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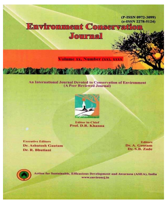

Investigation of trends in basin-scale temperature variables

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ABSTRACT

This research paper presents an analysis of temperature variables over the West Banas basin in order to detect the presence of underlying trends employing historical temperature data for three points viz., Abu Road, Mount Abu and Pindwara obtained for a period of 40 years (1981 – 2020) from MERRA-2 database. The study aims to investigate the long-term changes in temperature trends and identify any significant patterns or anomalies in mean, maximum and minimum temperatures at monthly, seasonal and annual timescales at the three locations amounting to a total of 162 series. The trends were evaluated using the Mann-Kendall test, a popular and powerful statistical technique formulated for analysing abnormal distributions. Prior to the application of the trend test, autocorrelated time series were identified and the trend test was modified using a variance correction approach to incorporate the influence of autocorrelations upon the resultant trends. The findings of autocorrelation analysis revealed that 11 of the 162 series were autocorrelated, a majority of which were associated with the temperature series at Abu Road. The results of the trend test showed that 27 out of the 162 series possessed significant trends with the mean and maximum monsoon temperatures in most of the series exhibiting a reducing trend while the minimum temperature appeared to be rising. Overall, the research highlights the importance of monitoring temperature trends, particularly in regions that may be more vulnerable to the impacts of climate change. The findings of this study can inform future climate adaptation strategies and support decision-making processes aimed at mitigating the effects of global warming on the natural and built environment.

Introduction

The Earth's climate is a complex and dynamic system that is constantly. One of the most significant changes observed in recent years is the increase in global temperatures. The average global temperature has increased by 1.1°C since the pre-industrial era and it has been predicted that a further rise by another 5°C may occur by the end of this century (IPCC, 2018). This warming of the planet has significantly impacted our environment and society and is the cause of rising sea levels, more intense and frequent extreme weather events and has added to the erratic nature of precipitation (IPCC, 2014). According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (ISPBE), climate change has an impact on a variety of sectors, including agribusiness, public health, and infrastructure (Ebi *et al.,* 2014; ISPBE, 2019). Given these very real

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influences of climate change upon the natural as well as artificial ecosystems of our world, there is an urgent need to better understand and predict changes in temperature patterns and aim at creating policies with the goal of mitigating the consequences of climate change.

Temperature is one of the most widely used indicators of climate change, and long-term temperature data aids in elucidating the effects of global warming on the planet. Recent decades have witnessed a tremendous growth in the research field pertaining to trend analysis of temperature owing to the abrupt changes being observed in global climate. By examining temperature trends over different spatial and temporal scales, this research aims to contribute to our understanding of the variations inherent to Earth's climate system with the aim of directing policymakers towards planning control measures for mitigating the impacts of climate change. Several studies have documented the observed warming trend in the Earth's surface temperatures and the phenomenon of global warming. Hansen et al. (2010) analysed the global surface temperature change from 1880 to 2009 and reported an increase of 0.8°C in the planet's temperature during that period. Although the magnitude of rise in temperature is overstated in various studies, increasing surface temperature of the planet remains an incontrovertible occurrence (Karl *et al.,* 2015).

However, most of these studies have assessed temperature trends over large-scale areas such as countries or continents, but smaller scale analysis is needed to better understand the regional consequences of climate change (Singh *et al.,* 2008). Hence, this study will deal with a comprehensive analysis of basin-scale variations in temperature to better understand the magnitude and direction of temperature changes over time.

Material and Methods

Study area and data acquisition

Rajasthan has 14 major river basins, but most of them have rivers with seasonal flows. The focus of this study is the West Banas basin, which is situated in the south-eastern region of Sirohi district (Fig. 1). The West Banas River originates from Pindwara village in Sirohi district at an elevation of 372.5 m above mean sea level and flows for about 50 km in a south-western direction before entering Gujarat and finally draining into the little Rann of Kachchh. The region is delineated by the Luni basin to the north and northwest, the Sukli basin to the west, and the Sabarmati basin to the east, while its southeastern boundary is contiguous with the state of Gujarat. The river has a total length of 266 km, draining an area of 8,674 km^2, of which 1831.34 km^2 in Rajasthan and the remaining in Gujarat.

