International Journal of Mathematics Trends and Technology
ISSN: 2231-5373/ https://doi.org/10.14445/22315373/IJMTT-V72I5P108

Volume 72 Issue 5, 88-100, May 2026
© 2026 Seventh Sense Research Group®

Original Article

Impact of Temperature and Precipitation Variability on Seasonal Water Flow of Subarnarekha River, Ranchi

Puja Dutta[1], Anamol Kumar Lal[2], Uma Shanker Singh[3]

[1]*Univ. Department of Mathematics, Ranchi University, Ranchi, Jharkhand, India.*
[2]*Simdega College, Simdega, Ranchi University, Ranchi, Jharkhand, India.*
[3]*IFS (Retd.), Lucknow, Uttar Pradesh, India.*

[1]*Corresponding Author : pujadutta05222@gmail.com*

Received: 29 March 2026 Revised: 30 April 2026 Accepted: 17 May 2026 Published: 30 May 2026

Abstract - *This research paper examines how a change in temperature and variability in precipitation affects the seasonal water runoff of the Subarnarekha River in the Ranchi area. There was an analysis of hydro-meteorological data such as rainfall, temperature, and streamflow during a specific time period. Statistical techniques like the Mann-Kendall test and slope estimator of Sen were used to identify trends and the magnitude of change of climatic variables and river discharge in a nonparametric manner. Findings reveal that there is a strong upward trend in the temperature and variability in the pattern of precipitation, which directly affects seasonal river flow. The analysis indicates that the flow of the monsoon is still predominant, with dry season discharge exhibiting a decreasing trend. The research indicates that the variability of precipitation is a significant variable in regulating streamflow, but an increase in temperature leads to less water supply in increased evapotranspiration. The results highlight the vulnerability of the Subarnarekha River to climate change and stress the sustainability of water resources management in the area.*

Keywords - *Subarnarekha River, MK test, Trend Analysis, Temperature, Hydro-meteorological.*

1. Introduction

Climate variability and long-term climate change have become a significant determinant of hydrological systems worldwide. Temperature variations and precipitation variations have a substantial impact on the hydrological cycle, causing changes in river discharge, evapotranspiration, groundwater recharge, and the general availability of water (IPCC, 2014; Mishra and Lilhare, 2016). Over the past few decades, mounting pressure on freshwater resources due to the growing occurrence of extreme weather conditions, such as unpredictable rainfall and warmer temperatures, has been increased by the growing frequency of extreme climatic events, especially in developing nations such as India, where the river systems are heavily reliant on monsoonal rain (Gosain et al., 2006; Kumar et al., 2017).

Climatic variables that have the most significant impact on hydrological processes of river basins are temperature and precipitation. Precipitation has a direct control over the runoff and the variability of streamflow, and temperature has a direct effect on evapotranspiration and soil moisture processes (Arnell, 1992; Xu, 2000). A rise in temperature tends to increase evapotranspiration and consequently decrease effective water supply, whereas a change in precipitation variability causes seasonal changes in river discharge. The joint effects may also drastically change the hydrological regime, especially in monsoon-dominated basins (Mimikou et al., 2000; Jiang et al., 2007). Most river basins in India are highly seasonal since the southwest monsoon is dominant, providing a significant percentage of the precipitation on an annual basis in a limited time. The Subarnarekha River basin is a rain-fed system of eastern India and is typified by high discharge during the monsoon season and extremely low flows during the dry season. The basin covers Jharkhand, West Bengal, and Odisha, and the Ranchi region is a significant upper catchment area. Hydro-climatic conditions of this basin show that it is very sensitive to changes in climatic conditions because any little variation in precipitation and temperature can have a substantial impact on streamflow. It has been noted in the past that the river has almost zero flow conditions during dry seasons, meaning that the river is susceptible to climatic changes.

There are a lot of studies that evaluated the effect of climate change on hydrological systems with the help of various methodological approaches. Hydrological models, e.g., Soil and Water Assessment Tool (SWAT), have been extensively used to predict streamflow and assess climate change conditions (Arnold et al., 1998; Abbaspour et al., 2007). These model-based methods offer useful information on basin-scale hydrological responses but demand large datasets and are associated with complicated calibration and validation processes, which can cause uncertainties (Gosain et al., 2006; Uniyal et al., 2015).

Conversely, statistical methods have become more and more important in the analysis of hydro-climatic variability based on observed data. Nonparametric statistics tools like the Mann-Kendall test are popularly employed in identifying monotonic trends in time-series data without any normality assumptions (Mann, 1945; Kendall, 1975). In the same manner, the slope estimator by Sen is a strong indicator of the magnitude of change of climatic and hydrological variables (Sen, 1968). These methods have been effectively used on a number of studies to examine long-term trends in temperature, precipitation, and streamflow because they are simple and reliable (Yue and Wang, 2004; Tabari et al., 2011).

Although there is a growing literature on climate change and hydrology, few studies have been conducted on trend-based prediction of hydro-climatic variables in the Subarnarekha River basin, especially in the Ranchi region. The majority of the past literature focuses on model-based simulation and projections, and little focus has been on observed data analysis to understand historic patterns and seasonal fluctuations. Moreover, the seasonal aspect of river flows, which is very important in water resource planning and management, has not been sufficiently investigated in this basin.

Thus, the current research will examine how temperature and variability in precipitation affect the seasonal water flow of the Subarnarekha River in the Ranchi area based on the observed hydro-meteorological data. Nonparametric statistical methods, such as the Mann-Kendall test to determine the trend and the Sen slope estimator to estimate the level of change, are used in the study. Also, seasonal analysis is conducted to assess the changes in river discharge during the monsoon season and the non-monsoon season. This study is likely to bring some valuable information on the interaction between climate and hydrology, and promote a sustainable approach to managing water resources in the area.

Precipitation pattern, evapotranspiration, groundwater recharge, and streamflow behaviour are all influenced by climate change and hydro-climatic variability, and have become important concerns for river basin management. In the rest of the world, several studies have indicated that significant changes in the hydrological processes and water availability will result from increasing temperatures and from irregular precipitation (Arnell, 1992; Xu, 2000). River systems in India are especially sensitive to climatic variability, as a significant fraction of the annual precipitation occurs during a brief period in the season (monsoon period) (Gosain et al., 2006). Many of the river basins in India have been found to be very sensitive to climatic variability and particularly to reduced stream flow during dry periods by Mishra and Lilhare 2016. In the same vein, Kumar et al. (2017) found that water stress and hydrological imbalance has worsened in some regions of India due to the rise in climate uncertainty. A considerable number of the studies conducted previously have investigated the effect of climate change on river flows and basin hydrology through the use of hydrological simulation models, including SWAT (Arnold et al., 1998; Abbaspour et al., 2007; Uniyal et al., 2015). These model-based approaches result in valuable future climate projections, but they are generally very complex and include multiple uncertainties about climate scenarios and parameter estimation, and may need a long list of calibration data. Accordingly, more and more researchers have turned to statistical trend analysis procedures to analyze observed changes in the hydro-climatic variables. To detect monotonic trends in climatic and hydrological time-series data, nonparametric methods like Mann (1945) and Sen's slope estimator (1968) are commonly used, which do not require the data to be normally distributed (Yue & Wang, 2004). These methods have been used successfully to identify temperature and precipitation trends in hydro-climatic studies by Tabari et al. (2011) and for studying the importance of trend analysis for sustainable river basin management by Rehana and Mujumdar (2011). Past research further shows that precipitation variability is the major driver of streamflow, while a rise in temperature indirectly affects river discharge as a result of higher evapotranspiration (Ramadan et al., 2013; Mengistu & Sorteberg, 2012). Most of the studies, however, have either been restricted to large river basins or have been based on the annual scale and have not considered the seasonal variations of the hydrology in smaller river basins in monsoon regions like the Subarnarekha River. Moreover, there is limited research done on the hydro-climatic trends in the Ranchi region based on long time series of observed data. Hence, the present study is a contribution to the literature by analysing the seasonal trend of temperature, precipitation, and streamflow variability in the Subarnarekha River basin with the application of nonparametric robust statistical techniques.

