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Research Article

Analysis of Rainfall and Temperature Trends in Gomti River Basin

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ABSTRACT

Analysis of trends in hydro-climatic variables such as rainfall, temperature and stream flow provide useful information for planning of water resources, control of flood, management of drought and agricultural production. Trends in rainfall (1982-2011) and temperature (1972-2007) in districts of Gomti River basin were assessed using the Mann-Kendall and Sen's slope estimator. Streamflow (1982-2012) at the downstream end of the basin, *Maighat* was also assessed and relationships between trends in streamflow and rainfall were evaluated. All the districts in the upstream area showed significant increasing trend in annual rainfall ($p < 0.05$) while downstream areas showed decreasing trend. A similar drift was observed in the monsoon rain. Pre-monsoon rains had increasing trend, particularly in the month of May. In contrast, post-monsoon and winter rainfall were significantly decreasing especially towards the downstream areas. Streamflow was also reducing irrespective of the scale of assessment and this could be attributed partly to the decreasing rainfall. Decrease in rainfall and consequent decline in streamflow of the basin along with increasing temperature indicate possibility of dryness in the lower basin over the years. The results of this study could be helpful in implementing adaptation and mitigation strategies for alleviating the environmental and livelihood threats in Gomti River basin.

Key words: Mann-Kendall, Rainfall, Streamflow, Temperature, Gomti River basin

Introduction

Rainfall and temperature are the two most important driving factors for year-to-year variability in crop production and the available water resources. Streamflow is primarily driven by change in precipitation (Milliman *et al.,* 2008), which is intimately related to water availability. Furthermore, rainfed agriculture directly depends on the magnitude and temporal distribution of the rainfall. The global average precipitation is likely to increase, although at regional and continental scales, this may either increase or decrease (Dore, 2005). Global mean surface air temperature is projected to rise by 0.74°C (IPCC, 2007) while Kothawale and Rupa Kumar (2005) have reported diurnal temperature asymmetry over India, indicating that the warming is contributed by the maximum temperature. It is logical to analyze the hydro-climatic variables at small scale to obtain precise estimates (Rai *et al*., 2010). Thus, analysis of the same at river/sub-river basin scale could be useful in water resource and agri-production management.

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Precipitation in the Ganges basin is reported, by and large, stable (Mirza *et al.*, 1998) compared to Brahmaputra and Meghna river basins. Singh *et al.* (2008) studied the changes in rainfall in river basins of north-west and central India and found increasing trends in annual rainfall (2–19% of the mean per 100 years). Large decline in streamflow without significant change in rainfall was reported in Himayat Sagar catchment, which was attributed to anthropogenic factors (Nune *et al.*, 2012). In another study, Panda *et al.* (2013) linked changes in rain and stremflow in the Mahanadi River basin to El Niùo-Southern Oscillation (ENSO).

In this paper, the trends in rainfall and temperature in the Gomti River basin and its relation with the changes in streamflow are described.

Materials and Methods

Study area

The Gomti, an alluvial river of the Indo-Gangetic Plains is one of the important tributaries of river Ganges. Originated near Mainkot from a lake (*Fulhaar Jheel*), about 30 km east of the Pilibhit town in Uttar Pradesh, the river meets the Ganges at Kaithi, in Varanasi (U.P.) after traversing 960 km in south, south-east direction (Fig. 1). The total area of the basin is 30,437 km^2. Topography is undulating and elevation varies from 58 to 238 m above msl. The climate

