Chapter

Trend Analysis of Streamflow and Rainfall in the Kosi River Basin of Mid-Himalaya of Kumaon Region, Uttarakhand

Utkarsh Kumar, Rashmi, Dhirendra Kumar Singh, Suresh Chandra Panday, Manoj Parihar, Jaideep Kumar Bisht and Lakshmi Kant

Abstract

Due to climate change phenomenon and substantial decrease in water resources, analyzing the streamflow trend is of significant importance. In the present study, investigation was carried out to find rainfall and streamflow trends in the Kosi river watershed at different timescales from 1986 to 2016. Kosi river is one of the principal rivers in the Kumaon region. The different methods employed for trend detection of streamflow and rainfall were the Mann–Kendall (MK) test and the Sen's slope (SS) estimator. Results showed a statistically significant decreasing trend in pre-monsoonal and annual rainfall with a Sen's slope of -2.27 and -1.49 mm/year, respectively. The decreasing trends in pre-monsoon, post-monsoon, and winter streamflow were found during 1986–2016, which were not statistically significant. The results of the study help in understanding the variation and availability of rainfall and streamflow in different seasons of the year and motivate to adopt effective water management and agricultural practices for rainfed hills.

Keywords: Himalayas, climate change, streamflow, trend analysis, statistical test

1. Introduction

The prominent challenge being faced by the Indian Himalayan region (IHR) is climate change [1]. Study in connection with climate change is of great importance for the Kumaon region of Uttarakhand [2]. Changing temperature and precipitation patterns and their impact on water resources, glaciers, ecology, and agriculture are the results of changing climate over the Himalayas region [3]. Several researchers have studied the impact of climate change on Himalayan region and found that temperature is showing an increasing trend in the western Himalayas, while precipitation is showing a decreasing trend during winter and summer periods [4–8]. The nonuniform distribution of rainfall in the mountains results in differential rainfall trends within small distances [9]. For example, the central Himalayas receives 80% of annual precipitation due to the Indian summer monsoon (ISM), while the western Himalayas receives ∼30% due to western disturbances [10–12].

It has been observed that low rainfall or shift in rainfall patterns at different altitudes had resulted in crop failure, declining in food grain yield. It was reported that traditional crops will soon be replaced with cash crops in the Kumaon region [13].

The impact of change on land use and land cover (LULC) plays an important role in climate change on local to regional scale. Increased urbanization or changes in LULC is known to alter changes in LULC directly affecting the rainfall and mesoscale convective system [14–19]. Therefore, understanding rainfall variability in the Himalayan region becomes extremely critical for holistic Himalayan spatial planning for water resource management.

A growing literature suggests that the Western Himalayas region is witnessing above normal increasing temporal trend in temperature and decreasing trend in rainfall. The worst case is the large-scale devastation owing to the Nanda Devi glacier burst in Uttarakhand's Chamoli district, which triggered a mass of snow, ice, and rocks falling speedily down a mountainside known as an avalanche that led to the water level rising in the river Rishiganga and heavy flood in Dhauliganga [19].

Finding variability and trend in long-term historical streamflow is of crucial importance for the appropriate management and planning of water resources. Some of the important reasons for trend analysis of streamflow are to understand the design flow rate for hydraulic structure and assigning water rights beyond the capacity of river supply.

This study applies Mann–Kendall (MK) test, the Sen's slope (SS) estimator, and nonparametric tests for evaluating the trends in streamflow time series. The MK checks whether the trend increases or decreases with time by examining whether to reject the null hypothesis or accept the alternative hypothesis. SS indicates the median of all pairwise slope values of a set of observed data. These two parameters have been employed in several studies for hydrological assessment of trends over various regions of globe for last decade.

There are several factors that impact the hydrology of a river basin, such as land use, climate change, and hydraulic infrastructure management [20, 21]. Therefore, investigating the hydrological characteristics from the historical time series of discharge data is considered one of the most important objectives in the field of water resource planning [22]. Salarijazi [23] reported that in several published research studies, the hydrological time series from different regions describe significant non-consistency or non-stationary. Due to this concern, trend analysis and change point detection in streamflow time series and other climatic variables (rainfall, evapotranspiration, and temperature) have been studied by many researchers in different watersheds or river basins at different time scales throughout the globe. Hyvärinen [24] analyzed streamflow data from 1913 to 2008 using Mann–Kendall test. He reported a significant decrease in high flow trend in Hawaii. Trend analysis and change point detection are two important tests, which have been popularly used at same time as mentioned by [23]. There is loss of spatial information of the hydro-climatic variable at large scale. Hence, it is recommended to analyze hydro-climatic variables at a small scale [24]. In the present study, the Kosi river watershed was undertaken to investigate the trend in measured streamflow data and the possible linkage for the observed changes in streamflow with rainfall and anthropogenic factors.

