CLIMATE VARIABILITY AND TRENDS IN PART OF BRAHMAPUTRA RIVER BASIN

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ABSTRACT

One of the most significant consequences of global warming would be an increase in magnitude and frequency of extreme events like heat waves (IPCC 2007). The detection of trends in meteorological data, in particular rainfall and temperature is essential for the assessment of the impacts of climate variability and change on the water resources of a region. The Brahmaputra River is a trans-boundary river with its origin in southwestern Tibet going through the Himalayas in the great gorges and into Arunachal Pradesh. It flows southwest through the Assam State of India (Brahmaputra River Basin) and south through Bangladesh. This study focuses on the Subansiri sub-basin of the Brahmaputra River which is one of its principal tributaries and forms one of its largest sub-basins. This study aims to determine trends in the annual and seasonal daily rainfall and temperature (maximum, minimum and mean) over Subansiri river basin. The data used in this study consists of daily gridded rainfall data at 0.25º×0.25º resolution for a period of 37 years (1970-2007) and daily gridded temperature data at 1º×1º resolution for a period of 36 years (1969-2005). Historical trends in daily rainfall as well as maximum, minimum and mean temperature (daily) have been examined using regression analysis and Mann-Kendall (MK) statistics. The non parametric MK statistical test has been widely applied to asses the significance of trends in hydrological time series. On the basis of regression and MK test, rising and falling trend in rainfall and anamolies at various grid points have been analysed. The result shows that many of these variables demonstrate statistically significant changes occurred in last three decades. However, there is no systematic trend of rainfall in the basin. The temperature trend analysis shows that minimum temperature in general is increasing at all of the grid points considered for analysis, however, maximum temperature shows no trend. The mean temperature shows no significant trend in annual, pre-monsoon and post-on seasons, however there is rising trend in monsoon and winter seasons.

INTRODUCTION

The climate of earth was never stable for any extended period. Potential climate change and its impacts on hydrologic systems pose a threat to water resources throughout the world. There are a number of natural causes of climate variability, namely variations in the amount of energy emitted by the Sun, changes in the distance between the Earth and the Sun, the presence of volcanic pollution in the upper atmosphere and presence of green house gases, etc. Natural and human influences, called "forcings" in the climate-science literature alter the flow of radiant energy in the atmosphere, cooling and warming Earth by perturbing its energy balance. Positive forcings warm the planet while negative ones cool it. One of these forcings is induced by the greenhouse gases, which alter the planet's energy balance by absorbing infrared radiation that would otherwise escape to space. The major greenhouse gases include CO_2, methane, nitrous oxide, tropospheric ozone, chlorofluorocarbons (CFCs), and water vapor. With the exception of water vapor, the concentrations of all the greenhouse gases are more or less directly depend on human activities. (Water vapor levels depend on Earth's temperature and the availability of liquid water, and thus are indirectly affected by humans). Other forcings include reflective aerosols (mostly sulfate particles from burning of fossil fuel), black carbon particles (soot), land-cover changes, variations in solar output, and cloud-cover changes resulting from global temperature variations and aerosols (IPCC 2007).

The important climatic variables that influence the ecosystem are precipitation, radiation, temperature and stream flow. It is a challenge to the scientific community to understand the complicated processes involved in climate change and alert the society to tackle the problem. Temperature is the driving force for all the climatic variability. Increasing temperatures will decrease snowfall because of which snow may cease to occur in areas where snowfall currently is marginal (Bown and Rivera, 2007). Increased temperatures in the winter may lead to early snowmelt events and a shift in runoff from the spring to late winter with a corresponding decrease in runoff in the summer period (Burn and Elnur, 2002). The major indications of the climate change and their adverse effects are the increase in frequency of flood/flash flood, Glacial Lake Outburst Flood (GLOF), glacial retreat, decrease in seasonal snow cover, rise in sea level, etc.