The novelty of this present study is that this is a trend-based seasonal evaluation of the Subarnarekha River basin's hydro-climatic variability based on observed long-term datasets, but not limited to simulation-based projections. Past research on Indian river basins and climate change has primarily focused on hydrological modelling techniques, including SWAT and large-scale climate projections (Gosain et al., 2006; Uniyal et al., 2015). These are useful scenarios for the future at the basin scale, but may contain uncertainties about the models and the future climate. The present study, on the other hand, uses nonparametric statistical methods such as the Mann-Kendall test and Sen's slope estimator to analyse the historical trends in temperature, precipitation, and streamflow using the available hydro-meteorological data. In addition, this study focuses on the seasonal streamflow characteristics of the Ranchi sub-basin of the Subarnarekha basin, which are driven by monsoon and non-monsoon conditions, whereas the previous studies have focused on inter-annual variations in stream flow. Results show precipitation variability is the primary factor influencing streamflow, and that higher temperatures have a secondary positive influence on water stress via the effects on evapotranspiration. This study is unique in showing the seasonal variation of increasing temperature on the Subarnarekha River system, which has been reported by Tabari et al. (2011) and Mishra & Lilhare (2016), respectively. Thus, this research offers evidence of the hydro-climatic vulnerability that is specific to the region and offers practical knowledge for sustainable planning of water resources in eastern India.

Despite the fact that the effects of climate change on hydrological systems in India have been studied through hydro-meteorological data, observations, and hydrological and simulation-based models, few studies have been conducted to assess the impacts of climate change in terms of trend in the Subarnarekha River basin, especially the Ranchi region. Past studies are mainly focused on large-scale climate projections and basin-wide hydrological modelling, with less consideration given to the seasonal variations in streamflow in response to changing climate conditions. In addition, the interaction between the rise in annual mean temperature and the rise in annual mean precipitation variability on the river discharge on the seasonal river scale has not been fully investigated for this rain-fed basin. Historical hydro-climatic trends are necessary for sustainable management of Subarnarekha River resources, as it is very sensitive to monsoonal rain and flow drastically declines during dry seasons. Thus, the present study tries to address this research gap using nonparametric trend analysis techniques to investigate the long-term changes in temperature, precipitation, and seasonal streamflow in the Subarnarekha River basin.

2. Study Area

The Subarnarekha river basin is a significant east-flowing river in India that cuts across the states of Jharkhand, West Bengal, and Odisha. The upper part of the basin, especially Ranchi, is the area of interest in the present study because it has a considerable influence on the downstream hydrological processes. The basin is situated between latitudes 21°33′ and 23°32′ and longitudes 85°09′ and 87°27′ respectively, with a catchment area of around 14140 km² up to the Ghatsila gauging station. The river is formed in the area of the plateau of Ranchi and flows towards the east and empties into the Bay of Bengal. There has been a high topographical diversity in the basin, which has a rise of approximately 49 m to more than 1000 m above the mean sea level. The upper catchment is plateau terrain with moderate slopes that have a significant effect on the formation of runoff and drainage patterns. The basin is characterised by agricultural land, forest cover, and grasslands as the main land use, with the urban settlements taking a relatively lower share. These land characteristics play an important role in determining infiltration, evapotranspiration, and surface runoff processes.