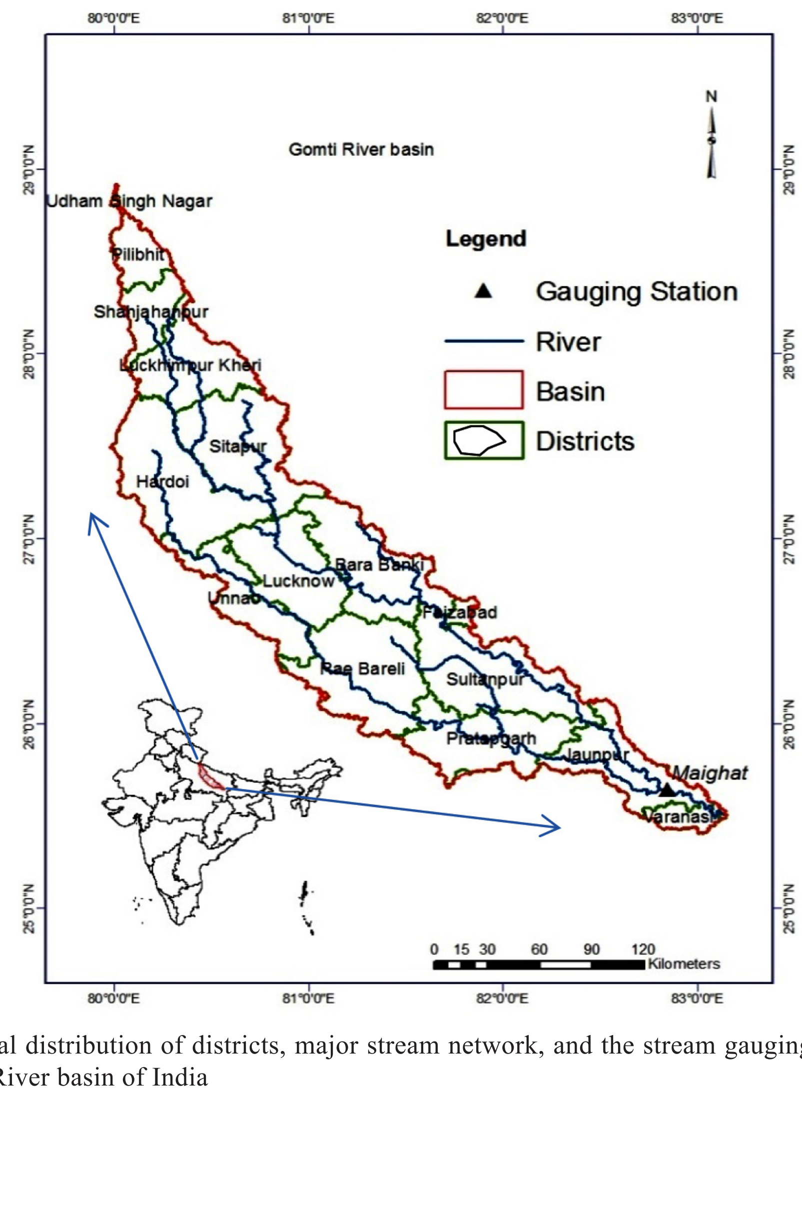

Fig. 1. Geographical distribution of districts, major stream network, and the stream gauging station *Maighat* of the Gomti River basin of India

is ranging from semi-arid to sub-humid tropical with average annual rainfall varying between 850 and 1100 mm. About 75% of total annual rainfall is received between June and September due to south-west monsoon (Rai *et al*., 2009). The river is the main source of water supply to cities of Lucknow and Jaunpur in Uttar Pradesh and other habitations downstream.

Data set and data preprocessing

District-wise daily rainfall (1982-2011) and temperature (1972-2007) data were obtained from NICRA (National Initiative on Climate Resilient Agriculture, http://www.nicra-icar.in/nicrarevised/) web portal and used for the analysis. The data pertains to 14 districts covering the entire basin. Ten-day-average streamflow data (1982-2012) at the gauging site at *Maighat* which is closer to the basin outlet were collected from the Central Water Commission (CWC), Govt. of India. A sub-basin was delineated taking *Maighat* gauging station as the outlet in order to analyze the rainfall over the basin and to investigate the prospective association between streamflow and rainfall.

Different district areas falling in the sub-basin were normalized with respect to total sub-basin area and used as a weight to calculate monthly average rainfall for the sub-basin. Using these weighted average monthly rainfall values, seasonal rainfall for each of the seasons were calculated for the sub-basin *Maighat*. We assume that the sub-basin *Maighat* represent the entire basin as the gauging site is located closer to the outlet of the Gomti River basin (Fig. 1).

Following indicators were calculated:

- Inter-annual monthly rainfall: Monthly rainfall of the same month over the years.
- Annual rainfall: Summation of monthly rainfall values from January to December.
- Seasonal rainfall: Summation of monthly rainfall values for pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and winter (December–February) seasons, where the mean of winter was based on December of the previous year and January and February of the following year.
- Monthly maximum rainfall: Maximum rainfall values recorded in a month.
- Annual, seasonal and monthly weighted average rainfall for the sub-basin.
- Means of inter-annual, monthly, seasonal and annual streamflow at gauging site [monthly mean was calculated using the mean of three decadal (10-day) streamflow values of a given month].
- Annual and seasonal mean temperature for each district.
- Annual mean maximum and minimum mean temperature for each district.

Statistical analysis

Monotonic trend of rainfall and temperature were tested using widely used methods of Mann-Kendall (MK) test (Mann, 1945, Kendall, 1975) and Sen's slope estimator (Sen, 1968; Gautam and Acharya, 2012).

Though the MK test is robust and useful in many hydrological studies, the use of MK test for detecting trends may not always be ideal. That is because the original MK test does not account for the serial correlation that very often exists in a hydro-climatic time series (Hamed and Rao, 1998; Yue *et al.,* 2002). The presence of serial correlation in a data set may lead to a misleading result interpretation because it enhances the probability of finding a significant trend, when actually there is an absence of a significant trend. We checked each time series data to find significant lag-one autocorrelation, if exists. If a time series exhibited no significant autocorrelation, the original MK test was used to analyze the data. When there was a significant lag 1 autocorrelation in a time series, we adopted Modified MK test proposed by Hamed and Rao (1998). The trends were evaluated at 0.05 and 0.01 levels of significance (p values) as an indicator of the trend strength (Sharif *et al.,* 2013).

