**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, Temperature, Mann-Kendall test, Seasonal, 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) Nath et al. (2023) 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**

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 Fig1. 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 time series analysis 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.

 Positive value of S is an indicator of increasing trend while negative value of S denotes decreasing trend. Also here, higher value of S represent maximum tendency and lower value to minimum tendency.

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

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