The changing pattern of precipitation deserves urgent and systematic attention as it will affect the availability of food supply (Dore, 2005) and the occurrence of water related disasters triggered by extreme events. Precipitation is the major driving force of the land phase of the hydrologic system, and changes in its pattern could have direct impacts on water resources. A higher or lower rainfall or changes in its distribution would influence the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and would alter the frequency of droughts and floods. The southwest monsoon, which brings about 80% of the total precipitation over the country, is critical for the availability of fresh water for drinking and irrigation. Changes in climate over Indian region, particularly the southwest monsoon, would have significant impact on agriculture production, water resources management and overall economy of the country. According to IPCC (2007), future climate change is likely to affect agriculture, increase risk of hunger and water scarcity and would lead to more rapid melting of glaciers. Freshwater availability in many river basins in Asia is likely to decrease due to climate change. This reduction along with population growth and rising living standards could adversely affect more than a billion people in Asia by the 2050s. Accelerated glacier melt is likely to cause increase in the number and severity of glacier melt related floods, slope destabilization and a decrease in river flows as glaciers recede (IPCC 2007). Lal (2001) has discussed implications of climate change on Indian water resources. Gosain *et al.* (2006) have quantified the impact of climate change on the water resources of Indian river systems.

In last few decades, several individual and collaborative researches were undertaken to study climate change. The linear relationship is one of the most common methods used for detecting rainfall trends (Hameed et al., 1997). Both parametric and non-parametric tests are widely used for trend study. The advantage with a non-parametric test is that it only requires data to be independent and can tolerate outliers in the data (Hameed and Rao, 1998). One of the popular non-parametric tests widely used for detecting trends in the time series is the Mann-Kendall test (Mann, 1945; Kendall, 1955). The two important parameters of this test are the significance level that indicates the trend strength and the slope magnitude that indicates the direction as well as the magnitude of the trend (Burn and Elnur, 2002). The advantage of the test is that it is distribution-free, robust against outliers and has a higher power than many other commonly used tests (Hess et al., 2001). Many climate studies applying Mann-Kendall test have been carried out in the last decade. Modarresa and Silva (2007) studied the rainfall trend in Iran; Birsan et al. (2005) used the test to study the stream flow trend in Switzerland; Zhang et al. (2005) analysed the trend of precipitation, temperature and runoff in the Yangtze basin China.

Keeping in view the above back ground, the present study has been carried to evaluate the trend of rainfall and temperature in a part of Subansiri River basin, the biggest tributary of Brahmaputra River in India. The Subansiri sub-basin located in the eastern Himalayan region has been selected for the study. Subansiri River is a large transboundry river flowing through two states of India namely, Arunachal Pradesh and Assam. Several major and minor hydro-electric power stations are being built over the river and several more are under consideration. Hence, it is very important to understand the impact of climate change on the hydrology of this mountain basin for proper planning and management of the water resources

THE STUDY AREA AND DATA USED

In the present study, the Subansiri sub-basin has been taken up as the study area. It is a major north bank tributary of river Brahmaputra. The river originates beyond the Great Himalayan Range (Central Himalaya) at an altitude of around 5340 m.

The total length of the river in the mountainous terrain is about 208 km. The riverbed falls from a height of 4206 m to 80 m near Dulangmukh in the foothills. After flowing for about 70 km from the hills, the river falls in to the Kherkutia Suti and thereafter flowing for another 60 km it outfalls into the river Brahmaputra. Throughout its journey from the central Himalaya to the Arunachal foothills, the Subansiri receives the discharges of numerous mountainous big and small streams. The number of its tributaries is more in the Siwalik foothills than in other zones. The total length of the known and well-defined tributaries of Subansiri is 1960 km.

The region may be divided into four parts; the distant Tibetan mountains beyond the international border, the reach lying between the international boundary and Miri hills of Arunachal Pradesh, the Arunachal Pradesh portion between the outskirt of Miri hills and the interstate boundary of Assam and Arunachal Pradesh and lastly the plains of Assam. The first two belongs to the great Himalayan range, the third belonging to the Sub-Himalayas and the fourth in the fertile plains of Assam. The total catchment area of Subansiri sub-basin is 37000 sq.km, out of which about 14000 sq.km lies in Tibet.

