**Spatial and temporal analysis of rainfall and temperature trend of Kagina river catchment India**

**Abstract**

Change poses a significant challenge, causing notable variations in temperature and precipitation patterns worldwide. This study analyzes the rainfall and temperature trends over the Kagina river catchment in India for a 42-year period (1981–2022) to assess the spatial and temporal impacts of climate change in the region. Changes in annual, seasonal and monthly rainfall and temperature patterns were investigated using statistical analysis and the non-parametric Mann-Kendall (MK) test. The analysis revealed that annual rainfall in the catchment averaged 863.25 mm, with a minimum of 501.62 mm and a maximum of 1425.71 mm. While most months exhibited weak to moderate trends, only the post-monsoon season showed a statistically significant increasing trend (τ=0.213, p=0.049). Annual rainfall exhibited a weak positive trend (τ=0.108, p=0.319) but was not statistically significant. Temperature analysis indicated a significant rise in maximum temperature (Tmax) during January, August, November, December, the post-monsoon season and annually. Minimum temperature (Tmin) showed a significant increasing trend in August and annually. Overall, Tmax exhibited more pronounced and frequent significant trends compared to Tmin. These findings highlight the effects of climate variability in the Kagina River Catchment and emphasize the need for sustainable water resource management and agricultural adaptation strategies to mitigate climate change impacts.

**Keywords:** Rainfall trend, Temperature variability, Mann-Kendall test, Seasonal analysis, Climate variability.

1. **Introduction**

Climate change and variability are among the most important global challenges of the present era, with widespread and profound effects (Din et al. 2022; Swain et al. 2022). Both natural factors and human activities have significantly contributed to these climatic shifts (Saroar et al. 2016). The study of climate change primarily focuses on variations in key climatic variables such as temperature and precipitation, as these fluctuations play a crucial role in understanding long-term climatic trends (Ekwueme and Agunwamba 2021). Precipitation and temperature are vital climate factors that influence the frequency, duration and intensity of extreme weather events, including droughts and floods. These variables also impact the hydrological cycle, water resources, vegetation, agricultural productivity, water quality and overall socioeconomic development (Eris et al. 2019; Singh et al. 2021; Esit et al. 2021; Aksoy and Cavus 2022; Gao et al. 2022). Even minor shifts in precipitation and temperature patterns can lead to severe consequences, such as prolonged droughts and devastating floods (Salman et al. 2019; Ita and Ogbemudia 2023). According to the Intergovernmental Panel on Climate Change (IPCC), human-induced greenhouse gas emissions have significantly increased since the pre-industrial period, leading to a rise in global temperatures. The frequency of cool days and nights has drastically declined, while the occurrence of warm days and nights has surged (IPCC 2014). Furthermore, the IPCC (2018) projects that global temperatures could rise by 1.5 °C the lower threshold set by the Paris Climate Agreement as early as 2030, highlighting the urgent need for mitigation efforts to control further warming. Existing literature provides extensive evidence of climate change manifestations, including rising global temperatures, increasing sea levels, greenhouse gas emissions and erratic, unpredictable rainfall patterns. Additionally, much of the research on climate change has focused on glacial melt, floods, droughts and large-scale climatic phenomena such as El Niño-Southern Oscillation (ENSO) (IPCC 2018).

The combination of decreasing precipitation over land, rising temperatures and increased evapotranspiration has led to widespread drying and contributed to drought conditions in many regions. The tropics, in particular, have been significantly affected by recurring droughts. Numerous studies have analysed rainfall trends, highlighting regional variations. For instance, increasing precipitation has been reported in Australia (Suppiah and Hennessy 1998), New York, USA (Burns et al. 2007) and Mexico from 1920 to 2004 (Gonzalez et al. 2008). Conversely, declining precipitation trends have been observed in Italy (Buffoni et al. 1999), Kenya (Kipkorir 2002) Zheng et al. 2019; Xin et al. 2020; Li et al. 2021; Ravichandran et al. 2022; Aliyar et al. 2022; Zhu et al. 2022). Additionally, Nicholls and Lavery (1992) reported a rise in precipitation during the summer months in Australia, while Rodrigo et al. (2000) identified significant rainfall variability in Spain. Other studies examining rainfall variations include the works of Akinremi et al. (2001), Modarres and Silva (2007), Ati et al. (2008), Gonzalez et al. (2008), Conway et al. (2009) Vicente-Serrano et al. 2022; Ahmadi et al. 2022; Wei et al. 2023.

