

RESEARCH ARTICLE

Climate Variability and Rainfall Patterns in Hyderabad: A 42-Year Statistical Analysis

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ABSTRACT:

This study investigates the variability and trends in rainfall and temperature in Hyderabad over 42 years from 1981 to 2022. The research uses non-parametric tests and statistical tools to analyze meteorological data to understand regional climatic changes. The findings reveal significant seasonal variations in rainfall, with the highest variability observed during the pre-monsoon, post-monsoon, and winter seasons. The study also highlights a consistent increase in maximum temperatures and a slight increase in minimum temperatures. Evapotranspiration (ET_o) data analysis indicates considerable monthly variability, reflecting Hyderabad's diverse climatic conditions. Notably, the study identifies a declining trend in seasonal rainfall during the JJAS season and significant variability in ET_o across different months. These results underscore the importance of continuous monitoring and adaptive strategies to manage water resources and mitigate the impacts of climate change.

Keywords: Climate variability, Mann–Kendall's test, Sen's slope estimator, Coefficient of variation (CV), Potential Evapotranspiration (ET_o).

INTRODUCTION

A crucial component of the Earth's system is the climate. Factors that affect the weather and climate include humidity, evapotranspiration, temperature, rainfall, and air pressure. Climate is frequently predicted using average weather. More broadly, it is the statistical characterization of important values of mean and variability across intervals of time ranging from months to millions or hundreds of years. (IPCC, 2007). An essential part of climate change detection research is examining long-term changes in climatic variables. Understanding past and current climate change has attracted a lot of interest due to additions and upgrades to several datasets and more advanced

data analysis globally (Kumar *et al.*, 2010). Long-term rainfall patterns may change due to global climate change, impacting water supply and the likelihood of more frequent droughts and floods (Pal and Mishra, 2017). According to Singh *et al.*, (2013), the two most important basic physical components of a climate are temperature and rainfall, as they determine the environmental conditions of a given area (Modarres and da Silva, 2007; Kumar and Gautam, 2014). Providing enough water and a conducive atmosphere in any place is vital for several industries, food security, and energy security. The amount of water available to satisfy different demands, such as the production

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of hydroelectric power and the supply of water for domestic and industrial applications, depends on the amount of rainfall an area receives. The pattern and amount of rainfall have a significant impact on India's economy and people's standard of living (Gajbhiye *et al.*, 2016). Even with its recent development, India's economy depends on hydrological events such as rainfall, which in turn affects temperature (Kumar and Gautam, 2014). Temperature (Arora *et al.*, 2005; Karanurun and Kara, 2011; Meshram *et al.*, 2018) and rainfall (Partal and Kahya, 2006; Addisu *et al.*, 2015; Neil and Notodiputro, 2016; Singh and Srivastava, 2016) trend analysis, as well as other climatic variables at various spatial scales, will help to develop future climate scenarios. According to research, evapotranspiration (ET_o) may influence a range of processes, including water storage, which has raised worries about agricultural production, and mass transfer. According to the dual water cycle, urban ET_o encompasses more than only ET_o on the natural side of grassland, bushes, and other ground plants. As a result, this study used the Penman-Monteith equation to calculate ET_o. As a result, this study aims to investigate the variability in rainfall, temperature, and ET_o in Hyderabad, Telangana, India. The seasonal pattern of the parameters was explored, and the fluctuations were computed monthly, focusing on the monsoon season (June-September). This requires researching the region's temperature and rainfall trends. Knowing the uncertainty surrounding temperature and rainfall patterns in the chosen region would serve as the foundation for improved water management and other associated activities.

MATERIALS AND METHODS

Hyderabad is located at a north latitude of 17.4065° and an east longitude of 78.4772° (Figure 1). The climate in this region is extreme, with monsoon-like weather on average. Summers are intensely hot, while winters are severely cold. The year consists of four distinct seasons. The South-West monsoon lasts from June to September, while the hot season extends from March to May. The months of October and November are considered post-monsoon. The cold season runs from December to February. The yearly average precipitation is 736.5 millimeters. The southwest monsoon is the primary cause of precipitation in Hyderabad. The JJAS season, which takes place from June through September, accounts for around 80% of the total rainfall. The annual temperature and rainfall seldom change from one year to the next.

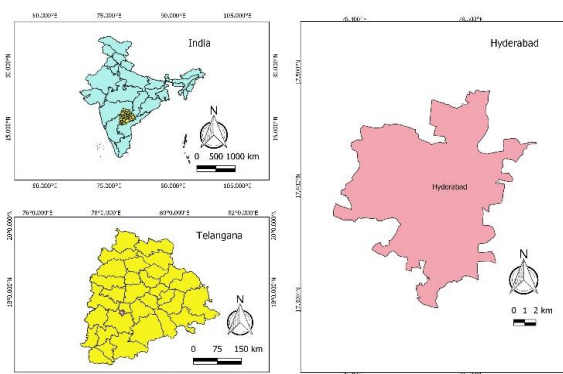


Fig.1. Study area map of Hyderabad

Weather data

Rainfall, maximum and lowest temperature monthly s from 1981 to 2022 (43 years) were obtained from NASA's Power website, which was used in this study (<https://power.larc.nasa.gov/data-access-viewer/>).