Subansiri sub-basin extends from tropical to temperate zones and therefore the area exhibits a great diversity in rainfall characteristics. In the Northern and Central Himalayan tracts precipitation is scarce on account of high altitudes. Southeast part of the Subansiri sub-basin comprising the sub-Himalayan and the plain tract in Arunachal Pradesh and Assam, lies in the tropics. Precipitation occurs in this region in copious quantities due to Northeast as well as Southwest monsoon. Particularly the Southwest monsoon causes very heavy precipitation in the whole of this region during May to October. July and August are generally the high flood months. The Eastern and Central Himalayas function as a great climate divide. In winter, it serves as a barrier to the intense cold continental air flowing southwards and in monsoon months, the moist rain bearing winds are forced up the mountains to deposit their moisture.

The rainfall data used in this study consists of daily gridded data at 0.25º×0.25º resolution from APHRODITE (Yatagai et al., 2009) for the period 1970-2007. The basin lies between latitude 27ºN to 29ºN and longitude 91.5ºE to 95ºE. However, only five grids, spatially well distributed within the basin and lying in different climatic zones of the basins (ranging from cold arid to tropical humid) have been taken up for the present analysis. These five grids with geographical location of the centre as 27.275ºNX94.125ºE, 28.1255ºNX92.525ºE, 28.1255ºNX93.525ºE, 28.525ºNX92.125ºE and 28.525ºNX93.125ºE hereafter referred to as R1, R2, R3, R4 and R5 respectively represent the entire Subansiri sub-basin in this study.

The temperature data used in this study consists of daily gridded maximum, mean and minimum temperature data at 1º×1º resolution for the period 1969-2005 procured from IMD. The basin lies between latitude 27ºN to 29ºN and longitude 91.5ºE to 95ºE. However only three grid points, i.e., 27.5ºNX93.5ºE, 28.5ºNX92.5ºE, 28.5ºNX93.5ºE hereafter referred to as T1, T2 and T3 respectively have taken for the present analysis which represent the different climatic regions within the basin. For T1, the data is available for 1069- 2005 but for T2 and T3, data is available for only 30 years, i.e., 1969-1999.