The standardized anomaly or 'Z-score' (subtracting the mean from the original value and then dividing it by the respective standard deviation) was calculated for time series data of each parameter and the anomaly was smoothened by moving-window-average with a span of 5years and then it was subjected to trend analysis. This indicator minimizes the spatial bias and reduces the random fluctuation and thus helps in comparing spatio-temporal variability in the parameters over the basin. Non-parametric Spearman's correlation coefficient ($\tilde{n}$) was also used to find out the prospective association of streamflow with rainfall.

Results and Discussion

We found that districts in upstream areas recorded maximum rainfall in August (Kheri=301.18 mm with coefficient of variation, CV 34.8%; Pilibhit=303.47 mm with CV 42.3%) whereas districts in mid-stream and down-stream recorded their maximum rainfall in July (Lucknow 220.3 mm with CV 49.4%; Sultanpur 256.2 mm with CV 39.2%; and Jaunpur 236.18 mm with CV 37.6%) (Fig. 2). It was also observed that the rainfall towards the upstream is higher than the downstream areas of the basin. For the entire basin, the maximum temperature occurs in the month of May and the lowest in the month of January. However, upstream areas had comparatively lower temperature than other basin areas.

Trends in annual rainfall

All the upstream districts showed significant increasing trend in annual rainfall ($p < 0.05$) while rainfall trend showed to be reducing in downstream areas (Fig. 3). However, only Jaunpur district annual rainfall exhibited significant decreasing trend for MK test ($p < 0.05$). Mid-stream areas showed mixture of trends which were non-significant. For example, Lucknow and Unnao showed increasing trend while Bara Banki and Rae Bareli indicated a decreasing trend over the period. For some representative districts, 1987 and 2002 experienced negative anomaly/ drought years while for the same districts in 2008 experienced positive anomaly/wet/flood year (Fig. 4).

Seasonal rainfall trends

Rainfall patterns are characterized by marked seasonal differences (Table 1). Over the years, it increased in pre-monsoon seasons ($p < 0.05$),

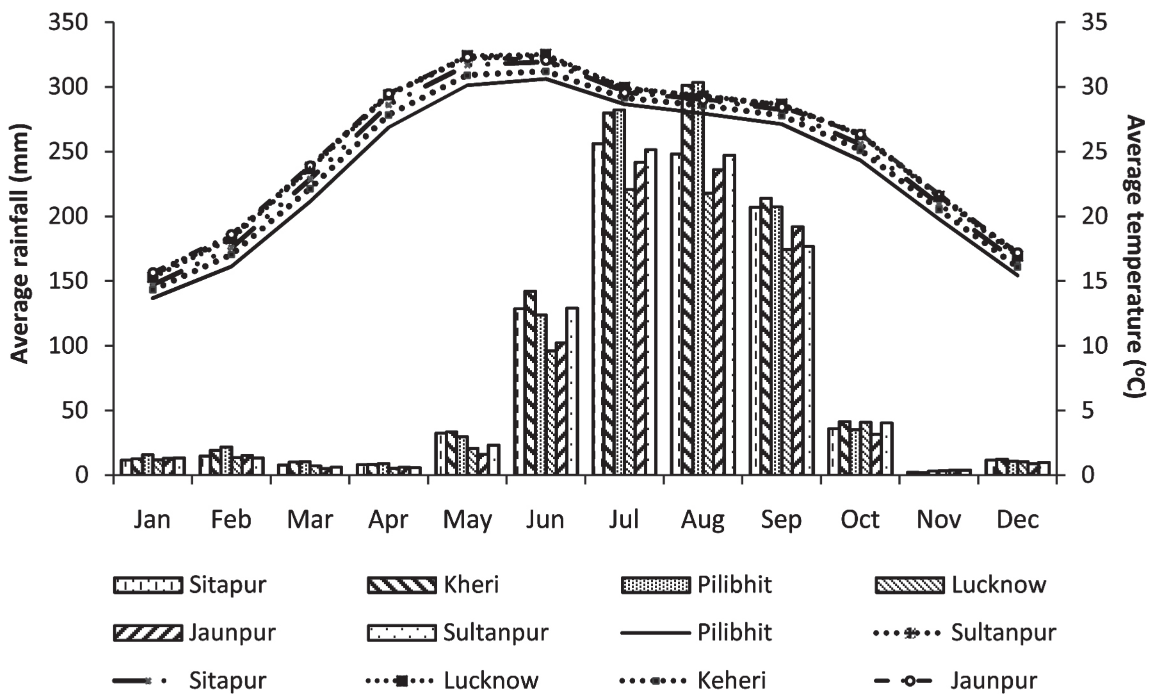

Fig. 2. Mean monthly rainfall and temperature of major districts of Gomti River basin