Trend analysis

According to Webber and Hawkins (1980), a trend is the general movement of a series over time. It also refers to the long-term evolution of the dependent variable over time. Trend is determined by the relationship between the two variables, rainfall and temperature, as well as by their temporal resolution. Regression analysis and the coefficient of determination R^2 are two statistical techniques used to assess the significance of temperature and rainfall patterns. The trend was generated and evaluated using the Mann-Kendall (M-K) trend test, and the slope of the regression line was ascertained using the least squares approach. The mean, standard deviation (SD), and coefficient of variation (CV) of temperatures and rainfall were calculated to examine the relationship.

Mann-Kendall's Test

The MK test is a prominent nonparametric statistical test used to examine trends in hydrological and climatological time series data. Developed by Mann in 1945, it has been extensively used in environmental time series analysis. Using this exam has two advantages. Firstly, normally distributed data is not required since it's a nonparametric test. Secondly, the test shows low sensitivity to abrupt stops brought on by non-uniform time series. This test's null hypothesis (H₀) suggests that there is no trend. This is contrasted with the alternative theory H₁, which maintains that a trend exists. This is how the MK statistic is computed.

$$S = f(z) = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k)$$

A time series X_k rated from $k = 1, 2, 3, \dots, n-1$ and ranked from $j = i + 1, i + 2, i + 3, \dots, n$ is subjected to the trend test. Every single data point x_j acts as a point of reference.

$$\begin{aligned} \text{sgn}(x_j - x_k) &= 1 & \text{if } x_j - x_k > 0 \\ &= 0 & \text{if } x_j - x_k = 0 \\ &= -1 & \text{if } x_j - x_k < 0 \end{aligned}$$

Sen's Slope Estimator Test

Sen's estimate (Sen, 1968) is a nonparametric method for determining the amplitude of a trend in a time series. Sen's nonparametric method, tested using R software, is used to find the proper slope of an existing trend, such as the annual change in quantity. When Sen's slope is positive, the time series shows an upward or increasing tendency; when it is negative, the trend is downward or declining.

Innovative Trend Analysis

The data should be divided into two subsets before performing the ITA on any specific time series. The data for each subset is then sorted in ascending (or descending) order. Furthermore, the diagram is split into two separate triangles by the 1:1 (45°) axis of no trend, which indicates the increasing (area above the 1:1 line) and decreasing (area below the 1:1 line) time-series data trends (Aher & Yadav, 2021). The scattering of the data rises above (or falls below) the 1:1 line whenever the monotonic trend is increasing (or decreasing) (Aksu et al., 2021). Similarly, if the data points fall in the upper triangular portion of the 1:1 line, a positive trend is indicated. In contrast, a negative trend is shown by data points falling in the bottom triangular area of the 1:1 line (Aher & Yadav, 2021). For simpler understanding, the scatter points on 1:1-line graphs were divided into three groups: low, medium, and high. ITA may also detect and investigate the trends of any hydrometeorological variable's low, middle, and high time-series values.

Potential evapotranspiration

The Penman-Monteith equation, recommended by the FAO in 1998, is widely used for computing ET_0 . Many studies have found that the Penman-Monteith equation is more appropriate for various regions (Alexandris et al., 2008). The total potential evapotranspiration (ET_0) was estimated through built-

in FAO Penman-Monteith equation as shown below using the ET_0 calculator version 3.2 developed by the FAO (Jabloun and Sahli, 2008) was used in this study to estimate ET_0 with these available inputs.

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)}$$

Where,

ET_0 is the potential evapotranspiration rate (mm.d^{-1}); G is the soil heat flux density ($\text{MJ.m}^{-2}.\text{day}^{-1}$); T is the mean daily air temperature at 2 m height ($^{\circ}\text{C}$); U_2 is the wind speed at 2 m height (m.s^{-1}); e_s is the saturation vapour pressure (KPa); e_a is the actual vapour pressure (KPa); Δ is slope of vapour pressure curve ($\text{KPa.}^{\circ}\text{C}^{-1}$); γ is the psychrometric constant ($\text{KPa, }^{\circ}\text{C}^{-1}$); R_n is the net radiation at the crop surface ($\text{MJ.m}^{-2}.\text{day}^{-1}$).

RESULTS AND DISCUSSION

Nonparametric approaches were widely employed, according to trend analysis of several studies (Hollander and Wolfe, 1973). Many researchers recommended the MK test (Mann, 1945; Kendall, 1975) as one of the finest methods. (Jain and Kumar, 2012). Table 1 displays the rainfall data's mean, standard deviation, coefficient of variation, kurtosis, and skewness. The computed data reveal that average monthly rainfall's coefficient of variation (CV) ranges between 43.5 and 269.4%. November had the most skewness (3.41) and kurtosis coefficient (14.30). The research area receives the most rain during the monsoon season, from June to September, as shown in Figure 2, indicating the monthly rainfall trend. The linear regression equation reveals that the seasonal rainfall in the studied region has a negative slope value ($a = 0.08$), as illustrated in Figure 3.