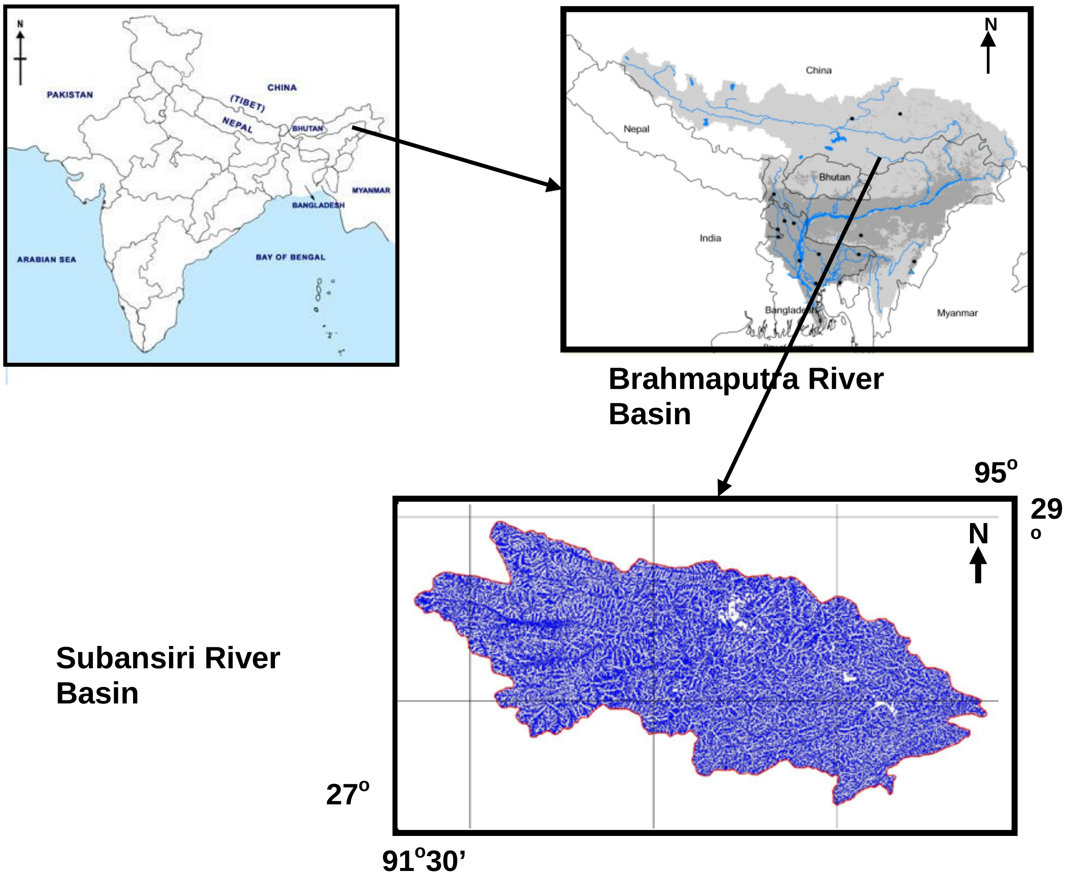

Fig. 1: The Study Area

METHODOLOGY

In the present study, two methods viz. regression and MK test have been used. These are described in the following sections.

Regression Model

One of the most useful parametric models to detect the trend is the "Simple Linear Regression" model. The method of linear regression requires the assumptions of normality of residuals, constant variance, and true linearity of relationship (Helsel and Hirsch, 1992). The model for Y (e.g. precipitation) can be described by an equation of the form:

$$Y = at + b \tag{1}$$

Where,

t = time (year)

a = slope coefficient; and

b = least-squares estimate of the intercept

The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is significantly different from zero statistically, it is entirely reasonable to interpret that there is a real change occurring over time. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative.

Mann Kendall Model

Simple linear regression analysis may provide a primary indication of the presence of trend in the time-series data. Other methods, such as the non-parametric Mann- Kendall (MK) test, which is commonly used for hydrologic data analysis, can be used to detect trends that are monotonic but not necessarily linear. The MK test does not require the assumption of normality, and only indicates the direction but not the magnitude of significant trends (Helsel and Hirsh et al., 1992).

The trend in the data if any has been quantified using Mann-Kendall's S-statistic (Mann, 1945; Kendall, 1955). The MK method assumes that the time series under research are stable, independent and random with equal probability distribution (Zhang et al., 2005). The MK test is applied to uncorrelated data because it has been reported that the presence of serial correlation might lead to an erroneous rejection of the null hypothesis (Helsel and Hirsch, 1992; Kulkarni and von Storch, 1995; Yue et al., 2002; Yue and Wang, 2002; Yue and Pilon, 2003).

The computational procedure for the MK test is described below. Let the time series consist of n data points and Ti and Tj be two sub –sets of data where i = 1,2,3…….., n-1 and j = i+1, i+2, i+3,…………n. Each data point T is used as a reference point and is compared with all the Tj data points such that:

$$Sign(T) = \begin{cases} 1 \quad for \;\; T_j > T_i \\ 0 \quad for \;\; T_j = T_i \\ -1 \; for \;\; T_j < T_i \end{cases} \tag{2}$$

The MK test used in the present study is based on the test statistic, *S*, defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(Tj - Ti) \tag{3}$$

The variance for the S-statistic is defined by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(i)(i-1)(2i+5)}{18} \tag{4}$$

Where t_i denotes the number of ties to extent i. The summation term in Eq. (4) is only used if data series contains the "tied" values. The test statistic, Z*s*, can be calculated as

$$Z_s = \begin{cases} (S-1)/\sigma \quad for \;\; S > 0 \\ 0 \quad for \;\; S = 0 \\ (S+1)/\sigma \;\; for \;\; S < 0 \end{cases} \tag{5}$$

In which Z_s follows a standard normal distribution. Equation (5) is useful for record lengths greater than 10 and if the number of tied data is low (Kendall, 1962). The test statistic, Z_s is used as a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H0: There is no monotonic trend in the data. If $|Z_s|$ is greater than $Z_{\alpha/2}$ where α represents the chosen significance level (usually 5%, with $Z_{0.025}$=1.96), then the null hypothesis is rejected, meaning that the trend is significant. For this study, the simple regression analysis technique has been used to test the slopes of the trend lines for statistical significance at 5% level. The Mann-Kendall trend test procedure is applied to further verify the outcomes of regression analysis for the hydrological variables considered

