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Short Comminucation

Study of climate variability in Ramganga catchment of Central Himalaya

SUSAMA SUDHISHRI[1] , AKHILESH KUMAR[3], A.K. SHUKLA[3], ANCHAL DASS[2] and J.K. SINGH[3]

[1]*Water Technology Center and* [2]*Division of Agronomy, IARI, Pusa, New Delhi-110012, India*
[3]*GB Pant University of Agriculture and Technology, Pantnagar, US Nagar-263145, Uttarakhand, India*
susama_s@rediffmail.com

Climate variability and climate change seem to have increased the severity of flood and drought hazards, changing the nature of occurrence of hydrological events in time and space resulting in highly uneven distribution of available water in several areas and this tendency is likely to continue (IPCC, 2007). It is envisaged that such changes will have a large effect on the Himalayan Rivers (Sudhishri *et al.,* 2014a). Studies related to changes in rainfall over India have shown that there is no significant trend in the all India rainfall. However, there has been a decrease in heavy rainfall events in August in north Indian region. In case of temperatures, monsoon temperatures do not show a significant trend in any part of the country except for significant negative trend over north-west India. Again intra-region variability for extreme monsoon seasonal rainfall had been large and mostly exhibited a negative tendency leading to increasing frequency and magnitude of monsoon rainfall deficit and decreasing frequency and magnitude of monsoon rainfall excess everywhere in India except in the peninsular Indian region. This is further exacerbated by increased and more variable extreme temperatures (Pal, 2009). Whereas in another study for Alaknanda catchment of Central Himalaya, decline in rainfall and rise in temperature was observed (Kumar *et al.*, 2008). Understanding the effects of climate change is therefore, necessary for planning responsive measures and it will be more helpful if studied on watershed basis, as watershed is the basic study area for hydrology and other interventions (Sudhishri *et al.*, 2014b). Since Himalaya is greatly vulnerable to climate change, a representative Bino watershed in Ramganga catchment of Uttarakhand in Himalayan range was selected to study the climate variability for further water resource planning and management. Air temperature and precipitation are the principle elements of weather systems; examination of their behavior is important for understanding of climate variability because both are highly variable spatially and temporarily at different local, regional and global scales (Karabulut *et al.,* 2008).

The study was conducted using climatic parameters *viz.* daily rainfall (1970–2008), maximum and minimum temperatures (1989–2008) data which were obtained from Forest Department of Ranikhet Division, Uttarakhand. Monthly, seasonal (monsoon (June–September) and non-monsoon)) and annual values of above parameters were determined and used for trend and change point analysis as the implications of changes at the seasonal scale are particularly significant for water resource management processes related to seasonal cycles (Longobardi and Villani, 2009). Daily mean temperature was calculated by taking average of daily maximum and minimum temperatures. Safari (2012), Rahman and Begum (2013), Karabulut *et al.* (2008) and Longobardi and Villani (2009) have used Mann-Kendal test for trend detection. But in this study, a modified version of Mann-Kendal test which is robust in the presence of autocorrelation, known as 'modified Mann-Kendal (MMK) test' (Hamed and Rao, 1998 and Chakravaorty *et al.,* 2013) for monotonic trend detection was used on monthly, seasonal and annual basis. In this test the value of autocorrelation between the ranks of observations ($\rho_S(i)$) were calculated after subtracting a suitable non-parametric Sen's estimator (Sen, 1968) and finally, the standardized test statistic 'Z' was estimated and tested at the significance level '±' ranging between 0.01 and 0.05 (Gan, 1998). The index to quantify the monotone trend is Kendal slope (â) which is the median of all possible combinations of pairs for the whole data set initially proposed by Sen (1968), and later extended by Hirsch *et al.* (1982) was also estimated and the whole analysis was conducted in MATLAB environment. The non-parametric method developed by Pettitt (1979) was used for detecting the timing of a change in the distribution of a time series when the exact time of the change is unknown; the result is referred to as a 'change point'.

