

# Assessing Rainfall and Temperature Variability in the Upper Watrak River Basin: A Spatio-Temporal Approach

P. K. Lalwani<sup>1\*</sup>, V. M. Patel<sup>2</sup>, S. B. Jha<sup>3</sup>, D. J. Mehta<sup>4</sup>, and R. T. Sahu<sup>5</sup>

<sup>1</sup> Gujarat Technological University, Ahmedabad, Gujarat, 380015, India

<sup>2</sup> Department of Civil Engineering, Shantilal Shah Engineering College, Bhavnagar, Gujarat, 364060, India

<sup>3</sup> Department of Civil Engineering Department, L. D. College of Engineering,  
Ahmedabad, Gujarat, 380015, India

<sup>4</sup> Department of Civil Engineering, Dr. S. & S. S. Ghandhy Government Engineering College, Surat,  
Gujarat, 395001, India

<sup>5</sup> Department of Civil Engineering, Amrutvahini College of Engineering, Sangamner, 422608, Maharashtra

Received 10 September 2025; revised 21 October 2025; accepted 10 December 2025; published online 28 December 2025

**ABSTRACT.** Climatic variability continuously affects the globe. From the last two-three decades, industrialisation and urbanization the greenhouse gases continuously rise. Because of that the hydro-metrological parameters are continuously changing their characteristics. It is necessary to understand the characteristics and change patterns of this parameter. Trend analysis is the technique for it. Various parametric and non-parametric tests were used for trend analysis globally. The present work is carried out non-parametric trend analysis. The hydro-metrological parameters such as (1) precipitation, (2) maximum temperature, and (3) minimum temperature done over the upper Watrak River Basin using 24 IMD Gridded station data set. This study is beneficial in understanding the impact of climate change and climate variability on rainfall dynamics across the study area, which may further guide the policymakers and beneficiaries for optimizing the use of hydrological resources.

**Keywords:** climate change (CC), trend analysis, M-K method, Sen's slope method, ITA's method

## 1. Introduction

Extreme climate events often do not occur in isolation but are triggered by complex processes leading to multiple extremes. climate variability is long term process (Verma et al., 2016). The significant impacts due to change in climate are faced by various countries and the community around the world (Alibašić, 2022; Mehta and Yadav, 2022a). As per IPCC AR-6 Report, the global Surface temperature rise very fast from last 4 to 5 decades and notable changes observed in rainfall pattern (IPCC, 2023). Precipitation is one of the climatic variables which can affect the pattern of availability of water in both time and space (Mehta and Yadav, 2021a; Krishn et al., 2022). Variation in climatic element provide the sign of change in ecosystem (Modarres and da Silva, 2007).

In country like India (Mehta and Yadav, 2021b; Muthiah et al., 2024), Agriculture is the largest industry which is highly affected due to climate change. For the rainfall, major portion of India depends on summer monsoon (Sharma et al., 2018; Mehta and Yadav, 2022b) and it is observed changes in it. It is

necessary to understand the precipitation frequency and its intensity (Dash et al., 2011). Multiple spatio-temporal changes have been observed due to Indian summer monsoon (Mehta et al., 2022; Sahastrabuddhe et al., 2023).

Identification of change in hydrometeorological trends major concern (Esit et al., 2024). The climate projections over India indicate that temperature may rise to be around 3 °C and rainfall increase is expected to be 10 ~ 20% over the central part of India by the end of this century (Pastagia and Mehta, 2023; Chowhan et al., 2024). Water is a vital natural resource and finding it may be a big challenge for any project that needs to be planned, built, and run (Mehta et al., 2023; Das et al., 2025).

The Watrak River Basin was selected for this study due to its hydrological, climatic, and socio-environmental significance within the semi-arid region of Gujarat. The basin forms a vital tributary of the Sabarmati River and supports extensive agricultural activities, rural livelihoods, and groundwater dependent ecosystems. The Watrak river basin has experienced fluctuations in rainfall and temperature, leading to nonuniform water availability, seasonal droughts, and increased vulnerability to climatic extremes. Despite these challenges, limited comprehensive research has been carried out to assess long-term spatio-temporal climate variability in the basin. Therefore, analyzing the rainfall and temperature trends using statistical methods, non-parametric test provides valuable insights into the extent and nature of cli-

---

\* Corresponding author. Tel.: 942-895-9910.  
E-mail address: prashant.lalwani86@gmail.com (P. K. Lalwani).

mate change impacts, supporting sustainable water resource management and regional adaptation planning.

Trend analysis is the technique to understand the spatio-temporal changes associated with climate (Swain et al., 2015; Pastagia and Mehta, 2022). It is necessity to understand the impact due to climate change on the environment (Anand et al., 2025). Different parametric and non-parametric stastical methods are used for trend analysis study, but non-parametric, i.e., Mann-Kendall test (M-K test) (Mann, 1945), Modified Mann Kendall test (MMK test) (Kumar et al., 2017), Sen’s slope test, Sen’s innovative trend analysis (ITA’s), innovative trend analysis (ITA), innovative polygon trend analysis (IPTA) (Ali-fujiang et al., 2020), Mann-Whitney U test (Sammut and Erskine, 1995) etc. are used globally to check the trend of hydro-metrological parameter. Hydro-climatological time series might embed characteristics of past changes concerning climate variability in terms of shifts, cyclic fluctuations, and more significantly in the form of trends (Zekai, 2015; Patel et al., 2021).

The effects of climate change on the small-regional scale research area at the Watrak and Mazum river watershed confirm an increase in the annual rainfall size, an increase in the intensity of rainfall in July and August, and a shifting of the monsoon season to start and conclude later (Nyaupane et al., 2018; Patel and Mehta, 2023).

After reviewing various literature, in India many trend analysis studies have been done but, not much more work to be done on the upper Watrak river basin. In this present work, trend analysis done for precipitation, maximum temperature and minimum temperature of 9 IMD gridded station having an interval of  $0.25^\circ \times 0.25^\circ$  data which cover the study area as surround.

It is implied that the dry region of Western India’s changing climate poses a serious threat to both agricultural and water resources (Machiwal et al., 2019; Patel et al., 2024).