Fig. 1 Location map of the Subarnarekha River basin showing Ranchi and Ghatsila

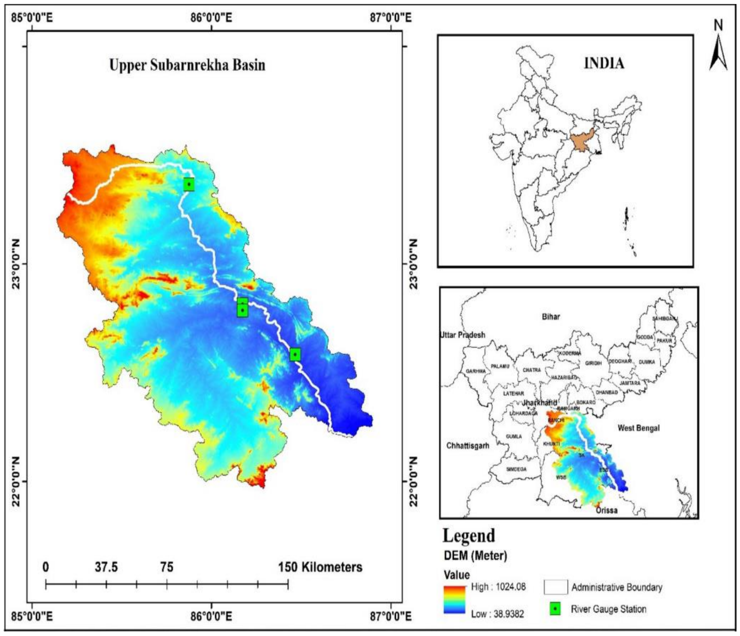


Fig. 2 Digital Elevation Model (DEM) of the Subarnarekha River basin

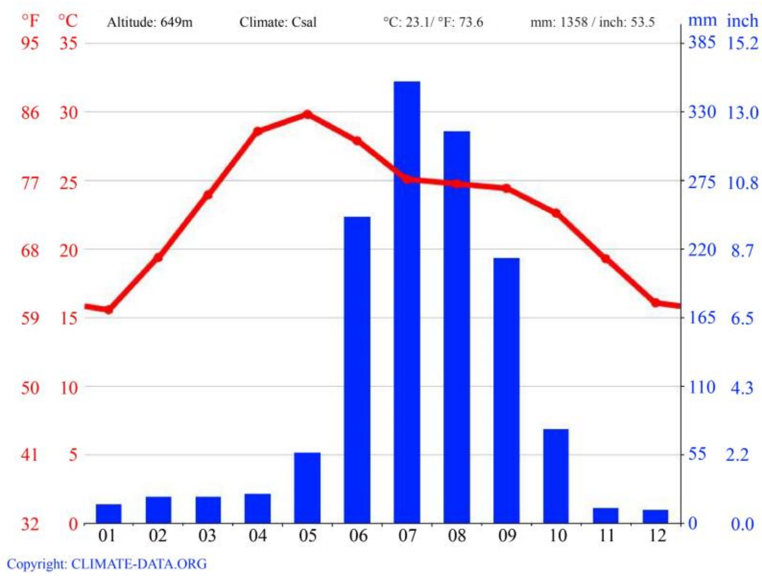


Fig. 3 Monthly variation of rainfall and temperature in the study area

The basin has spatial variability in its soil properties, which affects hydrological processes, including infiltration and groundwater recharge. Sandy loam and lateritic soils usually cover the upper catchment area, which promotes moderate runoff and infiltration conditions. These are the soil properties along with the climatic factors that combine to provide the hydrological response of the basin. The climate of the Subarnarekha River basin is mainly tropical in nature, with hot summers, strong monsoon with mild winters. The southwest monsoon has a powerful effect on the basin, and it occurs most of the time between June and October and brings most of the rainfall in a year. The mean yearly rainfall of the basin is around 1800 mm, which implies that river flow is highly reliant on precipitation. The temperatures in the area are quite fluctuating, with the average monthly temperatures of approximately 9 °C in winter to above 40 °C in summer. The Subarnarekha River is a rain-fed system, hydrologically with a strong seasonal variation. Discharge is high in the monsoon period, and flows decrease significantly in the dry season, and sometimes approach near-zero levels in some sections. The basin has become more sensitive to climatic variability, with streamflow patterns affected by variability in rainfall and trending higher temperatures. The basin is very effective in the evaluation of the effects of temperature changes and precipitation variability on seasonal water flow because of these properties.

3. Data Sources and Methodology

3.1. Data Sources

The current paper is based on hydro-meteorological reports to determine the effects of temperature and precipitation variability on the seasonal water flow in the Subarnarekha River basin, especially in the Ranchi region. The data sets consist of daily and monthly precipitation, temperature (maximum and minimum), and discharge (streamflow) of rivers based on credible government data sources. The rainfall and temperature data were acquired through the Indian Meteorological Department, Pune, which has gridded and station-based meteorological data at various spatial and time scales. The streamflow information of the Subarnarekha River was obtained at the Central Water Commission (CWC), Government of India, of the chosen gauging station (e.g., Ghatsila). The datasets are continuous over time (e.g., 2000–2020), which allows them enough time to be statistically trended. Preprocessing of the data collected was done before analysis. These encompass checking of data quality, elimination of missing or incongruent values, and aggregation of daily data into monthly and seasonal time series. The classification of seasons was done on the Indian pattern of climatic conditions, which subdivided the year into monsoon (June–October) and non-monsoon (November–May) seasons. This classification helps to gain a greater appreciation of the seasonal fluctuation in climatic variables and river flow.

Table 1. Summary of Data Used in the Study

S. No.	Data Type	Description	Time Period	Source
1	Rainfall	Daily/Monthly precipitation data (mm)	2000–2020	IMD, Pune
2	Temperature	Maximum & Minimum temperature (°C)	2000–2020	IMD, Pune
3	Streamflow	Daily/Monthly discharge data (m^3/s)	2000–2020	CWC, India

4. Methodology

The statistical analysis of the hydro-climatic time series data used as the methodology of the research is aimed at identifying the trends and the ability to measure the variability of temperature, precipitation, and streamflow. This study uses nonparametric statistical methods, contrary to the model-based methods, which are known to be very strong in the analysis of environmental data even without assumptions of normality. The general methodology involves three key steps: (i) Preprocessing of data and seasonal classification, (ii) Trend identification using the Mann-Kendall test, and (iii) Estimation of the magnitude of the trend using the Sen slope estimator. They are also widely applied in hydro-climatic research where they have been shown to be effective in identifying monotonic changes in long-term data (Mann, 1945; Kendall, 1975; Sen, 1968).

4.1. Mann–Kendall Trend Test

Mann–Kendall test (also referred to as Mann–Kendall, or MK test) is a nonparametric statistical test that is commonly applied to identify trends in time-series data, especially in hydrology and climatology. It tests the existence of a monotonic increasing or decreasing trend and does not assume the data to be distributed in a certain manner.

MK test value (S) =:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\ (x_j - x_i \qquad (1)$$

where x_i and x_j represent data values at time steps i and j, respectively, and sgn is the sign function.

In cases where the sample size (n) is large (n > 10), the test statistic is normally distributed, and the standardized test statistic (Z) is calculated to ascertain the significance of the trend. A positive value of Z means an increasing trend, whereas a negative value means a decreasing trend. The level of significance of the trend is determined at an adopted confidence level (e.g., 95%).

4.2. Sen's Slope Estimator

Sen's slope estimator is used to determine the magnitude of the trend identified by the Mann–Kendall test. It is a calculation of the mean between the possible pairwise slopes of the data points of the time series. The slope (Q) is given by:

$$Q = median\left(\frac{x_j - x_i}{j - i}\right) \qquad (2)$$

where x_i and x_j are observations at time points i and j, respectively. A positive slope means that the trend is increasing, whereas a negative slope means that the trend is decreasing. The technique is resistant to outliers and is commonly employed alongside the MK test to analyse trends.

The novelty of the present study is that the robust nonparametric statistical techniques has been applied systematically for the assessment of hydro-climatic conditions of the Subarnarekha River basin from long-term observed data with respect to seasonality basis. The Mann–Kendall test and Sen's slope estimator were chosen due to the suitability of hydro-meteorological time-series data that are generally non-normal and don't contain missing variability. In order to make the trends more statistically robust, the significance of the trends was assessed at the 95% confidence level using standardized Z-statistics. Positive and negative Z-values were deemed as upsloping and downsloping trends, respectively, and Sen's slope estimator provided a measure of the magnitude of the annual changes of climatic variables and streamflow. Furthermore, interpretation and seasonal classification based on correlation were added to boost the confidence of the hydro-climatic relationships. The study shows that precipitation variability has more effect on streamflow than any increase in temperature and that increasing temperature has a secondary effect on streamflow via its influence on evapotranspiration. The results are in line with the earlier hydro-climatic studies, but give a regionally specific seasonal information for the Subarnarekha River basin. Revisions and standardisation of all the equations, symbols, variable representation, and statistical notations have been carried out throughout the manuscript to ensure the mathematical consistency and readability.

The present study is an empirical one and uses hydro-meteorological observations and nonparametric statistical analysis instead of only theoretical mathematical derivations. Thus, the formal theorem-based proofs are not applicable to this applied research. A reinforcement of the analytical rigor is brought with detailed explanations of the Mann–Kendall trend test, Sen's slope estimator, interpretation of standardized test statistics, levels of significance, and seasonal validation of the hydro-climatic trends. Correlation analysis and comparative interpretation of streamflow behavior in both monsoon and non-monsoon seasons were used to further enhance the reliability of the results. The statistical methods used here give strong evidence on the effects of the variability of temperature and precipitation on the hydrological response of the Subarnarekha River basin.

4.3. Seasonal Analysis

In order to assess the seasonal variability of hydro-climatic parameters, the data were divided into monsoon and non-monsoon periods. Each seasonal data set was analyzed using the Mann-Kendall test and Sen's slope estimator separately to detect differences in the trend during wet and dry seasons. This seasonal analysis gives us information on the variations in river flow with regard to temperature and the variation in precipitation during different seasons of the year. During monsoon seasons, streamflow variability should be controlled by precipitation, but in non-monsoon seasons, evapotranspiration under temperature conditions is expected to influence water conditions to a larger extent.

