Assessing Meteorological and Anthropogenic Factors on Streamflow Trends in the Ramganga River Basin in North India

Abstract

The analysis of stream flow trends of hydro-climatic variables such as stream flow, rainfall, and temperature provides useful information for effective water resource planning, design, and management. Trends in observed stream flow at seven gauging stations in the Ramganga river basin of North India were examined from 1981 to 2012 using the Mann-Kendall and Sen's slope. Lag 1 autocorrelation analyses were used to investigate the relationships between trends in stream flow and rainfall. Annual, monsoonal, and winter seasonal stream flow (p0.05) decreased gradually from upstream to downstream of the river, as did crop seasonal and decadal moving averaged standardized anomalies of streamflow for the entire basin. The streamflow's declining trend was partly attributed to higher water withdrawal, higher air temperature, and higher population, and partly to a significantly declining post-monsoon rainfall trend, particularly upstream and downstream. The changing monsoon rainfall pattern and the growing population both contributed significantly to the development of this trend. The significant decreasing trend in stream flow at the upstream gauging station (-0.39 m3/s/year) was attributed to the significant decreasing trend in catchment rainfall (-8.40 mm/year). This study shows a strong positive correlation between stream flow and catchment rainfall (r=0.60). The Ramganga River basin is showing signs of drying up, as evidenced by the declining stream flow, post-monsoon rainfall, especially in the downstream area, and concurrently rising temperature trends. The Ramganga River basin's sustainable water management planning will be aided and made possible by the study's findings and recommendations, which will help stakeholders design strategies for stream flow restoration. This study thus highlights the urgent need for comprehensive water management planning in this basin by implementing procedures at various spatial scales that may be able to halt the trend of drying by improving river water use efficiency in a variety of sectors.

Keywords: Ramganga River basin, Mann-Kendall, streamflow trend, meteorological, and anthropogenic

Introduction

Stream flow is defined as the flows required to maintain the ecological integrity of rivers, their associated ecosystems, and the goods and services they provide, as well as to meet people's aspirations. According to Barnett et al. (2005), stream flow is an integrated process involving the atmosphere, hydrosphere, pedosphere, and cryosphere in basin change. Water demand has increased dramatically in the Ramganga River basin as a result of rapid urbanization, expanding industrialization, and increased agricultural activity. Ramganga's ecological degradation is also attributed to lean flows caused by large-scale irrigation abstractions and increased pollution from multiple sources. This harms both the river's aquatic biodiversity and the health of the residents of the surrounding community who live across the basin.

The magnitude and direction of climate change are likely to have an impact on the variation in stream flow because it depends on numerous physical and hydrological processes within a basin. The Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report (AR5) states that there is a strong likelihood that the observed and projected increases in temperature and precipitation variability are the primary causes of the reported and projected impacts of climate change on water resources, having a significant impact on a river basin and related river systems (Zhang et al. 2015).

The availability of water per person in India has decreased from 2309 m3 in 1990 to 1820 m3 in 2001 and will decrease to 1140 m3 by 2050, creating a critical water situation (Gupta and Deshpande, 2004). The time series of a stream flow can be changed by changes in hydro-climate and various human developments. Long-term analysis of stream flow trends is a crucial tool for spotting hydrological system changes and aiding decision-makers in better planning (Chang, 2007). Additionally, spatial, temporal, and directional trends may aid in directing the development of adaptive management strategies by water resource planners to deal with unfavorable changes (Abeysingha et al. 2015).

Several studies on trend assessments at various scales for various global regions were reported. But due to the lack of long-term stream flow data, there is a dearth of literature on stream flow studies at the river basin scale in India. According to Abeysingha et al. (2015), anthropogenic and climatic factors are both to blame for the declining trends in Gomti River stream flow.

According to Fu et al. (2007), stream flow in the Yellow River basin was sensitive to temperature and precipitation, and climate variability had a significant impact on stream flow.

According to Yang and Saito (2003), the reduction in annual stream flow is due to water consumption, diversion, and reservoir construction, which has resulted in significant environmental problems. Nune et al. (2012) investigated the trends in rainfall and stream flow in the Himayat Sagar catchment in southern India and discovered a significant decline in stream flow without a significant change in rainfall, which they attributed to anthropogenic influences in the catchment.

Panda et al. (2013) examined stream flow trends in the Mahanadi River basin in eastern India and associated the changes with the El Nio-Southern Oscillation (ENSO). Over about 82 years, Bhutiyani et al. (2008) examined how the stream flow patterns in the rivers of the North Western Himalayas changed. Their research revealed a significantly declining trend in the Beas River's average annual and monsoon discharge over the last four decades of the previous century and a decreasing but insignificant trend for the Ravi River. The Chenab River's winter discharge, on the other hand, showed a statistically significant rise over those 40 years. These alterations were attributed to snow and glacier melting variability.

The spatial information of the variable may be lost during the analysis of hydro-climatic conditions at a regional level. In light of this, it would seem logical to examine hydro-climatic variables at a small scale (Rai et al., 2010). The largest tributary of the Ganga River, the Ramganga River basin, was examined in this study. Our research focused on trends in measured stream flow data, their spatial variation, and the connections between observed changes in stream flow and anthropogenic interventions such as rainfall.

Study area

The Ramganga, an alluvial river in the Indo-Gangetic Plain, is an important tributary of the Ganga. It is thought to have originated near the lower Himalayas at latitude 290 30' to 300 5' N and longitude 780 36' to 790 34'E, at an altitude of about 3089 m above mean sea level (Bhagat et al. 2021). The river Ramganga joins the Ganga on its left bank at Kannauj in Fatehgarh district after traveling 596 kilometers in a south, south-east direction, and the total area of the Ramganga river basin is estimated to be 58,869 km2. The river runs in a southwestern direction for approximately 32 km before turning right and flowing in a southwestern direction. For around 112 km, proceed through Almora and Garhwal districts in succession. The river travels across mountainous terrain in these two areas, producing a lot of falls and rapids. The river comes from the hills and reaches the plains at the boundary of the Garhwal districts at Kalagarh. A storage Dam has been built across the river at Kalagarh. The river runs southeastward beyond Kalagarh. The river travels through the districts of Bijnor, Moradabad, Badaun, Rampur, Bareilly, and Shahjahanpur before joining the Ganga at Kannauj in Fatehgarh. The topography is undulating, with greater elevations in the basin's upstream end, and elevations range from 3473m to 113 m above mean sea level. The basin's climate ranges from semi-arid to sub-humid tropical, with average annual rainfall varying between 700 and 1200 mm at various sites. The South-West Monsoon accounts for over 75% of total yearly rainfall from June to September (Rai et al., 2009). The Ramganga River is the primary source of water supply for the cities of Moradabad, Bijnor, Badaun, Bareilly, Kannauj, and Shahjahanpur. Several tube wells have also been drilled along the riverbed to access groundwater in the basin.

Material and Methods

Data set and data pre-processing

Table 1 shows the features of stream flow data obtained from the Central Water Commission (CWC), Government of India. The CWC is India's principal agency for recording, computing, validating, and archiving all river hydrological data. Because data were few, this research relied on monthly 10-day average stream flow data from six gauging sites indicating near-natural flow. Figure 2 depicts the original ten daily stream flow data from the various gauging sites used in this study. The length of the records varied depending on the gauging stations, but 27 years of data were acquired for the Dabri station near the basin's exit, which represented the whole basin. Furthermore, common record periods (1981-2012) were utilized to analyze and compare the regional distribution of stream flow and rainfall trends. We were unable to get a sufficient number of stations for point rainfall and temperature data in the basin, thus monthly district rainfall (1981-2005) and temperature data (1981-2005) were acquired from the WRIS (Water Resources Information System) online site at http://www.india-wris.nrsc.gov.in. The meteorological data were obtained for 15 districts encompassing the whole basin. These districts include Chamoli, Pauri-Garhwal, Almora, Bijnor, Champawat, Jyotiba Phule Nagar, Moradabad, Rampur, Udham Singh Nagar, Bareilly, Pilibhit, Badaun, Shahjahanpur, Etah, and Hardoi. Anthropogenic statistics from the Office of the Registrar General and Census Commissioner of India for the census years 1991 and 2011. Geohive may be found at http://www.geohive.com/cntry/in-09.aspx.

This study used 90 m resolution SRTM data (Jarvis et al., 2008) set in ArcGIS to outline the river basin, and the total drainage area of the river was calculated to be 58,869 km2 (Fig.1). District borders were overlaid with catchment limits about seven gauging stations using ArcGIS (Ver 9.3) (Fig. 2). By crossing the district boundary layer with the catchment boundary layer, it was possible to identify the district areas that lie inside each catchment. Different district areas that are part of a catchment were normalized about the catchment's overall area and utilized as weights to determine the catchment's monthly average rainfall. Total catchment-wise seasonal rainfall for each agricultural season was estimated using these weighted average monthly rainfall data.

Indicator analyzed

The data was used to derive the following indicators:

- Monthly mean stream flow: The average of three decadal (10 daily) monthly data for a gauging station.
- Interannual monthly mean stream flow: Monthly mean stream flow for a gauging station across the years (Jan 1982, Jan 1983, Jan 1984, etc.).
- Annual mean stream flow: The average of a gauging station's twelve-monthly mean streamflow data from January to December.
- Crop season mean stream flow: The average of monthly mean stream flow values for the Rabi crop season (November-March), Kharif crop season (July-October), and summer crop season (April-June), with the Rabi crop season means based on December of the previous year and January, February, and March of the following year.

Statistical Analysis

In this work, the monotonic trend of hydro-climatic data series was examined using two commonly used trend detection techniques: the Sen's slope estimator (Zhang and Lu 2009; Gautam et al., 2012) and the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Yue et al., 2002; Sharif et al., 2013, Abeysingha et al., 2015). Though the MK test is stable and useful in many hydrological probes, using it to detect trends is not always appropriate. This is due to the MK test failing to account for the serial correlation that is common in hydrological time series (Hamed and Rao, 1998; Yue et al., 2002). The presence of serial correlation in a data set might lead to a false result interpretation since it increases the likelihood of identifying a significant trend when there is none. As a result, in our study, each time series was initially evaluated to see if there was a substantial lag-one autocorrelation. The initial MK test was performed to assess the data if a time series did not show a substantial autocorrelation. We used the Modified MK test suggested by Hamed and Rao (1998) when there was a large lag 1 autocorrelation in a time series. According to Sharif et al. (2013), all hydro-climatic trends were assessed at significance levels of 0.05 and 0.1 to determine the intensity of the trends.