Tables 2 and 3 show the highest and lowest temperatures and the descriptive statistics used (mean, SD, coefficient of variation, skewness, and kurtosis). The skewness and kurtosis data demonstrate higher variability than rainfall, even though the CV for the highest and lowest temperatures is shown to be lower than for rainfall. The findings of examining the observed data from 1981 to 2022 are displayed in Figures 5 and 7. In contrast to the lowest temperatures, which are low during post-monsoon seasons and relatively high during monsoon months,

Table 1. Statistical data about Hyderabad's rainfall

Month	Maximum (mm)	Minimum (mm)	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis
January	36.9	0.0	5.7	9.8	171.7	1.75	2.16
February	42.2	0.0	3.9	10.5	269.4	2.72	6.11
March	147.7	0.0	14.0	26.0	186.0	3.38	14.05
April	79.1	0.0	19.9	20.9	105.4	1.13	0.34
May	147.7	0.0	31.4	30.9	98.6	1.51	2.84
June	258.4	15.8	101.9	58.6	57.5	0.94	0.41
July	390.2	36.9	155.3	79.8	51.4	0.80	0.33
August	379.7	42.2	161.5	70.3	43.5	0.83	1.06
September	279.5	31.6	133.1	62.6	47.0	0.27	-0.54
October	242.6	5.3	88.0	65.4	74.3	0.75	-0.44
November	189.8	0.0	18.3	33.2	180.9	3.41	14.30
December	36.9	0.0	3.5	8.1	229.3	2.76	7.43

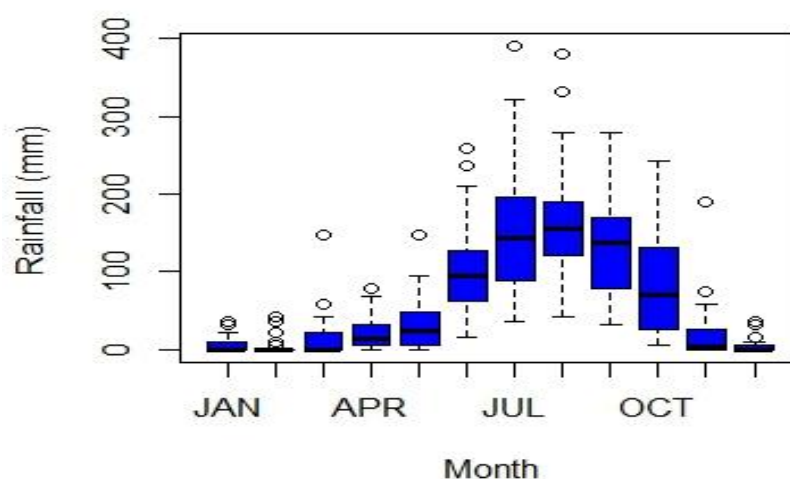


Fig. 2. Boxplot of monthly rainfall (mm) for Hyderabad districts from 1981 to 2022

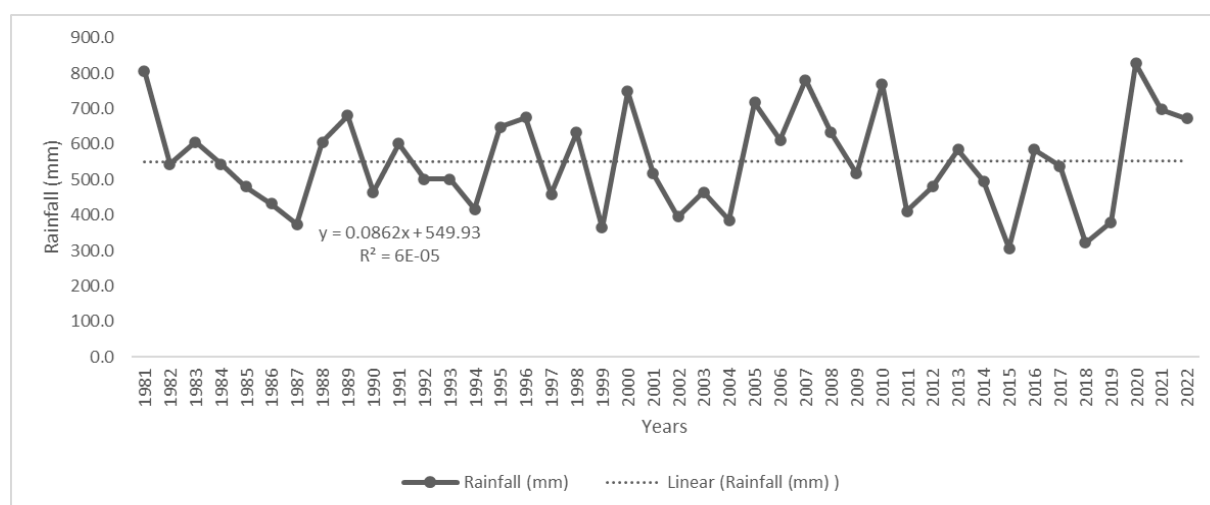


Fig.3 Trend of Seasonal Rainfall from 1981 to 2022

maximum temperatures are low during monsoon seasons and relatively high during pre-monsoon months, according to these figures. Seasonally-based temperature changes for both maximum temperature data from 1981 to 2022 are quite significant. Table 4 displays the result of the Penman-Monteith equation (ET_o) and the descriptive statistics. Figures 6 and 8, respectively, examine the temperature trends at the highest and lowest values. Table 5 illustrates how often the MK test is used in trend testing. The findings (Table 5) demonstrate that the seasonal rainfall pattern in the area under study is trending. The MK method, a nonparametric test, was used to determine if the variable has a monotonic upward or decreasing trend over time. Rainfall patterns between