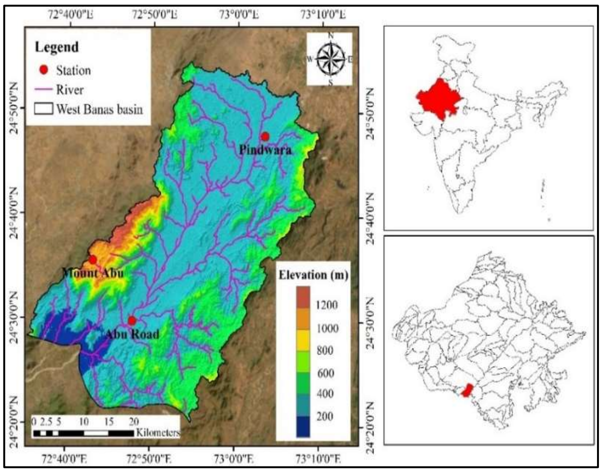

Figure 1: West Banas basin of Rajasthan

Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2) is a widely-used global atmospheric reanalysis product developed by NASA. It provides a comprehensive picture of the planet's climate system from 1980 to the present day at a spatial resolution of approximately 0.5 degrees. The MERRA-2 temperature data refers to the 2D daily land surface temperature data, which is a crucial component in the analysis of the Earth's climate system. The information presented is sourced from the MERRA-2 reanalysis system, which employs sophisticated data assimilation methods to combine data from diverse sources, such as satellite and ground-based instruments, to generate a dependable and consistent account of the Earth's climate. Moreover, the application of this dataset has undergone verification by numerous researchers (Bosilovich *et al.,* 2016; Gupta *et al.,* 2019). The monthly temperatures (mean, maxima and minima) for a duration of 40 years (1981 – 2020) for three points viz., Abu Road, Mount Abu and Pindwara, were obtained from NASA's MERRA-2 dataset. The temporal variation of these temperature variables are shown in Fig. 2.