Table 1. Summarized results of Mann–Kendall test with Sen's slope estimator for seasonal and monthly rainfall of districts of Gomti River basin

District	Pre-monsoon	Monsoon	Post-monsoon	Winter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pilibhit	0.02**	0.05**	-0.01	-0.02*	-0.29	0.09	-0.05	0.00	0.68	1.31	3.53	5.85**	2.99	-0.03	0.00	-0.21*
Shahjahanpur	0.04**	0.05**	-0.005	0.00	-0.25	0.10	-0.06	0.04	0.67*	2.64*	2.22	3.311	1.33	0.00	0.01	-0.2*
Kheri	0.06**	0.05	-0.01	-0.02**	-0.27	0.08	-0.04	0.08	0.97*	1.87	2.66	5.75**	0.9	-0.16	0.00	-0.20*
Sitapur	0.07**	0.07	-0.01	-0.006	-0.14	0.01	-0.02	0.07	1.72**	2.91*	3.08	4.53*	1.33	-0.58	0.00	-0.07
Hardoi	0.07**	0.08**	-0.007	0.00	-0.06	0.03	-0.01	0.09	1.56**	4.1**	3.52*	2.68	0.84	-0.16	0.00	0.00
Unnao	0.04**	0.02	-0.02**	-0.02**	-0.51**	-0.04	0.00	0.07	0.57**	2.23	1.04	-0.54	-0.75	-0.24	0.00	0.00
Lucknow	0.05**	0.03	0.02**	-0.02**	-0.42**	-0.05	-0.06	0.07	1.00**	2.3	0.83	0.38	-0.72	-0.63*	0.00	-0.18
Rae Bareli	0.04**	0.01	-0.04**	-0.03**	-0.35**	-0.11	0.00	0.00	0.83**	1.78	-0.35	-0.48	-1.87	-0.83*	0.00	-0.07
Pratapgarh	0.02**	-0.01	-0.03	-0.03**	-0.46**	-0.05	0.00	-0.04	0.5*	0.21	-3.07	-0.75	-1.51	-0.57	0.00	-0.02
Bara Banki	0.06**	0.01	-0.03**	-0.04**	-0.30*	0.00	0.00	0.02	1.53**	1.4	-1.8	2.2	-1.2	-0.93*	0.00	-0.20
Faizabad	0.03**	0.00	-0.03**	-0.04**	-0.40*	0.01	0.00	-0.02	1.01**	1.47	-2.30	0.6	-0.99	-0.74	0.00	-0.12
Sultanpur	0.03**	0.00	-0.04**	-0.04**	-0.41*	0.00	0.00	-0.00	0.82**	1.52	-1.66	0.55	-1.05	-0.81*	0.00	-0.10
Jaunpur	0.04**	-0.03**	0.01	-0.02**	-0.43**	0.00	0.00	-0.01	0.05**	0.66	-5.65**	-0.8	-1.32	-0.16	0.00	-0.01
Varanasi	0.04**	-0.02**	0.02	-0.01*	-0.34**	-0.01	0.00	0.00	0.62	1.3	-5.47**	0.16	-0.58	-0.04	0.00	0.00

Note: ** significant at 0.05 and * significant at 0.1 level based on MK test.

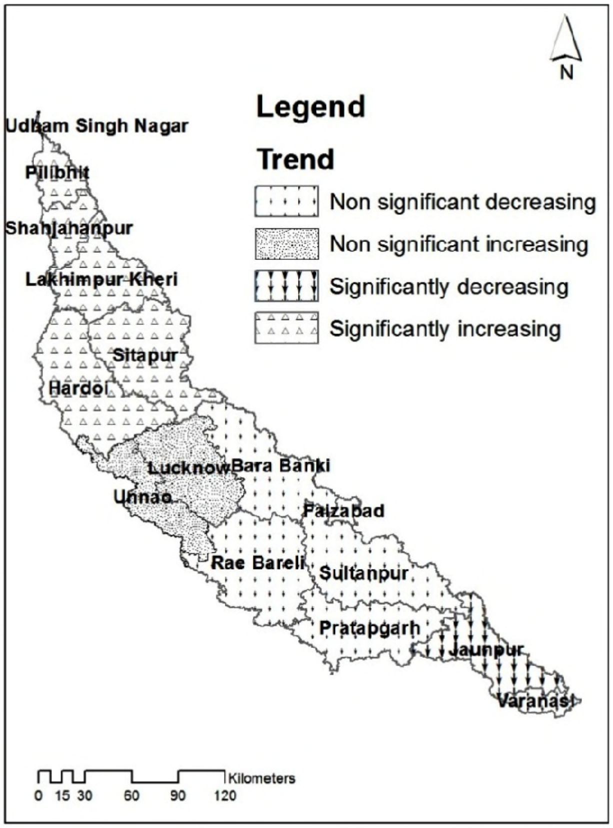

Fig. 3. Trend of five year moving averaged standardized anomalies of annual rainfall in Gomti River basin