Temperature is widely regarded as a key indicator for assessing global climate trends (Jhajharia and Singh 2011). Several studies provide evidence of rising temperatures, such as the findings of Reiter et al. (2012), who observed a temperature increase in the upper Danube basin, with a 0.8°C rise per decade during summer. Additional research on temperature trends has been conducted by Ventura et al. (2002), Feidas et al. (2004), Turkes and Sumer (2004), and Andrighetti et al. (2009). Long-term trends in mean annual temperature were analyzed by Ghahraman (2006) in Iran, revealing that the increase in Earth's surface temperature is primarily driven by rising minimum temperatures rather than maximum temperatures (Vose et al. 2005). In India, a significant rise in temperature across the subcontinent was documented by Arora et al. (2005) and Dash et al. (2007). Seasonal temperature trends were explored by Sen Roy and Balling (2005), who found increasing minimum and maximum temperatures over the Deccan Plateau, while the diurnal temperature range remained largely insignificant, except in Kashmir. Studies by Kothawale and Rupa Kumar (2005) and Pal and Al-Tabbaa (2010) also confirmed an increasing trend in air temperature over India.

Various statistical methods have been employed to analyze climatic parameters such as temperature and rainfall. Both parametric and non-parametric tests are commonly used, with non-parametric methods being particularly advantageous due to their ability to handle independent datasets and outliers (Hamed and Rao 1998). Among these, the Mann-Kendall test is one of the most widely used global techniques for trend analysis (Yue et al. 2003; Burns et al. 2004; Ludwig et al. 2004; Singh et al. 2008; Gonzalez et al. 2008; Batisani and Yarnal 2010), frequently applied to rainfall and temperature to assess climate change. More recent studies utilizing this method include those conducted by Tabari et al. (2012), Du and Shi (2012), Wang et al. (2012), Mekonen and Berlie (2020), Gadedjisso-Tossou et al. (2021) and Dubey et al. (2023).

All these studies, as mentioned, dealt with the trend analysis of rainfall and temperature in different parts of the world as well as in India. However, information and analysis of the trend of both rainfall and temperature together for the catchments are very few and limited with respect to the seasonal (pre-monsoon, monsoon, post-monsoon and winter) and annual variations over different spatial scales. The major objective of the present study is to find the Annual and seasonal (pre-monsoon, monsoon, post-monsoon and winter) trend analysis was done with the temperature (minimum and maximum) and rainfall from 1981 to 2022 (42 years) in Kagina river catchment. The statistical techniques Mann-Kendall (MK) test, is applied to the analysis.

1. **Study area and data**

The Kagina River, a tributary of the Bhima River, flows westward and merges with the Bhima near Shahabad. Its geographical coordinates extend from 17° 1' 56" N to 17° 56' 32" N latitude and from 77° 56' 42" E to 76° 19' 12" E longitude, as illustrated in Figure 1. The river's catchment area spans approximately 9,620 km², covering three states: Maharashtra (Osmanabad and Latur districts), Telangana (Rangareddy, Medak, and Mahbubnagar districts), and Karnataka (Kalaburagi, Bidar, and Yadgir districts) from upstream to downstream. The majority of the catchment area, 6,236.61 km² (64.82%), lies within Karnataka, followed by 2,454.32 km² (25.51%) in Telangana and 929.38 km² (9.66%) in Maharashtra. This region falls under the Southern Plateau and Hills agro-climatic zone of India. The major crops cultivated in the area include red gram, soybean, cotton, paddy, jowar, maize, wheat, sunflower, and groundnut.



**Fig 1. Study area**

1. **Methodology**

The temporal analysis of climatic parameters such as precipitation and temperature were performed using historical data. Statistical method the Mann-Kendall test was employed to detect trends and assess the significance of climate variability over the observed period. This non-parametric test provides robust insights into long-term changes (Mann, 1945, Kendall, 1975), enabling the identification patterns and potential implications for the catchment’s hydrology.