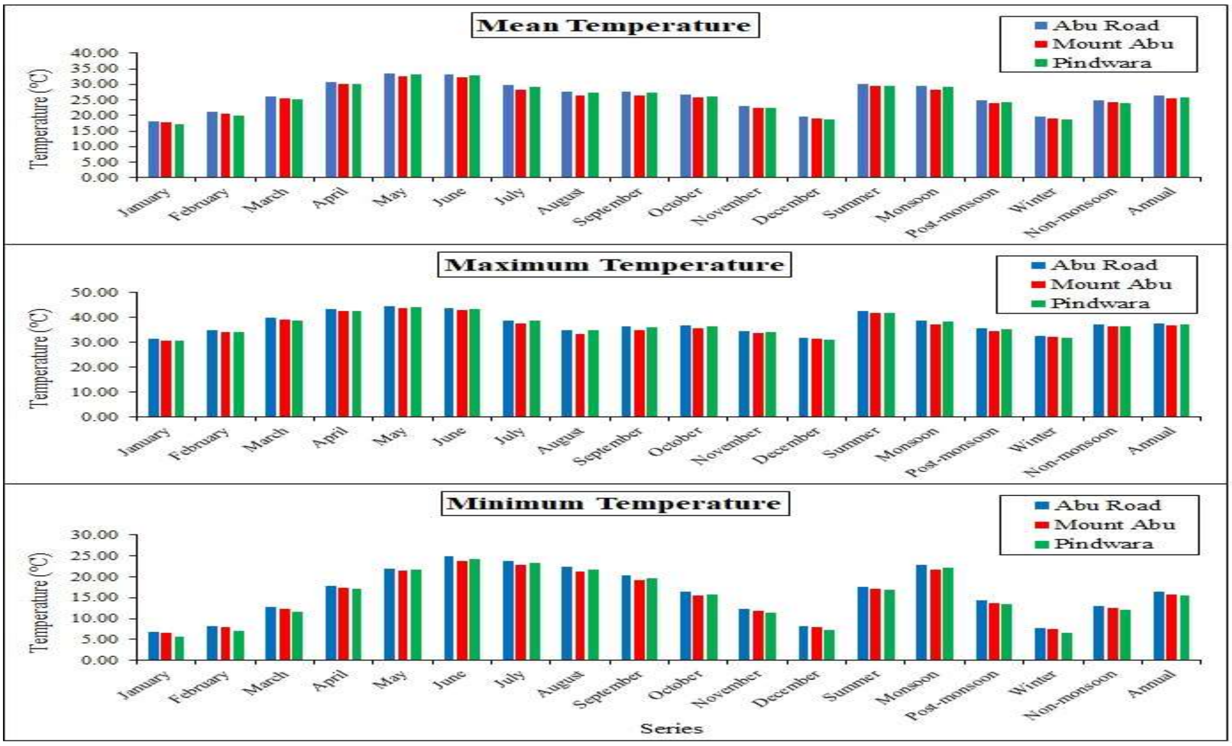

Figure 2: Overview of the temperature dataset

Autocorrelation

The only factor requiring serious consideration while application of MK test is that no autocorrelation (serial correlation) should be present in the time series data as positive autocorrelation in time series tend to increase the possibility of detection of trends whereas that possibility reduces in case of a negative autocorrelation. It has been established that the presence of autocorrelation in time series has an influence upon the variance of MK test statistics. From analysis perspective concerned with the present study, it is imperative to determine the lag 1 autocorrelation coefficients of each time series which can be according to Box and Jenkins (1970) as:

$$r_1 = \frac{\sum(x_t - \bar{x})(x_{t+1} - \bar{x})}{\sum(x_t - \bar{x})^2} \qquad (1)$$

Where, r_1 is the autocorrelation coefficient at lag 1, x_t and x_{t+1} are observations at time t and $t+1$, $\bar{x}$ denotes the time series mean.

The autocorrelation coefficients are usually depicted as a series of stem plots which were developed using Python in this study. Based on a 95% significance level, the time series possessing significant autocorrelations were identified as the individual plots which extended beyond the limits of the confidence interval.

Trend analysis using Mann-Kendall test

Trend in a time series is characterized as the deterministic component which causes successive values to possess increasing or decreasing tendencies with time (Haan, 2002). Trend in a time series may be linear or nonlinear, caused by variations in hydrologic characteristics accounted by natural factors or artificial intervention. A global shift in climatic characteristics and anthropogenic activities are the major factors responsible for the presence of trends in meteorologic variables such as temperature.

The Mann Kendall (MK) method of trend analysis has been extensively used in a plethora of studies (Nalley *et al.,* 2013; Pingale *et al.,* 2016) for analysing trends in rainfall as well as other climatic variables and is viewed as a standard tool for trend detection worldwide. The MK test is a non-parametric statistical technique used to identify patterns in a time series with their nonlinear aspect being derivable from Kendall test statistics (Mann, 1945; Kendall, 1975). The non-parametric attribute of the test provided it with an upper hand over parametric tests because its application omits the prerequisite of the input data being normally distributed and the effects of raw and skewed data are also heavily undermined (Yue *et al.,* 2003).

For time series X_i and X_j where i and j denote the ranks in the range of natural numbers with X_i and X_j being the points of reference being compared in an iteration of the test, a test statistic (S) for the MK test may be derived as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \qquad (2)$$

where n is the range of data points, X_i and X_j are the recorded values of a variable in time series i and j ($j > i$), respectively, such that $j > i$ and $sgn\ (X_j - X_i)$ is termed as the sign function evaluated as:

$$sgn(X_j - X_i) = \begin{cases} +1, (X_j - X_i) > 0 \\ 0, (X_j - X_i) = 0 \\ -1, (X_j - X_i) < 0 \end{cases} \qquad (3)$$

