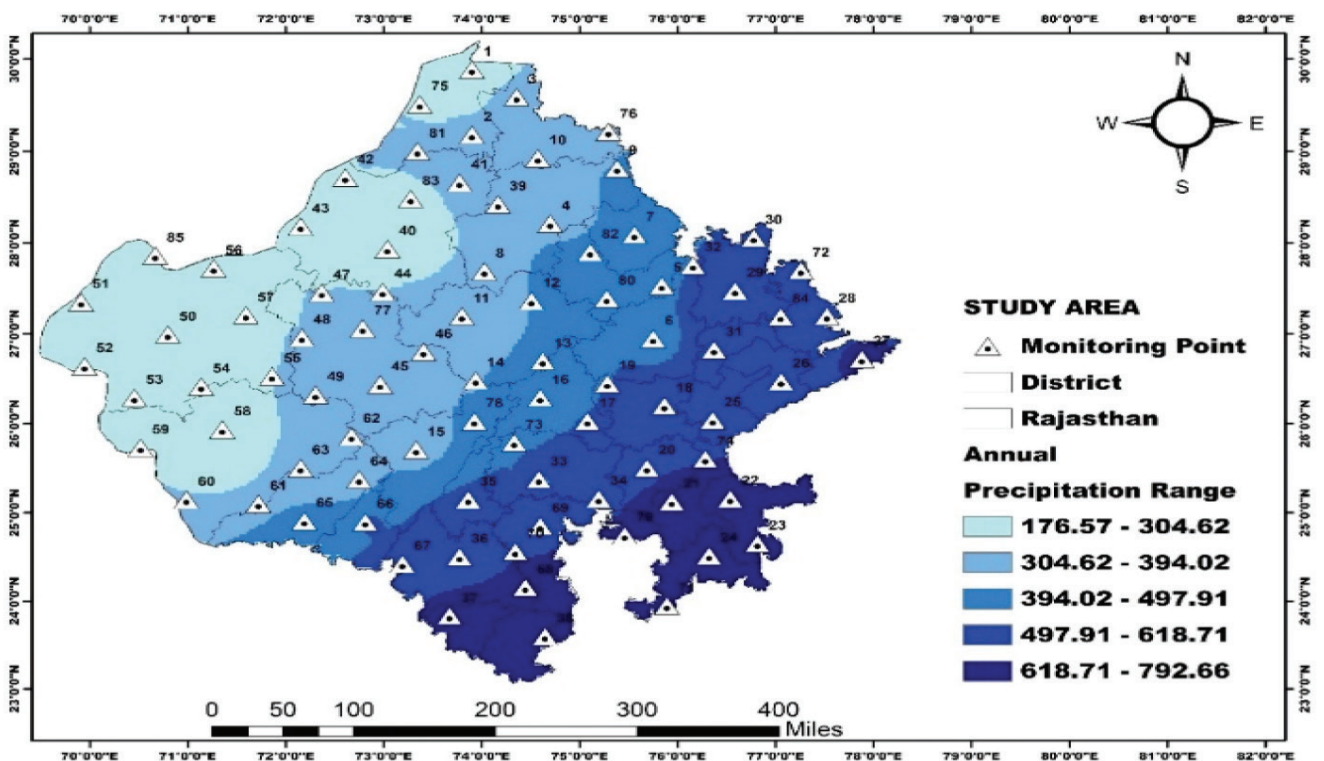


Figure 5: Variation of average precipitation on an annual basis.

2009 and 2016 and a minimum observed in 2008 and 2013.

3. The summer season experienced the maximum average temperature, i.e., 33°C in 2016.
4. There has been a significant increase in annual precipitation, with a maximum observed in 2019 and a minimum in 2002.
5. During the winter, Rajasthan's northern and western parts experience "Mawat" rain due to cyclones in the Mediterranean Sea.
6. The annual average temperature is maximum in Sriganganagar, Jaisalmer, Dholpur, Banswara, and Dungarpur districts and minimum in Ajmer, Bhilwara, Chittorgarh, and Rajsamand districts of Rajasthan.
7. The average value in the summer season is observed at 30.5°C in the northeast part, and the average value in the winter season is observed at 19.5°C in the central part of Rajasthan state.
8. The annual average precipitation for the past 40 years is observed at a maximum in the southern part and minimum in the Jaisalmer district.
9. The average summer season precipitation is recorded as maximum in Pratapgarh and Banswara districts, and the average precipitation of the winter season is observed maximum in the Pratapgarh and Sriganganagar districts.
10. Finally, these findings provide critical information for understanding the likely impact of activities on the hydrologic cycle, natural resources, and future management of water resources in the state of Rajasthan.