districts. Post-monsoon rainfall in all districts, except Jaunpur and Varanasi, showed decreasing trends, with significant decrease could be found in mid-stream basin. Districts representing comparatively upstream (u/s) areas of the basin showed significant increasing trend in rainfall in monsoon season and there was a reducing trend of monsoon rainfall towards the downstream (d/s) areas of the basin. Jaunpur and Varanasi representing most d/s area of the basin showed significant decreasing trend (Table 1). This trend is approximately similar to the annual rainfall trend of the districts of the basin.

Variation of monsoon anomaly is close to that of annual as nearly 80 % of annual rainfall is monsoonal (Fig. 5). The variability of monsoonal rainfall was also shown in Fig. 5 with CVs of Pilibhit (28.08%), Sitapur (26.35%), Lucknow (29.55%) and Jaunpur (24.71%). During the study period of 30 years, the year 1987 showed the most negative anomaly (- 2.29) whereas the year 2008 showed the most positive (+ 2.58) monsoon rainfall anomaly.

The south-west monsoon rainfall is classified as deficit when the actual rainfall is < LPA ± CV

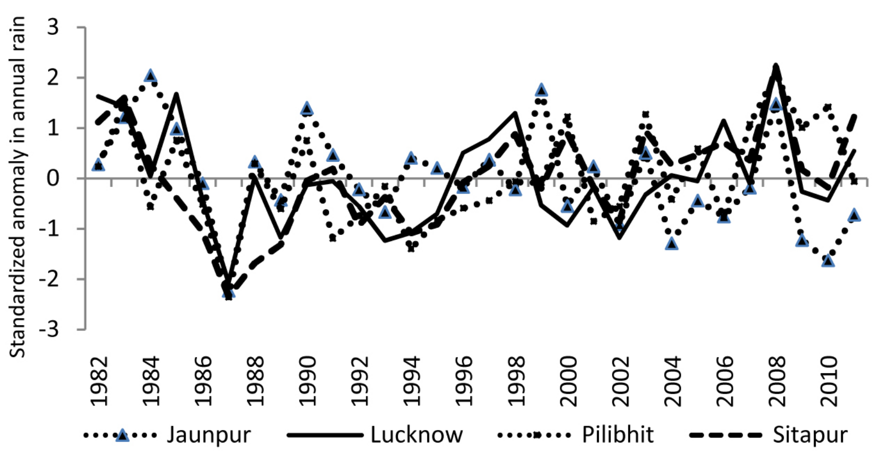

Fig. 4. Variation of standardized anomaly in annual rainfall in few representative districts in Gomti River basin

especially in Sitapur and Hardoi districts, as indicated by Sen's slope. In contrast, trends of winter rains decreased in most of the districts over the period. No significant trend in winter rains was recorded in Hardoi and Shahjahanpur (LPA, long-period average; CV); normal when actual rainfall is within LPA ± CV, and excess when actual rainfall was > LPA ± CV of the corresponding year (Choudhury *et al*., 2012). We also analyzed the monsoon rainfall as per these guidelines for the districts in Gomti River basin for the last 30 years and the results are shown for the most u/s district, Pilibhit, m/s district, Lucknow and d/s district, Jaunpur (Fig. 6). The magnitude of deficit in rains was comparatively higher in upstream than the downstream districts although the mean rainfall in upstream districts were greater and also in increasing trend (Fig. 6). Therefore, attention must also be paid on upstream districts to the rainfall deficit similar to the downstream basin. The year 1987 had been a drought year and 2008, a flood year for all the districts. However, deficit and excess rainfall events are not always coexistent in other years for all the districts. These analyses can be a tool in designing flood and drought management strategies.

Monthly rainfall trends

Monthly rainfall of the basin showed marked differences among districts and months (Table 1). In January, rainfall significantly decreased in districts located in mid-stream and d/s basin, while in the month of December, significant decrease was recorded in u/s. Furthermore, October rainfall had decreasing trend in all districts except Shahjahanpur (no trend). However, significant changes were observed only in Lucknow, Rae Bareli, Bara Banki and Sultanpur which are all the mid-stream districts. Rainfall in the months of May increased in all the districts except Pilibhit (increase but non-significant). Similarly, rainfall in the month of June was also increasing, but significant only in Sitapur, Hardoi and Shahjahanpur districts. The rainfall of the month of November in the entire basin showed no trend.