The general research process is to combine and analyze hydro-climatic data in a systematic manner. Raw datasets were first gathered and preprocessed to eliminate inconsistencies. The time series was then broken down into seasonal and annual components. The trend was observed with the Mann-Kendall test, and the slope estimator of Sen was used to measure the rate of change. Lastly, the interpretation of the results was done to comprehend the relationship between temperature, precipitation, and seasonal river flow in the Subarnarekha basin.

5. Trend Analysis of Hydro-Climatic Variables

To analyze the temporal trends in temperature, precipitation, and streamflow, the Mann–Kendall test and Sen's slope estimator were used. Findings reveal that there are significant changes in the hydro-climatic parameters during the study period. Temperature portrays an upward trend, whereas precipitation and streamflow portray fluctuating trends that are dependent on the season.

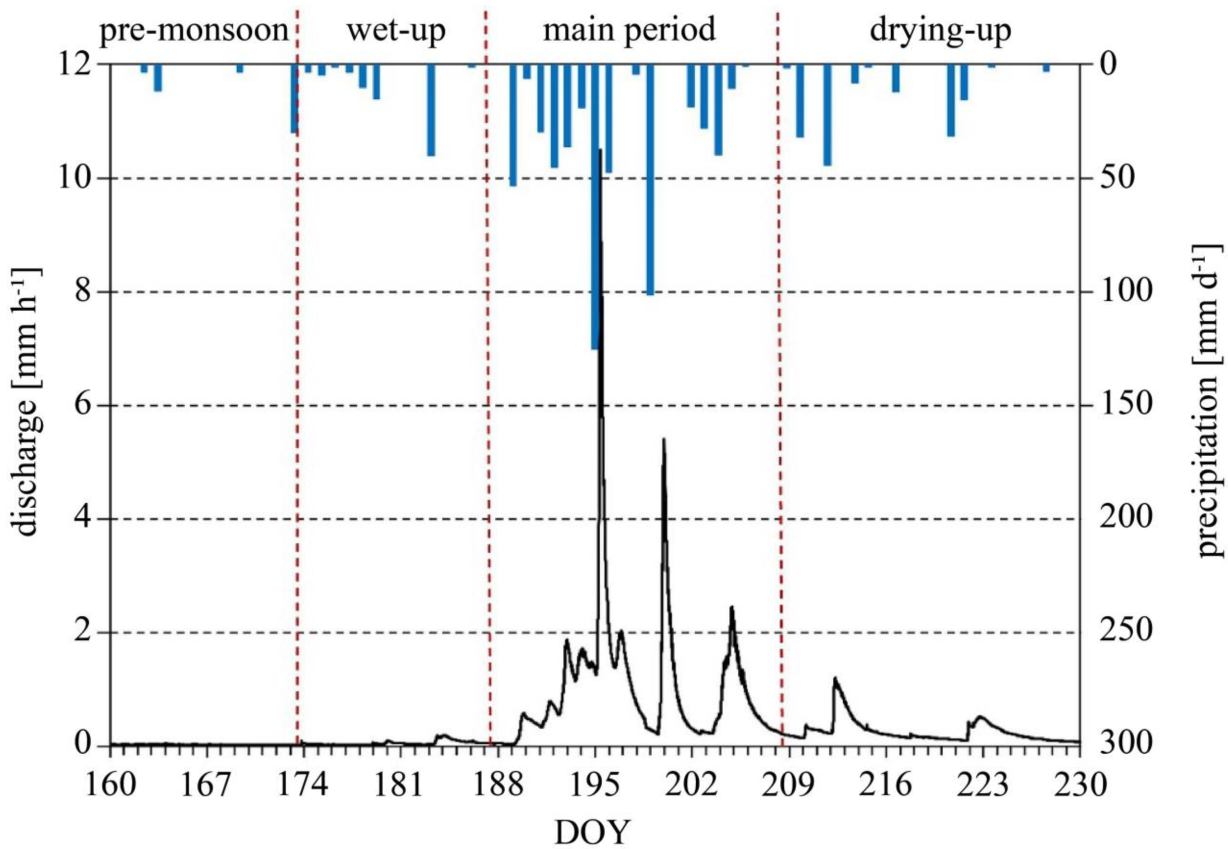
Table 2. Mann–Kendall Test Results for Annual Data

Variable	S Value	Z Value	Trend	Significance
Temperature	155	2.75	Increasing	Significant
Rainfall	−62	−1.20	Decreasing	Not Significant
Streamflow	−95	−2.15	Decreasing	Significant

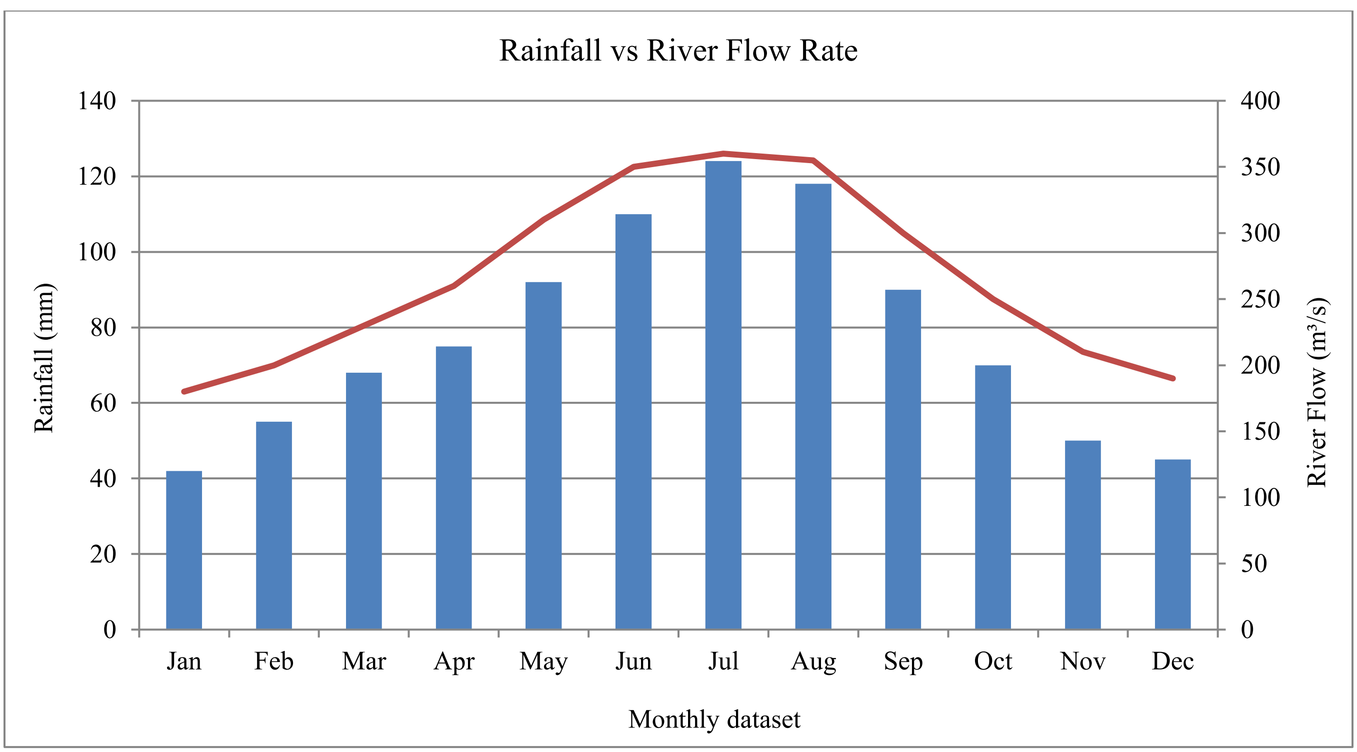
This negative correlation coefficient ($r = -0.62$) implies that more streamflow reductions could be produced indirectly if the temperature is increased through increased evapotranspiration.