Trends and change point of climate parameters

The long-term average annual precipitation in Bino watershed was 931.3 mm, and ranged from 6.0 to 215.1 mm in different months. No significant trend was observed in annual, monthly and seasonal maximum, minimum as well as mean temperatures except maximum and mean temperatures of August month. However, significant downward trend was observed in annual rainfall with a reduction rate of 18.92 mm year^{-1} (Table 1) which amounts to about 2 % of the mean

Table 1: Annual, seasonal and monthly trends of climate using modified Mann-Kendall test

Period	Test Z	Significance	^{2}(mm)	Average (mm)	Change point (Year)	Significance
Annual	-3.557	*	-18.920	931.3	1983	**
Monsoon season	-3.097	*	-15.022	665.6	1980	**
Non-monsoon season	-4.364	*	-4.612	268.9	1991	*
January	-2.649	*	-1.100	38.6	1983	***
February	-0.495	ns	-0.211	51.1	-	ns
March	-0.145	ns	-0.027	45.3	-	ns
April	-0.411	ns	-0.048	30.0	-	ns
May	-1.875	ns	-0.824	50.1	1983	*
June	-1.452	ns	-1.208	115.0	1980	*
July	-3.702	*	-6.079	210.3	1981	**
August	-4.638	*	-6.720	215.1	1983	**
September	-0.835	ns	-1.268	125.2	-	ns
October	-2.292	*	-0.156	22.4	1986	***
November	-0.127	ns	0.000	6.0	-	ns
December	-0.748	ns	-0. 003	22.3	-	ns

*, **, *** and ns indicates significance at 5%, 1% and 10% level and non-significant, respectively

Table 2: Trends of rainfall during different clusters of years in Bino watershed

Parameter		1970-82	1983-90	1991-2000	1983-2000	1991-2008	2001-2008	1983-2008
Rainfall	Test Z	-1.769	0.866	1.252	0.985	1.300	0.742	0.143
	Significance	ns	ns	ns	ns	ns	*	ns
	β	-23.799	68.815	33.111	14.500	0.956	11.206	0.582

• and ns represents significance at 5% level and non-significant, respectively

annual rainfall values. Monsoon and non-monsoon season rainfall also exhibited the significant reductions in their occurrence at a rate of 15.02 and 4.61 mm, respectively (Table 1). Similar results were also observed by Chakravorty *et al*. (2013). Monthly trend analysis revealed that no significant rainfall trend existed except for the months of January, July, August and October. Pettitt's test conducted for annual rainfall showed statistically significant trend and it was found that the change point at 5% probability level was in the year 1983 (Table 1), whereas change points for monsoon season and non-monsoon season rainfall was 1980 and 1991, respectively. The values of mean and standard deviation of annual rainfall were decreased by 41% and 9.83%, respectively from before change point period (BCPP) to after change point period (ACPP). However, there was increase in variability of rainfall except rainfall during March and June months. Statistical significant differences between mean and standard deviation of the two samples at 1% significant level were observed using Kolmogorov-Smirnov and t-test, and F-test, respectively. Similarly, significant difference between means of two samples was also observed at 1% level for monsoon and non-monsoon season rainfall. It was found that there was significant reduction in rainfall during January, July, August and October months. The results from change point analysis revealed that there was no consistency in change points for annual, seasonal and monthly rainfall values at different probability levels (Table 1), but mean and standard deviation were decreased from BCPP to ACPP. However, the coefficient of variation increased and the reduction in the mean was greater than the reduction in the standard deviation which will lead to enhancement in the irrigation water demand of agricultural crops in the study region.

The trend in precipitation on cluster of years' basis taking into account the change point was analyzed by dividing the whole rainfall period into different cluster of years viz. 1970–82, 1983–90, 1991–2000, 2001–2008, 1983–2000, 1983–2008 and 19991–2008.There was statistical significant upward trend of precipitation during the cluster period of 2001–2008 at a rate of 11.21 mm year^{-1} (Table 2), whereas in remaining cluster periods no statistical significant trends in annual precipitation were observed at 5% level. It was also observed that though there was increasing trend of annual rainfall during initial cluster of years, but gradually the rate decreased at the end of cluster of years. This shows that the number of years plays an important role in studying the trend analysis of climate parameters. These findings will be helpful in planning water resources for its efficient use.

The study concluded that there was no significant trend observed in maximum and minimum temperatures, but there was significant decrease in annual rainfall at 18.92 mm year^{-1}. A similar trend was also observed for seasonal rainfall. But, there was a significant increase in rainfall during the period of 2001–2008 at a rate of 11.21 mm year^{-1}. Decreasing trend in monsoon season rainfall was also greater than non-monsoon season rainfall. The major change point in annual rainfall occurred around 1983. There was increase in variability before change point period to after change point period which ultimately will increase the demand for irrigation water. These findings necessitate the proper planning of agricultural crops and water resource management to reduce the negative impacts of perturbances in weather and climate variables.

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