According to the published literature, no research study has addressed the trend in stream flow and rainfall, and their association with each other in the Kosi river watershed. Therefore, this study investigates trend of stream flow and rainfall data of this watershed at Ramnagar station during the last 31 years from 1986 to 2016.

2. Study area

Kosi River watershed extending between 29° 18′ N–79° 02′ E and 29° 51′ N–79° 51′ E is located in the Kumaon Lesser Himalaya (**Figure 1**). The Kosi River flows North–South in the northern and southern parts of the watershed while in the middle part, it follows the East–West trend incising the bedrocks and forming broad valleys, strath as well as unpaired terraces. The Kosi River mainly receives its water from several springs, aquifers, and tributaries in its course. Kosi river watershed falls within Almora and Nainital districts of Uttarakhand. The word Kosi refers to "river." Kosi is a Himalayan river that originates from Koshimool near Kausani and flows in the central part of Almora and the western part of Nainital district. River Kosi has the total catchment area of 3,420 sq. km. Kumaon is a mountainous region of eastern Uttarakhand in India. This region consists of the great Himalayan tract. Many rivers and their tributaries got their course from Kumaon. Four major rivers Kali, western Ramganga, Kosi, and Gaula make the surface drainage of Kumaon Himalaya. Kosi is the main river of Almora and Nainital districts. It is an important river flowing in the hills of the Kumaon region and drains central part of Almora and western part of Nainital district. The soil of the watershed falls under the loamy to clay categories. The major agricultural crops in the watershed are wheat, paddy, barley, pulses, and vegetables. The study area is also rich in the temperate horticulture fruit crops.