**3.1 Mann Kendall test**

 Mann Kendall test is the rank based nonparametric test used to detect trends in precipitation and temperature parameters. It is based on the test statics S defined as

|  |  |  |
| --- | --- | --- |
|  | $$S=\sum\_{i=1}^{n-1}\sum\_{j=i+1}^{n}sign\left(x\_{j}-x\_{i}\right)$$ | ……….(1) |

Where, x1, x2…. xn represent n data points where xj and xi are the annual values in years
j and i, j>i respectively.

 A very high positive value of S is an indicator of an increasing trend and a very low negative value indicates a decreasing trend.

|  |  |  |
| --- | --- | --- |
|  | $$sign\left(x\_{i}-x\_{i}\right)= f\left(x\right)=\left\{ \begin{array}{c}+1, \& x\_{j}>x\_{i}\\0, x\_{j}=x\_{i}\\-1, \& x\_{j}<x\_{i}\end{array}\right.$$ | ….…….(2) |

Where n is the sample size. The statistics S is approximately normally distributed when n ≥ 8, with the mean and the variance, respectively.

|  |  |  |
| --- | --- | --- |
|   | $$V\left(s\right)= \frac{n\left(n-1\right)\left(2n+5\right)-\sum\_{i=1}^{n}t\_{i }i\left(i-1\right)(2i+5)}{18}$$ | ……….(3) |

where ti is the number of ties of extent i (Zero difference between compared values). The standardized statistics (Z) for one-tailed test is calculated as follows

|  |  |  |
| --- | --- | --- |
|  | $$Z= f\left(x\right)=\left\{\begin{array}{c}\frac{S-1}{\sqrt{Var(s})} S>0\\ 0 S=0 \\ \&\frac{S+1}{\sqrt{Var(s}) } S\geq 0\end{array}\right.$$ | ………. (4) |

The hypothesis that there has not trend will be rejected if,

|  |  |  |
| --- | --- | --- |
|  | $$\left|Z\right|> Z\_{1-\frac{α}{2}}$$ | ………. (5) |

 Z (1-α/2) is the value read from a standard normal distribution table with α being the significance level of the test. At the 99 per cent significance level, the null hypothesis of no trend is rejected if |ZMK|>2.575; at 95 per cent significance level, the null hypothesis of no trend is rejected if |ZMK|>1.96; and at 90 per cent significance level, the null hypothesis of no trend is rejected if |ZMK|> 1.645.

1. **Results**

**4.1 Temporal analysis of climatic parameters for Kagina river catchment**

The temporal analysis of the Kagina river catchment examines the variability and trends in climatic parameters, such as rainfall and temperature, over the past four decades. This analysis was conducted to assess the impacts of changing climatic conditions on the hydrological cycle and water resources within the catchment. Long-term data from the Indian Meteorological Department (IMD) for a 42-year period (1981–2022) were utilized in this study. Monthly, seasonal and annual patterns were investigated using statistical tools and trend detection methods, including the Mann-Kendall (MK) test.

**4.1.1 Rainfall trend analysis**

The present study dealt with variability and trends in seasonal and annual rainfall in the study area. IMD data for 42 years (1981-2022) were used in this study. Initially, rainfall data was examined with general statistics on the basis of total study area. The general statistics (minimum, maximum, mean, standard deviation and coefficient of variation) are presented in Table 1. The minimum and maximum rainfall recorded in the study area was 501.62 mm and 1425.71 mm respectively with an average annual rainfall of 863.25 mm.

**4.1.2 Mann Kendall test**

Mann Kendall (MK) test was carried out for entire study area at monthly, seasonal and annual basis for the period of 42 years (1981 to 2022). The MK test was used to check the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. The results of MK test for average rainfall data for entire study area were given in Table 2. The analysis of monthly, seasonal and annual trends revealed that most of the months exhibited weak to moderate trends, both positive and negative, but none were statistically significant except for the post-monsoon period. Among the months, March (τ=0.189, p=0.094) and September (τ=0.173, p=0.109) showed moderate positive trends, though neither reached statistical significance. In contrast, January, February, July, October and December exhibited weak negative trends, with p-values indicating no significant changes. Seasonal trends were also largely insignificant with pre-monsoon and monsoon showing very weak and weak positive trends, respectively. However, the post-monsoon season stood out with a moderate and statistically significant positive trend (τ=0.213, p=0.049). Annual data indicated a weak positive trend (τ=0.108, p=0.319), which was not statistically significant. Overall, while the majority of trends lacked significance, the post-monsoon season demonstrated a notable positive change.