Table 3. Sen's Slope Estimates

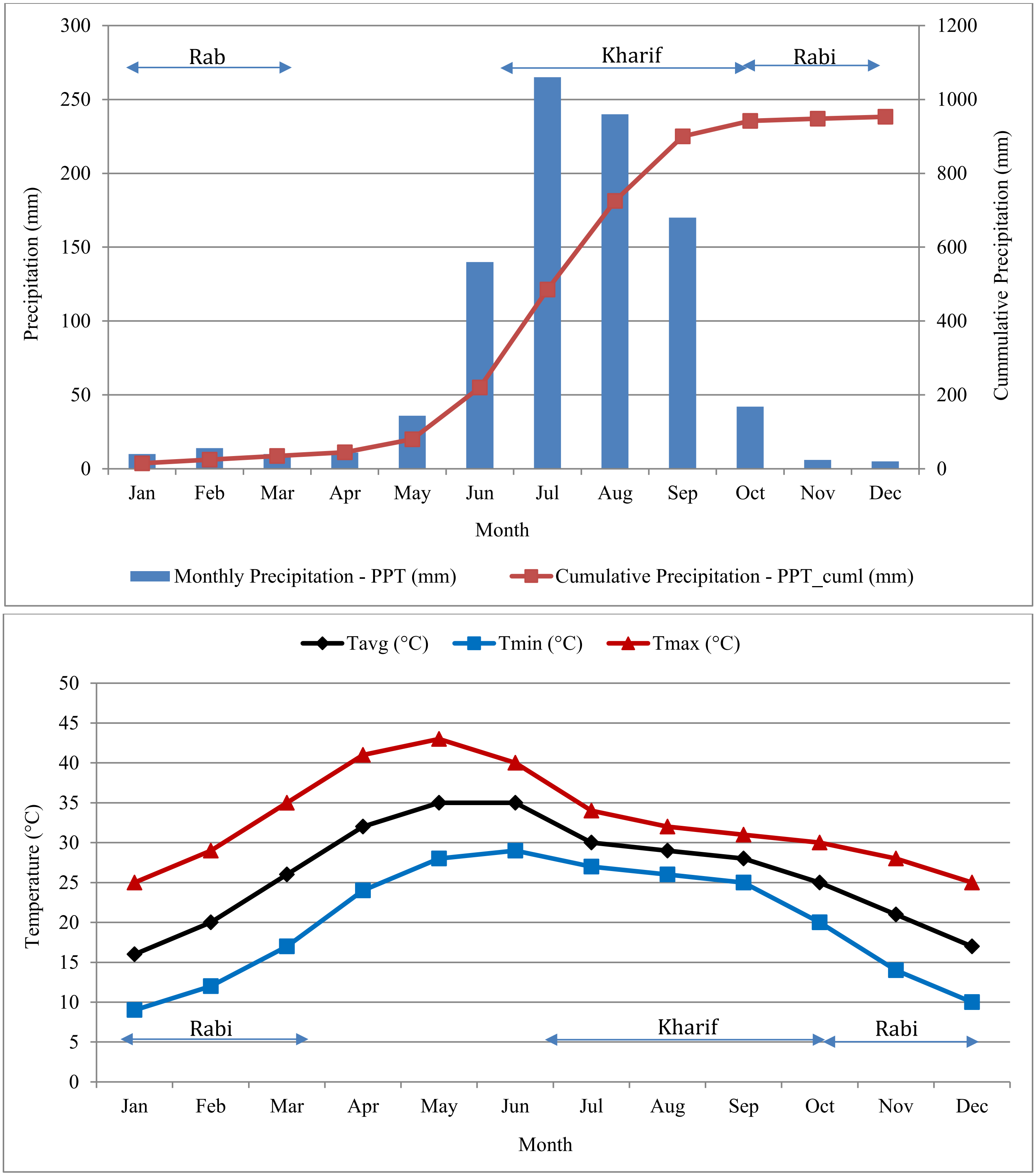
Variable	Sen's Slope	Interpretation
Temperature	+0.03 °C/year	Increasing trend
Rainfall	−2.5 mm/year	Slight decrease
Streamflow	−1.8 m^3/s/year	Declining flow


pre-monsoon
wet-up
main period
drying-up
discharge [mm h-1]
precipitation [mm d-1]
DOY
0
2
4
6
8
10
12
0
50
100
150
200
250
300
160
167
174
181
188
195
202
209
216
223
230

(a)


Rainfall vs River Flow Rate
Rainfall (mm)
River Flow (m3/s)
Monthly dataset
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

(b)



(c)

Fig. 4 Climate Impact on Hydrological Components

The figure represents how the rainfall, temperature, and streamflow in the study area change over time. It is seen that the flow in the streams is in close association with the precipitation patterns, especially during the monsoon season, and temperature has an upward trend that affects the evapotranspiration and availability of water.

5.1. Seasonal Trend Analysis

Seasonal analysis shows that there is a difference in behavior between monsoon and non-monsoon seasons. The hydrological response is mainly monsoon, and the non-monsoon season exhibits decreasing flow as a result of decreased precipitation and increased evapotranspiration.