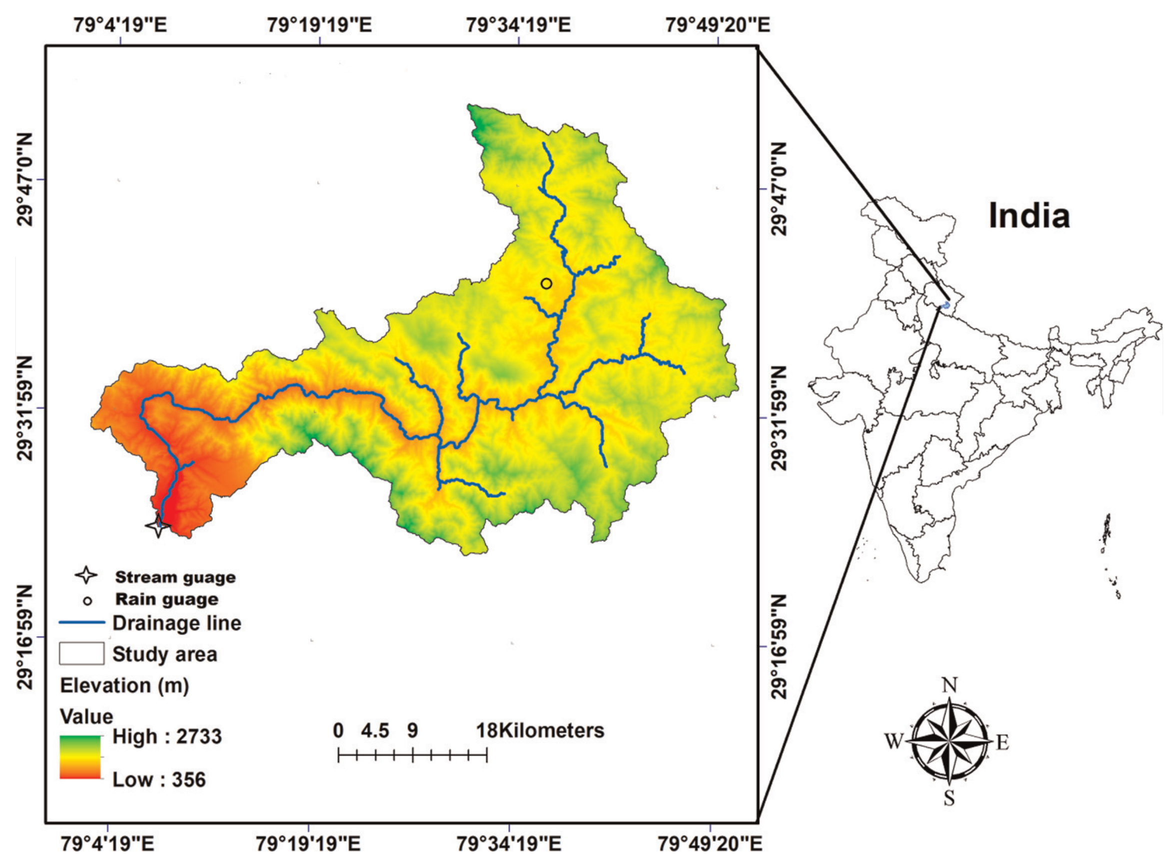

Figure 1.
Kosi river basin.

The average annual rainfall at different locations of the watershed ranges from 850 to 1100 mm. About 75% of annual rainfall is received between June and September due to southwest monsoon. The river Kosi is the major source of water supply to cities of Almora, Pithoragarh, and other cities in the Kumaon region of Uttarakhand.

3. Methodology

Streamflow data were collected from the executive engineer office, Ramnagar Irrigation Division, Nainital, Government of Uttarakhand. The 31 years of streamflow data were obtained for Ramnagar station near the outlet of the basin, which represents the entire river basin. The meteorological data were collected from ICAR–VPKAS, experimental farm Hawalbagh observatory (1986–2016). The limitation of this study is only this station has long-term data of rainfall. The watershed was delineated using 90-m-resolution SRTM data set in ArcGIS.

3.1 Parameters analyzed

The following parameters were analyzed from the data:

- Interannual monthly mean streamflow: monthly mean streamflow of the same month over the years (Jan 1986, Jan 1987, ———).
- Annual mean streamflow: mean of 12 monthly mean streamflow values from January to December for the gauging station.
- Seasonal streamflow: mean or monthly mean streamflow values for the pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November), and Winter (December–February) season.
- Annual seasonal and monthly rainfall.

3.2 Trend analysis

In this study, monthly streamflow trend analysis was evaluated using nonparametric approach namely Mann–Kendall (MK) [25–33] and Sen's slope estimator (magnitude of change) [34, 35]. MK test is a robust and widely accepted method in different hydro-climatic studies. Although the MK test is robust and widely accepted, it does not account for serial autocorrelation that usually occurs in a hydro-climatic variable time series. The presence of serial correlation in a time series may lead to wrong information because it enhances the probability of finding a significance when actually there is an absence of a significant trend. The trend of different hydro-climatic variables was evaluated at 5% and 10% significant levels (p value) as an indicator of trend strength

3.3 Mann–Kendall (MK) test

The MK test [29–30] computes statistics as Eq. (1)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}\left(x_j - x_k\right) \quad (1)$$

where S = normal distribution with the mean, n = number of observations (≥ 10), x_j is the jth observation, and sgn () is the sign function defined as sgn (α) = 1 if α >0; sgn (α) = 0 if α = 0; and sgn (α) = -1 if α<0.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad (2)$$

where n = number of tied groups having similar value for a data group and t_i = number of data in the ith tied group. The actual MK statistics are given as Eqs. (3–4)

$$Z = \frac{S+1}{\sqrt{V(S)}}, if S < 0 \quad (3)$$

$$Z = 0, if S = 0 \quad (4)$$

$$Z = \frac{S+1}{\sqrt{V(S)}}, if S < 0 \quad (5)$$

Two hypotheses are made, that is, H_o (null hypothesis) and H_1 (alternative hypothesis). H_o indicates no statistically significant trend, while H_1 indicates a statistically significant trend.

3.4 Sen's slope

Computation of the magnitude of change in a dataset is done by Sen's slope [36, 38]. This is a simple linear regression method, which can estimate the slope of the median of two different variables (dependent and independent). It can be estimated using Eq. (6)

$$d_{ijk} = \frac{X_{ij} - x_{ik}}{j - k} \quad (6)$$

where X_{ij} and x_{ik} are data values and j and k are the time series.