Maximum inter-annual monthly rainfall in May increased while the same in October decreased in all the districts (Table 2). These maximum rainfall trends are approximately in consistent with monthly rainfall. In addition, maximum rainfall recorded in September month showed decreasing trend except Sitapur, Hardoi and Pilibhit where the trends were in increasing. Maximum rainfall trends in June, July and August showed mixture of response for the districts in the basin. However, the maximum rain recorded in June month showed significant increasing trend for two upstream districts, Hardoi and Sitapur. Maximum rainfall in July month showed decreasing trend in districts towards the d/s though the trends were not significant. Similarly, August month showed decreasing trend of its maximum rainfall towards the d/s except the district Varanasi.

We found that the pre-monsoon seasonal rainfall was increasing significantly, particularly in the month of May. In addition, maximum May rainfall was also increasing. However, post-

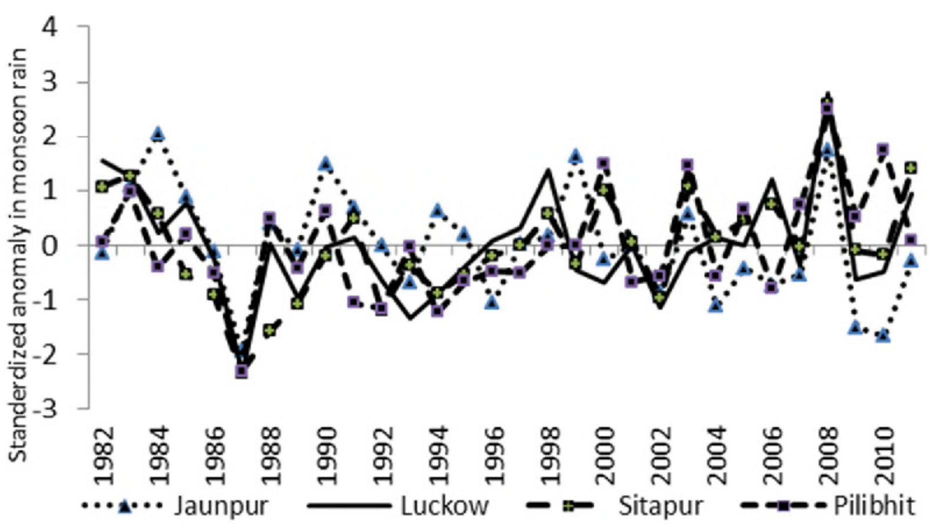

Fig. 5. Variation of standardized anomaly in monsoon rainfall in few representative districts in Gomti River basin