The variance in the values of test statistic thus obtained is computed as:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i - 1)(2t_i + 5)\right] \qquad (4)$$

with P being the number of tied groups and t_i is called the number of data values in the P^{th} tied group. A tied group comprises a set of sample data containing numerically equal data values. In case the sample data doesn't contain the same data values, the summation portion in eqn. (3) can be omitted (Kisi & Ay, 2014). For a sample size $n > 30$, the standard normal test statistic Z is computed as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, & S < 0 \end{cases} \qquad (5)$$

A $|Z| > Z_{1-\alpha/2}$, results in rejection of the null hypothesis of no trend indicating a significant trend. Also, rising trends are characterized by positive values of Z whereas negative values of Z represent a reducing trend over time. In the present study, a confidence levels of $\alpha = 0.05$ was used for which the null hypothesis can be rejected if $|Z| > 1.96$.

Modified Mann-Kendall test

Based on the limitations incurred upon MK test due to presence of autocorrelation in a time series, Hamed and Rao (1998) suggested a variance correction approach to inhibit the effects of autocorrelation upon the time series which required a modification in the variance of a time series by altering its sample size using the following formula:

$$V^*(S) = V(S) \times \frac{n}{n^*} \qquad (6)$$

Where, n denotes the actual sample size (ASS) of the data, n^* denotes the effective sample size (ESS) derived from the same data and n/n^* is termed as the correction factor.

In the present study, computation of n^* has been carried out as follows:

$$n^* = n / \left[1 + \left\{\frac{2}{n(n-1)(n-2)} \times \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2)\rho_s(i)\right\}\right] \qquad (7)$$

This MK test, when applied to a time series while following an algorithmic approach (variance correction in present study) to prevent autocorrelations from influencing the trends, is termed as modified MK (MMK) test.

Sen's slope

In order to complement and quantify the results of MK/MMK test, the trend magnitudes in the time series data were derived from the slopes of N pairs of data points using Sen's slope estimator (Sen, 1968) given by:

$$Q_i = \frac{X_j - X_k}{j - k} \ (i = 1, 2, \ldots, N) \qquad (8)$$

where X_j and X_k are data values at times j and k, respectively, such that $j > k$.

If each time period corresponds to a single data point, then for n number of time periods, N may be computed as:

$$N = \frac{n(n-1)}{2} \qquad (9)$$

The set of slopes thus obtained are arranged in an ascending order and Sen's slope (β) is derived as the median of these ordered values as:

$$\beta = \begin{cases} Q_{(N+1)/2} & N \text{ is odd} \\ \frac{1}{2}\left(Q_{\frac{n}{2}} + Q_{\frac{n+1}{2}}\right) & N \text{ is even} \end{cases} \qquad (10)$$

The positive and negative values of Sen's slope are assessed as rising and reducing trends, respectively. The change in magnitude is usually conveyed in the form of percentage of the mean. As per Yue and Hashino (2003), the linear trend is computed as follows:

$$\text{Percentage change } (\%) = \frac{\beta \times \text{length of year}}{\text{Mean}} \times 100 \qquad (11)$$

Results and Discussion

Arranging the dataset with respect to each combination of location, temperature variable and temporal scale resulted in formation of 162 unique time series that were to be tested for presence of inherent trends. The autocorrelated series were identified and MMK test was applied to these series. The following sections provide a detail of the outcomes of the analysis implemented in the present study.