For streamflow and rainfall, the standardized anomaly or 'Z-score' was produced for each gauging station (by subtracting the mean from the original value and then dividing it by the appropriate standard deviation). This indicator minimizes spatial bias and thus helps in evaluating spatiotemporal variability in hydro-climatic parameters across the basin's gauging stations. Non-parametric The Spearman's rho correlation coefficient () was also utilized to determine the potential relationship between stream flow and rainfall. To decrease random variation and provide an overview of the whole basin, standardized anomalies in stream flow and rainfall were smoothed on a crop season and decadal basis and then compared.

Results

We assessed the lag-one autocorrelation in all time-series datasets (monthly, crop seasonal, decadal, and annual) before examining the trend in stream flow and rainfall, and around 8% of the tested series revealed statistically significant autocorrelation at the 5% significance level. Monthly time series have higher autocorrelation than yearly time series (Hirsch and Slack, 1984), and we only found substantial autocorrelation in monthly mean stream flow and crop seasonal mean stream flow.

Mean monthly stream flow and mean monthly rainfall of seven catchments were estimated from 1981 to 2005 to better understand the basin's general behavior of stream flow and rainfall (Fig. 4). The greatest mean monthly streamflow occurred in September most of the time in all gauging stations, except Moradabad in August, whereas the maximum mean monthly rainfall occurred in

July and August. This means that the majority of the rainfall in September may be contributing to streamflow. The largest stream flow was recorded at the Bhakra Dhaneta station, which is located in the River basin's mid-stream (m/s), while the lowest was at the Moradabad station, which is located in the basin's upstream (u/s).

Trends in annual stream flow and rainfall

Figure 5 depicts the trends in the annual mean stream flow of the seven stations and yearly rainfall of the Ramganga basin's seven catchments. The size of the trend as Sen's slope and Spearman's rho correlation coefficient () between stream flow and rainfall are also presented in Fig 5. There was a statistically significant declining trend in both stream flow and catchment rainfall at Moradabad and Dabri stations, as evidenced by negative Sen's slope values that were significant at p=0.05. This station is located in the Ramganga river basin's most upstream (u/s) and downstream (d/s) reaches. All the other stations, except the Fatehganj gauging station, demonstrated a considerably increasing trend of stream flow (positive values of Sen's slope), as well as a decreasing trend of rainfall. It is clear from the size of the yearly stream flow trend and the location of the gauging stations that the river from Moradabad to Dabri has a diminishing trend of stream flow that increases from the upstream (m/s) to the downstream (d/s). The correlation analysis for the three sites during the research showed a substantial positive association between stream flow and rainfall. The most u/s station, Moradabad, had the greatest value of 0.6; as we moved m/s to Ramnagar, Bhakra Dhaneta, Kiccha Dhaneta, and Bareilly, the values declined to -0.01, -0.28, and -0.26, respectively.

In Figure 6, the correlation between standardized stream flow anomaly and rainfall anomaly at various sites throughout time is depicted. With an intercept that is close to zero and a substantial linear relationship between the two, the strength of the relationship (R2) exhibits a declining trend from u/s to d/s.

Trends in mean crop seasonal stream flow and seasonal rainfall

Monotonic trends in stream flow and rainfall for three seasons (Rabi, Kharif, and summer season) were analyzed for each of the catchment regions and the results are shown in Figure 7. It shows that stream flow and rainfall patterns are characterized by marked seasonal differences. At the upstream(u/s) region of the Ramganga river basin, the relationship between crop seasonal stream flow and rainfall showed the lowest in Rabi (ρ = 0.24) and summer crop season (ρ = 0.38) while in Kharif crop season were highest (ρ = 0.51). However, at midstream (m/s) and downstream (d/s) catchment areas of the Ramganga river basin showed a negative relationship in the Rabi crop season which represents the decreasing trend. During the monsoon season, the size of the stream flow's falling tendency steadily increases from m/s to d/s. This was consistent with the yearly pattern. It is noteworthy to note that virtually all stations indicated a decreasing stream flow trend over the summer crop season, although catchment rainfall also showed a decreasing trend. Kharif crop season rainfall at all stations (except Dabri) exhibits a declining tendency, with statistically significant falling trends recorded in the basin's lower reaches. The decrease in rainfall throughout the summer and Kharif agricultural seasons has minimal impact. Both climatic and human variables were responsible for the declining trend in stream flow while quantifying the contributions of any particular element is challenging.

The trend in the decadal period, annual, and crop seasonal mean streamflow

To study the stream flow trends at decadal, annual, and crop seasonal periods for all the gauging stations in the Ramganga river basin, historical data was analyzed. For the decadal period (1981-1990) the stream flow trend showed the decreeing trend at three gauging stations (Bhakra & Kiccha Dhaneta and Fatehganj) while all other stations showed an increasing trend. The annual mean streamflow trends were showing decreasing trend at Moradabad and Dabri which is upstream (u/s) and downstream (d/s) gauging stations while midstream (m/s) represented an increasing trend in the Ramganga river basin. Based on crop seasons, stream flow trends showed an increasing trend in Rabi crops at all gauging stations except Fatehganj. However, the Kharif crop season represented decreasing trend at the upstream gauging station (Moradabad), in the midstream (m/s) gauging station (Bareilly); while the Dabri gauging station showed an increasing trend which is the most downstream (d/s) gauging station of Ramganga river basin. Even with increased rainfall, decreasing patterns in stream flow show that the rate of water extraction from the basin is substantially greater than the rise in rainfall-generated runoff.

Trends in monthly stream flow and rainfall

Interannual monthly mean flows were examined for trend using the MK test and the Sen's slope to comprehend the behavior of stream flow on a month-by-month basis (Table 2). Similarly, the Interannual mean monthly rainfall for the watershed was also examined (Table 2). The interannual monthly stream flow showed decreasing trend in number of the months at different gauging stations i.e. Moradabad, Bareilly, Kiccha Dhaneta (March –June); Fatehganj East (January- December). At the Bareilly gauging station, significant decreasing trends were observed for January – March. Stream flow decreasing trends were also observed in different months, at gauging station Bhakra Dhaneta (June-September) and Ramnagar (January and April) respectively. Streamflow at the Dabri gauging station, on the other hand, increased in all months but was not statistically significant. Rainfall decreased from April to August at all four locations, except September. Other months' rainfall revealed varied tendencies, but none were deemed to be significant. It suggests that the timing of the monsoon season may be altering, with early commencement and early departure. Furthermore, precipitation dropped in most of the months in all catchment regions of the Ramganga River basin, from upstream to downstream, indicating that the impact of precipitation change on stream flow is negligible.

Trends in air temperature

Table 3 summarizes the trend analyses of annual and seasonal temperatures for the seven catchments over 25 years. Mean annual and monsoon season temperatures increased significantly across the basin. Even when the records were condensed to a single period of 1991 to 2005, the average air temperature of the basin's catchments increased. Even though the winter average temperature increased, it was not statistically significant.

Identifying the causes of stream flow trends

In the present study, Due to the lack of long-term relevant data collection, we were unable to ascribe distinct drivers to the identified trend of stream flow, but an attempt was made to qualitatively define the likely drivers of trends of stream flow.

Surface water removal from the basin has a significant impact on stream flow. We examined trends in the basin's irrigated area since rice and wheat are the primary crops in the Kharif (June-October) and Rabi (November-March) seasons, respectively. Figure 11 depicts the total irrigated acres under rice and wheat crops in the main regions of the basin from 1993-94 to 2012-13. The increase in irrigated area for rice is 68% and 22% for wheat throughout the research period. The irrigated area under both crops is expanding, as shown in Figure 11. This suggests that the irrigation water consumption in the basin has been rising steadily over time, which may have had a detrimental impact on the river's water flow. The population of the districts in the Ramganga River basin in 1991 and 2011 is shown in Table 4, along with the percentage change over this time. It shows that there has been a 21% growth in population, with districts like Bareilly and Moradabad showing larger increases (36% and 38%). higher population throughout the research period suggests higher water consumption, which may have had a detrimental influence on river stream flow.

Discussion

Climatic change impacts stream flow

Stream flow is an important component of fresh surface water resources that is crucial for human societies and natural ecosystems. Climate change and anthropogenic intervention is the main cause explain the change in the stream flow of the river basin. In general, stream flow is positively related to precipitation but negatively correlated with temperature (Fu et al., 2007; Xu et al., 2010). Melting glaciers and precipitation in the high mountain regions are the main water resources of the semi-arid areas in northern India. Increasing air temperature induced more glaciers and snow melting during the past decades which contributed significantly to the increasing stream flow in the river basin. From monthly changes in average streamflow data, the impact of climate change can be seen more clearly in the Ramganga River basin. Taking the stream flow of the Bhakra Dhaneta (BD) station as an example (Figure 5), stream flow increased in the spring. The spring season (March to May), is the snow melting season, and the rising stream flow can be attributed to higher temperatures. There is hardly any runoff generated in the m/s and d/s of the Ramganga basin due to low precipitation and high evapotranspiration, and the change in precipitation does not affect stream flow. In addition, precipitation decreased in most of the months of all catchment areas of the Ramganga River basin from upstream to downstream region, which showed that the impact of the precipitation change on the stream flow is negligible. Moreover, the relationships between stream flow and air temperature are different in the m/s and d/s of the Ramganga River basin. Higher air temperature could lead to higher actual evapotranspiration which resulted in the decrease of streamflow.

Anthropogenic impacts on stream flow

Stream flow is the most important water resource that sustains irrigated agriculture in the Ramganga River basin. During the last several decades, the hydrological regime of the Ramganga river basin had been strongly affected by extensive human activities. They impacted the surface water stream flow. At Moradabad station, which is situated at the u/s of the basin, during the research period, we saw a considerable decline in stream flow, notably on an annual basis. For the Moradabad watershed rainfall, particularly on an annual basis, a similar major declining trend was seen. As a result, the high levels of human activity in the Ramganga River basin's upstream area are principally responsible for the stream flow's declining tendency in the river's upstream section. According to Milliman et al. (2008), variations in yearly streamflow for several rivers were predominantly caused by fluctuations in precipitation. The statistically significant correlation coefficient between stream flow and rainfall at this site ($\rho = 0.56$) further supports this claim.

Annual and monsoon season catchment rainfall in the individual catchments, on the other hand, shows substantial declining tendencies. Significant declining trend rainfall supported the overall lowering trend of stream flow. In contrast, rainfall throughout the basin decreased during the Rabi and Kharif crop seasons (p 0.05). In terms of trends in crop seasonal rainfall distribution, we discovered that summer crop season rainfall is growing considerably, notably in May. In contrast, post-monsoon rainfall is drastically decreasing, particularly in the d/s region. It suggests that the time of the monsoon season has shifted, i.e. early commencement and early withdrawal. Furthermore, monsoon season rainfall is increasing dramatically across the basin. Even with increasing rainfall, the declining trends in stream flow show that the rate of water extraction from the basin is substantially greater than the increased rainfall-generated runoff.