1981 and 2022 are statistically significant, with a 99% confidence level. The “z” score calculated a 99% confidence level. Rainfall has decreased during the JJAS season (Sen’s slope = -0.0002). The trend analysis of rainfall, minimum temperature, and maximum temperature yields statistically significant results at the 95% confidence level, even though the minimum temperature trend (Sen’s slope = 0.02) and maximum temperature trend (Sen’s slope = 0.012) for the observed period showed a slight increasing trend. However, the trend analysis’s conclusions are not statistically significant. A minor declining tendency is indicated by the findings of the innovative trend analysis for rainfall throughout the monsoon season (Fig. 4).

Table 2. Statistical data about Hyderabad’s maximum temperature

Month	Maximum (°C)	Minimum (°C)	Mean (°C)	SD (°C)	CV (%)	Skewness	Kurtosis
January	35.6	29.6	33.1	1.5	4.6	-0.26	-0.76
February	39.1	33.9	36.5	1.2	3.4	-0.07	-0.75
March	42.0	37.6	40.1	1.0	2.5	-0.63	0.13
April	43.8	39.2	42.0	1.1	2.6	-0.50	-0.31
May	45.0	38.8	42.7	1.5	3.5	-1.08	0.69
June	43.5	33.4	38.7	2.5	6.4	-0.25	-0.42
July	37.3	30.5	33.4	1.6	4.7	0.37	0.15
August	35.9	29.6	31.7	1.4	4.4	1.03	0.58
September	35.2	29.6	31.3	1.5	4.7	0.95	0.16
October	36.7	28.9	30.9	1.7	5.4	1.53	2.26
November	34.0	26.9	30.7	1.8	5.9	-0.06	-0.96
December	34.9	26.8	30.7	2.0	6.5	-0.22	-0.85

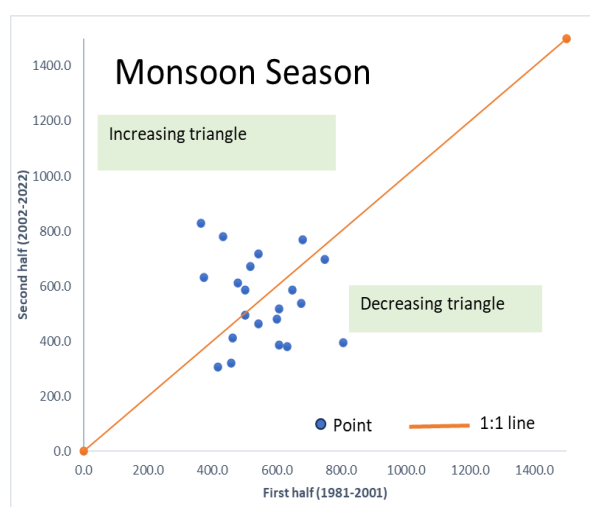


Fig. 4. Innovative Trend Analysis of Seasonal Rainfall from 1981 to 2022

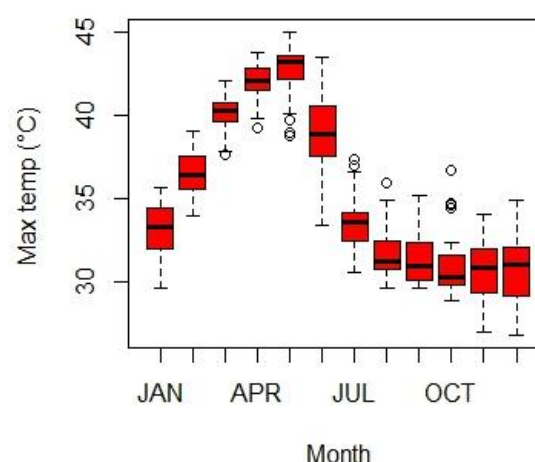


Fig. 5. Boxplot of monthly Maximum temperature (°C) for Hyderabad districts from 1981 to 2022