Autocorrelation

Autocorrelation refers to the degree of similarity between observations of a variable with its past values. In other words, it measures the extent to which a variable is correlated with itself over time. Autocorrelation plots provide an analytical and intuitive visualization of the autocorrelations present in the time series data. The autocorrelation plots created for each set of time series data considered in the present study are shown in Fig. 3. The significant autocorrelations are evaluated as the plots extending beyond the computed confidence intervals. It was found through the autocorrelation plots that 11 of the 162-time series tested were autocorrelated (Fig. 3). The time series pertaining to the maximum temperature at Abu Road consisted of the highest number of autocorrelated time series, i.e., 5, out of all the datasets. At Abu Road, the mean and minimum temperatures for the Non-monsoon period and the month of May were assessed as autocorrelated. The maximum temperature series for January, November, Post-monsoon, Winter and Non-monsoon were also found to be autocorrelated. In the case of Mount Abu, only the maximum and minimum temperatures during May and Non-monsoon, respectively, were identified as autocorrelated. For Pindwara, only the maximum temperature series for January and Non-monsoon showcased and autocorrelation. Temperature series for Abu Road were attributed with the highest number of autocorrelated time series containing 7 out of the total 11 autocorrelated series. It was also observed that the temperature datasets for the non-monsoon period, especially the maximum temperature series, stood out as being the most likely series to have a significant autocorrelation. Through the segregation of the autocorrelated time series from the non-autocorrelated ones, the type of test (MK or MMK) to be utilized for trend analysis was selected and applied to the relevant time series dataset.

Trends in Temperature Variables

The trends in temperature were evaluated for the series of all the individual months as well as seasonal and annual datasets. Furthermore, in addition to the spatial and temporal classification, the temperature dataset was also divided into mean, maximum and minimum temperature dataset adjoined to each spatio-temporal classification. This means that a total of 162 time series were tested.The MMK method of trend analysis was applied to various time series encompassing temperatures at the three stations in the study area. The results revealed the statistical significance of 27 out of the total 162 series tested for trend. The computed test statistics for the MMK temperature trend test at Abu Road were shown in Table 1. At Abu Road station, mean and maximum temperatures in monsoon as well as minimum temperatures in April, May, summer, non-monsoon and annual series were found to be significant out of which, the mean and maximum temperature possessed a reducing trend whereas the minimum temperature seemed to be rising.The nature and significance of trends observed at Mount Abu station, shown in Table 2, resembling those observed at Abu Road. An additional increasing trend was also observed in case of the non-monsoonal mean temperatures at Mount Abu. The significant trends observed at Pindwara, as shown in Table 3, were somewhat similar to those at