These opposing patterns in stream flow and rainfall seen in the majority of basin areas show that endogenous changes (such as being more vulnerable to climate change, intermittent flow, and drying tendency) in the catchment predominate over external changes. Despite this, the d/s catchments exhibited a statistically significant declining trend in rainfall over the Rabi crop season (p 0.1). Furthermore, we found a statistically significant relationship between catchment rainfall and stream flow at several gauging stations across the basin. Since the importance of this correlation declined from u/s to d/s, driving mechanisms other than rainfall may be prominent in the d/s part of the basin. The declining trend in stream flow in the river's d/s regions can be attributed to fluctuations in rainfall as well as other human influences. Human activities such as increased water consumption, changes in land use and land cover caused by forest disturbance, soil and water conservation projects, new dam construction, and city expansion, among others, have resulted in significant hydrological changes (Li et al., 2007; Wei and Zhang, 2010, Ahmed et al. 2021).

The Ramganga River's water is used for industrial purposes in the surrounding area, and the Ramganga barrage is used to control the river's level in Moradabad during the summer (Maurya 2013) study on the environmental effects of human activity on the river's morphology at Moradabad and Bareilly. Additionally, the basin's irrigated area significantly grew from 1993–1994 to 2013–2014 (Fig. 11). Additionally, the 21% increase in population over the basin between 1991 and 2011 suggested a corresponding rise in river water abstraction. Therefore, all of these reasons may have contributed to increasing water extraction, which in turn caused a downward trend in stream flow, particularly in the basin's d/s region. Nune et al. (2012) discovered a falling trend in stream flow without major changes in precipitation in the Himayat Sagar basin in India from 1980 to 2004. They also ascribed the stream flow patterns to anthropogenic influences such as changes in land use, watershed development, groundwater abstraction, and storage. Lloyd (2010) examined the Breede River flows in South Africa over the past 43 years and discovered a decreasing stream flow trend in most of the gauging stations, concluding that changes in land use, creation of impoundments, and increasing abstraction were primarily responsible for changes in the observed flows.

During the research period, air temperature in the whole basin increased at a rate of 0.010C/year (Table 3). Hingane et al. (1985) found that the mean annual temperature in India's north-central and northeastern areas rose between 1901 and 1982. raised evaporation and evapotranspiration raised the atmospheric water demand. The rising temperature trend may potentially be a role in the increased water loss from the basin and the declining trend in stream flow. Additionally, Zhang et al. (2014) noted a considerably increased rise in annual mean temperature and potential evapotranspiration in the Chinese Xitiaoxi River basin, which they believe contributed to a large decreasing trend in annual stream flow between 1975 and 2009. According to Abeysingha et al. (2015), the Gomti River basin's catchments as a whole demonstrated a rising trend in average air temperature, which led to a decline in stream flow.

Reduced stream flow in the Ramganga River, particularly during the dry season, might have an impact on the aquatic biodiversity of the river and its tributaries, groundwater recharge capacity, and the natural purifying capacity of river water. Furthermore, because the Ramganga River is a tributary of the sacred Ganga River, diminished streamflow may have an impact on river water rituals. Lokgariwar et al. (2014) emphasized the need of considering cultural water requirements in environmental flow assessments. Reduced stream flow also demonstrated the importance of monitoring the Ramganga River's environmental flow requirements, including cultural water flow.

Overall, it is evident that the Ramganga River basin is displaying signs of drying at the gauging stations in Moradabad (u/s), Fatehganj (m/s), and Dabri (d/s), and both the decadal trend and crop seasonal revealed statistically significant decrease trends in streamflow. It is of little relevance that the rainfall decreased throughout the Kharif and summer crop seasons. Although it is impossible to measure each factor's impact, both climatic and human variables were to blame for the declining trend in stream flow.

This study contains some flaws, as has been pointed out. One of the most significant was the lack of consistent long-term data on rainfall and stream flow for the basin. The study's records ranged in duration from 21 to 30 years. While a minimum record length of 25 years assured statistical validity of the trend results in climate change research, rainfall data covering over 30 years were thought to be lengthy enough for valid mean statistics (Kahya & Kalayci, 2004). We examined the to confirm the veracity of trend results, The averaged normalized anomaly for the whole basin as well as for each station includes the annual mean trend, decadal average, and crop seasonal average. The confidence in the findings is increased by the declining trends in streamflow at the gauging stations in Moradabad (u/s), Fatehganj (m/s), and Dabri (d/s). Consequently, the current research undoubtedly offers crucial insights into the anticipated hydrological picture of the Ramganga River basin for water management to start appropriate corrective strategies. To stop the consequences of climate change and population growth, which would lead to desertification, efforts should be done to protect the Ramganga River Basin from upstream to downstream regions. To support and direct action, more research should be done to address the implications of the river basin's inclination to dry out.

Conclusions

The Ramganga River, a significant main tributary of the Ganga River, irrigates vast areas of land used for growing rice and wheat as well as providing housing for a sizable population. This research on the annual and crop seasonal changes in the stream flow of the Ramganga River basin demonstrated that there is a tendency for the basin's stream flow to dry out, especially in the places further downstream. Even if crop season rainfall is on the decline, this is the case. The study showed that the diminishing trends in Ramganga river stream flow are caused by both climate and human influences. A large increase in air temperature and a significant decrease in rainfall are the two most crucial climatic elements. The population has grown by roughly 21% over the past 30 years, and growing patterns in agricultural areas under irrigation may have contributed to the basin's increased water use. The predicted patterns of climate change and regional population growth accentuate the diminishing trends in stream flow.

The Ramganga River basin stream flow is likely to negatively affect the aquatic biodiversity of the river and areas nearby, the capacity of the groundwater to recharge, and the natural purification capabilities of the river water unless immediate corrective measures are taken. It has the effect of jeopardizing the region's food security as well as the livelihood and other rights of a sizable population. This study thus highlights the urgent need for comprehensive water management planning in this basin by implementing procedures at multiple spatial scales that may be able to halt the trend of drying by improving river water usage efficiency in a variety of sectors.

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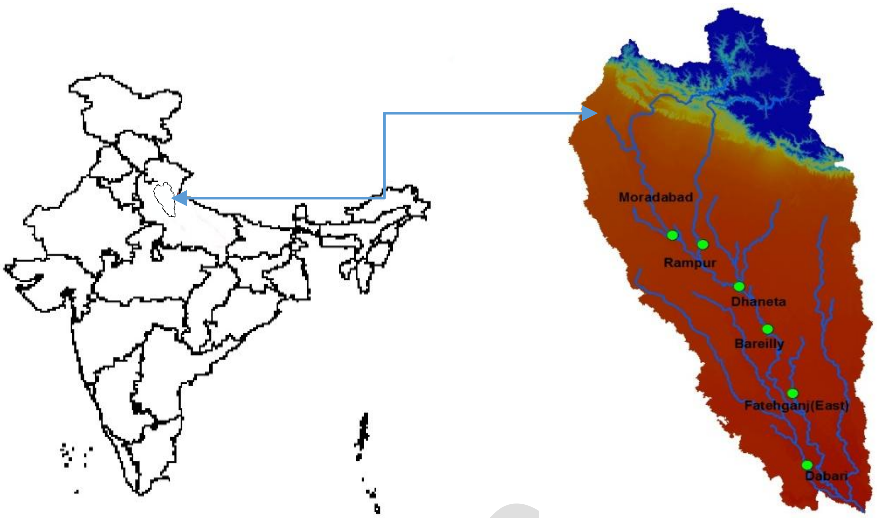