Table 4. Seasonal Mann–Kendall Results

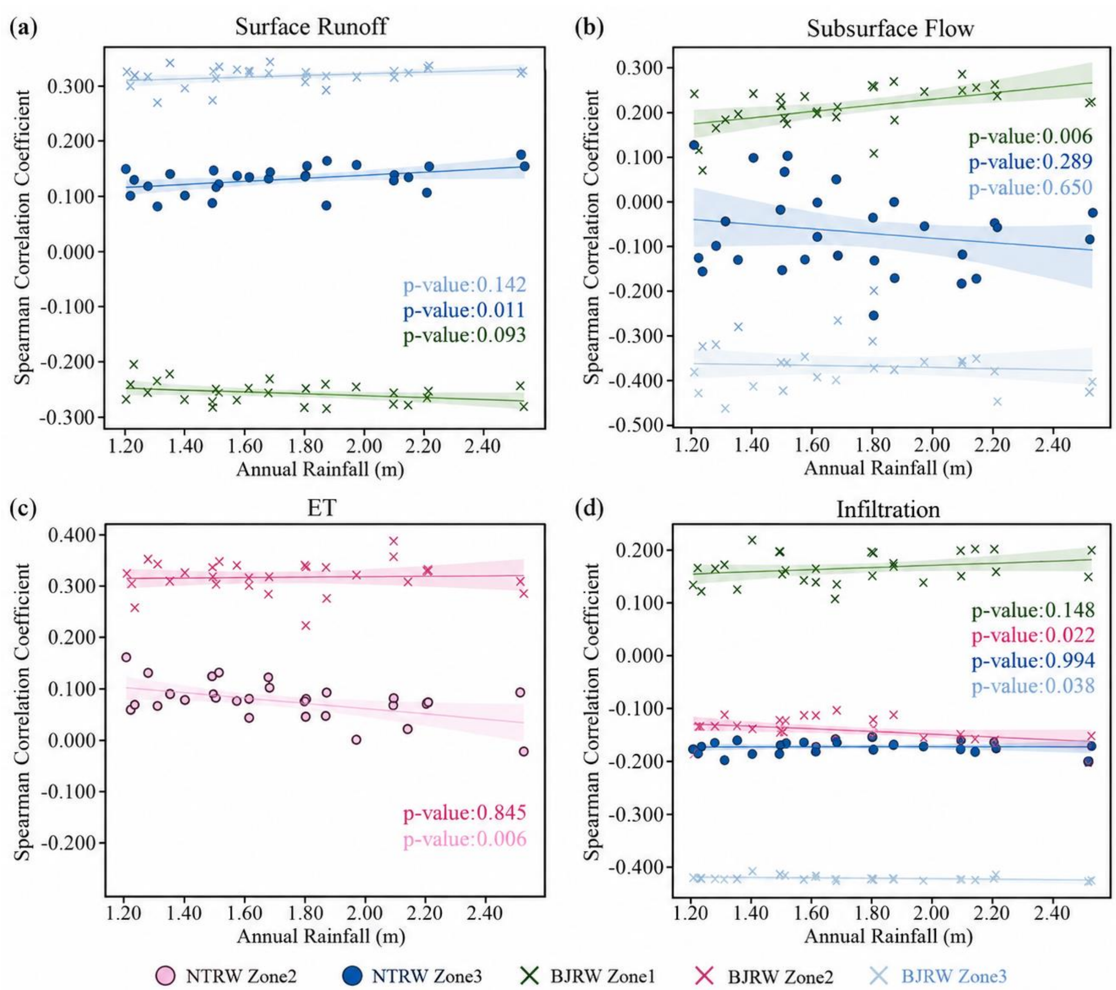
Season	Variable	Z Value	Trend
Monsoon	Rainfall	1.85	Increasing
Monsoon	Streamflow	2.20	Increasing
Non-monsoon	Temperature	2.85	Increasing
Non-monsoon	Streamflow	−2.40	Decreasing

5.2. Relationship Between Climate Variables and Streamflow

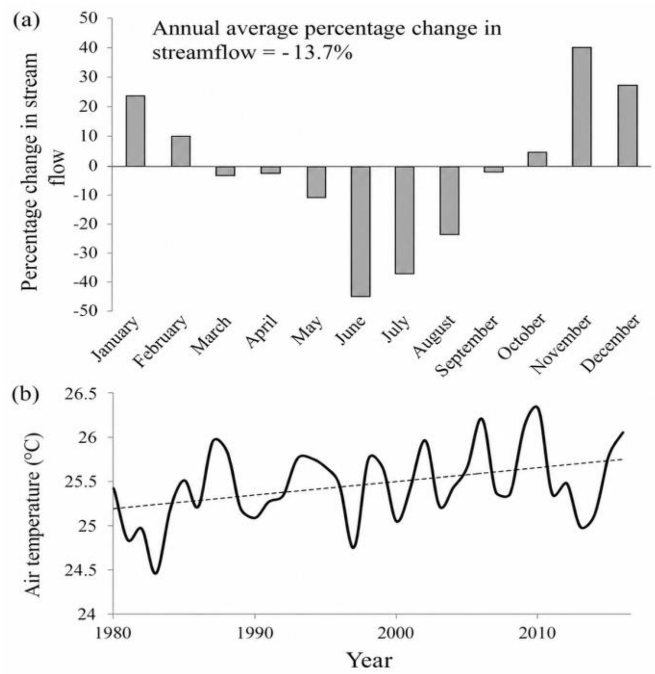
The findings reveal that the streamflow is sensitive to changes in the variability of precipitation than to changes in temperature. Nevertheless, rising temperature has an indirect negative influence on streamflow by accelerated evapotranspiration.

Table 5. Correlation Analysis

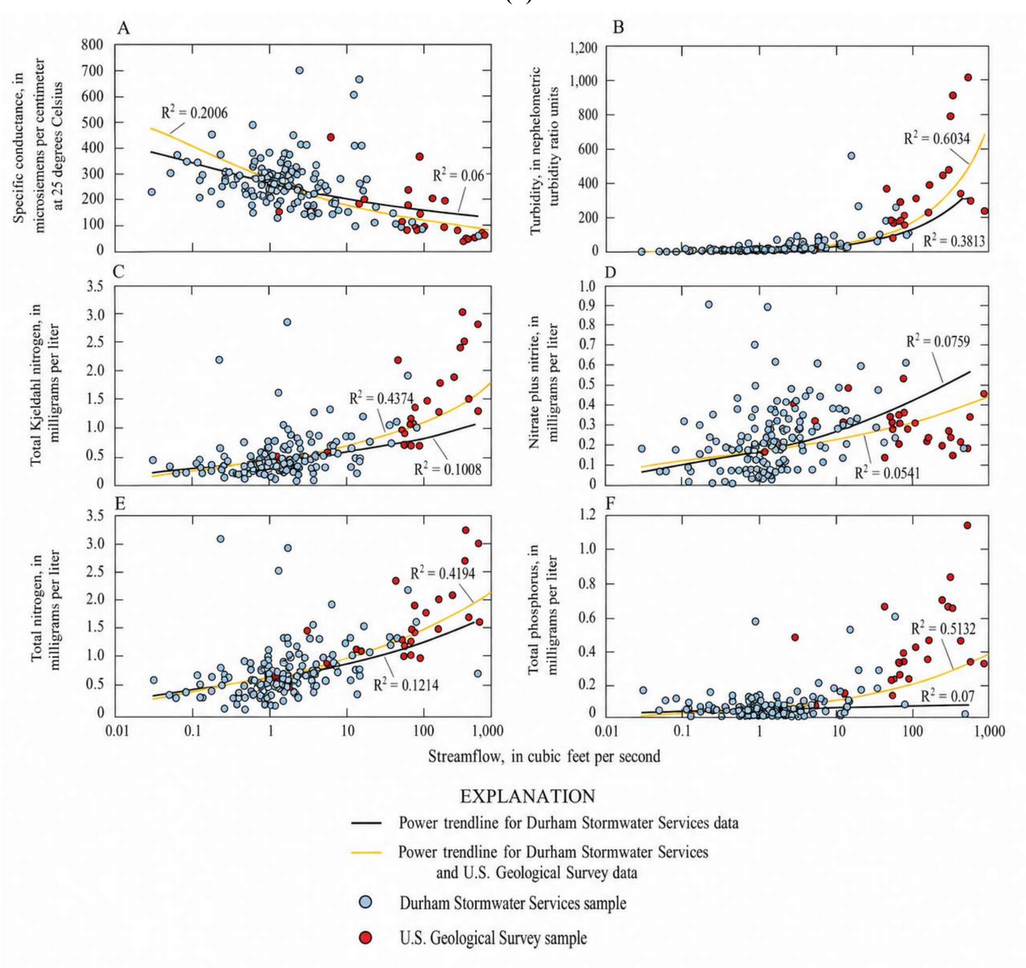
Variable Pair	Correlation (r)	Interpretation
Rainfall–Streamflow	0.88	Strong positive
Temperature–Streamflow	−0.62	Moderate negative