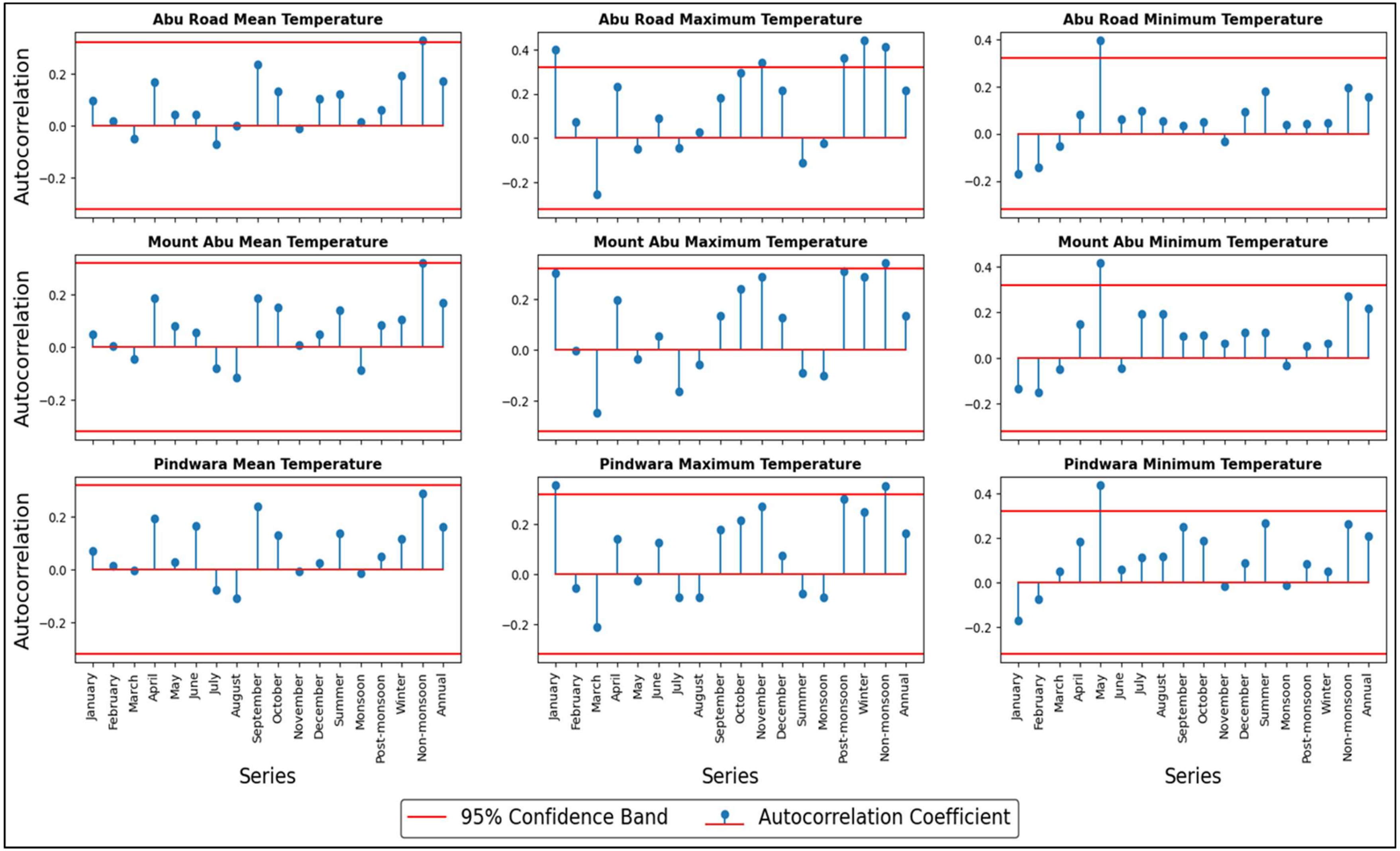

Figure 3: Lag 1 autocorrelation plots for all datasets

Table 1: MMK trends for temperature at Abu Road station

Time series	Mean			Maximum			Minimum		
	Z	↑/↓	%	*Z*	↑/↓	%	*Z*	↑/↓	%
January	-0.589	↓	3.95	-0.317	↓	3.57	0.052	↑	0.82
February	1.570	↑	10.18	1.033	↑	6.66	0.706	↑	25.79
March	1.546	↑	4.83	0.680	↑	3.60	0.209	↑	4.16
April	1.190	↑	4.15	0.837	↑	2.47	**2.171***	**↑***	**21.30***
May	1.452	↑	4.34	0.301	↑	1.26	**2.433***	**↑***	**17.60***
June	-1.818	↓	6.80	-0.392	↓	1.87	1.177	↑	5.66
July	-1.570	↓	6.25	-1.530	↓	7.85	1.112	↑	2.90
August	-1.177	↓	4.25	-1.779	↓	10.21	0.615	↑	2.37
September	-1.923	↓	11.10	-1.648	↓	15.87	-1.034	↓	9.12
October	0.955	↑	5.49	-1.805	↓	13.18	0.576	↑	6.11
November	0.170	↓	1.03	-0.994	↓	6.55	1.818	↑	23.44
December	-0.105	↓	1.67	0.078	↑	0.16	0.406	↑	9.384
Summer	1.478	↑	3.78	0.889	↑	2.29	**2.119***	**↑***	**18.08***
Monsoon	**-2.511***	**↓***	**7.12***	**-2.864***	**↓***	**8.86***	1.242	↑	2.77
Post-monsoon	-0.275	↓	1.35	-1.373	↓	9.11	1.766	↑	14.86
Winter	0.296	↑	2.19	0.250	↑	2.07	1.462	↑	16.64
Non-monsoon	1.675	↑	2.61	-0.051	↓	0.57	**2.263***	**↑***	**16.96***
Annual	-0.510	↓	1.37	-1.622	↓	4.186	**2.498***	**↑***	**10.77***

N.B., *significant trend. Z = test statistic; ↑ = increasing; ↓ = decreasing; NT = no trend; % = Sen's slope as percentage change