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References

Action Plan, July, 2022. Draft of Action Plan on Climate Change. vol. 2022, no. July 2021, pp. 1-12. <https://environment.rajasthan.gov.in/content/dam/environment/>

- Env/Pdf_Files/Draft%20of%20State%20Action%20Plan%20on%20Climate%20Change%202022.pdf
- Das, J., Gayen, A., Saha, P. and Bhattacharya, S.K., 2020. Meteorological drought analysis using standardized precipitation index over Luni River Basin in Rajasthan, India. *SN Applied Sciences*, **2**: 1-17.
- Dash, S.K., Sharma, N., Pattanayak, K.C., Gao, X.J. and Shi, Y., 2012. Temperature and precipitation changes in the north-east India and their future projections. *Global and Planetary Change*, **98**: 31-44.
- Devi, S., Purohit, R.C., Bhakar, S.R. and Lakhawat, S.S., 2005. Spatial and temporal trends of precipitation and temperature for the MPUAT service area, Rajasthan, India. *IOSR Journal of Agriculture and Veterinary Science*, **10(7)**: 15-20.
- Gosling, S.N. and Arnell, N.W., 2016. A global assessment of the impact of climate change on water scarcity. *Climatic Change*, **134**: 371-385.
- Gunawat, A., Dubey, S.K. and Sharma, D., 2016. Development of indices for aridity and temperature changes pattern through GIS mapping for Rajasthan, India. *Climate Change and Environmental Sustainability*, **4(2)**: 178-189.
- Gupta, A., Kamble, T. and Machiwal, D., 2017. Comparison of ordinary and Bayesian kriging techniques in depicting rainfall variability in arid and semi-arid regions of north-west India. *Environmental Earth Sciences*, **76**: 1-16.
- Hadi, S.J. and Tombul, M., 2018. Comparison of spatial interpolation methods of precipitation and temperature using multiple integration periods. *Journal of the Indian Society of Remote Sensing*, **46**: 1187-1199.
- India Meteorological Department, 2020. MONSOON REPORT-2020 (RAJASTHAN) Meteorological Centre Jaipur," vol. 2020.
- IPCC, 2022. *Intergovernmental Panel on Climate Change 2022*, (Vol. 1). [Online]. Available: <https://www.ipcc.ch/report/ar6/wg2/>.
- Kumar, S., Chanda, K. and Pasupuleti, S., 2020. Spatiotemporal analysis of extreme indices derived from daily precipitation and temperature for climate change detection over India. *Theoretical and Applied Climatology*, **140**: 343-357.
- Malik, A. and Kumar, A., 2020. Spatio-temporal trend analysis of rainfall using parametric and non-parametric tests: Case study in Uttarakhand, India. *Theoretical and Applied Climatology*, **140**: 183-207.
- Martinez, C.J., Maleski, J.J. and Miller, M.F., 2012. Trends in precipitation and temperature in Florida, USA. *Journal of Hydrology*, **452**: 259-281.
- Meena, H.M., Machiwal, D., Santra, P., Moharana, P.C. and Singh, D.V., 2019. Trends and homogeneity of monthly, seasonal, and annual rainfall over arid region of Rajasthan, India. *Theoretical and Applied Climatology*, **136**: 795-811.
- Meshram, S.G., Singh, V.P. and Meshram, C., 2017. Long-term trend and variability of precipitation in Chhattisgarh State, India. *Theoretical and Applied Climatology*, **129**: 729-744.

- Pingale, S.M., Khare, D., Jat, M.K. and Adamowski, J., 2014. Spatial and temporal trends of mean and extreme rainfall and temperature for the 33 urban centers of the arid and semi-arid state of Rajasthan, India. *Atmospheric Research*, **138**: 73-90.
- Schröer, K. and Kirchengast, G., 2018. Sensitivity of extreme precipitation to temperature: The variability of scaling factors from a regional to local perspective. *Climate Dynamics*, **50**: 3981-3994.
- Singh, C., Osbahr, H. and Dorward, P., 2018. The implications of rural perceptions of water scarcity on differential adaptation behaviour in Rajasthan, India. *Regional Environmental Change*, **18**: 2417-2432.
- The Royal Society, 2021. "Climate change- Evidence and Causes," *Genet. Modif. Plants*, pp. 283-296. doi: 10.1016/b978-0-12-818564-3.09991-1.
- TKIM, "World Trade Organisation (WTO) Annual Report 2022," *Fresenius.Com*, no. December, pp. 2-2, 2018.
- Trenberth, K.E., 2011. Changes in precipitation with climate change. *Climate Research*, **47(1-2)**: 123-138.
- Weststrate, J., Dijkstra, G., Eshuis, J., Gianoli, A. and Rusca, M., 2019. The sustainable development goal on water and sanitation: Learning from the millennium development goals. *Social Indicators Research*, **143**: 795-810.
- Zhong, L., Ma, Y., Salama, M.S. and Su, Z., 2010. Assessment of vegetation dynamics and their response to variations in precipitation and temperature in the Tibetan Plateau. *Climatic Change*, **103(3-4)**: 519-535.