Figure 1. The Location of the study area

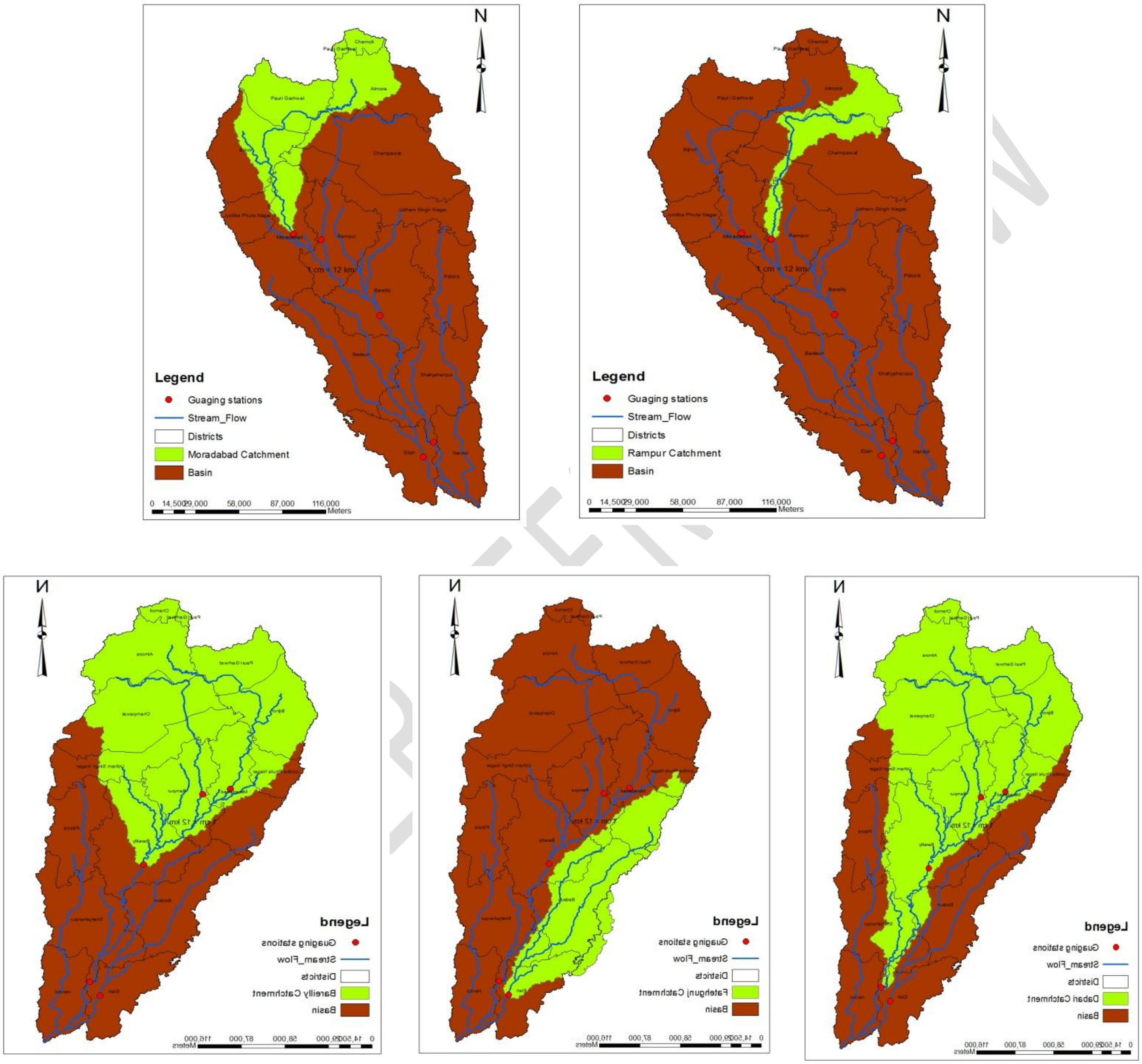
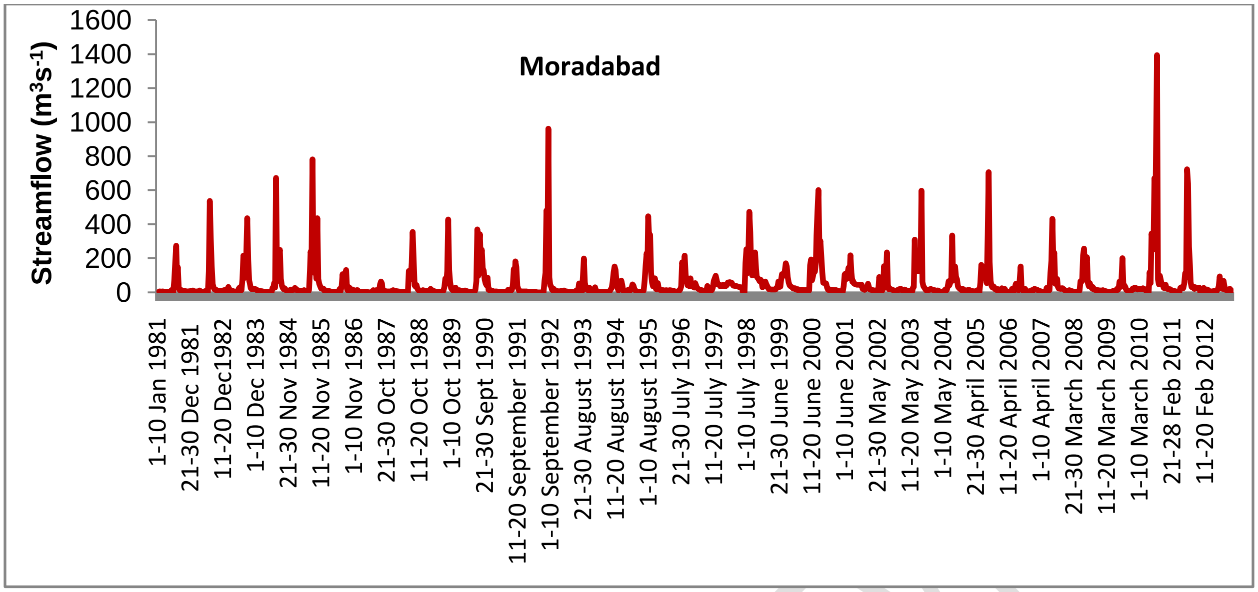
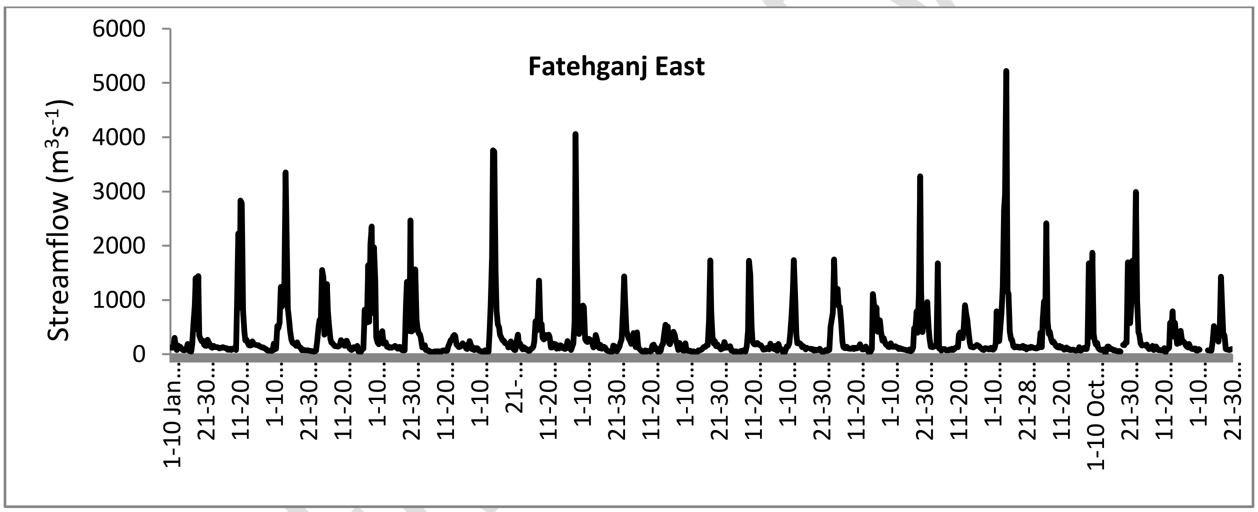
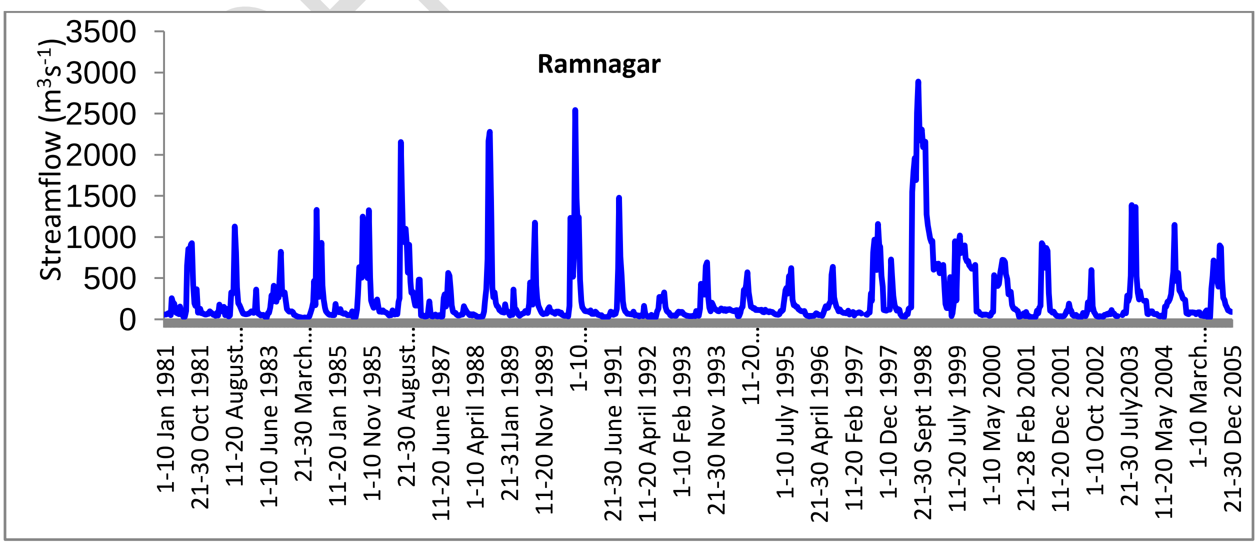
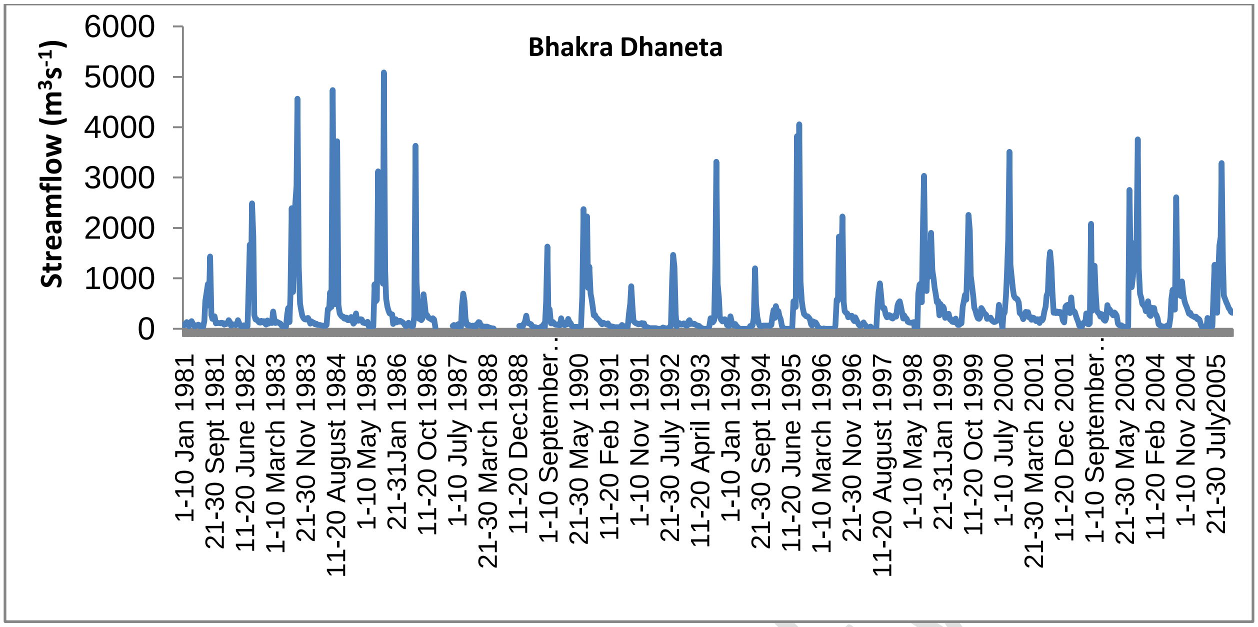