**4.1.3 Trend analysis of temperature**

The present study dealt with variability and trends in seasonal and annual maximum and minimum temperatures in the study area. IMD data for the 42 years (1981-2022) were used in this study. The general statistics of maximum and minimum temperatures were also calculated to understand the data before going for trend analysis. The general statistics (minimum, maximum, mean, standard deviation and coefficient of variation) were presented in Table 3. The annual mean maximum temperature and minimum temperature was recorded as 33.18 and 22.89 °C respectively. Standard deviation and coefficient of variation of annual maximum temperatures and minimum temperatures were 0.42, 0.01 and 0.35, 0.02 respectively.

Maximum and minimum temperatures trend and its significance was identified by Mann Kendell test. This analysis was done for monthly, seasonal and annual basis. The results of MK test for annual average maximum temperature of the study area are presented in Table 4. The analysis of Tmax and Tmin trends reveals varying results across months, seasons and annually. For Tmax, significant positive trends were observed in January (τ=0.296, p=0.006), August (τ=0.213, p=0.049), November (τ=0.359, p=0.001), December (τ=0.398, p=0.000), the post-monsoon season (τ=0.461, p=0.001) and annually (τ=0.292, p=0.007). Other months and seasons showed weak or no significant trends. For Tmin, significant positive trends were found in August (τ=0.336, p=0.002) and annually (τ=0.233, p=0.030), while other months and seasons exhibited weak or no significant changes. Overall, Tmax exhibited more pronounced and frequent significant trends compared to Tmin, particularly during the post-monsoon and annual period.

**Table 1. General statistics of rainfall data (1981-2022)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Season | Minimum rainfall (mm) | Maximum rainfall (mm) | Mean rainfall (mm) | SD | CV |
| Pre-monsoon | 16.15 | 242.08 | 62.24 | 43.90 | 0.71 |
| Monsoon | 411.44 | 1379.66 | 775.37 | 227.37 | 0.29 |
| Post-monsoon | 0.00 | 131.86 | 26.07 | 31.15 | 1.19 |
| Annual | 501.62 | 1425.71 | 863.25 | 222.74 | 0.26 |

**Table 2. Results of MK test for the monthly, seasonal and annual precipitation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month/ Season** | **z** | **S** | **τ** | **p-value** |
| **Jan** | -0.112 | -10.000 | -0.015 | 0.911 |
| **Feb** | -0.690 | -53.000 | -0.085 | 0.490 |
| **Mar** | 1.675 | 151.000 | 0.189 | 0.094 |
| **Apr** | 0.954 | 89.000 | 0.104 | 0.340 |
| **May** | 1.095 | 102.000 | 0.119 | 0.274 |
| **Jun** | 0.715 | 67.000 | 0.078 | 0.474 |
| **Jul** | -0.477 | -45.000 | -0.052 | 0.633 |
| **Aug** | 0.585 | 55.000 | 0.064 | 0.558 |
| **Sep** | 1.604 | 149.000 | 0.173 | 0.109 |
| **Oct** | -0.087 | -9.000 | -0.010 | 0.931 |
| **Nov** | 0.573 | 53.000 | 0.065 | 0.567 |
| **Dec** | -0.759 | -63.000 | -0.091 | 0.448 |
| **Pre monsoon** | -0.401 | -38.000 | -0.044 | 0.688 |
| **Monsoon** | 0.824 | 77.000 | 0.089 | 0.410 |
| **Post monsoon** | 1.972 | 183.000 | 0.213 | 0.049 |
| **Annual** | 0.997 | 93.000 | 0.108 | 0.319 |