M-K and Sen’s ITA procedures serve as best tools for trend analysis, Sen’s ITA method overcome the disadvantages of M-K particularly for noisy, small, or nonlinear data. The M-K procedure is still a foundation for statistical trend Analysis, while ITA offers a more flexible and visually intuitive method. Their complementary strengths imply a synergistic combination in environmental data analysis for robust and insightful detection of trends (Şen, 2012; Shaikh et al., 2022).

Sen’s innovative trend analysis method is a valuable contribution to trend detection for time series data, particularly when classical assumptions are not feasible to be met. Its flexibility, non-parametric characteristics, and capacity to detect complex and partial trends render it as a useful tool for scientists and researchers working with environmental and hydrologic data sets. Although it will not supersede traditional hypothesis testing approaches, it offers a complementary, perceptive analysis, particularly in exploratory data analysis (Şen, 2012; Verma et al., 2023).

The objectives of the study are to analyse the climatic trend of various climatic variables, i.e., precipitation, maximum temperature and minimum temperature over the study area. The M-K Test and Sen’s innovative method are used for trend analysis.

Previous studies on rainfall and temperature variability have primarily relied on conventional trend detection methods, often overlooking spatial heterogeneity and non-linear variations. To overcome these limitations, this study adopts an integrated spatio-temporal framework combining the M-K test, Sen’s slope estimator, and the innovative Sen’s slope method to evaluate climatic trends in the upper Watrak river basin. The integration of statistical and innovative approaches enhances the reliability and precision of trend detection and provides deeper insights into regional climatic variability essential for effective water resource planning and climate adaptation.

## 2. Study Area

The Watrak river originates in Panchara hills, in Dungarpur district of Rajasthan. The Watrak river is left bank tributary of Sabarmati river. The river flow travelling 248 km in southwest direction, falls in Sabarmati River near Dholka village of Gujarat state (Jasodani and Lodha, 2020). The upper Watrak river basin is located between  $23^\circ 11'$  to  $23^\circ 72'$  N and  $73^\circ 81'$  to  $73^\circ 02'$  E. In the present work, total 24 grid station data have been analysed for trend analysis. The catchment area of the study basin is 1,615.800 Sq. km. The length of river in study basin is 124.117 km. The study basin elevation varies from 55 to 380 m. The study basin contain clayey and loamy type of soil (Kishanlal et al., 2020). The average annual rainfall is nearby 800 mm. Temperature range varies from 6 to 40 °C. The grid station cover  $23^\circ$  to  $23^\circ 75'$  latitude and  $72^\circ 25'$  to  $74^\circ$  longitude direction of  $0.25^\circ \times 0.25^\circ$  interval.

## 3. Data Collection and Methodology

Precipitation, maximum temperature and minimum temperature data of upper Watrak river basin has been analysed for 73 years (1951 ~ 2023). For the study, the data collection details as follows in Table 1.

**Table 1.** Study Parameter with Resolution and Data Source Detail

Sr. No.	Data	Source
1	Rainfall $0.25^\circ \times 0.25^\circ$ Gridded Data (From 1951 to 2023)	Indian Metrological Department Website - Pune
2	Maximum Temperature $0.25^\circ \times 0.25^\circ$ Gridded Data (From 1951 to 2023)	Indian Metrological Department Website - Pune
3	Maximum Temperature $0.25^\circ \times 0.25^\circ$ Gridded Data (From 1951 to 2023)	Indian Metrological Department Website - Pune
4	Digital Elevation Model	USGS Earth Explorer Website

The hydro-metrological data is download from the IMD Pune website using Google colab python programming tool. The data analysis done by a statistical test, which is primarily used

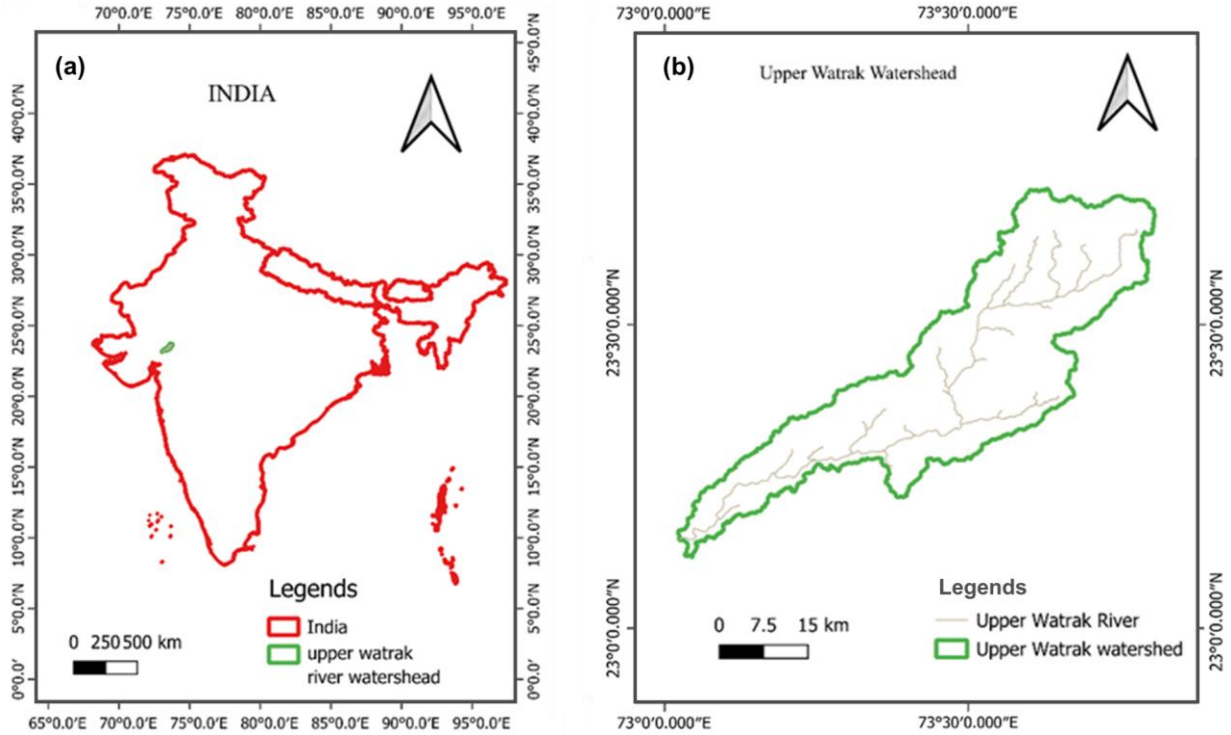


Figure 1. Location map of the study area.