MK test holds well in the case of non-auto correlated time series data. For auto-correlated data, modified Mann-Kendall test proposed by Hamed and Rao (1997) was used, which is robust in presence of autocorrelation. It is based on the modified variance of *S given* by Eq. (5).

$$V^*(S) = \mathrm{var}(S)\frac{n}{n_s^*} = \frac{n(n-1)(2n+5)}{18}\frac{n}{n_s^*} \tag{6}$$

The recommended approximate value of n/n_s^* n/n_2 is given by the Eq. (7)

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)}\sum_{i=1}^{n-1}(n-i)(n-i-1)(n-i-2)\rho_s(i) \tag{7}$$

where n is the actual number of observations and $\rho_s(i)$ is the autocorrelation function of the ranks of the observations. The accuracy of the approximation given by the Eq. (6) was found to improve as n increases. The autocorrelation between ranks of observations $\rho_s(i)$ is first evaluated. The value of ranks of observations $\rho_s(i)$, however, must be calculated after subtracting a suitable non-parametric trend estimator (Sen, 1968). Due to the nature of calculation in Eq. (5), which involve large number of terms, it was found that insignificant value of $\rho_s(i)$ will have an adverse effect on the accuracy of the estimated variance of *S*. Therefore, only significant values of $\rho_s(i)$ are used in Eq. (6). This is achieved by requiring a suitable preset significance level for the autocorrelation to be included in the calculations, which can be taken equal to that of the rest.

In the present study, non-parametric Mann-Kendall trend test and modified Mann-Kendall test as proposed by Hamed and Rao (1997) were applied to study the trend in daily temperature described in the following sections.

TREND ANALYSIS

For the seasonal analysis, data were divided into four seasons, namely pre-monsoon (March-May), monsoon (June-Septembert), post-monsoon (October-November) and winter (December-February) based on the prevailing climate of India. At first, the time series were checked for randomness, autocorrelation and long-term persistence before conducting the Mann-Kendall test. Time series having no autocorrelation have been analyzed with Mann-Kendall's Test for the detection of trend and if significant autocorrelation was found in the data, the time series was tested with modified Mann-Kendall test as suggested by Hamed and Rao (1997).

In this study, rainfall for five grid points were analyzed as given in Table 1. The selected grids have 37 years of record length each. Temperature for three grid points were analyzed as given in Table 2 Linear regression analysis has been carried out for all the grids. Graphical representation are shown in Figure 2 for annual rainfall trend and in Figure 3 for annual maximum and minimum temperature trend of the grids only because of space limitations.

RESULTS AND DISCUSSIONS

Seasonal analysis of rainfall trends shows that annual rainfall has increased (at 5% significance level) over the grid R5 which lies in the north east part of Subansiri sub-basin which does not observe heavy rainfall compared to lower parts of the basin. Grid R4 shows an increasing trend of rainfall in the premonsoon period. Grid R5 also shows an increasing trend of rainfall in the premonsoon period besides annual rainfall. Graphical plots show a decreasing trend of annual rainfall in grids R1 and R3, however, it is not significant at 5% significance level. The trend as seen from regression analysis is matching very well with that of Man Kendall analysis.

Table 1: Trend in different Season for Rainfall Data

	Grid	Mann-Kendall test statistic Z	Dominant trend
ANNUAL	R1	-1.28	No Trend
	R2	0.98	No Trend
	R3	-1.06	No Trend
	R4	1.68	No Trend
	R5	3.19	Increasing
WINTER (December to February)	R1	-0.8	No Trend
	R2	0.8	No Trend
	R3	-0.38	No Trend
	R4	1.27	No Trend
	R5	1.18	No Trend
PRE MONSOON (March to May)	R1	-0.53	No Trend
	R2	1.84	No Trend
	R3	1.58	No Trend
	R4	1.92	No Trend
	R5	2.87	Increasing
MONSOON (June to September)	R1	-1.11	No Trend
	R2	0.15	No Trend
	R3	-0.68	No Trend
	R4	-0.03	No Trend
	R5	1.87	No Trend
POST MONSOON (October to November)	R1	-0.68	No Trend
	R2	1.08	No Trend
	R3	-0.4	No Trend
	R4	1.31	No Trend
	R5	1.06	No Trend