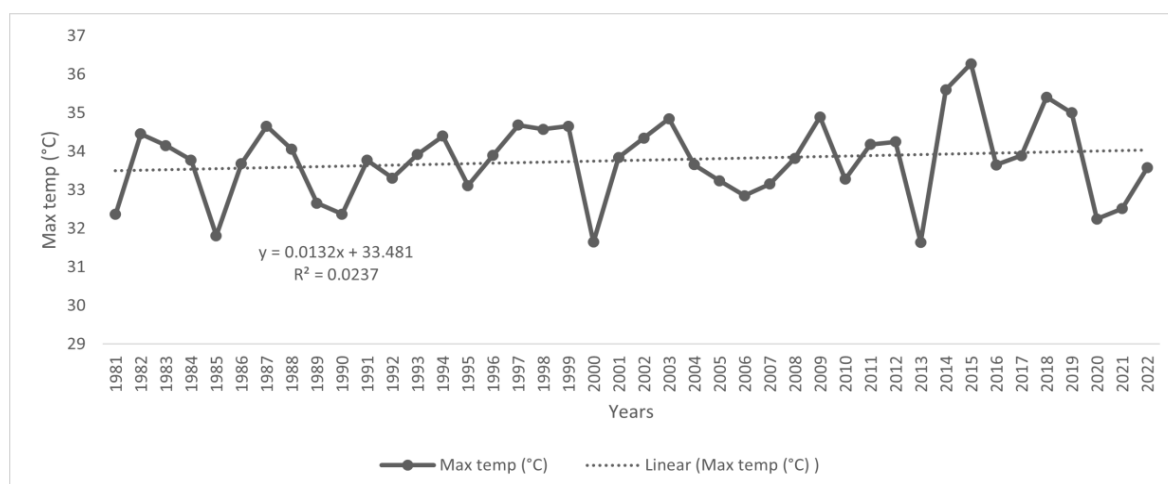


Fig. 6. Trend of Seasonal Maximum temperature (°C) from 1981 to 2022

Table 3. Statistical data about Hyderabad's minimum temperature

Month	Maximum (°C)	Minimum (°C)	Mean (°C)	SD (°C)	CV (%)	Skewness	Kurtosis
January	15.0	8.6	11.7	1.5	13.2	-0.10	-0.87
February	16.3	10.8	14.0	1.2	8.6	-0.61	0.24
March	19.3	14.5	17.0	1.1	6.6	0.02	-0.80
April	23.7	16.5	20.7	1.3	6.5	-0.64	1.50
May	24.9	21.0	23.0	1.2	5.1	-0.08	-1.30
June	23.7	20.0	21.2	0.7	3.5	0.53	0.78
July	21.8	18.6	20.6	0.6	3.0	-0.67	0.79
August	21.8	18.0	20.3	0.7	3.5	-0.84	1.72
September	20.9	16.6	19.4	0.8	4.4	-0.71	0.90
October	19.9	12.9	15.7	1.4	9.1	0.65	0.43
November	17.6	9.5	12.7	1.7	13.7	0.57	0.27
December	13.8	8.3	11.2	1.3	11.5	-0.31	-0.28

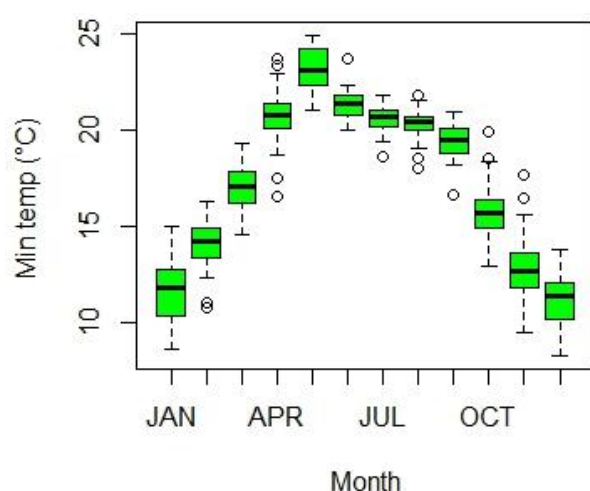


Fig. 7. Boxplot of monthly Minimum temperature (°C) for Hyderabad districts from 1981 to 2022

Because rainfall is crucial in influencing how water is used in a specific place, researchers and policymakers should consider the variation of meteorological data when making decisions. First, box plots were employed to show monthly rainfall fluctuations. The small size of box plots (Tukey, 1977) makes it simple to compare assessments of multiple datasets side by side, which is challenging when using more comprehensive representations such as histograms (Banacos, 2011). These charts provide a clear visual depiction of the statistical distribution for an extensive array of audiences. The horizontal line in the middle of the box plot, which is positioned between the interquartile range's top and bottom horizontal lines, represents the median. The 25th and