3.5 Coefficient of variation

The coefficient of variation (CV) is defined as the standard deviation divided by the mean. It was used in the study to reveal the interannual variation of an annual average of rainfall. It is calculated using Eq. (7)

$$CV = \frac{\sum_{i=1}^{n} \left(ARF_i - \overline{ARF}\right)^2}{\overline{ARF}} \quad (7)$$

where ARF_i is the annual rainfall in the year i and $\overline{ARF}$ is the average annual rainfall from 1986 to 2016 (n = 31).

4. Results and discussion

The descriptive statistics of 31-year monthly and seasonal streamflow data are shown in **Table 1** and **2**, respectively.

4.1 Statistical analysis of streamflow

To understand the hydrological characteristics of the Kosi river watershed, the overall behavior of streamflow and rainfall of the watershed, mean monthly rainfall, and mean monthly streamflow were analyzed over the periods from 1986 to 2016 (**Figure 2**). The mean monthly streamflow varies from 9.31 m^3/sec (May) to 92.37 m^3/sec (August). The month of high streamflow generally matches with the monsoon season, which clearly demarcates that streamflow in this area is largely dependent on rainfall. The maximum mean monthly streamflow occurs in August,

Months	Mean ± SD	Minimum (m^3/sec)	Maximum (m^3/sec)	CV (%)
January	14.33 ± 8.30	3.68	32.17	0.58
February	15.80 ± 8.14	4.14	33.11	0.52
March	14.03 ± 7.53	3.25	28.89	0.54
April	10.13 ± 6.19	2.37	23.76	0.61
May	9.31 ± 6.12	2.33	23.17	0.66
June	22.84 ± 31.25	1.91	153.30	1.37
July	66.47 ± 38.36	10.67	174.80	0.58
August	92.37 ± 44.70	23.00	235.86	0.48
September	78.36 ± 66.10	17.96	306.40	0.84
October	26.75 ± 11.21	9.23	54.84	0.42
November	14.55 ± 6.12	5.69	28.81	0.42
December	13.39 ± 7.14	4.13	29.54	0.53

Table 1.
Mean monthly streamflow dynamics for the period from 1986 to 2016.

Season	Mean ± SD	Minimum (m^3/sec)	Maximum (m^3/sec)	CV (%)
MAM[@]	11.16 ± 6.18	2.79	24.22	0.55
JJAS[@]	52.01 ± 20.01	19.39	102.03	0.38
ON[@]	20.65 ± 7.76	7.52	35.46	0.38
Annual	31.53 ± 10.11	12.43	55.07	0.32
DJF[@]	14.51 ± 6.92	4.67	27.87	0.48

[@]*MAM = March, April, and May; JJAS = June, July, August, and September; ON = October, November; DJF = December, January, and February*

Table 2.
Mean seasonal streamflow dynamics for the period from 1986 to 2016.

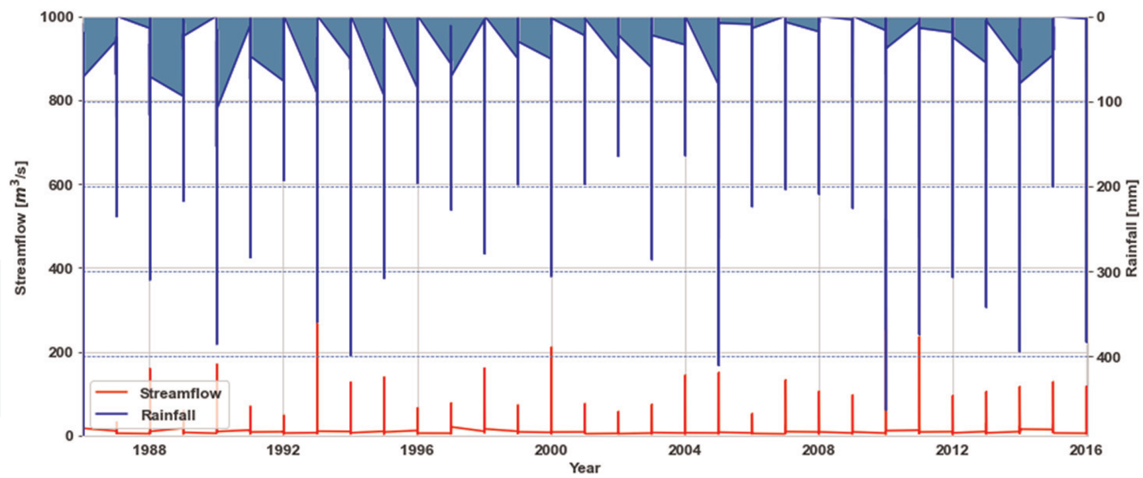

Figure 2.
Mean monthly streamflow and mean monthly rainfall of Kosi watershed from 1986–2016 at Ramnagar gauging station.