**Table 3. General statistics of average monthly, seasonal and annual maximum and minimum temperature**

|  |  |  |
| --- | --- | --- |
| **Season** | **Tmax (℃)** | **Tmin (℃)** |
| **Max** | **Min** | **Mean** | **SD** | **CV** | **Max** | **Min** | **Mean** | **SD** | **CV** |
| **Pre-monsoon** | 40.12 | 36.89 | 38.58 | 0.74 | 0.02 | 25.64 | 22.91 | 23.97 | 0.59 | 0.02 |
| **Monsoon** | 33.62 | 30.33 | 31.79 | 0.63 | 0.02 | 23.19 | 21.40 | 22.20 | 0.37 | 0.02 |
| **Post-monsoon** | 32.21 | 28.99 | 30.87 | 0.65 | 0.02 | 18.70 | 15.57 | 16.86 | 0.69 | 0.04 |
| **Annual** | 34.22 | 32.05 | 33.18 | 0.42 | 0.01 | 23.71 | 22.12 | 22.89 | 0.35 | 0.02 |

**Table 4. Results of MK test for the monthly, seasonal and annual maximum and minimum temperature**

|  |  |  |
| --- | --- | --- |
| **Month/ Season** | **Tmax** | **Tmin** |
| **z** | **S** | **Τ** | **p-value** | **z** | **S** | **τ** | **p-value** |
| **Jan** | 2.753 | 255.000 | 0.296 | 0.006 | -0.672 | -63.000 | -0.073 | 0.502 |
| **Feb** | 0.368 | 35.000 | 0.041 | 0.713 | -0.455 | -43.000 | -0.050 | 0.649 |
| **Mar** | 0.997 | 93.000 | 0.108 | 0.319 | -0.412 | -39.000 | -0.045 | 0.680 |
| **Apr** | 0.585 | 55.000 | 0.064 | 0.558 | 1.040 | 97.000 | 0.113 | 0.298 |
| **May** | -0.022 | -3.000 | -0.003 | 0.983 | 1.214 | 113.000 | 0.131 | 0.225 |
| **Jun** | -0.347 | -33.000 | -0.038 | 0.729 | 1.149 | 107.000 | 0.124 | 0.251 |
| **Jul** | -0.477 | -45.000 | -0.052 | 0.633 | 1.452 | 135.000 | 0.157 | 0.146 |
| **Aug** | 1.972 | 183.000 | 0.213 | 0.049 | 3.121 | 289.000 | 0.336 | 0.002 |
| **Sep** | -1.214 | -113.000 | -0.131 | 0.225 | 0.130 | 13.000 | 0.015 | 0.897 |
| **Oct** | 1.019 | 95.000 | 0.110 | 0.308 | 0.737 | 69.000 | 0.080 | 0.461 |
| **Nov** | 3.338 | 309.000 | 0.359 | 0.001 | 0.954 | 89.000 | 0.103 | 0.340 |
| **Dec** | 3.706 | 343.000 | 0.398 | 0.000 | 0.802 | 75.000 | 0.087 | 0.423 |
| **Pre monsoon** | 0.542 | 51.000 | 0.059 | 0.588 | 0.889 | 83.000 | 0.096 | 0.374 |
| **Monsoon** | -0.173 | -17.000 | -0.020 | 0.862 | 1.301 | 121.000 | 0.141 | 0.193 |
| **Post monsoon** | 4.292 | 397.000 | 0.461 | 0.001 | 0.954 | 89.000 | 0.103 | 0.340 |
| **Annual** | 2.709 | 251.000 | 0.292 | 0.007 | 2.168 | 201.000 | 0.233 | 0.030 |

1. **Conclusion**

The temporal analysis of climatic parameters in the Kagina River catchment from 1981 to 2022 reveals critical insights into rainfall and temperature variability. Using high-resolution data from the Indian Meteorological Department (IMD) and robust statistical approaches, including the Mann-Kendall (MK) test, this study identifies significant trends across monthly, seasonal, and annual scales. While rainfall trends exhibit considerable variability, with most changes remaining statistically insignificant except during the post-monsoon period, temperature trends present a stark contrast. Maximum temperatures show a pronounced and statistically significant increase, particularly in specific months and seasons, with the most notable shifts occurring in the post-monsoon and annual periods. These findings underscore the evolving climate dynamics in the Kagina River catchment, emphasizing the growing impact of rising temperatures on the region’s hydrological and ecological balance.