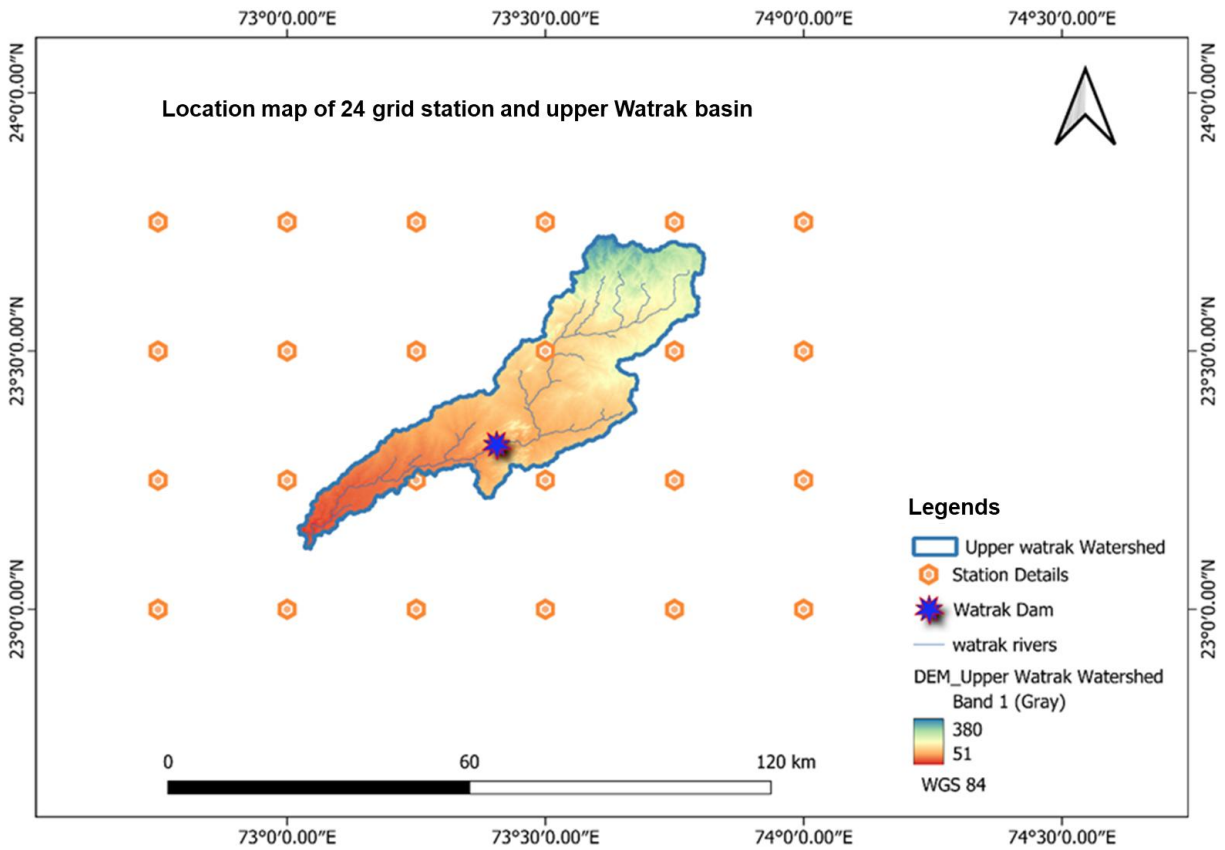
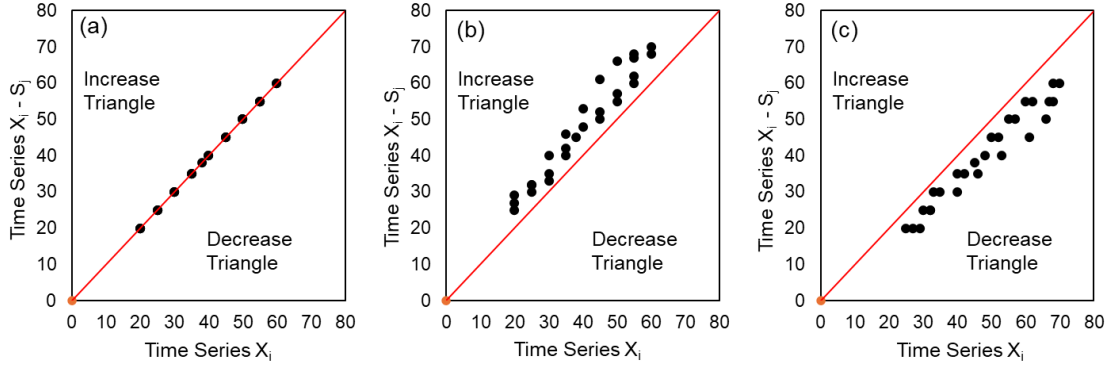


Figure 2. Location map of grid station and DEM of study area.



**Figure 3.** (a) Trendless time series, (b) increasing trend and (c) decreasing trend (Şen, 2012).

to evaluating data and determining the most appropriate course of action among two or more options. (Mann, 1945). The QGIS used for preparing digital elevation model and location map of study area.

### 3.1. Mann-Kendall Test

Mann (1945) suggested the nonparametric M-K test for trend analysis of hydro-metrological data time series (Panda and Sahu, 2019). The advantage of the test is it does not require the normal distributed data and second, the test has poor sensitivity to abrupt breaks due to heterogeneous data series (Panda and Sahu, 2019). In this test null hypothesis ( $H_0$ ) is assume means there is no trend and checked for alternative hypothesis ( $H_1$ ) means there is trend. The statistics for the M-K test are calculate using Equation (1):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(X_j - X_k) \quad (1)$$

In Equation (1),  $S$  indicates how many pairs of observations in the sequence  $X_1, X_2, \dots, X_n$  are increasing versus decreasing. The test is applied to a series where  $X_k$  which is ranked from  $k = 1$  to  $n - 1$  which is ranked  $j = k + 1$  to  $n$ . Every data point  $X_j$  is considered as a reference point.