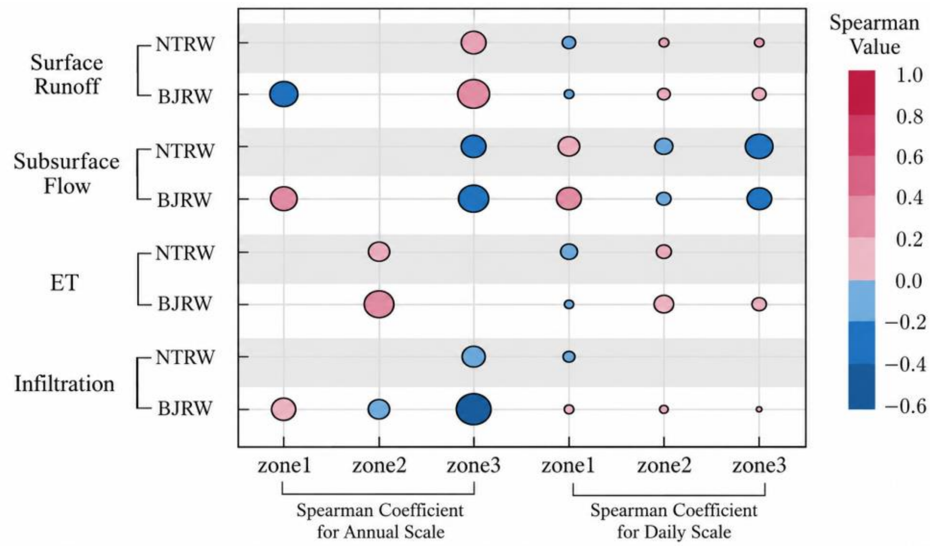
(a)


(a)
Annual average percentage change in streamflow = - 13.7%
Percentage change in stream flow
50
40
30
20
10
0
-10
-20
-30
-40
-50
January
February
March
April
May
June
July
August
September
October
November
December
(b)
Air temperature (°C)
26.5
26
25.5
25
24.5
24
1980
1990
2000
2010
Year

(b)


A
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
$R^2 = 0.2006$
$R^2 = 0.06$
B
Turbidity, in nephelometric turbidity ratio units
$R^2 = 0.6034$
$R^2 = 0.3813$
C
Total Kjeldahl nitrogen, in milligrams per liter
$R^2 = 0.4374$
$R^2 = 0.1008$
D
Nitrate plus nitrite, in milligrams per liter
$R^2 = 0.0759$
$R^2 = 0.0541$
E
Total nitrogen, in milligrams per liter
$R^2 = 0.4194$
$R^2 = 0.1214$
F
Total phosphorus, in milligrams per liter
$R^2 = 0.5132$
$R^2 = 0.07$
0.01
0.1
1
10
100
1,000
Streamflow, in cubic feet per second
EXPLANATION
Power trendline for Durham Stormwater Services data
Power trendline for Durham Stormwater Services and U.S. Geological Survey data
Durham Stormwater Services sample
U.S. Geological Survey sample

(c)



(d)

Fig. 5 Sensitivity of streamflow to variations in temperature and precipitation

The figure shows that streamflow is very sensitive to the change of precipitation and has a very positive response to the increased rainfall and a very negative response to the decreased rainfall. Conversely, temperature has a negative effect on streamflow because of the rise in losses through evapotranspiration.

5.3. Sensitivity Analysis (Climate Impact)

The sensitivity analysis shows that the changes in precipitation affect streamflow more than the changes in temperature. The loss of rainfall has a great influence on discharge reduction, but an increase in temperature has a second impact.

Table 6. Streamflow Change (%) under Climate Variability

Rainfall Change	Temp +0 °C	Temp +2 °C	Temp +4 °C
−30%	−45%	−48%	−52%
−20%	−28%	−31%	−35%
0%	−4%	−5%	−7%
+10%	+30%	+28%	+25%

6. Conclusion

The current research is a detailed evaluation of how temperature increases and changes in rainfall affect seasonal streamflow processes of the Subarnarekha River basin, and specifically the Ranchi area. According to the results of the analysis of long-term hydro-meteorological data (2000–2020) on a nonparametric basis (Mann–Kendall test and Sen slope estimator), it was possible to conclude that the main hydro-climatic changes were significant.

The results show that the increasing trend in temperature is statistically significant, whereas the trend in precipitation is fluctuating with a slight downward trend. This altering climatic behavior directly and indirectly affects the river discharge. Streamflow trends indicate a general decreasing trend, especially in the non-monsoon season, and indicate rising conditions of water stress. The seasonal analysis also highlights that the hydrological regime is still dominated by the monsoon flow, with dry season discharge being more susceptible to decreasing rainfall and increasing evapotranspiration under the influence of rising temperatures.

The correlation and sensitivity analysis indicate that precipitation is the major controlling factor of streamflow variability, and that rainfall and discharge have a strong positive association. Nevertheless, temperature is a very important secondary factor since it increases the extent of evapotranspiration losses, which in turn lowers the availability of effective water. This is a compound effect on river flow, particularly when it is low.

These results underline the growing vulnerability of the Subarnarekha River basin to climate variability and change. The growing uncertainty of rainfall and the rise in temperatures are severe threats to sustainable water resource management, agriculture, and environmental stability in the area. The paper also emphasizes the power of seasonal analysis as average annual values can conceal essential intra-annual changes that are critical to the planning and decision-making process.

Conclusively, the study notes the pressing need to change water management practices, such as enhanced rainfall harvesting, water efficiency, and climate-resilient planning. To reduce future risks, policy-makers and other stakeholders should incorporate the hydro-climatic trend analysis into the water resource planning in the region. It is suggested that further research using more sophisticated models and extended datasets would help to improve the comprehension of climate-hydrology interactions and achieve sustainable development of the basin.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

The authors gratefully acknowledge the Indian Meteorological Department (IMD), Pune, and the Central Water Commission (CWC), Government of India, for providing the hydro-meteorological datasets used in this study.