Table 2: MMK trends for temperature at Mount Abu station

Time series	Mean			Maximum			Minimum		
	Z	↑/↓	%	*Z*	↑/↓	%	*Z*	↑/↓	%
January	-0.353	↓	2.19	0.550	↓	0.02	-0.065	↓	1.58
February	1.661	↑	11.34	1.177	↑	0.04	1.007	↑	29.06
March	1.385	↑	4.84	0.850	↑	0.3	0.144	↑	3.71
April	1.217	↑	4.09	1.020	↑	0.02	**2.093***	**↑***	**19.29***
May	1.635	↑	5.02	0.523	↑	0.01	**3.074***	**↑***	**23.05***
June	-1.740	↓	7.97	0.327	↓	0.01	0.419	↑	1.60
July	-1.204	↓	4.86	1.177	↓	0.04	1.060	↑	3.39
August	-0.065	↓	0.16	1.112	↓	0.02	1.060	↑	4.68
September	-1.426	↓	8.42	1.151	↓	0.06	-0.955	↓	9.20
October	-0.377	↓	1.19	1.177	↓	0.05	0.798	↑	8.02
November	0.693	↑	5.23	0.275	↓	0.007	1.753	↑	21.21
December	0.118	↑	1.38	1.386	↑	0.02	0.693	↑	23.54
Summer	1.609	↑	4.25	1.073	↑	0.02	**2.393***	**↑***	**17.47***
Monsoon	**-2.067***	**↓***	**1.14***	**2.132***	**↑***	**0.03***	0.837	↑	2.87
Post-monsoon	0.157	↑	1.34	-0.876	↓	0.03	1.805	↑	16.17
Winter	0.907	↑	2.19	0.981	↑	0.02	**2.015***	**↑***	**24.09***
Non-monsoon	**2.178***	**↑***	**3.91***	0.562	↑	0.01	**4.241***	**↑***	**18.24***
Annual	0.000	NT	0.001	0.719	↓	0.01	**2.603***	**↑***	**11.73***

Mount Abu with an addition in the form of significantly increasing trends in temperature during the month of November, post-monsoon and winter season as well as during the non-monsoon period.With due consideration to the spatial consistency of trends across different stations, it could be said with certainty that the overall minimum temperatures were predominantly increasing.

Table 3: MMK trends for temperature at Pindwara station

Time series	Mean			Maximum			Minimum		
	Z	↑/↓	%	*Z*	↑/↓	%	*Z*	↑/↓	%
January	-0.188	↓	1.16	-0.396	↓	3.18	0.458	↓	16.72
February	1.530	↑	12.37	0.811	↑	6.14	0.955	↑	35.91
March	0.981	↑	6.36	0.785	↑	5.89	0.249	↑	6.57
April	1.465	↑	4.67	0.667	↑	1.73	**2.302***	↑*	**29.35***
May	1.347	↑	4.00	0.275	↑	1.11	**4.326***	↑*	**21.14***
June	-1.923	↓	8.52	-0.301	↓	0.83	0.353	↑	1.29
July	-1.269	↓	5.32	-1.452	↓	9.08	0.733	↑	2.04
August	-0.471	↓	2.22	-1.086	↓	5.98	0.955	↑	3.59
September	-1.487	↓	11.30	-1.177	↓	11.54	-1.347	↓	10.91
October	-0.794	↓	2.97	-1.426	↓	11.94	0.798	↑	8.46
November	0.798	↑	5.75	-0.262	↓	2.51	**2.210***	↑*	**34.32***
December	0.157	↑	1.28	0.249	↑	0.71	0.850	↑	23.06
Summer	1.530	↑	4.31	1.112	↑	2.50	**2.655***	↑*	**20.91***
Monsoon	**-2.433***	↓*	**7.26***	**-2.158***	↓*	**6.85***	0.327	↑	0.81
Post-monsoon	0.078	↑	0.43	-0.955	↓	6.84	**1.962***	↑*	**20.82***
Winter	1.211	↑	3.61	0.562	↑	2.37	**2.170***	↑*	**31.47***
Non-monsoon	**2.231***	↑*	**4.74***	0.248	↑	0.81	**4.436***	↑*	**22.93***
Annual	-0.013	NT	0.10	-1.321	↓	2.87	**2.603***	↑*	**13.27***