Table 2: Trend in different Season for Temperature Data

	Grid	Dominant trend (Max Temp)	Dominant trend (Mean Temp)	Dominant trend (Min Temp)
ANNUAL	T1	No Trend	No Trend	Increasing
	T2	No Trend	No Trend	No Trend
	T3	No Trend	No Trend	No Trend
WINTER (Dec to Feb)	T1	No Trend	No Trend	Increasing
	T2	No Trend	No Trend	Increasing
	T3	No Trend	No Trend	No Trend
PRE MON (March to May)	T1	Decreasing	No Trend	No Trend
	T2	Decreasing	No Trend	No Trend
	T3	Decreasing	No Trend	No Trend
MON (Jun to Sept)	T1	No Trend	No Trend	No Trend
	T2	No Trend	No Trend	No Trend
	T3	No Trend	No Trend	No Trend
POST MON (Oct to Nov)	T1	No Trend	No Trend	No Trend
	T2	No Trend	No Trend	No Trend
	T3	No Trend	No Trend	No Trend

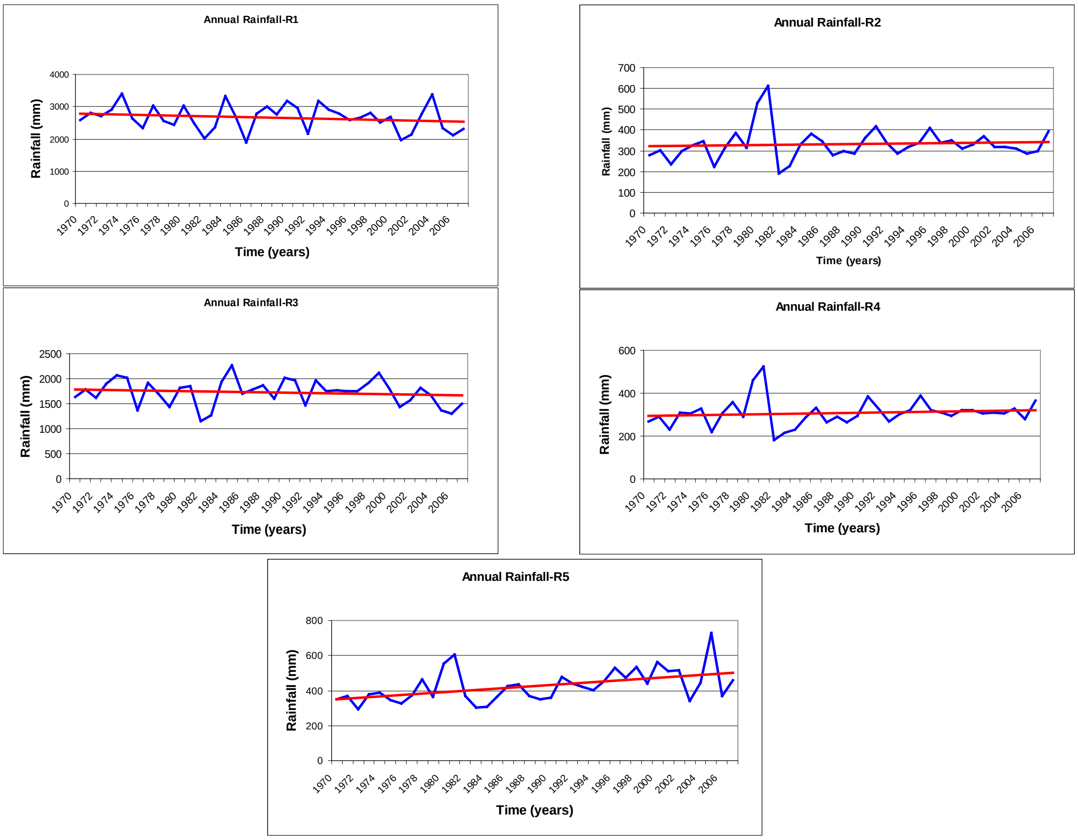

Fig.2: Trend of Annual Rainfall over 37 Years (1970-2007)