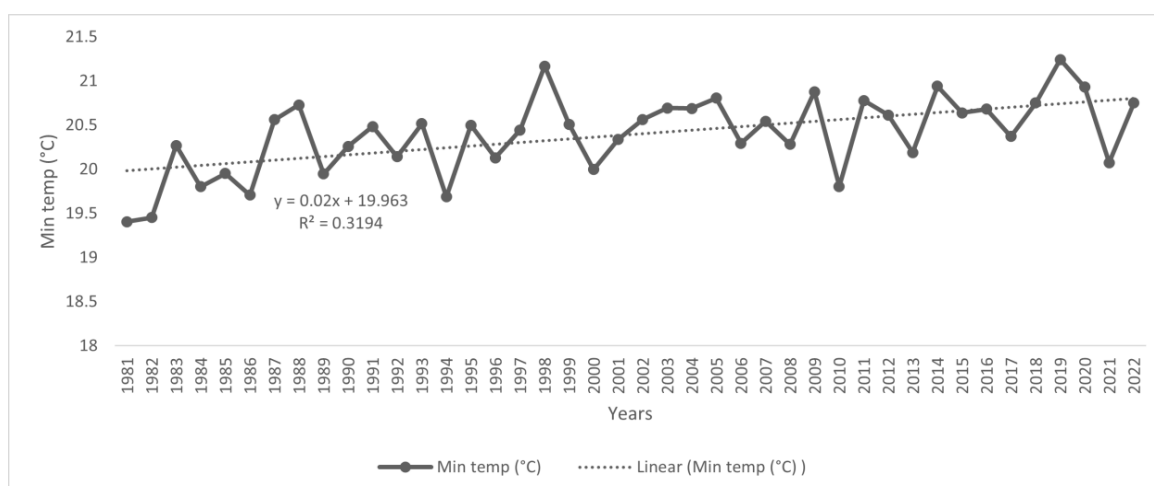


Fig. 8. Trend of Seasonal Minimum temperature (°C) from 1981 to 2022

Table 4. Statistical data about Hyderabad's ETo

Month	Maximum (mm)	Minimum (mm)	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis
January	217.1	120.1	161.3	18.9	11.7	0.3	0.4
February	215.1	160.2	190.8	13.5	7.1	-0.1	-0.4
March	285.5	208.8	251.9	18.5	7.3	-0.5	-0.4
April	305.4	213.5	260.6	24.4	9.4	0.0	-1.0
May	365.8	205.0	289.4	40.6	14.0	-0.3	-0.8
June	250.4	142.8	194.7	28.1	14.5	0.1	-0.8
July	233.5	115.9	153.8	25.7	16.7	0.8	0.2
August	168.8	102.5	129.5	17.2	13.3	0.6	-0.7
September	145.3	89.8	109.8	13.5	12.3	0.6	-0.2
October	172.0	87.7	113.6	18.8	16.5	1.0	0.9
November	169.3	82.6	119.3	24.5	20.5	0.5	-1.0
December	176.7	96.3	135.1	22.7	16.8	0.1	-1.2

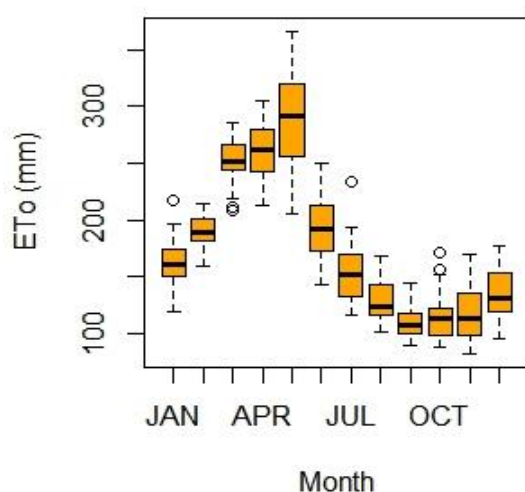


Fig. 9. Boxplot of monthly ETo (mm) for Hyderabad districts from 1981 to 2022

75th percentiles are indicated by the horizontal lines at the top and bottom of the boxes, respectively. Vertical lines denote the outer ranges.

As evidenced by the lower kurtosis and skewness values, the kurtosis values suggest that the dataset is light-tailed and has a symmetric pattern throughout the monsoon months (June, July, August, and September). The other thing is that the examined area experiences symmetrical rainfall throughout the monsoon season. In comparison, rainfall during the post- and pre-monsoon months has a significant tail in the dataset, indicating the likelihood of outliers or extreme values. Precipitation in the research region is unpredictable before and throughout the monsoon

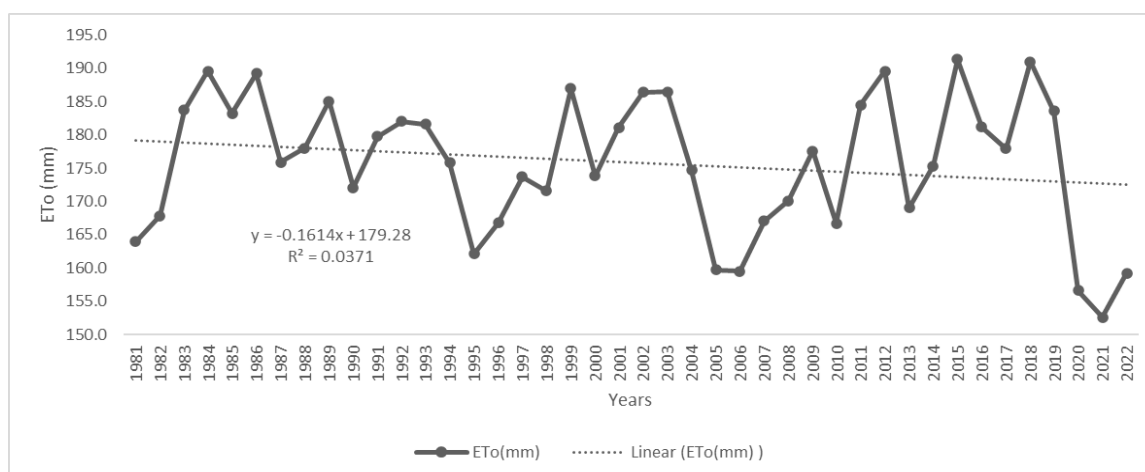


Fig. 10. Trend of Seasonal ETo (mm) from 1981 to 2022

Table 5. Mann–Kendall trend analysis

	Seasonal rainfall	Seasonal maximum temperature	Seasonal minimum temperature	Seasonal ETo
Kendall's tau	-8.16	7.90	0.41	3.13
Sen's slope	-0.0002	0.012	0.02	0.608
S	-7.00	6.80	354.00	2.70
P-value	0.47	0.0001	0.95	0.78
Significance	Non-significant	significant	Non-significant	Non-significant