In Equation (2), the sign function compares all possible pairs of observations to assess whether later values are higher or lower than earlier ones:

$$\begin{aligned} \text{sgn}(X_j - X_k) &= 1 \text{ if } X_j - X_k > 0 \\ &= 0 \text{ if } X_j - X_k = 0 \\ &= -1 \text{ if } X_j - X_k < 0 \end{aligned} \quad (2)$$

The function assigns +1 when a subsequent value is greater than a previous one, -1 when it is smaller, and 0 when both values are equal. This helps in identifying the overall increasing or decreasing trend in the dataset without assuming any specific data distribution.

In Equation (3), statistic  $S$  is approximately Gaussian when  $n = 18$  with the mean  $E(S)$  and variance  $Var(S)$  of the statistic  $S$  given by the expression:

$$E(S) = 0$$

$$Var(S) = \frac{N(n-1)(2n+5)}{18} \quad (3)$$

However, if the data set exists, variance of  $S$  is calculated by the following equation:

$$\begin{aligned} Var(S) &= \frac{1}{18} [ \{ N(n-1)(2n+5) \} \\ &\quad - \sum_{p=1}^n t_p(t_p-1)(2t_p+5) ] \end{aligned} \quad (4)$$

The variable  $N$  and  $t_p$  are the tied group numbers and  $p$ th group data value numbers, respectively.

The normal Z-statistics are computed as:

$$Z = \frac{S-1}{\sqrt{Var(S)}} \text{ if } S > 1$$

$$Z = \frac{S+1}{\sqrt{Var(S)}} \text{ if } S < 1 \quad (5)$$

In equation (5), the  $Z$  value describes the negative and positive trend and computing Z-statistics describe significance level of trend. If Z-Statistics value denote zero means there is no trend (Agarwal et al., 2021). All the  $\alpha = 0.10$  ( $Z = \pm 1.66$ ) significance level.

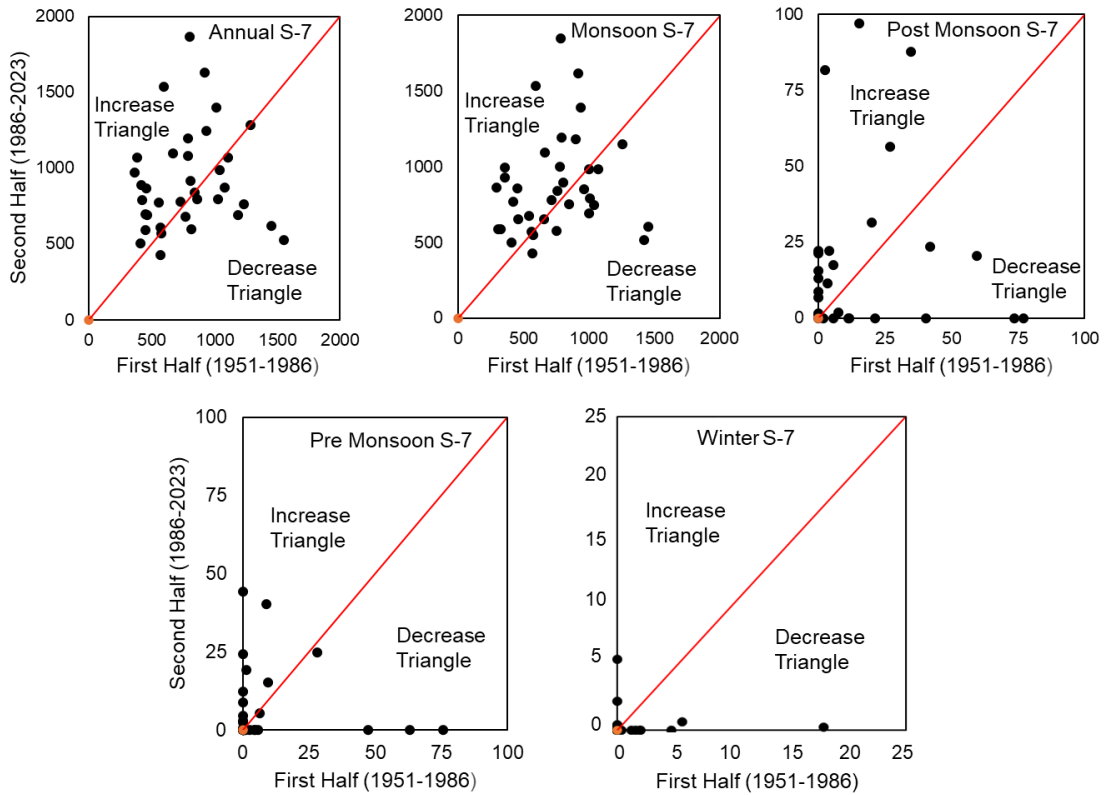
### 3.2. Innovative Trend Analysis Sen's Method (ITA's)

The innovative trend analysis Sen's method is non-parametric and widely used by researchers to visualize the interpretation of data series. The methods are applied for two equal length sections of consecutive time data series on a graph (Karcosta et al., 2023). In this study, the method is used for quantitative identification of seasonal precipitation, annual precipitation, monthly maximum temperature and monthly minimum temperature. In this method first, the data series is divided in two-time series and then first-time data series is plotted on horizontal axis (X-axis) and second time series data is plotted on