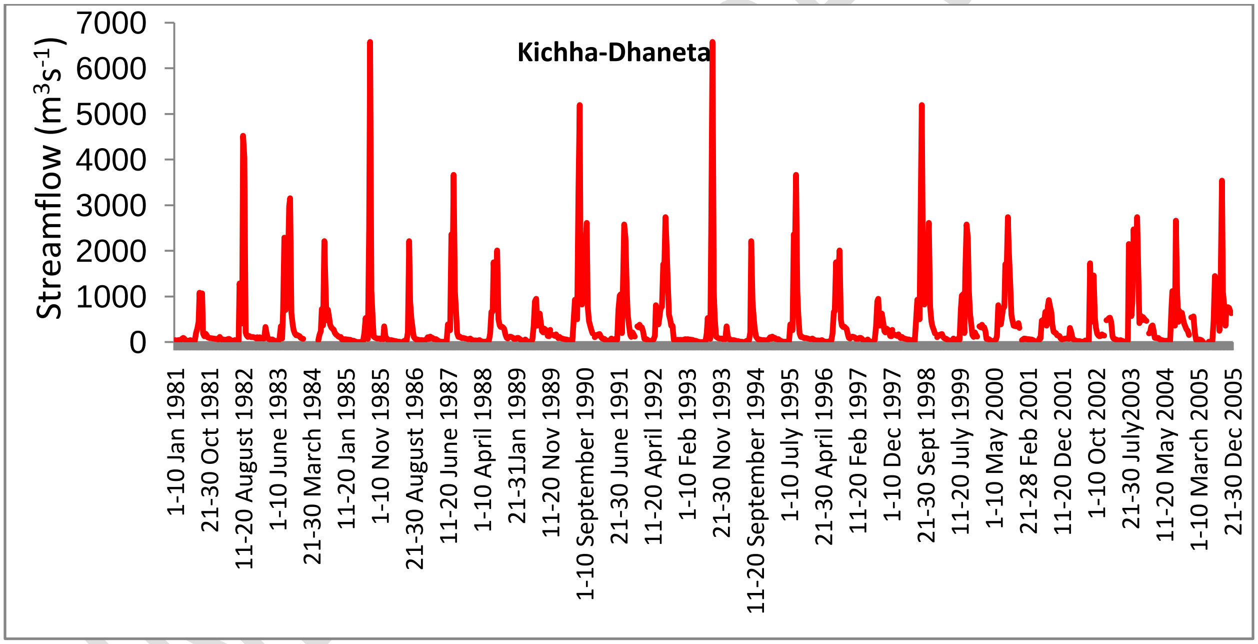
Figure 2. Delineated catchments of a) Moradabad, b) Rampur, c) Bareilly, d) Fatehgunj, and e) Dabri in Ramganga River basin


Moradabad
Streamflow (m3s-1)
1600
1400
1200
1000
800
600
400
200
0
1-10 Jan 1981
21-30 Dec 1981
11-20 Dec1982
1-10 Dec 1983
21-30 Nov 1984
11-20 Nov 1985
1-10 Nov 1986
21-30 Oct 1987
11-20 Oct 1988
1-10 Oct 1989
21-30 Sept 1990
11-20 September 1991
1-10 September 1992
21-30 August 1993
11-20 August 1994
1-10 August 1995
21-30 July 1996
11-20 July 1997
1-10 July 1998
21-30 June 1999
11-20 June 2000
1-10 June 2001
21-30 May 2002
11-20 May 2003
1-10 May 2004
21-30 April 2005
11-20 April 2006
1-10 April 2007
21-30 March 2008
11-20 March 2009
1-10 March 2010
21-28 Feb 2011
11-20 Feb 2012


Fatehganj East
Streamflow (m3s-1)
6000
5000
4000
3000
2000
1000
0
1-10 Jan…
1-10 Oct…


Ramnagar
Streamflow (m3s-1)
3500
3000
2500
2000
1500
1000
500
0
1-10 Jan 1981
21-30 Oct 1981
11-20 August…
1-10 June 1983
21-30 March…
11-20 Jan 1985
1-10 Nov 1985
21-30 August…
11-20 June 1987
1-10 April 1988
21-31Jan 1989
11-20 Nov 1989
1-10…
21-30 June 1991
11-20 April 1992
1-10 Feb 1993
21-30 Nov 1993
11-20…
1-10 July 1995
21-30 April 1996
11-20 Feb 1997
1-10 Dec 1997
21-30 Sept 1998
11-20 July 1999
1-10 May 2000
21-28 Feb 2001
11-20 Dec 2001
1-10 Oct 2002
21-30 July2003
11-20 May 2004
1-10 March…
21-30 Dec 2005


Bhakra Dhaneta
Streamflow (m3s-1)
6000
5000
4000
3000
2000
1000
0
1-10 Jan 1981
21-30 Sept 1981
11-20 June 1982
1-10 March 1983
21-30 Nov 1983
11-20 August 1984
1-10 May 1985
21-31Jan 1986
11-20 Oct 1986
1-10 July 1987
21-30 March 1988
11-20 Dec1988
1-10 September…
21-30 May 1990
11-20 Feb 1991
1-10 Nov 1991
21-30 July 1992
11-20 April 1993
1-10 Jan 1994
21-30 Sept 1994
11-20 June 1995
1-10 March 1996
21-30 Nov 1996
11-20 August 1997
1-10 May 1998
21-31Jan 1999
11-20 Oct 1999
1-10 July 2000
21-30 March 2001
11-20 Dec 2001
1-10 September…
21-30 May 2003
11-20 Feb 2004
1-10 Nov 2004
21-30 July2005


Kichha-Dhaneta
Streamflow (m3s-1)
7000
6000
5000
4000
3000
2000
1000
0
1-10 Jan 1981
21-30 Oct 1981
11-20 August 1982
1-10 June 1983
21-30 March 1984
11-20 Jan 1985
1-10 Nov 1985
21-30 August 1986
11-20 June 1987
1-10 April 1988
21-31Jan 1989
11-20 Nov 1989
1-10 September 1990
21-30 June 1991
11-20 April 1992
1-10 Feb 1993
21-30 Nov 1993
11-20 September 1994
1-10 July 1995
21-30 April 1996
11-20 Feb 1997
1-10 Dec 1997
21-30 Sept 1998
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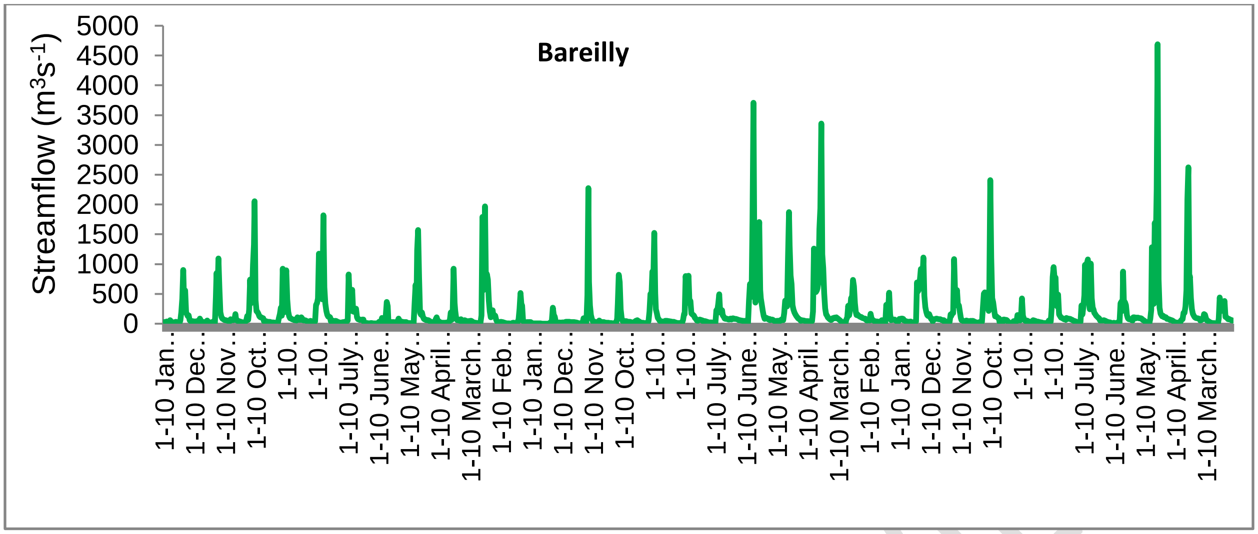
1-10 March 2005
21-30 Dec 2005



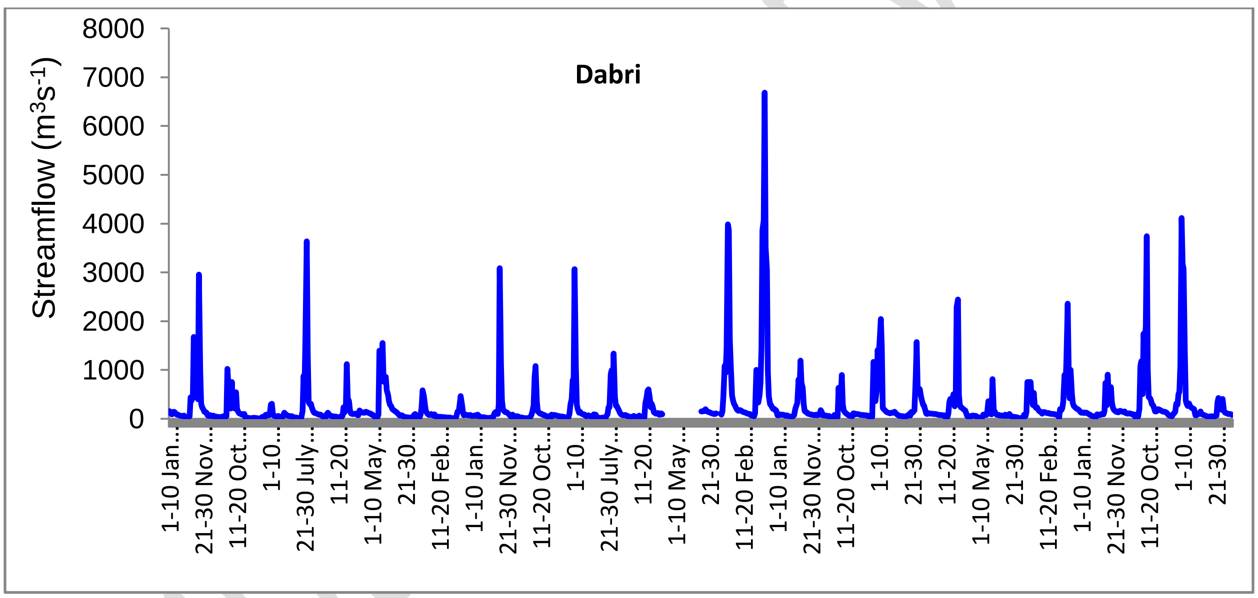


Figure 3. Decadal measuring average streamflow at gauging station (a) Moradabad (b) Fatehgunj (c)Ramnagar (d) B-Dhaneta (e) K- Dhaneta (f) Bareilly and (g) Dabri over the available data period