season in its most basic form. Understanding surface air temperature behavior is critical for understanding climatic variability, which can occur on a local, regional, or global scale. Weather and climate forecasting are greatly influenced by surface air temperature (Ghasemi, 2015). Despite overwhelming evidence that global temperatures are rising, accurately tracking temporal trends remains difficult (Gil-Alana, 2018). The air temperature at the study site carries a substantial impact on the water cycle; therefore, more research is required to properly understand this phenomenon. The research region experiences the most rainfall in July, August, and September, resulting in lower seasonal maximum temperatures than in other months.

Throughout the research period, Figure 5 displays the seasonal average maximum temperature and its trend. A linear regression model's slope, which in the present scenario is approximately 0.0132°C for 42 years from 1981 to 2022, indicates the pace of change. This result deviates from the previous ten-year projection of 0.9 °C global warming. This conclusion shows that the approach utilized in global warming studies significantly impacted the local climate throughout the previous 20 years

in the study area. Furthermore, the coefficient of variation (CV) of the average monthly maximum temperature for the examined period ranges from 2.5 to 6.5%, showing that the maximum temperature remains relatively consistent over time. October has the most excellent kurtosis coefficient (2.26), and its maximum temperature readings are positively skewed. The linear regression's best-fit lines are commonly used to produce trends in seasonal mean minimum temperatures across several years. Figure 7 depicts linear regression trends and the matching linear regression equations and coefficients of determination. According to Hayelom *et al.* (2017), the monthly mean minimum temperature has a coefficient of variation ranging from 3.0 to 13.7%. Despite the modest difference, the study found that the lowest temperature swings were greater than the highest temperature swings. The maximum temperature and data exhibit a positive skew, coefficient of kurtosis reaching its peak in August at 1.72. The ITA's time series computations revealed that the higher and lower temperatures exceeded the 1:1 line, indicating that Hyderabad is trending higher (Figs. 11 and 12).

As shown in Table 4, the computed data indicated that the statistical analysis of Hyderabad's monthly evapotranspiration (ET_o) data shows significant variations. January's mean ET_o is 161.3 mm with a standard deviation (SD) of 18.9 mm and a coefficient of variation (CV) of 11.7%, indicating slight positive skewness. February has a mean ET_o of 190.8 mm, an SD of 13.5 mm, and a CV of 7.1%, suggesting a nearly symmetrical distribution. March's mean ET_o is 251.9 mm with an SD of 18.5 mm and a CV of 7.3%, showing slight negative skewness. April's mean ET_o is 260.6 mm with an SD of 24.4 mm and a CV of 9.4%, indicating symmetry. May has a higher mean ET_o of 289.4 mm, an SD of 40.6 mm, and a CV of 14.0%, with slight negative skewness. June's mean ET_o is 194.7 mm with an SD of 28.1 mm and a CV of 14.5%, indicating near symmetry. July has a mean ET_o of 153.8 mm, an SD of 25.7 mm, and a CV of 16.7%, showing positive skewness. August's mean ET_o is 129.5 mm with an SD of 17.2 mm and a CV of 13.3%, indicating positive skewness. September's mean ET_o is 109.8 mm with an SD of 13.5 mm and a CV of 12.3%, showing near normal distribution. October has a mean ET_o of 113.6 mm, an SD of 18.8 mm, and a CV of 16.5%, indicating strong positive skewness. November's mean ET_o is 119.3 mm with an SD of 24.5 mm and a CV of 20.5%, showing slight positive skewness. December's mean ET_o is 135.1 mm with an SD of 22.7 mm and a CV of 16.8%, indicating near symmetry. Overall, the data indicates considerable monthly variability in ET_o, reflecting Hyderabad's diverse climatic conditions throughout the year. The overall decreasing trend of seasonal ET_o in the studied region is shown in Figure 10, which illustrates the general declining trend of seasonal ET_o in the examined region, and the linear

regression equation reveals a negative slope value ($a = -0.16$). The ET_o values that ITA computed using the time data exceeded the 1:1 line, suggesting general upward tendencies for Hyderabad (Figure 13).

Meteorological data is a key source of data for assessing these patterns and comprehending the alterations in the climate system. In climate research, non-parametric tests are frequently employed because of their ability to identify trends in time series information instead of requiring assumptions about the underlying distribution (Ampofo *et al.*, 2023). These tests assess various meteorological parameters, such as wind speed, humidity, temperature, precipitation, on various scales. Spatial distribution analysis is critical in climate research since it helps to understand regional differences in climatic variables and how they change over time. This research attempted to do so with statistical tools and rainfall data. The pre-monsoon, post-monsoon, and winter variables have large CV values, indicating that there tend to be significant annual variations in the amount of rainfall experienced throughout these seasons.