**Table 2.** Trend Analysis Results for Seasonal Precipitation and Annual Precipitation over the 24-Grid Station

Station	Winter			Pre Monsoon			Monsoon			Post Monsoon			Annual		
	Z	S	P	Z	S	P	Z	S	P	Z	S	P	Z	S	P
1	↓	→	×	↘	→	✓	↗	↑	×	↘	→	×	↗	↑	×
2	↘	→	✓	↗	→	✓	↗	↗	×	↘	→	×	↗	↗	×
3	↘	→	✓	↘	→	×	↗	↑	×	↘	→	×	↗	↑	×
4	↘	→	×	↘	→	×	↗	↗	×	↘	→	×	↗	↗	×
5	↗	→	✓	↘	→	×	↘	↓	×	↘	→	×	↘	↘	×
6	↘	→	×	↗	→	✓	↗	↑	×	↘	→	×	↗	↑	×
7	↘	→	×	↘	→	×	↗	↑	×	↘	→	×	↗	↑	×
8	↓	→	×	↘	→	×	↗	↑	×	↘	→	×	↗	↑	×
9	↘	→	×	↘	→	✓	↘	↘	×	↘	→	×	↘	↘	×
10	↘	→	×	↗	→	×	↗	↑	×	↘	→	×	↗	↑	×
11	↘	→	×	↘	→	✓	↗	↑	×	↘	→	×	↗	↑	×
12	↘	→	×	↘	→	✓	↗	↑	×	↘	→	×	↗	↑	×
13	↘	→	×	↗	→	✓	↗	↑	×	↘	→	×	↗	↑	×
14	↘	→	×	↗	→	×	↗	↑	×	↘	→	×	↗	↑	×
15	↘	→	×	↑	→	×	↑	↑	×	↗	→	×	↑	↑	×
16	↘	→	×	↗	→	×	↘	↘	×	↘	→	×	↘	↘	×
17	↘	→	×	↗	→	✓	↘	↘	×	↘	→	×	↘	↘	×
18	↘	→	×	↗	→	×	↗	↗	×	↘	→	×	↗	↗	×
19	↘	→	×	↗	→	×	↗	↗	×	↘	→	×	↗	↗	×
20	↘	→	×	↑	→	✓	↗	↑	×	↘	→	×	↗	↑	×
21	↓	→	×	↘	→	×	↘	↓	×	↘	→	×	↓	↓	×
22	↗	→	×	↗	→	×	↗	↑	×	↘	→	✓	↗	↑	×
23	↘	→	×	↗	→	×	↑	↑	×	↘	→	×	↗	↑	×
24	↘	→	×	↗	→	×	↑	↑	×	↘	→	×	↑	↑	×

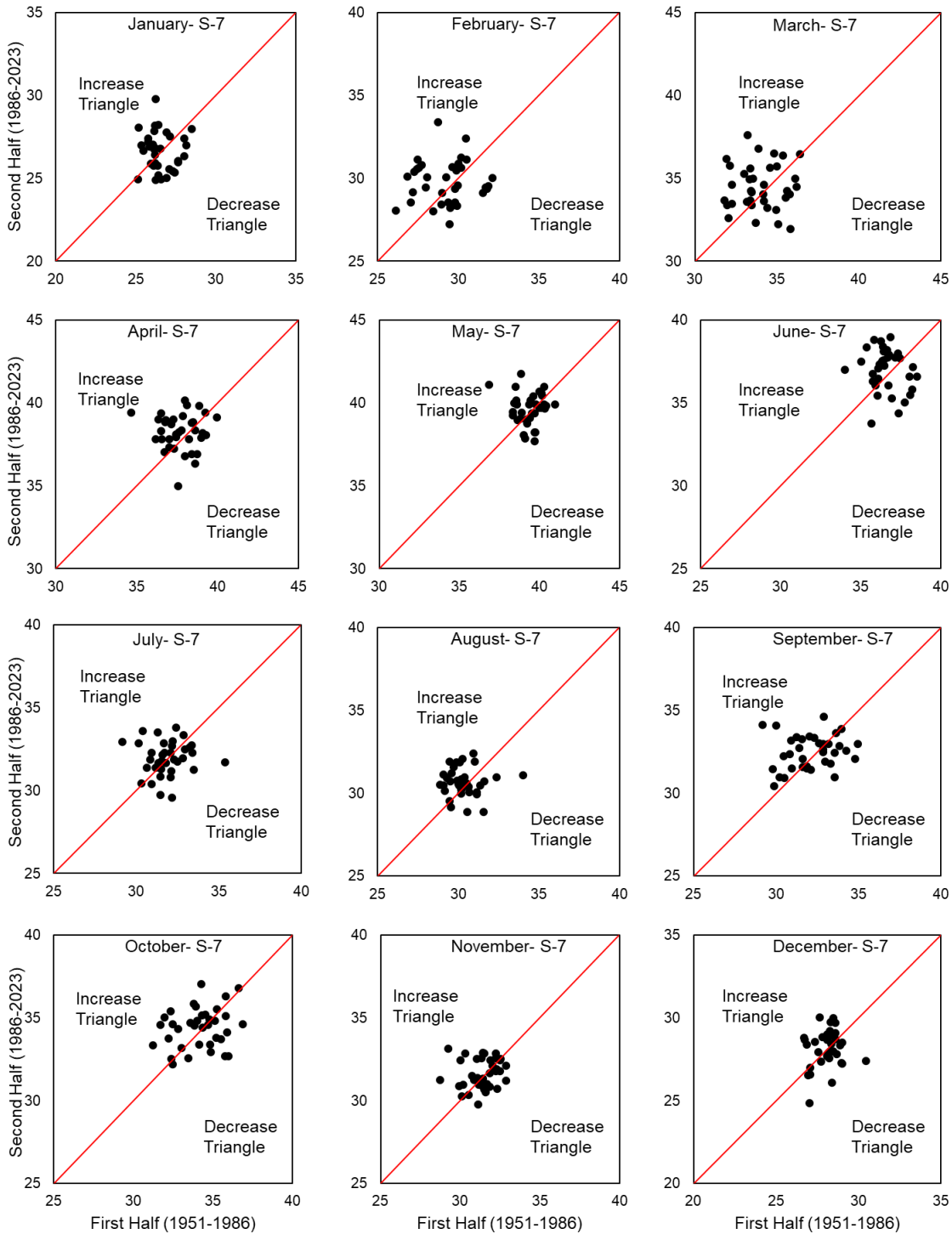
↑: Significant Positive; ↗: Positive Trend; →: No Trend; ↘: Negative Trend; ↓: Significant Negative