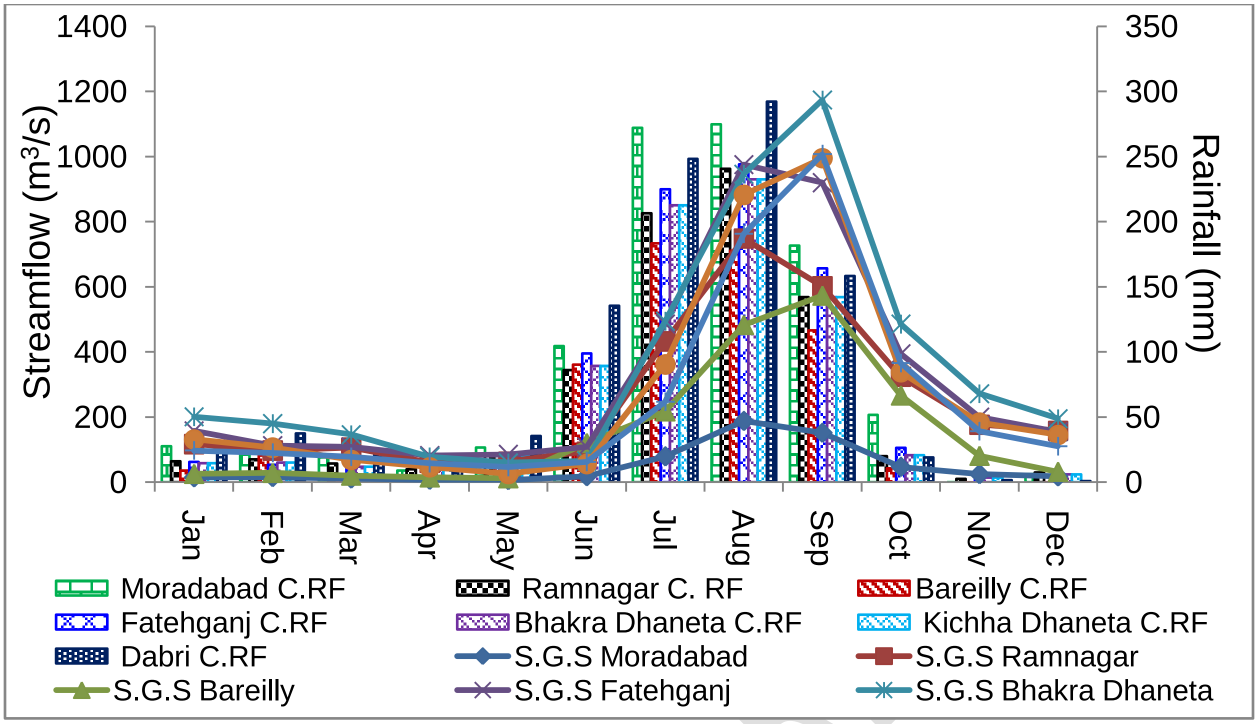


Figure 4. Mean monthly streamflow and mean monthly rainfall of Ramganga River basin catchments (1981–2005).

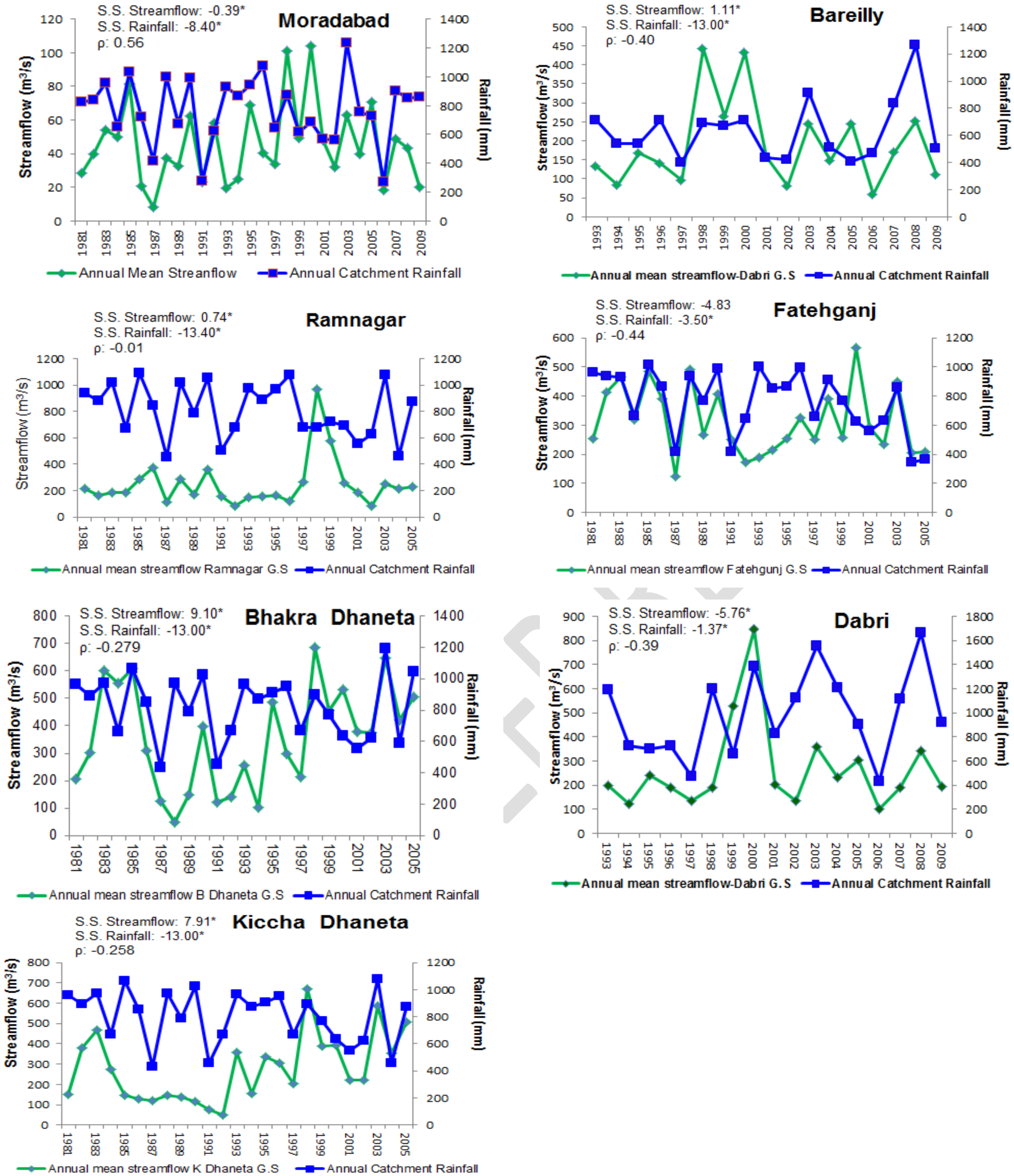


Figure 5. The spatial distribution of yearly mean streamflow and annual rainfall, as well as their connections for (a) Moradabad, (b)Ramnagar, (c) Bhakra Dhaneta (d) Kiccha Dhaneta (e) Bareilly, (f) Fatehganj, (c) Dabri

(Where: S.S. Sen's Slope: Correlation coefficient, where a single asterisk denotes significance at the 0.05 level)

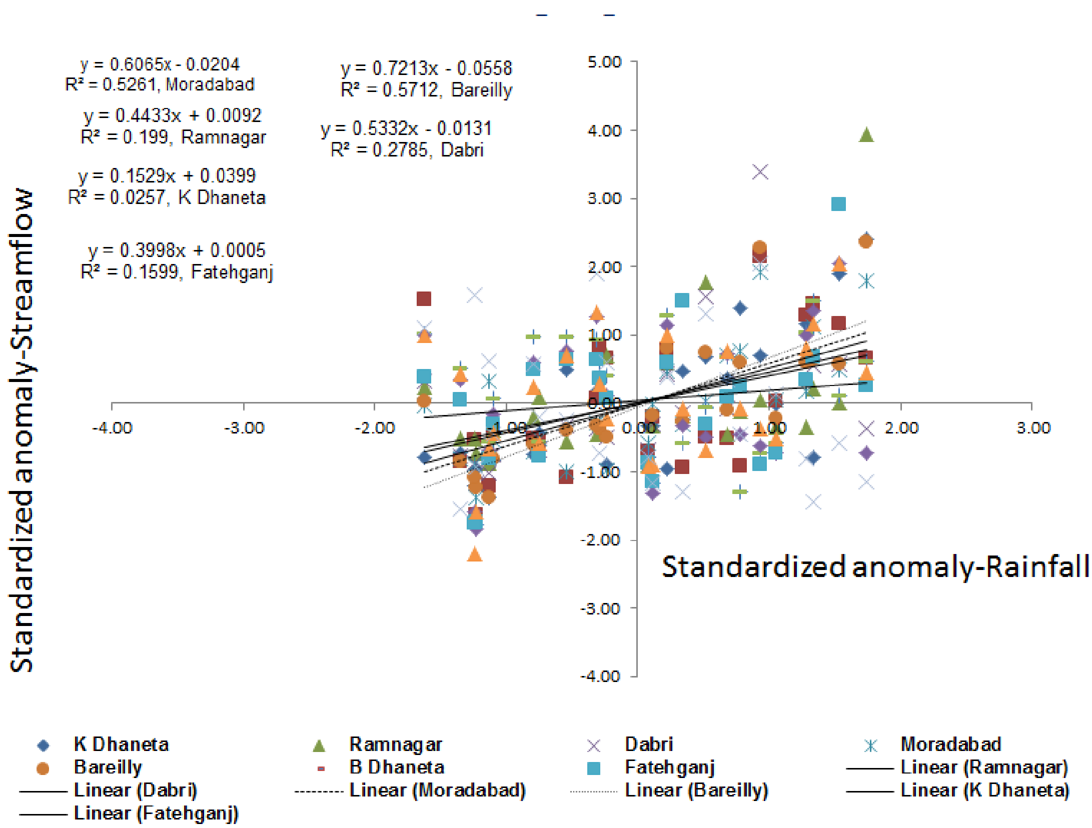


Figure 6. Anomaly of yearly streamflow against rainfall in several Ramganga River basin catchments