while the maximum mean monthly rainfall of the catchment occurs in August in most of the years. This concludes that most of the rainfall occurring in August may be the majority contributing to streamflow.

4.2 Temporal variation of annual mean streamflow and rainfall

The variation of streamflow is shown in **Figure 3**. The annual mean streamflow varies from 12.43 m^3/sec to 55.07 m^3/sec with annual mean value of 31.53 m^3/sec, standard deviation of 10.11 m^3/sec, and coefficient of variation of 0.32.

4.3 Variation of seasonal streamflow

The variation of seasonal streamflow and monthly rainfall was represented in **Figures 4** and **5**, respectively. It clearly shows that the highest value of streamflow was found in the June, July, August, and September (JJAS) seasons, while the March, April, and May (MAM) seasons exhibited the lowest streamflow value.

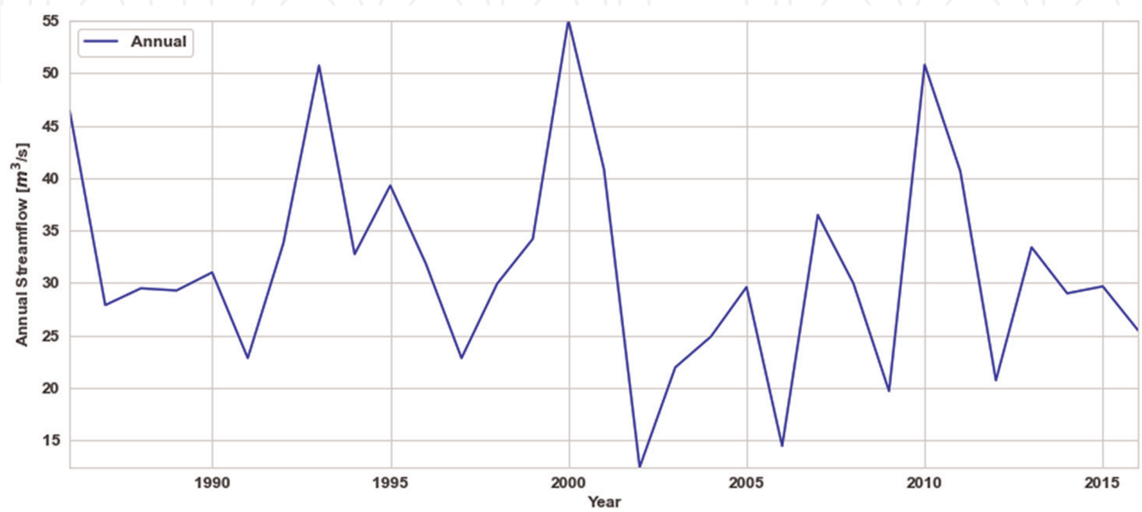

Figure 3.
The annual streamflow analysis (1986 and 2016).