**Figure 4.** Template for seasonal and annual precipitation analysis using ITA Sen's method.







**Figure 5.** Template for monthly maximum temperature analysis using ITA Sen's method.

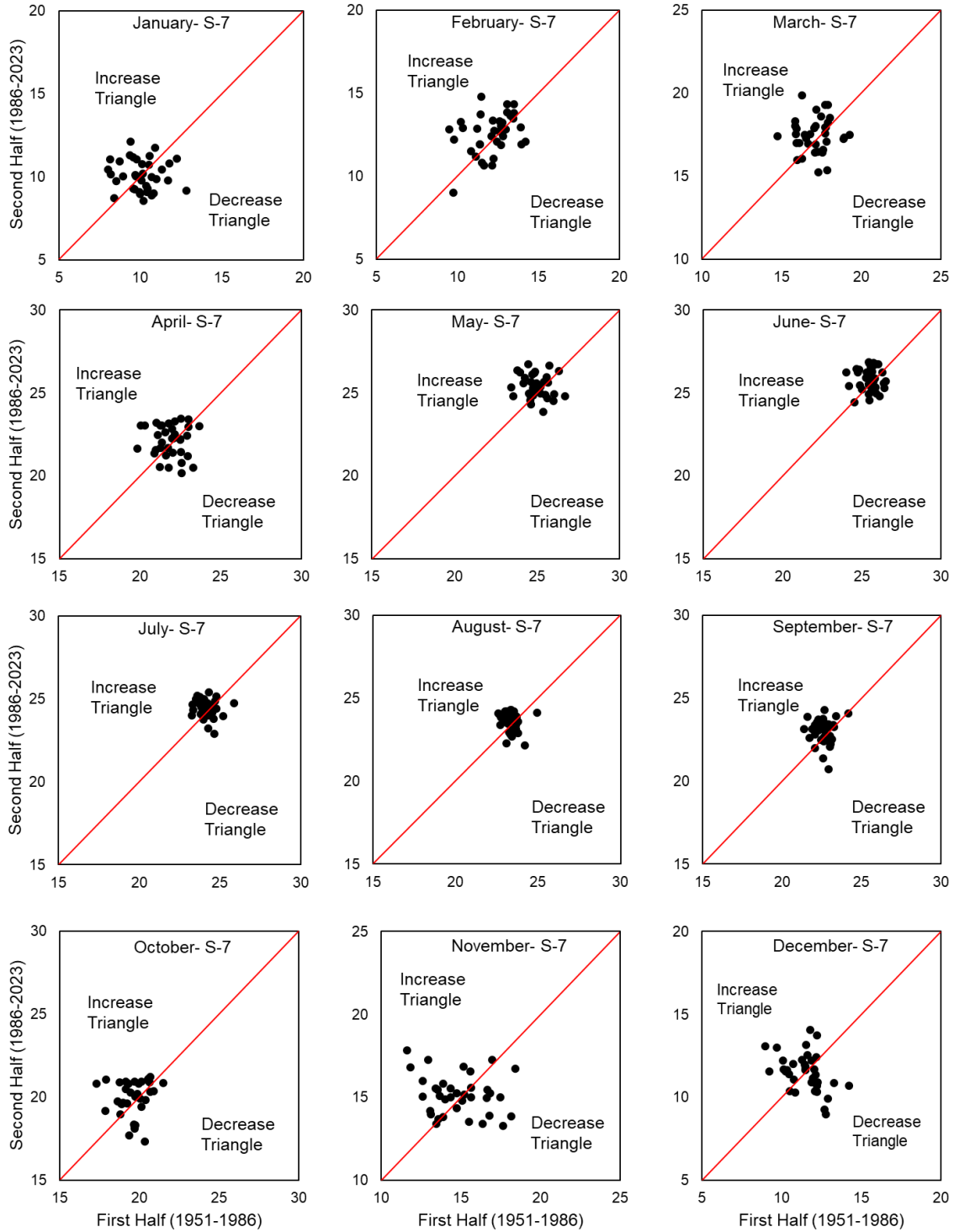
This implies that the rate of increase in minimum temperature is relatively consistent throughout the year, though slightly less pronounced in midwinter.

This sustained increase in minimum temperature could be attributed to factors such as increased atmospheric moisture, enhanced greenhouse gas concentration, and urban heat retention

effects, all of which can prevent effective nighttime cooling.

### 4.3. ITA Sen's Analysis for Precipitation, Maximum Temperature, and Minimum Temperature

The comparison of 24 IMD grid stations across the upper Watrak river basin shows clear spatial and temporal variations



**Figure 6.** Template for monthly minimum temperature analysis using ITA Sen's method

in precipitation and temperature trends.

Precipitation trends vary seasonally, with most stations showing an upward trend during the monsoon season, suggesting possible regional monsoon intensification. In contrast, pre- and post-monsoon rainfall patterns appear stable or random, indicating localized variability, while winter precipitation gener-

ally shows weak or neutral trends. Annual rainfall trends strongly correlate with monsoon rainfall, emphasizing the dominant role of the monsoon in the basin's hydrology.

For maximum temperature, most stations show a significant rise from April to June and again from October to December, reflecting regional warming during both pre- and post-mon-

soon periods. A few stations also show warming during August and September, pointing to higher monsoon temperatures.

Minimum temperature exhibits the most consistent warming, with nearly all stations showing positive and often significant trends, especially from April to October. The monsoon months (June ~ August) show the strongest increase in nighttime temperatures, while winter months remain relatively stable.

Overall, the spatial distribution of trends indicates a warming climate and increasing hydroclimatic variability in the upper Watrak river basin, driven by rising temperatures and inconsistent rainfall patterns.