This rise, especially during the summer season, can cause formation of hard pans in regions of heavier soils within the study area, which is a factor boosting the possibility of flash floods as a result of rains in the subsequent monsoon season. Overall, the results apparently indicated an increase in the annual minimum temperatures over the basin. This was corroborated with the findings of Sharma *et al.* (2021) who investigated the temperature trends over five districts of Rajasthan and also reported an increase in annual minimum temperatures across four districts which included Udaipur, the district neighbouring the West Banas basin. The results indicated that overall rising trend in maximum temperatures for summer season and months of post-monsoon and falling trends for individual months during monsoon. Roy (2015) analysed the trends in temperatures in the state of Rajasthan over the past century and reported similar findings. According to Basistha et al. (2009), the observed long-term trends over a basin may be a direct consequence of many relatively smaller-scale factors such as declining forest area (Gupta *et al.,* 2005; Ray *et al.,* 2003; 2006), local land use changes (Pielke Sr. *et al.,* 2007; Ramankutty *et al.,* 2006) and increase in aerosol content due to anthropogenic activities (Ramanathan *et al.,* 2005; Sarkar and Kafkos, 2004). The falling temperatures during the monsoon season observed in the present study contradicted the assessment of Singh et al. (2008) who reported rising mean and maximum temperature trends at Abu Road. This suggested that the influence of aforementioned smaller-scale factors over the temperatures in the basin had become significant since the beginning of last decade (2010s). Increasing summer temperatures also promote the rise in atmospheric water content which may eventually lead up to erratic weather patterns and frequent extreme events especially during the subsequent rainy season (Hardwick Jones *et al.,* 2010; Lenderink *et al.*, 2011; Molnar *et al.,* 2015; Utsumi *et al.,* 2011) which in turn may be responsible for the falling trends in temperature observed during monsoon season. The similarities between trends observed in the same time series (April, May and Monsoon) across different stations were consistent with the global climatic shift (Baines, 2006). This suggested that the basin environment and hydrometeorology was bound to gradually face the consequences of climate change. The monsoon season is critical for agriculture and water resources in India especially for an arid state such as Rajasthan, but rising global temperatures due to climate change have led to variabilities in monsoonal patterns that have significant implications for the region. For an agriculture-based economy, this may be viewed as a concerning matter based on the fact that any extreme climatic variations would influence the spatial and temporal distribution of runoff (Ramanathan *et al.,* 2001), soil moisture and groundwater reserves (Raucher, 2011), and also the frequency of droughts and floods (Mirza, 2002; Sinha Ray and Srivastava, 2000), which can gradually have an impact upon the cropping patterns and productivity (Mall *et al.,* 2007). Malhi *et al.* (2021) also stated that these changes were likely to affect water availability and agricultural productivity.

Conclusion

The trend analysis of temperature conducted in this study provides important insights into the changing climate in the study area. The results indicate significant changes in temperature trends at certain stations, with rising minimum temperatures and decreasing mean and maximum temperatures. These trends may have important implications for various sectors, including agriculture and water resources, and may exacerbate the risk of flash floods during the monsoon season. Further research is required to assess the sensitivity of temperature variables with respect to individual factors whose influence over these variables has already been established through literature. This can aid in assigning priorities to the significant factors based on which, specific action plans may be formulated for each of these factors. Moreover, the interactions between temperature and other hydro-climatic variables (rainfall, discharge etc.) can be studied in order to analyse the sensitivity of one variable with respect to another and the combined effect of variations in these variables upon the entire basin is also of interest. The findings of this study are consistent with previous research on temperature trends in the region and highlight the need to better understand the environmental and socio-economic impacts of these changes.

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Conflict of interest

The authors declare that they have no conflict of interest.

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