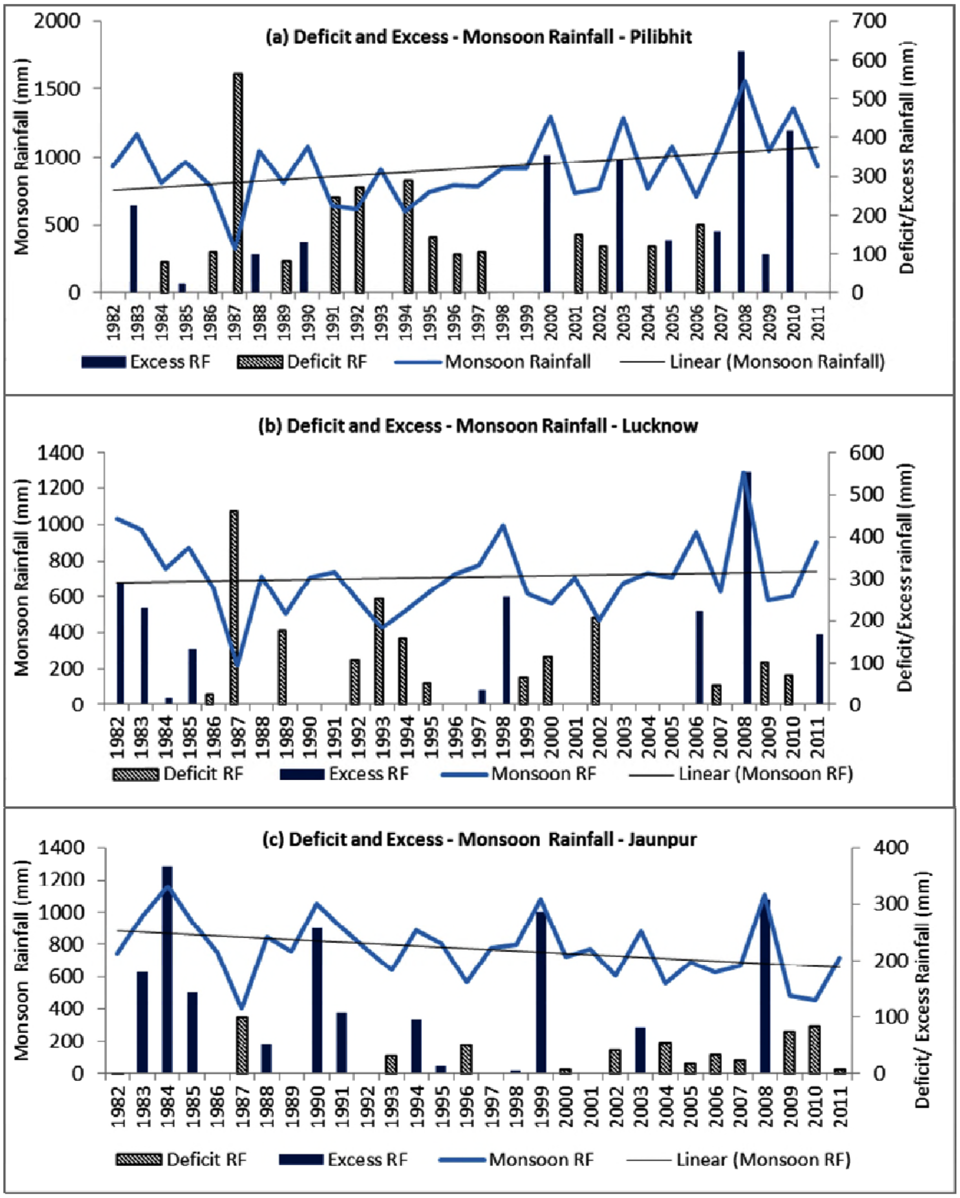

Fig. 6. Deficit and excess monsoon rainfall in few representative districts of Gomti River basin, a) Pilibhit, b) Lucknow, C) Jaunpur

monsoon rainfall was decreasing, especially the mid-stream area. Maximum rainfall in September and October months was also decreasing. These indicate that there may be an apparent shifting in timing of the monsoon season, *i.e.*, early onset and early withdrawal.

Trends in air temperature

We tested the mean annual temperature of its original time series and in terms of 5 years moving average standardized anomalies (Table 3). Both showed the similar trend though the magnitude of the trend and level of significance little varied. Mean annual temperature of the districts in the basin showed significant increasing trend (0.01 to 0.02 ^{0}C; $P < 0.05$) except Varanasi district which is located at the end of the basin and it has comparatively less geographical area lied over the basin. However, Varanasi also showed non-significant increasing trend. Hingane *et al.* (1985) also found that mean annual

Table 2. Summarized results of Mann–Kendall test with Sen's slope estimator for monthly maximum rainfall of districts in Gomti River basin

District	May	June	July	August	September	October
Pilibhit	0.02	-0.14	-0.02	1.07	0.87	0.00
Shahjahanpur	0.09	0.51	0.20	0.67	-0.01	-0.02
Kheri	0.09	0.46	0.66	1.2*	-0.07	-0.16
Sitapur	0.65**	0.75*	0.70	0.63	1.13*	-0.25
Hardoi	0.37**	1.15**	1.16*	0.62	0.74	-0.18
Unnao	0.23*	0.5	-0.27	-0.18	-0.41	-0.26
Lucknow	0.29	0.53	0.16	-0.05	-0.1	-0.35*
Rae Bareli	0.22	0.32	0.05	-0.24	-0.21	-0.47**
Pratapgarh	0.14	-0.36	-0.33	-0.25	-0.51	-0.19
Bara Banki	0.03*	0.1	-0.23	-0.34	-0.37	-0.55**
Faizabad	0.13	0.20	-0.06	-0.9**	-0.36	-0.45**
Sultanpur	0.24	0.5	-0.07	-0.72*	-0.5	-0.59**
Jaunpur	0.10	-0.5	-0.65	-0.45	-0.99	-0.14
Varanasi	0.24	-0.42	-0.23	0.06	-1.13*	-0.01

Note: **significant at 0.05 and * significant at 0.1 level based on MK test.

Table 3. Summarized results of Mann–Kendall test with Sen's slope estimator of mean temperature of different districts of Gomti River basin,1972 – 2007 (standardized anomalies after getting 5 yr moving average were tested for MK).