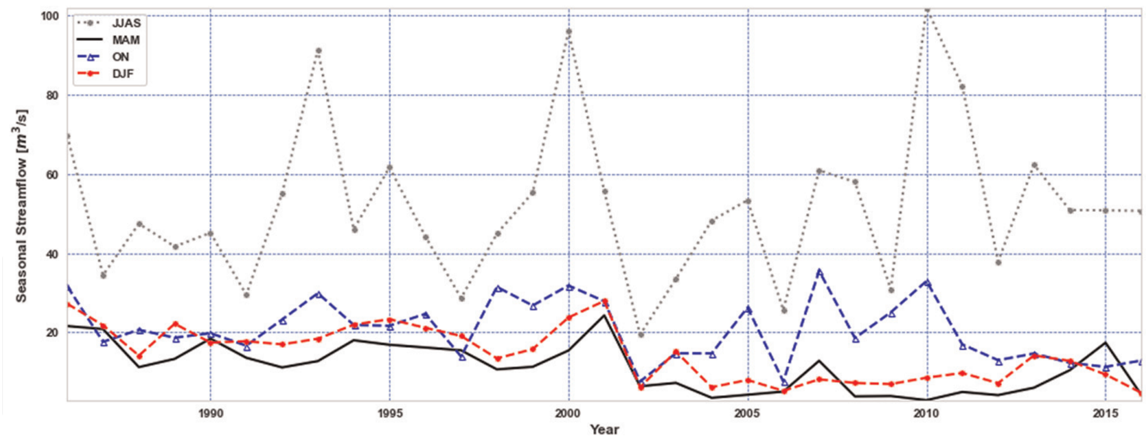

Figure 4.
The seasonal streamflow analysis (1986 and 2016).

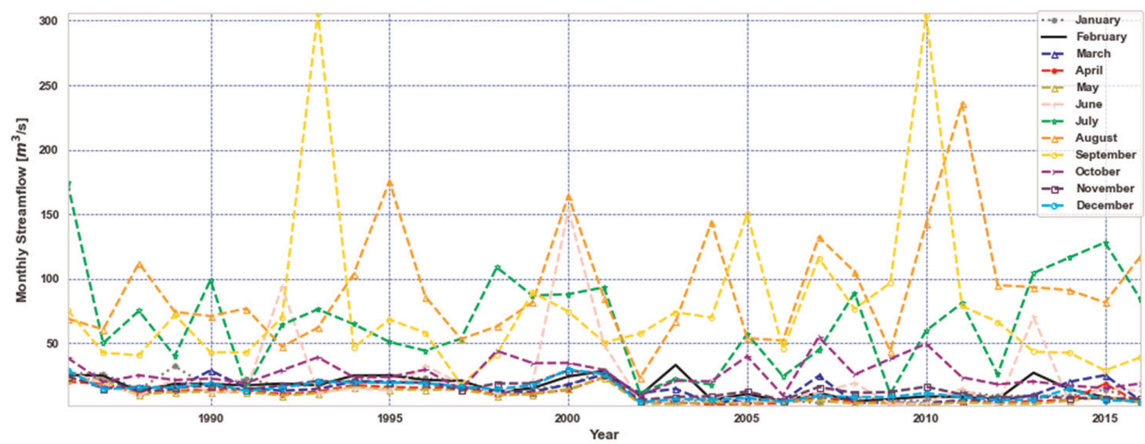

Figure 5.
Time series of monthly streamflow.

These results again corroborate the association between streamflow and rainfall. In this study area, most of the rainfall is received during June and September.

4.4 Trend analysis of monthly streamflow and rainfall

To understand the variations of monthly streamflow behavior, interannual monthly mean streamflow and rainfall were tested using the MK test and Sen's slope (**Table 3**). Similarly, seasonal rainfall and streamflow were analyzed using the MK test and Sen's slope (**Table 4**). The streamflow for all the months shows a decreasing trend at Ramnagar station, although all were not significant.

4.5 Characterizing the factors of trends in streamflow

In this study, we have tried to quantify different drivers for detecting the trend of streamflow. As most of this watershed is under forest land use, we considered urbanization and population growth as the most important factors. It is important to mention that the urban population in Uttarakhand increased from 16.36% of the total in 1971 to 20.7% in 1981, 22.97% in 1991, and 25.59% in 2001 (**Table 5**). The state registered the highest growth of urban population during 1971–1981 (56.38%);

Months	1986–2016 (Streamflow, Ramnagar)			1986–2016 (Rainfall, Hawalbagh)		
	Z value	Sen's slope	p value	Z value	Sen' s slope	p value
January	−0.76	−1.49	0.44	−1.08	−0.52	0.27
February	0.00	−0.02	1.0	−0.34	−0.40	0.73
March	−0.71	−0.92	0.47	−1.44	−0.92	0.14
April	−0.81	−0.79	0.41	−0.85	−0.51	0.39
May	−0.13	−0.20	0.89	−1.75	−1.45	0.07
June	0.30	0.82	0.75	−0.30	−0.62	0.75
July	1.93	48.14	0.05	−0.69	−1.25	0.48
August	0.88	29.35	0.37	−0.88	−1.34	0.37
September	0.61	11.11	0.54	−0.10	−0.17	0.91
October	1.08	6.87	0.27	0.78	0.15	0.43
November	−0.54	−0.75	0.58	−1.61	0.00	0.10
December	−0.95	−1.81	0.34	−0.64	0.00	0.52

** Significant at 5% level, ** significant at 10% level.*

Table 3.
Overall trend analysis of monthly streamflow and rainfall.