The low coefficient of variation (CV) for the monsoon and yearly variables suggested that there may be some variation in the total amount of rainfall during these times, but not a substantial one. The outcomes of other researchers, including Chandniha *et al.* (2017), Shree and Kumar (2018), and Warwade *et al.* (2018), are consistent with the results of a recent study on rainfall variability. In particular, the study discovered significant variability in winter, post-monsoon, and pre-monsoon rainfall. Additionally, according to Yadav and Singh (2023), there has been a

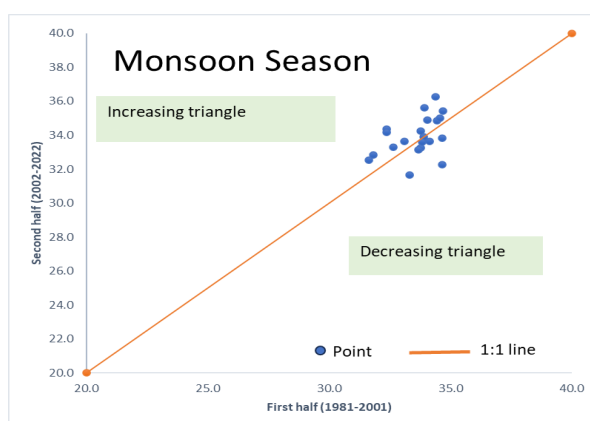


Fig. 11. Innovative Trend Analysis of Maximum temperature from 1981 to 2022

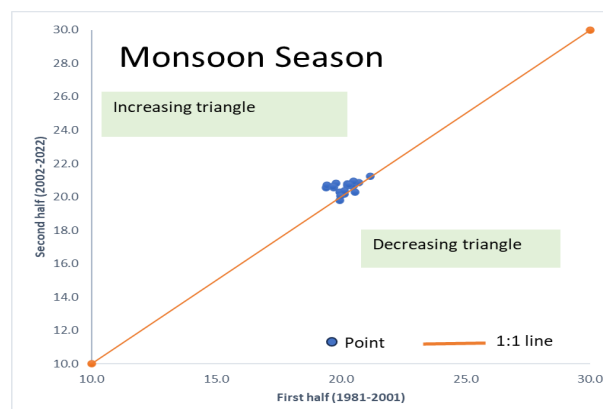


Fig. 12. Innovative Trend Analysis of Minimum temperature from 1981 to 2022

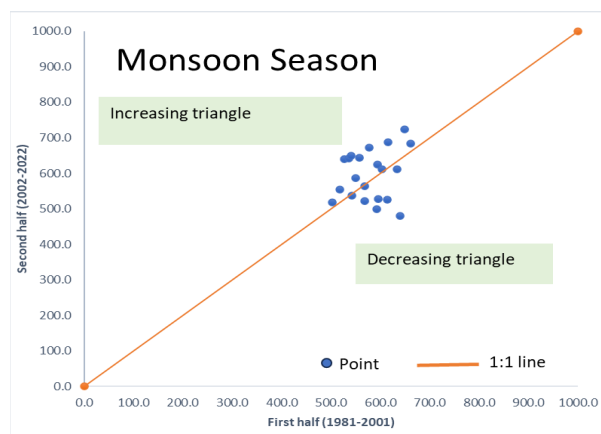


Fig. 13. Innovative Trend Analysis of ETo from 1981 to 2022

decline in intense rainfall during the past few decades. Sengupta and Thangavel (2023) examined variations in temperature and rainfall distribution patterns using meteorological data; they found that Maharashtra's altered precipitation patterns are causing a severe drought that seriously threatens the state's cotton production level.

The main findings of this study highlight the necessity of ongoing monitoring and analysis of the local climate and rainfall patterns to develop effective strategies and policies for managing and adapting to the changing climate and its effects on the environment and human activity in the area. These results draw attention to the region's difficulties in controlling its water supplies and responding to severe weather. To address water-intensive patterns and promote climate resilience, researchers and policymakers need to consider these changes. To confirm that resources are owed and decisions are made with the best interests of the region's sustainability and climate resilience in mind, the study offers insightful information.

CONCLUSION

This study quantifies the climatic variability in the research region over 42 years (1981–2022). Rainfall analysis reveals a coefficient of variation ranging from 43.5% to 269.4%, with a statistically significant declining trend during the monsoon season, supported by Sen's slope of -0.0002 and a 99% confidence level. The minimum and maximum temperatures exhibit slight increasing trends, with Sen's slopes of 0.02 °C and 0.012 °C, respectively, and coefficients of variation ranging from 3.0% to 13.7% (minimum) and 2.5% to 6.5% (maximum). Seasonal evapotranspiration (ETo) trends indicate a declining slope of -0.16, with

monthly ETo values varying significantly, such as May's peak mean ETo at 289.4 mm and September's lowest mean ETo at 109.8 mm. These quantified results highlight critical variations in regional meteorological parameters, demonstrating increasing temperature trends, decreasing rainfall, and significant seasonal variability in ETo. Such insights are vital for policymakers and researchers to strategize effective water resource management and address the region's climate change impacts.

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