District	Mean annual	Mean monsoon	Mean winter	Maximum annual mean	Minimum annual mean
Pilibhit	0.022**	0.023**	-0.000	0.000	0.067**
Shahjahanpur	0.024**	0.022**	0.000	-0.026**	0.067**
Kheri	0.023**	0.024**	0.007	-0.03	0.069**
Sitapur	0.020**	0.021**	0.003	-0.006	0.066**
Hardoi	0.020**	0.023**	0.005	-0.022*	0.066**
Unnao	0.021**	0.015**	0.011	-0.009	0.056**
Lucknow	0.020**	0.017**	0.009	0.007	0.061**
Pratapgarh	0.016**	0.011*	0.001	0.003	0.023**
Bara Banki	0.021**	0.021**	0.007	-0.01*	0.061**
Faizabad	0.017**	0.015**	0.004	-0.008	0.042**
Sultanpur	0.018**	0.017**	0.005	-0.014	0.047**
Jaunpur	0.016**	0.01	0.010	0.01	0.021**
Varanasi	0.011	0.005	0.007	-0.000	0.019*

Note: ** significant at 0.05 and * significant at 0.1 level based on MK test.

temperature to be increasing over the north central and north-eastern regions of India during 1901-1982. During the monsoon season, temperature trend showed an increase in the Gomti basin. Winter temperature showed non-significant trend for the MK test for all the districts in the basin. Minimum temperature showed significant increasing trends for all the districts. Moreover, increase in minimum temperature was greater in u/s districts when compared to increase in d/s districts. In contrast, maximum annual mean temperature in all most all districts in the basin

Table 4. Summarized results of Mann–Kendall test with Sen's slope estimatorof Streamflow and weighted average rainfall over the basin (considering basin out let as the Maighat GS) and Correlation coefficient between streamflow and rainfall

Scale of analysis	Streamflow	Weighted average rainfall	Correlation coefficient (ρ)
Annual	-5.35*	2.33	0.44**
Pre-monsoon	-0.44	1.29**	-0.01
Monsoon	-10.39**	1.06	0.67**
Post-monsoon	-4.64	-0.81*	0.46**
Winter	-3.68**	-0.42	0.16
Jan	-3.02*	-0.36	0.52***
Feb	-1.87*	0.01	0.36
Mar	-0.59	-0.04	0.21
Apr	-0.01	0.09	0.33
May	-0.09	1.23**	0.18
Jun	-1.31	2.11	0.44**
Jul	-1.15	0.29	0.62***
Aug	-1.22	1.34	0.51***
Sep	-14.4**	0.61	0.41**
Oct	-1.41	-0.56	0.44**
Nov	-5.28**	0.02	-0.21
Dec	-3.66**	-0.21	0.34

Note: Significant at **0.05 and * 0.1 levels based on MK test. *** Significant at 0.01, ** significant at 0.05 levels based on Spearman's rho correlation test.

decreased from 1972 to 2007. But, significant trend was observed only in Shahjahanpur ($p < 0.05$), Hardoi ($p < 0.1$), and Barabanki ($p < 0.1$) districts. Therefore, it is clear that mean annual temperature has increased due to the rise of minimum temperature of the basin.

Streamflow and weighted average rainfall

Annual, seasonal and monthly streamflow at *Maighat* gauging site decreased over the years (Table 4). The decreasing trend was significant for annual, monsoon, winter season and January, February, September, November and December months. However, weighted average rainfall indicated significant increase in pre-monsoon season and also in the month of May. Conversely, decreasing trends were observed during post-monsoon season. We also observed that the districts of mid-and downstream area witnessed decline in annul and monsoon rainfall. These results suggest decrease in rainfall contributes mostly for a decrease in streamflow, especially in downstream areas.This is further evident by the significant positive correlations between streamflow and rainfall. Milliman *et al*. (2008) concluded that trends in annual streamflow for many rivers primarily were driven by changes in precipitation. In addition, Gregory *et al.* (2012) examined the actual evapo-transpiration, runoff, and potential evapo-transpiration for the past century by using a monthly water-balance model and their analysis indicated that precipitation has been the primary driver of variability in runoff.

Rainfall records, covering a period over 30 years, are considered to be long enough for a valid mean statistics (Kahya and Kalayci, 2004) while a minimum record length of 25 years ensure statistical validity of the trend results in a climate change research (Burn and Elnur, 2002). In this study we used 30 years of rainfall and 36 years of temperature data and also tested the trends in terms of 5-year-average standardized anomaly to enhance the validity of the results. The current analysis thus certainly provides important insights into the likely hydro-climate scenario of Gomti River basin.

Conclusions

The study showed that there is a drying tendency of downstream area of the basin as evident by decreasing tendency of rainfall (annual, post-monsoon and winter season) and downward trend of streamflow and the increasing trend of air temperature. This is despite the fact that annual rainfall at upstream districts was in increasing trend. This study also found that the pre-monsoon rainfall is increasing significantly, particularly in the month of May. In contrast, post-monsoon rainfall is decreasing significantly especially the midstream basin. In addition, maximum rainfall of September and October month was in decreasing trend. These finding infer that there may be an apparent shifting in timing of monsoon season *i.e.*, early onset and early withdrawal. Therefore, these finding may be useful in implementing adaptation and mitigation strategies for alleviating the environmental and livelihood threats associated with the changes of hydro-climatic variables in the Gomti River basin.

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