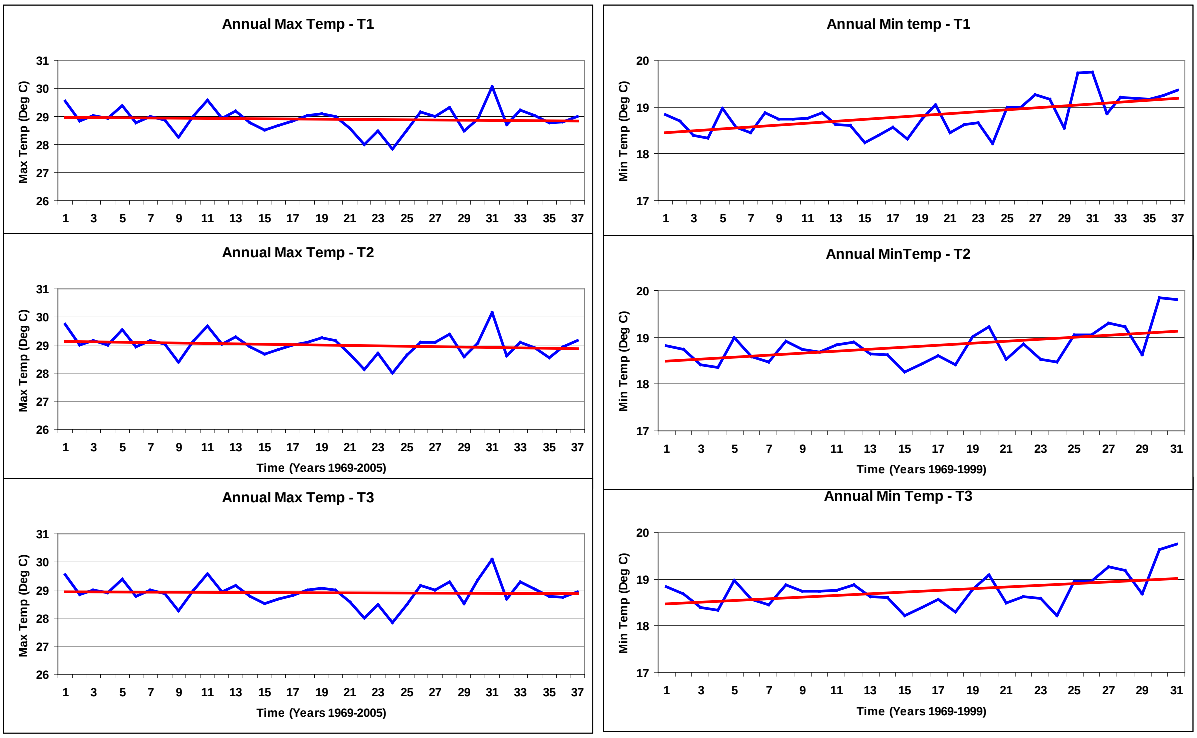

Fig. 3: Trends in Daily Maximum and Minimum Temperature

The temperature in the region starts rising during March to June. With the onset of monsoon, the temperature begins to falls again. The temperature drops uniformly during post- monsoon season. A rising trend is observed in minimum temperature for all the three grids during all the seasons, however, it is statistically significant only for grid T1 which lies in the southern (lower) part of the basin. No significant trend has been observed in maximum as well as mean temperature.The temperature trend in the basin are very much in line with the global observed temperature trends in general.

CONCLUSIONS

The Brahmaputra basin is highly sensitive to climate change. Any change in rainfall highly influences stream flow downstream. The Himalayan Rivers like Subansiri sub-basin has witnessed a steep rise glacial retreat in recent past. These events are strong indication of climate change in the basin. However, the influence of anthropogenic factors cannot be rejected. The present study is based on the analysis daily rainfall and temperature (max, mean and min) data using simple linear regression and non-parametric Mann-Kendall trend test. It demonstrates statistically significant changes in rainfall and temperature over the last three decades.

The rainfall analysis shows annual rainfall is increasing at one grid point, however, no trend has been observed in first four grids. The temperature analysis shows that minimum temperature in general is decreasing at all of the grid points, however, no significant trend has been observed in maximum and mean temperature. The results observed in this study are an encouragement to explore the impact of climate change on the local climate of the region. Also there is need to understand the behavior of this basin to climate change and its future impact to plan and manage the water resources.

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