## 5. Climate Change Impact on Study Area

Climate change has brought considerable alterations to the spatio-temporal distribution of rainfall and temperature within the Watrak river basin, resulting in significant hydrological and ecological transformations. From the result analysis, the basin has witnessed greater rainfall irregularity, including shifts in seasonal precipitation and an increased occurrence of intense rainfall events in some regions, contrasted by extended dry periods in others. Concurrently, the steady rise in temperature has intensified evapotranspiration, diminished soil moisture, and modified streamflow dynamics. These variations have led to uneven water availability across the basin and fluctuations in runoff and groundwater recharge over time. Collectively, the changing rainfall and temperature patterns indicate a distinct climatic transition that is reshaping the basin's hydrological balance, agricultural productivity, and overall ecosystem health.

## 6. Conclusion

Identification of trend is crucial for climate studies. Various methods of trend analysis are adopted by different researchers across the globe. In present work three climatic parameters: (1) precipitation, (2) maximum temperature, and (3) minimum temperature is considered for the trend analysis. M-K test and Sen's innovative trend analysis method are adopted for trend analysis of 73-year (1951 ~ 2024) data of study area.

For the precipitation, M-K results show most of stations having positive trend in that in monsoon season, pre-monsoon season. Annual data analysis also shows positive trends. Sen's slope also represents majority of the station represent positive trend in monsoon and annual. However, some stations' precipitation results show significant upward and downward trend at 5% significance level.

For maximum and minimum temperature, M-K test represents upward trend in March to October. However, some stations' maximum and minimum temperature's result show significant upward and downward trend at 5% significance level.

The Sen's innovative trend analysis (ITA) method applied to data for visualization of trend. The result supported the M-K test result at most data points.

These observations can be used to frame regional climate adaptation policies and aid sustainable resource management and planning. This study also contributes to trend detection meth-

ods by quantitatively evaluating the trend of time data series. Future studies also collect more data and predict monthly and seasonal changes over the study area.

**Acknowledgements.** The authors would like to express their sincere gratitude to all individuals and institutions who contributed to the successful completion of this research work. We are thankful to all the institutes for providing the necessary facilities and academic environment to carry out this study.

## References

- Agarwal, S., Suchithra, A.S. and Singh, S.P. (2021). Analysis and interpretation of rainfall trend using Mann-Kendall's and Sen's slope method. *Indian Journal of Ecology*. 48(2), 453-457.
- Alibašić, H. (2022). The administrative and ethical considerations of climate resilience: The politics and consequences of climate change. *Public Integrity*. 24(1), 33-50. <https://doi.org/10.1080/10999922.2020.1838142>
- Alifujiang, Y., Abuduwaili, J., Maihemuti, B., Emin, B. and Groll, M. (2020). Innovative trend analysis of precipitation in the Lake Issyk-Kul Basin, Kyrgyzstan. *Atmosphere*. 11(4), 332. <https://doi.org/10.3390/atmos11040332>
- Anand, S., Aarti and Singh, A. (2025). Investigation of the trends and variability in rainfall pattern in the upper Kumaon Himalayan region. *Frontiers in Climate*. 7, 1492260. <https://doi.org/10.3389/fclim.2025.1492260>
- Chowhan, V., Chandargi, D.M., Goudappa, S.B., Kammar, S.K., Koppalakar, B.G. and Lokesh G.B. (2024). Exploring climate patterns in Karnataka, India: A comprehensive examination of rainfall and temperature variability over time and space. *Journal of Scientific Research and Reports*. 30(4), 187-196. <https://doi.org/10.9734/jsrr/2024/v30i41904>.
- Das, M. and Saha, S. (2025). Trend and variability analysis of rainfall at Jaldhaka River Basin in the Himalayan Foreland, India. *Discover Applied Sciences*. 7(11), 1294. <https://doi.org/10.1007/s42452-024-06022-w>
- Dash, S.K., Nair, A.A., Kulkarni, M.A. and Mohanty, U.C. (2011). Characteristic changes in the long and short spells of different rain intensities in India. *Theoretical and Applied Climatology*. 105(3), 563-570. <https://doi.org/10.1007/s00704-011-0416-x>
- Esit, M., Yuce, M.I., Deger, İ.H. and Yasa, I. (2024). Trend and variability analysis in rainfall and temperature records over Van Province, Türkiye. *Theoretical and Applied Climatology*. 155(1), 451-472. <https://doi.org/10.1007/s00704-023-04644-5>
- IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change. <https://doi.org/10.59327/IPCC/AR6-978929169164>
- Jasodani, K.P. and Lodha, D.P.P. (2020). Identifying water harvesting sites in watrak river basin using GIS technologies and considering equity measures. *Gedrag and Organisatie Review*. 33(02). <https://doi.org/10.37896/gor33.02/173>
- Karacosta, P., Pakalidou, N., Douka, M. and Karacostas, T. (2023). Innovative polygon trend analysis (IPTA): A case study for precipitation in Thessaloniki during the last 50 years (1971-2020). *Environmental Sciences Proceedings*. 26(1), 161. <https://doi.org/10.3390/environsciproc2023026161>
- Kishanlal, D., Prakash, I. and Pham, B.T. (2020). Runoff estimation of machhu and Watrak Rivers Basins of Gujarat India using SCS-CN method and GIS. *Indian Journal of Ecology*. 47(3), 726-732.
- Krishn, P., Kumar, G. and Kale, G. (2022). Trend analyses in gridded rainfall data over the Sabarmati basin. *Mausam*. 73(2), 295-306. <https://doi.org/10.54302/mausam.v73i2.303>