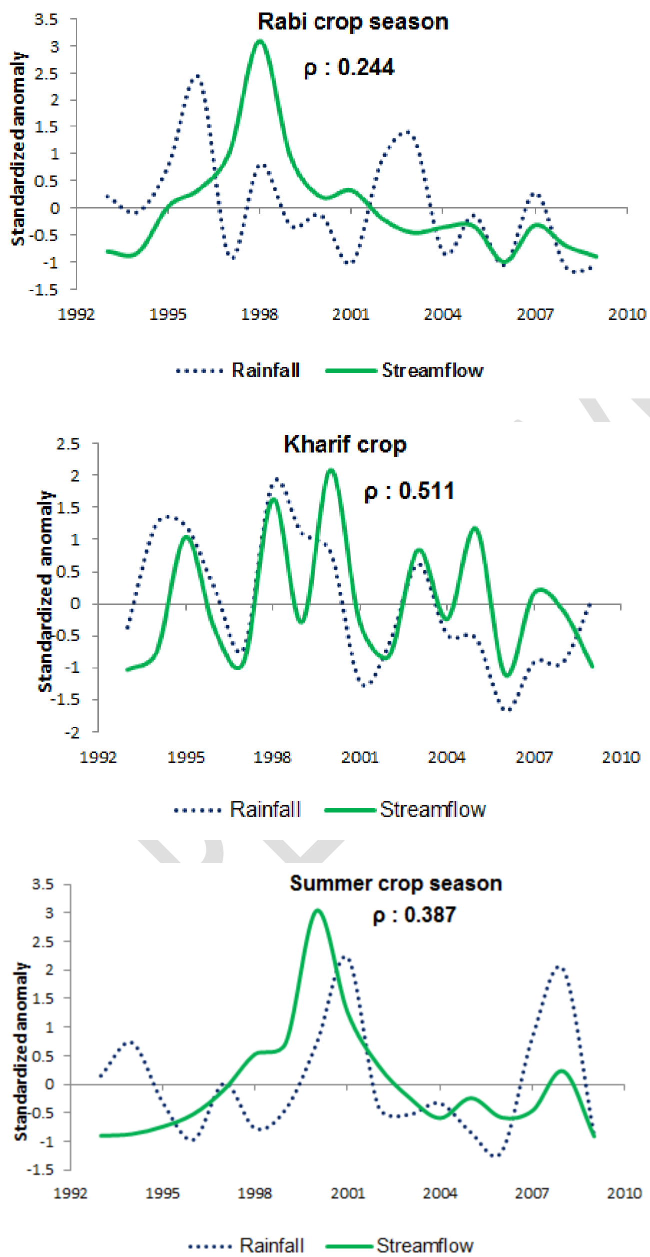


Figure 7. The temporal distribution of standardized anomalies of streamflow and rainfall in different agricultural crop seasons in the Ramganga River basin's upstream area

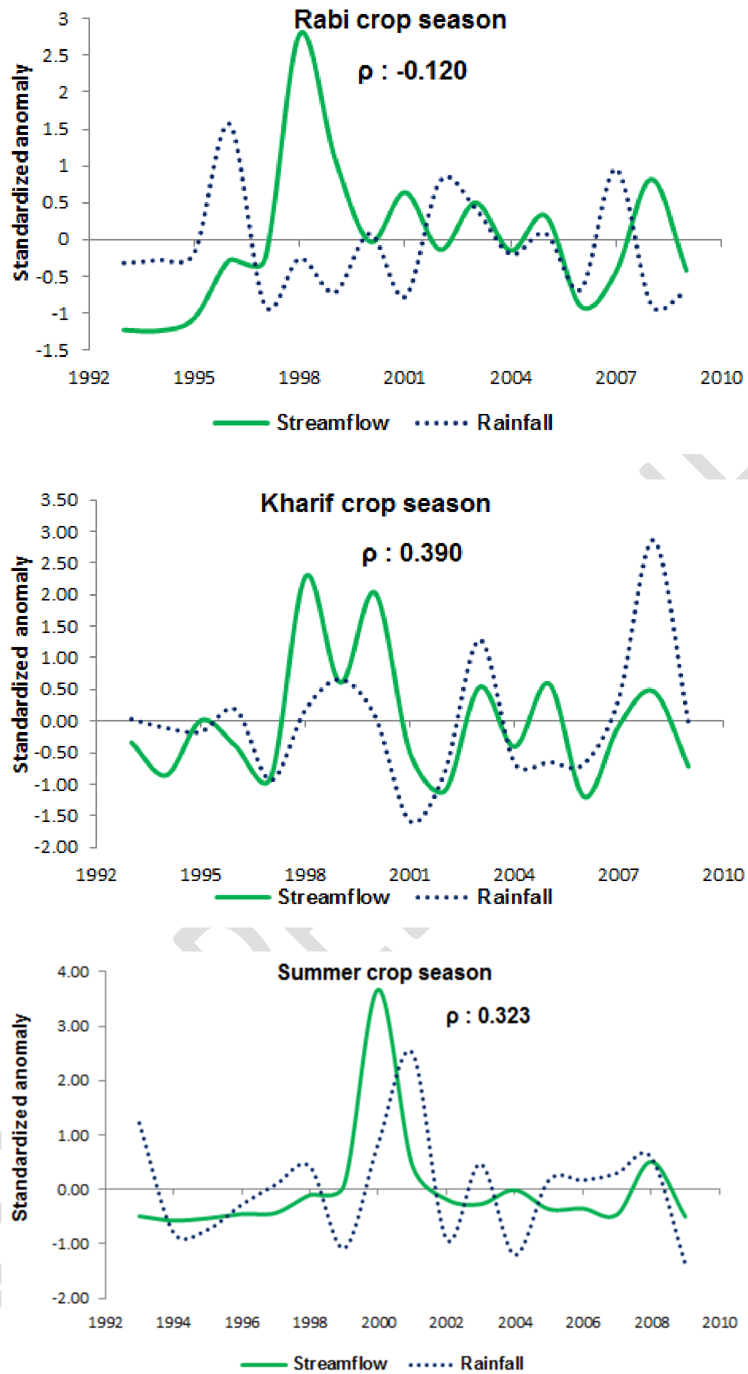


Figure 8. Temporal distribution of standardized anomalies of streamflow and rainfall in different agricultural seasons in Ramganga River basin's mid-stream area

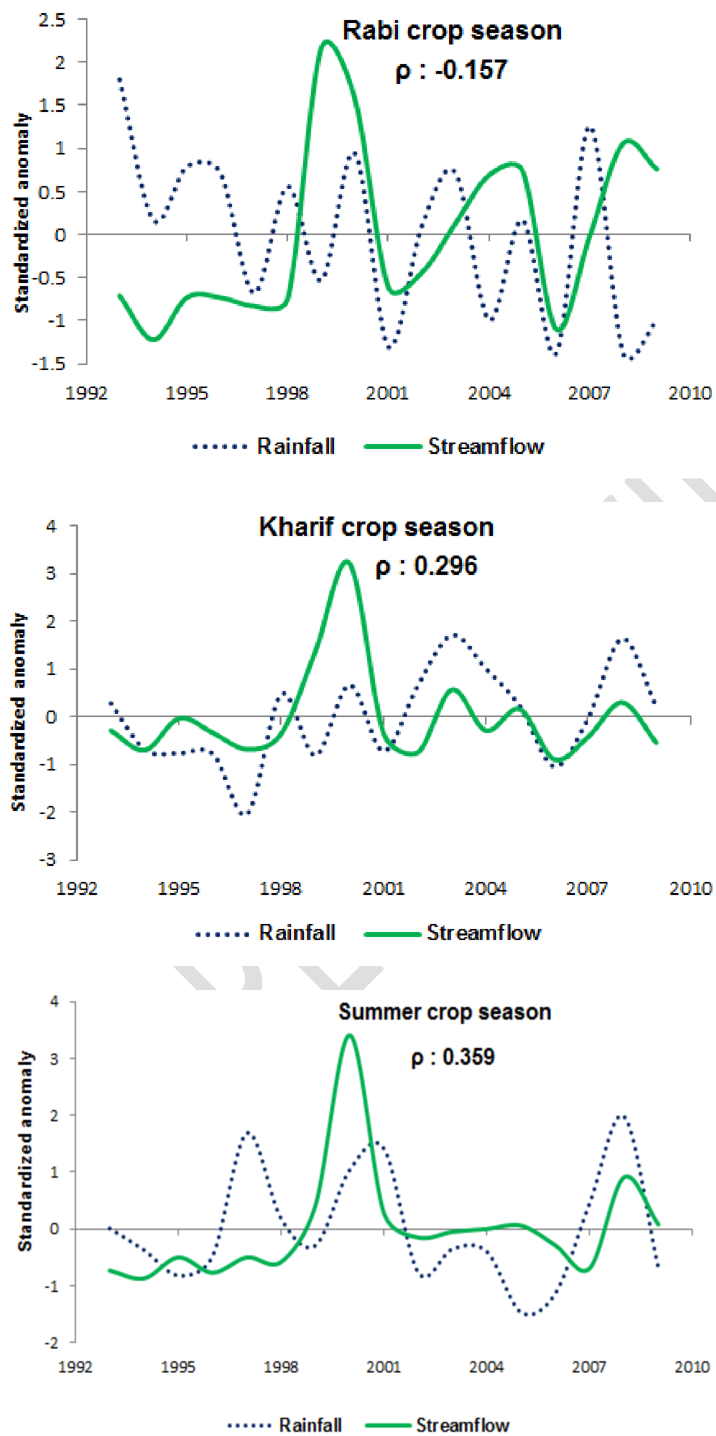


Figure 9. Temporal distribution of standardized streamflow and rainfall anomalies in different crop season of downstream region of Ramganga basin