Season	1986–2016 (Streamflow)			1986–2016 (Hawalbagh)		
	Z value	Sen' s slope	p value	Z value	Sen's slope	p value
MAM	−0.50	−0.63	0.61	−**2.27***	−3.32	0.02
JJAS	1.49	20.72	0.13	−0.88	−3.01	0.37
ON	−0.74	2.56	0.45	−1.49	−7.23	0.13
Annual	1.39	8.99	0.16	−1.49	−7.23	0.13
DJF	−0.64	−1.18	0.51	−1.17	−1.99	0.24

**Significant at 5% level.*

Table 4.
Overall trend analysis of annual and seasonal streamflow and rainfall.

however, decadal urban population growth declined slightly during 1981–1991 (42.20%) and 1991–2001 (32.81%) [39].

5. Conclusions

The time series of rainfall and streamflow data of the Kosi river watershed for the last 31 years (1986–2016) was statistically analyzed to determine the trend and understand the changes in the streamflow regime. Based on this study, following conclusions were drawn:

- The rainfall is assumed to be the dominant component in the streamflow of the Kosi river watershed.

Census years	Total population	Urban population	Urban content (%)	Urban growth(%)
1901	19,79,866	1,54,424	7.8	—
1911	21,42,258	1,79,332	8.37	16.13
1921	21,15,984	1,91,660	9.06	6.87
1931	23,01,019	1,95,797	8.51	2.16
1941	26,14,540	2,70,503	10.35	38.15
1951	29,45,929	4,00,631	13.6	48
1961	36,10,938	4,95,995	13.74	23.8
1971	44,92,724	7,34,856	16.36	48.16
1981	57,25,972	11,49,136	20.07	**56.38**
1991	71,13,483	16,34,084	22.97	42.2
2001	84,79,562	21,70,245	25.59	32.81
2011	1,01,16,752	30,91,169	30.55	42.43

Table 5.
Trends of urban growth in Uttarakhand (1901–2011).

- The Mann–Kendall analysis of mean monthly streamflow data for last 31 years showed a nonsignificant decreasing trend during monsoon with a significance level of 10%.

The opposite trends observed between the streamflow and rainfall in majority of the watershed area suggest that endogenous change in the catchment dominates over exogenous changes. Abeysingha et al. [40] reported that the trend in annual streamflow for different rivers primarily was driven by changes in rainfall. In addition, Tiwari et al. [41] evaluated the actual evapotranspiration, runoff, and potential evapotranspiration for the past century by using monthly water balance model, and their analysis indicated that rainfall has been the primary factor of variability in the runoff.

The decreasing trend of streamflow in the downstream area of the river may be partly caused by the variations in rainfall and partly by other anthropogenic factors. Human activities such as water consumption, land use, and land cover changes caused by forest disturbances, soil and water conservation projects, new drain construction and city expansion, soil water infiltration, and surface evapotranspiration result in significant hydrological alteration [42, 43]. Nune et al. [44] also found a declining trend in streamflow without significant changes in rainfall Himayat Sagar catchment in India over 24 years (1980–2008). They also reported that streamflow trends declined mainly due to anthropogenic factors, such as changes in land use, watershed development, groundwater abstraction, and storage. Regarding the trend in the seasonal distribution of rainfall, we found that the pre-monsoon seasonal rainfall is increasing significantly, particularly in the month of May. In contrast, post-monsoon rainfall is decreasing significantly, especially in the downstream area.

Conflicts of interest

The authors declare no conflicts of interest.

Author details

Utkarsh Kumar[1,2]*, Rashmi[3], Dhirendra Kumar Singh[1], Suresh Chandra Panday[2], Manoj Parihar[2], Jaideep Kumar Bisht[2] and Lakshmi Kant[2]

1 Division of Agricultural Engineering, ICAR-Indian Agricultural Research Institute, New Delhi, India

2 Crop Production Division, ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand 263601, India

3 Department of Agricultural Economics, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India

*Address all correspondence to: utkarsh.kumar@icar.gov.in

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