1. **References**

Ahmadi F, Nazeri Tahroudi M, Mirabbasi R, Kumar R (2022) Spati otemporal analysis of precipitation and temperature concentra tion using PCI and TCI: a case study of Khuzestan Province. Iran Theor Appl Climatol 149:743–760. https://doi.org/10.1007/ s00704-022-04077-6

Akinremi OO, McGinn SM, Cutforth HW (2001) Seasonal and spatial patterns of rainfall trends on the Canadian prairies. J Clim 14(9): 2177–2182

Aksoy H, Cavus Y (2022) Discussion of “drought assessment in a south Mediterranean transboundary catchment.” Hydrol Sci J 67:150–156. <https://doi.org/10.1080/02626667.2021.2009838>

Aliyar Q, Dhungana S, Shrestha S (2022) Spatio-temporal trend map ping of precipitation and its extremes across Afghanistan (1951 2010). Theor Appl Climatol 147:605–626. https:// doi. org/ 10. 1007/s00704-021-03851-2

Andrighetti M, Zardi D, Franceschi M (2009) History and analysis of the temperature series of Verona (1769–2006). Meteorol Atmos Phys 103:267–277.

Arora M, Goel NK, Singh P (2005) Evaluation of temperature trends over India. Hydrol Sci J 50(1):81–93.

Ati OF, Muhammed SQ, Ati MH (2008) Variations and trends in annual rainfall amounts and the onset of the rainy season for Kano for 87 years (1916–2002). J Appl Sci Res 4(12):1959–1962

Batisani N, Yarnal B (2010) Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. Appl Geogr 30:483–489

Buffoni L, Maugeri M, Nanni T (1999) Precipitation in Italy from 1833 to 1996. Theor Appl Climatol 63:33–40

Burn DH, Cunderlik JM, Pietroniro A (2004) Hydrological trends and variability in the Liard river basin. Hydrol Sci J 49(1):53–67

Burns DA, Klaus J, McHale MR (2007) Recent climate trends and implications for water resources in the Catskill Mountain region, New York, USA. J Hydrol 336:155–170

Conway D, Persechino A, Ardoin-Bardin S, Hamandawana H, Dieulin C, Mahé G (2009) Rainfall and water resources variability in subSaharan Africa during the twentieth century. J Hydrometeor 10:41–59

Dash SK, Jenamani RK, Kalsi SR, Panda SK (2007) Some evidence of climate change in twentieth-century India. Clim Chang 85:299–321.

Din MSU, Mubeen M, Hussain S et al (2022) World Nations priorities on climate change and food security. In: Jatoi WN, Mubeen M, Ahmad A et al (eds) Building Climate Resilience in Agriculture: Theory, Practice and Future Perspective. Springer International Publishing, Cham, pp 365–384

Du J, Shi C (2012) Effects of climatic factors and human activities on runoff of the Weihe River in recent decades. Quatern Int 1–8. doi:10. 1016/j.quaint.2012.06.036

Dubey V, Panigrahi S, Vidyarthi VK (2023) Statistical trend analysis of major climatic factors over Chhattisgarh State, India. Earth Syst Environ. https://doi.org/10.1007/s41748-023-00345-1

Ekwueme BN, Agunwamba JC (2021) Trend analysis and variability of air temperature and rainfall in regional river basins. Civil Eng J 7:816–826. <https://doi.org/10.28991/cej-2021-03091692>

Eris E, Aksoy H, Onoz B et al (2019) Frequency analysis of low flows in intermittent and non-intermittent rivers from hydrological basins in Turkey. Water Supply 19:30–39. https:// doi. org/ 10. 2166/ ws.2018.051

Esit M, Kumar S, Pandey A et al (2021) Seasonal to multi-year soil moisture drought forecasting. npj Clim Atmos Sci 4:1–8. https:// doi.org/10.1038/s41612-021-00172-z

Feidas H, Makrogiannis T, Bora-Senta E (2004) Trend analysis of air temperature time series in Greece and their relationship with circulation using surface and satellite data: 1955–2001. Theor Appl Climatol 79:185–208