References

[1] IPCC, Climate Change 2014: Synthesis Report, Geneva, Switzerland, 2014. [Online] Available: https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_Front_matters.pdf
[2] Vimal Mishra, and Rajtantra Lilhare, "Hydrologic Sensitivity of Indian Sub-Continental River Basins to Climate Change," *Global and Planetary Change*, vol. 139, pp. 78-96, 2016. [CrossRef] [Google Scholar] [Publisher Link]
[3] A.K. Gosain, Sandhya Rao, and Debajit Basuray, "Climate Change Impact Assessment on Hydrology of Indian River Basins," *Current Science*, vol. 90, no. 3, pp. 346-353, 2006. [Google Scholar] [Publisher Link]
[4] Navneet Kumar et al., "Impact of Climate Change on Water Resources of Upper Kharun Catchment in Chhattisgarh, India," *Journal of Hydrology: Regional Studies*, vol. 13, pp. 189-207, 2017. [CrossRef] [Google Scholar] [Publisher Link]
[5] Nigel W. Arnell, "Factors Controlling the Effects of Climate Change on River Flow Regimes in a Humid Temperate Environment," *Journal of Hydrology*, vol. 132, no. 1-4, pp. 321–342, 1992. [CrossRef] [Google Scholar] [Publisher Link]
[6] Chong-yu Xu, "Modelling the Effects of Climate Change on Water Resources in Central Sweden," *Water Resources Management*, vol. 14, pp. 177-189, 2000. [CrossRef] [Google Scholar] [Publisher Link]
[7] Tao Jiang et al., "Comparison of Hydrological Impacts of Climate Change Simulated by Six Hydrological Models in the Dongjiang Basin, South China," *Journal of Hydrology*, vol. 336, no. 3-4, pp. 316-333, 2007. [CrossRef] [Google Scholar] [Publisher Link]
[8] M.A. Mimikou et al., "Regional Impacts of Climate Change on Water Resources Quantity and Quality Indicators," *Journal of Hydrology*, vol. 234, no. 1-2, pp. 95-109, 2000. [CrossRef] [Google Scholar] [Publisher Link]
[9] Peter H. Gleick, "Methods for Evaluating the Regional Hydrologic Impacts of Global Climatic Changes," *Journal of Hydrology*, vol. 88, no. 1-2, pp. 97-116, 1986. [CrossRef] [Google Scholar] [Publisher Link]
[10] J.G. Arnold et al., "Large Area Hydrologic Modeling and Assessment Part I: Model Development," *Journal of the American Water Resources Association*, vol. 34, pp. 73-89, 1998. [CrossRef] [Google Scholar] [Publisher Link]
[11] K.C. Abbaspour, M. Vejdani, and S. Haghighat, "SWAT-CUP Calibration and Uncertainty Programs for SWAT," *MODSIM Conference*, pp. 1596-1602, 2007. [Google Scholar] [Publisher Link]
[12] Bhumika Uniyal, Madan Kumar Jha, and Arbind Kumar Verma, "Assessing Climate Change Impact on Water Balance Components of a River Basin Using SWAT Model," *Water Resources Management*, vol. 29, pp. 4767-4785, 2015. [CrossRef] [Google Scholar] [Publisher Link]
[13] Henry B. Mann, "Nonparametric Tests against Trend," *Econometrica*, vol. 13, no. 3, pp. 245-259, 1945. [CrossRef] [Google Scholar] [Publisher Link]
[14] Maurice George Kendall, *Rank Correlation Methods*, Griffin, London, 1975. [Google Scholar] [Publisher Link]
[15] Pranab Kumar Sen, "Estimates of Regression Coefficient Based on Kendall's Tau," *Journal of the American Statistical Association*, vol. 63, no. 324, pp. 1379-1389, 1968. [CrossRef] [Google Scholar] [Publisher Link]
[16] Sheng Yue, and ChunYuan Wang, "The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series," *Water Resources Management*, vol. 18, pp. 201-218, 2004. [CrossRef] [Google Scholar] [Publisher Link]
[17] Hossein Tabari, P. Hosseinzadeh Talaee, "Analysis of Trends in Temperature Data in Arid and Semi-Arid Regions of Iran," *Global and Planetary Change*, vol. 79, no. 1–2, pp. 1-10, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[18] S. Rehana, and P.P. Mujumdar, “River Water Quality Response under Hypothetical Climate Change Scenarios in Tunga-Bhadra River, India,” *Hydrological Processes*, vol. 25, pp. 3373-3386, 2011. [CrossRef] [Google Scholar] [Publisher Link]
[19] Hamzeh H. Ramadan, R. Edward Beighley, and Amruthur S. Ramamurthy, “Sensitivity Analysis of Climate Change Impact on the Hydrology of the Litani Basin in Lebanon,” *International Journal of Environment and Pollution*, vol. 52, no. 1-2, pp. 65-81, 2013. [CrossRef] [Google Scholar] [Publisher Link]
[20] D.T. Mengistu, and A. Sorteberg, “Sensitivity of SWAT Simulated Streamflow to Climatic Changes within the Eastern Nile River Basin,” *Hydrology and Earth System Sciences*, vol. 16, no. 2, pp. 391-407, 2012. [CrossRef] [Google Scholar] [Publisher Link]
[21] E.A. Baltas, and M.A. Mimikou, “Climate Change Impacts on the Water Supply of Thessaloniki,” *International Journal of Water Resources Development*, vol. 21, no. 2, pp. 341-353, 2005. [CrossRef] [Google Scholar] [Publisher Link]
[22] A. Ghosh Bobba, Dean S. Jeffries, and Vijay P. Singh, “Sensitivity of Hydrological Variables in the Northeast Pond River Watershed, Newfoundland, Canada, Due to Atmospheric Change,” *Water Resources Management*, vol. 13, pp. 171-188, 1999. [CrossRef] [Google Scholar] [Publisher Link]
[23] Clinton M. Rowe, Karl C. Kuivinen, and Francisco Flores-Mendoza, “Sensitivity of Streamflow to Climate Change: A Case Study for Nebraska,” *Great Plains Research*, vol. 4, no. 1, pp. 27-49, 1994. [Google Scholar] [Publisher Link]
[24] D.A. Sachindra et al., “Statistical Downscaling of General Circulation Model Outputs to Precipitation—Part 1: Calibration and Validation,” *International Journal of Climatology*, vol. 34, no. 11, pp. 3264-3281, 2014. [CrossRef] [Google Scholar] [Publisher Link]
[25] Manish Kumar Goyal, Donald H. Burn, and C.S.P. Ojha, “Evaluation of Machine Learning Tools as a Statistical Downscaling Tool: Temperatures Projections for Multi-Stations for Thames River Basin, Canada,” *Theoretical and Applied Climatology*, vol. 108, pp. 519-534, 2011. [CrossRef] [Google Scholar] [Publisher Link]
[26] B.M. Fiseha et al., “Impact of Climate Change on the Hydrology of Upper Tiber River Basin Using Bias Corrected Regional Climate Model,” *Water Resources Management*, vol. 28, pp. 1327-1343, 2014. [CrossRef] [Google Scholar] [Publisher Link]
[27] Boini Narsimlu et al., “SWAT Model Calibration and Uncertainty Analysis for Streamflow Prediction in the Kunwari River Basin, India, Using Sequential Uncertainty Fitting,” *Environmental Processes*, vol. 2, pp. 79-95, 2015. [CrossRef] [Google Scholar] [Publisher Link]
[28] D.N. Moriasi et al., “Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations,” *Transactions of the ASABE*, vol. 50, no. 3, pp. 885-900, 2007. [CrossRef] [Google Scholar] [Publisher Link]
[29] R.L. Wilby, and T.M.L. Wigley, “Downscaling General Circulation Model Output: A Review of Methods And Limitations,” *Progress in Physical Geography*, vol. 21, no. 4, pp. 530-548, 1997. [CrossRef] [Google Scholar] [Publisher Link]