- Kumar, S., Machiwal, D. and Dayal, D. (2017). Spatial modelling of rainfall trends using satellite datasets and geographic information system. *Hydrological Sciences Journal*. 62(10), 1636-1653. <https://doi.org/10.1080/02626667.2017.1304643>
- Machiwal, D., Gupta, A., Jha, M.K. and Kamble, T. (2019). Analysis of trend in temperature and rainfall time series of an Indian arid region: Comparative evaluation of salient techniques. *Theoretical and Applied Climatology*. 136(1), 301-320. <https://doi.org/10.1007/s00704-018-2487-4>
- Mann, H.B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the Econometric Society*. 13(3), 245-259. <https://doi.org/10.2307/1907187>
- Mehta, D. and Yadav, S. (2021a). Analysis of long-term rainfall trends in Rajasthan, India. *Climate Change Impacts on Water Resources*. Springer, 293-306. [https://doi.org/10.1007/978-3-030-64202-0\\_26](https://doi.org/10.1007/978-3-030-64202-0_26)
- Mehta, D. and Yadav, S. (2022a). Temporal analysis of rainfall and drought characteristics over Jalore District of SW Rajasthan. *Water Practice & Technology*. 17(1), 254-267. <https://doi.org/10.1007/978-3-030-98584-48>
- Mehta, D. and Yadav, S.M. (2021b). An analysis of rainfall variability and drought over Barmer District of Rajasthan, Northwest India. *Water Supply*. 21(5), 2505-2517. <https://doi.org/10.2166/ws.2021.053>
- Mehta, D., Waikhom, S., Yadav, V., Lukhi, Z., Eslamian, S. and Furze, J.N. (2022). *Earth Systems Protection and Sustainability*. Springer, 191-202.
- Mehta, D., Yadav, S., Ladavia, C. and Caloiero, T. (2023). Drought projection using GCM & statistical downscaling technique: A case study of Sirohi District. *Results in Engineering*. 20, 101605. <https://doi.org/10.1016/j.rineng.2023.101605>
- Mehta, D.J. and Yadav, S.M. (2022b). Long-term trend analysis of climate variables for arid and semi-arid regions of an Indian State Rajasthan. *International Journal of Hydrology Science and Technology*. 13(2), 191-214. <https://doi.org/10.1504/IJHST.2022.120639>
- Modarres, R. and da Silva, V.P.R. (2007). Rainfall trends in arid and semi-arid regions of Iran. *Journal of Arid Environments*. 70(2), 344-355. <https://doi.org/10.1016/j.jaridenv.2006.12.024>
- Muthiah, M., Sivarajan, S., Madasamy, N., Natarajan, A., and Ayyavoo, R. (2024). Analyzing rainfall trends using statistical methods across Vaippar Basin, Tamil Nadu, India: A comprehensive study. *Sustainability*. 16(5). <https://doi.org/10.3390/su16051957>
- Nyaupane, N., Bhandari, S., Rahaman, M.M., Wagner, K., Kalra, A., Ahmad, S. and Gupta, R. (2018). Flood frequency analysis using generalized extreme value distribution and floodplain mapping for Hurricane Harvey in Buffalo Bayou. *World Environmental and Water Resources Congress*, American Society of Civil Engineers Reston, VA, pp 364-375.
- Panda, A. and Sahu, N. (2019). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmospheric Science Letters*. 20(10), e932. <https://doi.org/10.1002/asl.932>
- Pastagia, J. and Mehta, D. (2022). Application of innovative trend analysis on rainfall time series over Rajsamand district of Rajasthan state. *Water Supply*. 22(9), 7189-7196. <https://doi.org/10.2166/ws.2022.276>
- Pastagia, J.H. and Mehta, D.J. (2023). Long term trend analysis on precipitation in Ajmer District of Rajasthan State, India. *International Journal of Hydrology Science and Technology*. 16(4), 409-421. <https://doi.org/10.1504/IJHST.2023.134624>
- Patel, P., Mehta, D., Waikhom, S. and Patel, K. (2021). *Analysis of rainfall variability and drought over Bardoli region*. Springer, 245-255.
- Patel, S. and Mehta, D. (2023). Statistical analysis of climate change over Hanumangarh district. *Journal of Water and Climate Change*. 14(6), 2029-2041. <https://doi.org/10.2166/wcc.2023.227>
- Patel, S., Mehta, D., Kumar, V., Patel, S. and Tiwari, D.K. (2024). Trend analysis of precipitation and drought characteristics over Churu district of northeast Rajasthan, India. *Journal of Water and Climate Change*. 15(9), 4457-4475. <https://doi.org/10.2166/wcc.2024.144>
- Sahastrabudde, R., Ghausi, S.A., Joseph, J. and Ghosh, S. (2023). Indian Summer Monsoon Rainfall in a changing climate: A review. *Journal of Water and Climate Change*. 14(4), 1061-1088. <https://doi.org/10.2166/wcc.2023.127>
- Sammur, J. and Erskine, W.D. (1995). Hydrological impacts of flow regulation associated with the upper nepean water supply scheme, NSW. *Australian Geographer*. 26(1), 71-86. <https://doi.org/10.1080/00049189508703132>
- Şen, Z. (2012). Innovative trend analysis methodology. *Journal of Hydrologic Engineering*. 17(9), 1042-1046. [https://doi.org/10.1061/\(asce\)he.1943-5584.0000556](https://doi.org/10.1061/(asce)he.1943-5584.0000556)
- Şen, Z. (2017). Innovative trend significance test and applications. *Theoretical and Applied Climatology*. 127(3), 939-947. <https://doi.org/10.1007/s00704-015-1681-x>
- Shaikh, M.M., Lodha, P., Lalwani, P. and Mehta, D. (2022). Climatic projections of Western India using global and regional climate models. *Water Practice & Technology*. 17(9), 1818-1825. <https://doi.org/10.2166/wpt.2022.090>
- Sharma, P.J., Loliyana, V., Timbadiya, P. and Patel, P. (2018). Spatio-temporal trends in extreme rainfall and temperature indices over Upper Tapi Basin, India. *Theoretical and Applied Climatology*. 134(3), 1329-1354. <https://doi.org/10.1007/s00704-017-2343-y>
- Swain, S., Verma, M., and Verma, M.K. (2015). Statistical trend analysis of monthly rainfall for Raipur District, Chhattisgarh. *International Journal of Advanced Engineering Research and Studies*. IV(II), 87-89.
- Verma, M.K., Verma, M. and Swain, S. (2016). Statistical analysis of precipitation over Seonath river basin, Chhattisgarh, India. *International Journal of Applied Engineering Research*. 11(4), 2417-2423.
- Verma, S., Kumar, K., Verma, M.K., Prasad, A.D., Mehta, D. and Rathnayake, U. (2023). Comparative analysis of CMIP5 and CMIP6 in conjunction with the hydrological processes of reservoir catchment, Chhattisgarh, India. *Journal of Hydrology: Regional Studies*. 50, 101533. <https://doi.org/10.1016/j.ejrh.2023.101533>