Gadedjisso-Tossou A, Adjegan KI, Kablan AKM (2021) Rainfall and temperature trend analysis by Mann-Kendall test and significance for rainfed cereal yields in Northern Togo. Sci 3:17. https:// doi. org/10.3390/sci3010017

Gao F, Chen X, Yang W et al (2022) Statistical characteristics, trends, and variability of rainfall in Shanxi province, China, during the period 1957–2019. Theor Appl Climatol 148:955–966. https:// doi. org/10.1007/s00704-022-03924-w

Ghahraman B (2006) Time trend in the mean annual temperature of Iran. Turk J Agric For 30:439–448

González JM, Cháidez JJN, Ontiveros VG (2008) Analysis of rainfall trends (1920–2004) in Mexico. Investigaciones Geográficas, Boletín del Instituto de Geografía, UNAM 65:38–55

González JM, Cháidez JJN, Ontiveros VG (2008) Analysis of rainfall trends (1920–2004) in Mexico. Investigaciones Geográficas, Boletín del Instituto de Geografía, UNAM 65:38–55

González JM, Cháidez JJN, Ontiveros VG (2008) Analysis of rainfall trends (1920–2004) in Mexico. Investigaciones Geográficas, Boletín del Instituto de Geografía, UNAM 65:38–55

Hamed KH, Rao AR (1998) A modified Mann-Kendall trend test for auto correlated data. J Hydrol 204:182–196

IPCC (2014) climate change 2014: impacts, adaptation, and vulner ability. Part A: Global and Sectoral Aspects.European Environment Agency.

IPCC (2018) Global Warming of 1.5 °C. https:// www. ipcc. ch/ sr15/. Accessed 23 Feb 2020

Ita RE, Ogbemudia FO (2023) Climate change impact on Nigerian ecology, vegetation/forest, carbon and biomass management. In: Egbueri JC, Ighalo JO, Pande CB (eds) Climate Change Impacts on Nigeria: Environment and Sustainable Development. Springer International Publishing, Cham, pp 303–316

Jhajharia D, Singh VP (2011) Trends in temperature, diurnal temperature range and sunshine duration in Northeast India. Int J Climatol 31: 1353–1367

Kipkorir EC (2002) Analysis of rainfall climate on the Njemps Flats, Baringo District, Kenya. J Arid Environ 50:445–458

Kothawale DR, Rupa Kumar K (2005) One the recent changes in surface temperature trends over India. Geophys Res Lett 32: L18714. doi: 10.101029/2005GL023528

Li X, Zhang K, Gu P et al (2021) Changes in precipitation extremes in the Yangtze River Basin during 1960–2019 and the association with global warming, ENSO, and local effects. Sci Total Environ 760:144244. <https://doi.org/10.1016/j.scitotenv.2020.144244>

Ludwig W, Serrat P, Cesmat L, Garcia-Esteves J (2004) Evaluating the impact of the recent temperature increase on the hydrology of the Teˆt River (Southern France). J Hydrol 289:204–221

Mekonen AA, Berlie AB (2020) Spatiotemporal variability and trends of rainfall and temperature in the Northeastern Highlands of Ethiopia. Model Earth Syst Environ 6:285–300. https:// doi. org/ 10.1007/s40808-019-00678-9

Modarres R, Silva VPR (2007) Rainfall trends in arid and semi-arid regions of Iran. J Arid Environ 70:344–355

Nicholls N, Lavery B (1992) Australian rainfall trends during the twentieth century. Int J Climatol 12(2):153–163

Pal I, Al-Tabbaa A (2010) Long-term changes and variability of monthly extreme temperatures in India. Theor Appl Climatol 100:45–56

Ravichandran V, Kantamaneni K, Periasamy T et al (2022) Monitoring of multi-aspect drought severity and socio-economic status in the semi-arid regions of eastern Tamil Nadu. India Water 14:2049. <https://doi.org/10.3390/w14132049>

Reiter A, Weidinger R, Mauser W (2012) Recent climate change at the upper Danube—a temporal and spatial analysis of temperature and precipitation time series. Clim Chang 111:665–696