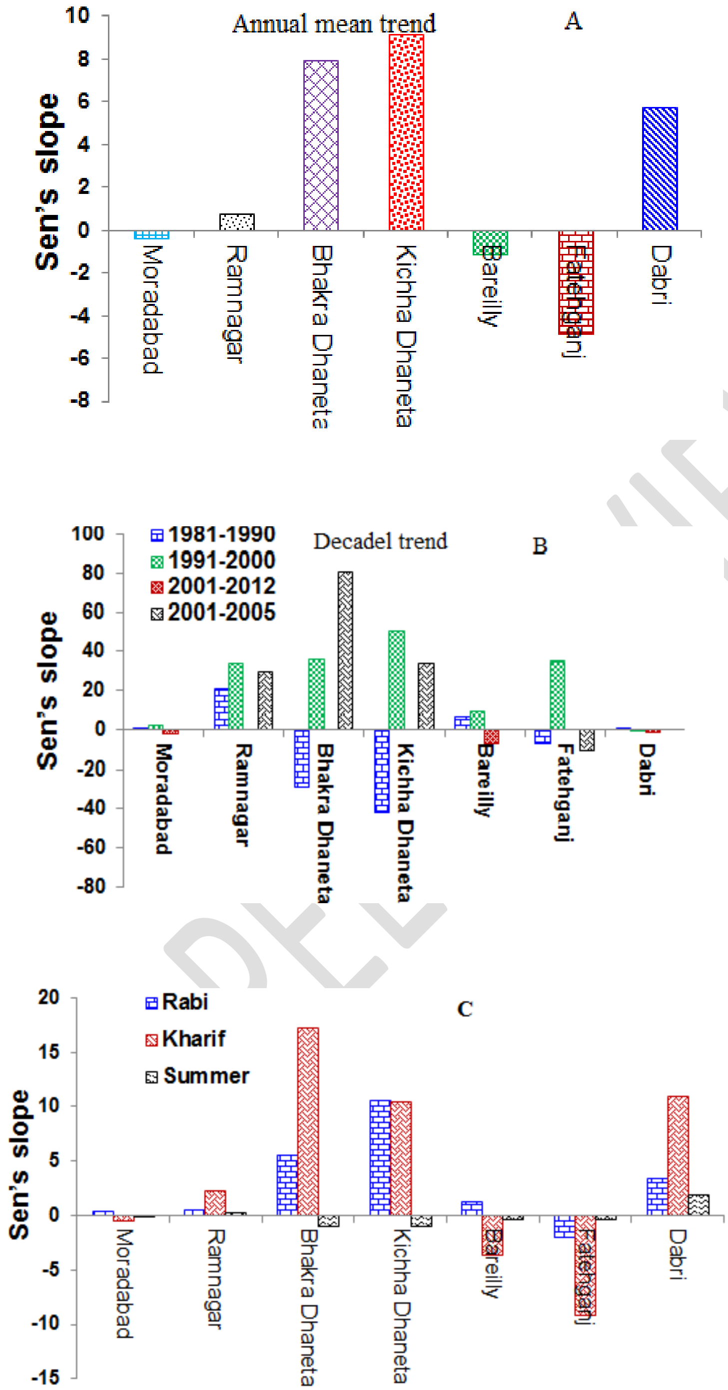


Figure 10. Statistical Mann–Kendall trend test with Sen's slope estimator for annual mean trend, decadal period and crop seasonal mean streamflow (m^3/s/year) for different catchment in Ramganga basin ((-) shows decreasing trend and (+) shows increasing trend)

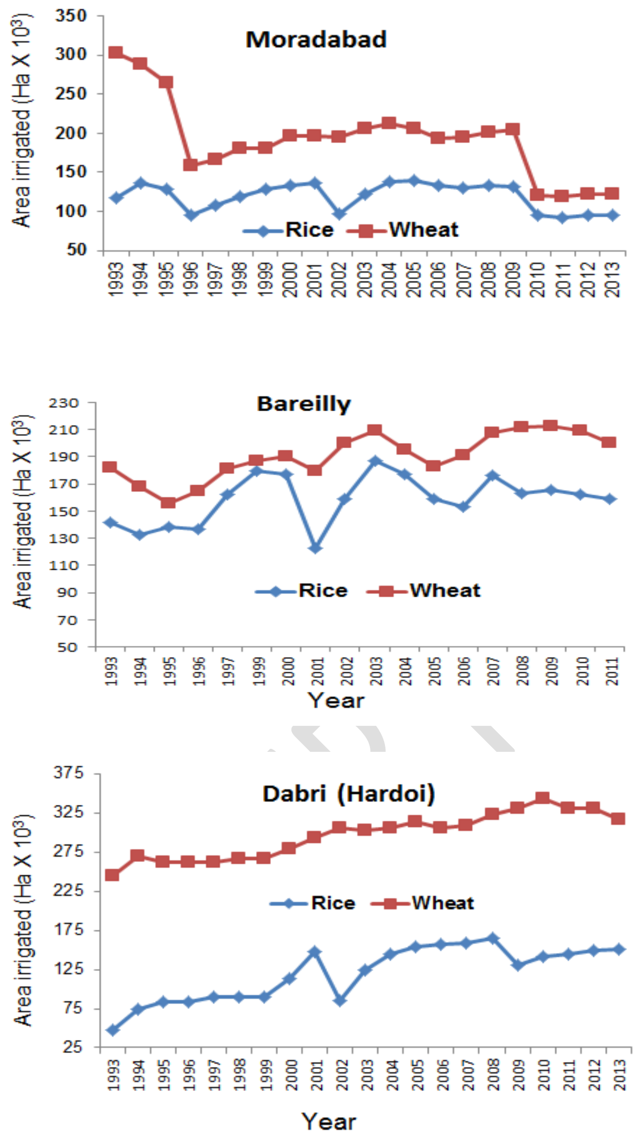


Figure 11. Total area irrigated under rice and wheat in Ramganga river basin key districts from 1993-1994 to 2013-14

Table 1. Characteristics of Streamflow of Ramganga River basin

Name of the Gauging Station	Latitude	Longitude	Catchment area (km^2)	Streamflow (m^3/s)	Period of records
Moradabad	28.83	78.78	6807	10 day average	1981–2012(31 ys)
Bareilly	28.36	79.41	18340	10 day average	1981–2012 (31 ys)
Ramnagar	28.80	79.00	7164	10 day average	1981-2005 (25 ys)
Fatehganj	28.46	79.30	2639	10 day average	1981-2005 (25 ys)
Dabri	29.49	78.40	23919	10 day average	1985–2012 (27 ys)

Table 2. Mann-Kendall test results with Sen's slope estimator for Interannual monthly mean streamflow ($m^3 s^{-1} year^{-1}$) and monthly rainfall ($mm\ year^{-1}$) for different catchments

Month / station	Moradabad		Ramnagar		Bhakra Dhaneta		Kiccha Dhaneta		Bareilly		Fatehganj East		Dabri	
	SF	RF	SF	RF	SF	RF	SF	RF	SF	RF	SF	RF	SF	RF
Jan	0.19	-0.02	-0.89	0.19	12.58	-0.21	4.34	-0.11	-1.18	-0.11	-2.19	0.15	2.42	-0.04
Feb	0.34	0.07	0.56	0.18	8.60	0.19	2.80	0.15	-1.45	0.15	-1.14	0.27	3.11	0.05
Mar	-0.21	0.02	0.79	-0.17	6.35	-0.21	-0.24	-0.16	-1.03	-0.16	-0.84	-0.08	2.36	-0.11
Apr	-0.09	-0.65	-0.30	-0.49	0.25	-0.69	-1.41	-0.37	0.41	-0.37	-0.65	-0.29	1.99	-0.21
May	-0.06	-0.50	0.31	-1.28	0.00	-0.55	-0.02	-0.76	0.01	-0.76	-0.50	-0.64	1.56	-0.39
Jun	-0.37	1.20	0.45	-2.58	-1.59	-0.58	-1.64	-0.58	0.34	-0.58	-0.07	1.21	1.17	-1.21
Jul	0.45	-3.55	0.94	-3.94	-9.65	-2.69	4.32	-3.69	0.58	-3.69	-2.60	1.51	2.10	1.59
Aug	-0.38	-3.70	6.47	-6.89	-2.90	-5.84	22.45	-5.82	0.14	-5.82	-10.44	-2.22	14.53	-0.23
Sep	0.85	1.34	1.96	1.49	-7.42	0.91	26.22	0.91	6.59	0.91	-9.02	4.11	20.73	0.77
Oct	0.62	-0.04	1.87	-0.06	18.35	-0.26	14.63	-0.21	4.79	-0.21	0.56	-0.26	8.61	-0.18
Nov	0.33	0.00	3.26	0.00	14.43	0.01	9.21	0.00	1.26	0.00	-4.23	0.00	5.29	0.00
Dec	0.24	-3.62	0.47	-3.28	8.54	-0.39	5.05	-0.35	1.19	-0.35	-2.84	-0.23	2.99	-0.26

Where SF: Streamflow; RF: Rainfall

Table 3. Summarized results of Mann-Kendall test with Sen's slope estimator ($^oC\ year^{-1}$) of mean temperature of different catchments of Ramganga River basin (1981-2005)

Catchment	**Mean annual**	**Mean Kharif**	**Mean Rabi**	**Maximum annual mean**	**Minimum annual mean**
Moradabad	0.014*	0.014*	0.010*	-0.001	0.035*
Ramnagar	0.012*	0.013*	0.010*	-0.001*	0.031
Bhakra Dhaneta	0.011*	0.012*	0.012*	-0.000*	0.027*
Kiccha Dhaneta	0.011*	0.012*	0.012*	-0.000	0.027*
Bareilly	0.011*	0.012*	0.012*	-0.000*	0.027
Fatehganj	0.013*	0.014*	0.01*	-0.001*	0.021*
Dabri	0.013*	0.012*	0.01	-0.002	0.025*

*0.05 (significance level based on MK test)

Table 4.Population of different districts of Ramganga river basin in 1991 and 2011

District	Area (km^2)	Population 3/1/1991 Census	Population 3/1/2011 Census	% change in Population
Chamoli	8,030	391,605	370,359	-5.74
Pauri Garhwal	5,329	687,271	697,078	1.41
Almora	3,144	630,567	622,506	-1.29
Bijnor	4,561	3,131,619	3,682,713	14.96
Champawat	1,766	224,542	259,648	13.52
Jyotiba Phule Nagar	2,249	1,499,068	1,840,221	18.54
Udham Singh Nagar	2,542	1,234,614	1,648,902	25.06
Moradabad	3,718	2,467,960	3,126,507	37.86
Rampur	2,367	1,923,739	2,335,819	35.69
Bareilly	4,120	3,618,589	4,448,359	36.28
Pilibhit	3,686	1,283,103	2,031,007	36.82
Budaun	5,168	2,630,710	3,127,621	15.89
Shahjahanpur	4,368	1,987,395	3,006,538	35.95
Etah	2,431	1,561,705	1,774,480	11.99
Hardoi	5,986	3,398,306	34,710,102	32.88
Total for the basin	59,845	26,263,890	34,710,102	20.65

Source: The Office of Registrar General & Census Commissioner of India. http://www.geohive.com/cntry/in-09.aspx