Rodrigo S, Esteban-Parra MJ, Pozo-Vázquez D, Castro-Díez Y (2000) Rainfall variability in southern Spain on decadal to centennial time scales. Int J Climatol 20(7):721–732

Salman SA, Shahid S, Ismail T et al (2019) Characteristics of annual and seasonal trends of rainfall and temperature in Iraq. Asia-Pacific J Atmos Sci 55:429–438. https:// doi. org/ 10. 1007/ s13143-018-0073-4

Saroar MM, Filho WL (2016) Adaptation through climate smart agri culture: status and determinants in coastal Bangladesh. In: Leal Filho W, Musa H, Cavan G et al (eds) Climate Change Adapta tion, Resilience and Hazards. Springer International Publishing, Cham, pp 157–178

Sen Roy S, Balling RC Jr (2005) Analysis of trends in maximum and minimum temperature, diurnal temperature range, and cloud cover over India. Geophys Res Lett 32:L12702. doi:10.1029/ 2004GL022201

Singh H, Najafi MR, Cannon AJ (2021) Characterizing non-stationary compound extreme events in a changing climate based on large ensemble climate simulations. Clim Dyn 56:1389–1405. https:// doi.org/10.1007/s00382-020-05538-2

Singh P, Kumar V, Thomas T, Arora M (2008) Changes in rainfall and relative humidity in different river basins in the northwest and central India. Hydrol Process 22:2982–2992

Suppiah R, Hennessy KJ (1998) Trends in total rainfall, heavy rain events and number of dry days in Australia, 1910–1990. Int J Climatol 10: 1141–1164

Swain S, Taloor AK, Dhal L et al (2022) Impact of climate change on groundwater hydrology: a comprehensive review and current status of the Indian hydrogeology. Appl Water Sci 12:120. https:// doi.org/10.1007/s13201-022-01652-0.

Tabari H, Hosseinzadeh Talaee P, Ezani A, Shifteh Some’e B (2012) Shift changes and monotonic trends in autocorrelated temperature series over Iran. Theor Appl Climatol 109:95–108. doi:10.1007/s00704-011-0568-8

Turkes M, Sumer UM (2004) Spatial and temporal patterns of trends and variability in diurnal temperature ranges of Turkey. Theor Appl Climatol 77:195–227

Ventura F, Rossi Pisa P, Ardizzoni E (2002) Temperature and precipitation trends in Bologna (Italy) from 1952 to 1999. Atmos Res 61: 203–214

Vicente-Serrano SM, García-Herrera R, Peña-Angulo D et al (2022) Do CMIP models capture long-term observed annual precipita tion trends? Clim Dyn 58:2825–2842. https:// doi. org/ 10. 1007/ s00382-021-06034-x

Vose RS, Easterling DR, Gleason B (2005) Maximum and minimum temperature trends for the globe: an update through 2004. Geophys Res Lett 32:L23822. doi:10.1029/2005GL024379

Wang S, Yan M, Yan Y, Shi C, He L (2012) Contributions of climate change and human activities to the changes in runoff increment in different sections of the Yellow River. Quatern Int 1–12. doi:10. 1016/j.quaint.2012.07.011

Wei W, Zhang X, Liu C et al (2023) A new drought index and its appli cation based on geographically weighted regression (GWR) model and multi-source remote sensing data. Environ Sci Pollut Res 30:17865–17887. <https://doi.org/10.1007/s11356-022-23200-8>

Xin X, Wu T, Zhang J et al (2020) Comparison of CMIP6 and CMIP5 simulations of precipitation in China and the East Asian summer monsoon. Int J Climatol 40:6423–6440. https://doi.org/10.1002/ joc.6590

Yue S, Hashino M (2003a) Temperature trends in Japan: 1900–1990. Theor Appl Climatol 75:15–27

Zheng J, Fan J, Zhang F (2019) Spatiotemporal trends of temperature and precipitation extremes across contrasting climatic zones of China during 1956–2015. Theor Appl Climatol 138:1877–1897. <https://doi.org/10.1007/s00704-019-02942-5>

Zhu W, Wang S, Luo P et al (2022) A quantitative analysis of the influ ence of temperature change on the extreme precipitation. Atmos phere 13:612. <https://doi.org/10.3390/atmos13040612>