Investigation of Climate Change Impact on Rainfall, Discharge and Temperature of Satluj Basin

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Abstract: *India mountain glaciers and weather system are key variables for early detection strategies in regional climate-related observations. In the present study, trends of climate change have been evaluated for the Satluj basin. The Satluj river basin is elongated in shape and covers an area of about 22,300 km^2 up to Bhakra. The elevation of the catchment varies from about 500 to 7000m. For evaluating the effect of climate change, attempts have been made to identify trends in time series of rainfall, discharge and temperature data by studying the anomalies with time and application of trend identification techniques. Trends for both low altitude and high altitude stations have been investigated. The modified Mann-Kendall test was applied to detect monotonic trends in each of the series. This study is an effort to analyze trends in three most important climatic variables i.e. rainfall, temperature and discharge on average data set of about 50 years.*

Keywords: *Glacier, Climate Change, Rainfall, Temperature, Discharge and Mann-Kendall Test.*

1. Introduction:

Water resource has become a prime concern for any development and planning including food production, flood control and effective water resource management. Studies have demonstrated that global surface warming is occurring at a rate of 0.74 ± 0. 18 °C over 1906–2005 (IPCC, 2007). Impact of climate change in future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been revealed that by the middle of 21st century, decrease in annual average runoff and availability of water will project up to 10–30% (IPCC, 2007).

Various researchers have contributed to the study of climate change (Dessens and Bucher, 1995; Serra et al., 2001; Marengo, 2004) with long term data. Study of different time series data have proved that trend is either decreasing or increasing, both in case of temperature and rainfall. Human interference is also leading to climate change with changing landuse from the impact of agricultural and irrigation practices (Kalnay and Cai, 2003).It is found that all India mean annual temperature is rising at the rate of 0.05 °C/decade over 1901–2003 which is mostly due to the rise of maximum temperature (0.07 °C/decade) rather than because of the rise of minimum temperature (0.02 °C/decade) (Kothawale and Rupa Kumar, 2005). There will be fall of −0.38°C per century in the north Indian average temperature with a contrasting rise of 0.42°C per century depicted by average temperature of India during the last half of 20th century (Arora et al., 2005). Some researchers have also studied the availability of quality freshwater which is of biggest concern forthe last half-century, because of higher demographic pressure leading to climatic variability (Gleick,1993, 2000; Vörösmarty et al., 2000; Shiklomanov and Rodda, 2003; Milliman et al., 2008). The problem is more flimsy in India and China where population is very high and posing continuous threat to the fresh water. According to Gleick, (2000), these two countries use about 40% of global freshwater for the purpose of irrigation. Some parts of the French Mediterranean area have been studied by Chaouche et al., (2010), which is sensitive to the climate change. Mann-Kendall Test has been used to find any trendof rainfall, temperature and evapotranspiration (both monthly and annual) which has shown some significance in case of rainfall and temperature. CUSUM (Cumulative Summation) test and MK Test has been used to analyse the long term rainfall trend in Zambia by Kampata et al., (2008). The trend of precipitation and run-off is also studied by Xu et al. (2010) in major Chinese rivers in order to find out any human intervention in the trend from 1951 to2000. He has also used the Mann-Kendall statistics for the detection of the trend of precipitation. According to some researchers, (Alcamo and Doll, 2003; Arnell et al., 2004), rising pressure of man on the landuse are the cause of adverse impact on environment resulting in extreme weather conditions and change in climatic parameters for short term period. The prime objective of this study is to analyse the trend of rainfall, discharge and temperature in Satluj river basin.

2. Study Area:

The River Satluj is one of the main tributaries of Indus and has its origin very near to the Indus headwaters. It rises in the lakes of Mansarovar and Rakastal in the Tibetan plateau at an elevation of about 4572 m. The entire area in the Tibetan plateau experiences very less rainfall and has a cold desert climate. In spite of covering about two-third part of total catchment area, low flow in the Satluj River until it joins its major tributary. Spiti, near Nimgia in India, are due to cold desert climate in the Tibetan plateau. The Spiti watershed experiences extensive snowfall in the winters and therefore substantially contributes to the Satluj flows in the form of snowmelt runoff in the summer months. There are several other tributaries which join the Satluj River in the downstream and swell its flow.

The area under study is shown in Fig. 1. In general this area experiences heavy snowfall in the winter season and little rainfall in the summer. The elevation varies from 1500 m to 7026 m for this area. The area-elevation curve suggests that only about 2.6% of the watershed area lies above 5400 m

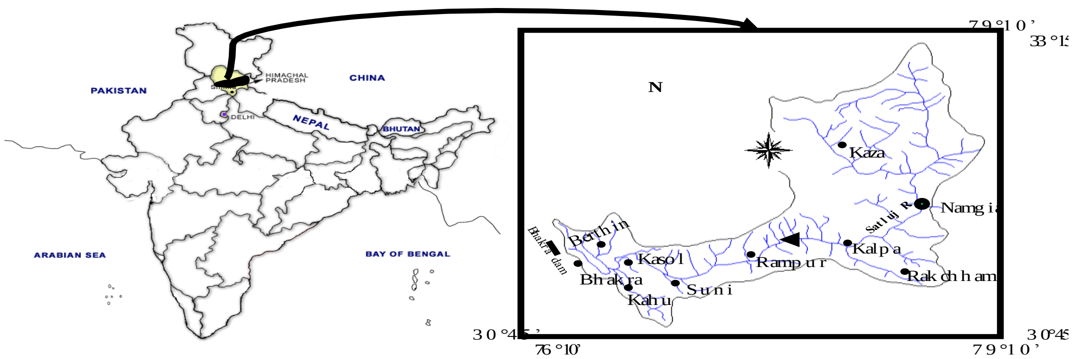

Figure 1. Map of the Satluj basin up to Bhakra dam with location of hydrometeorological stations

3. Materials and Methods:

3.1. Serial correlation:

One of the problems in detecting and interpreting trends in hydrologic data is the confounding effect of serial dependence. Specifically, if there is a positive serial correlation (persistence) in the time series, then the nonparametric test will suggest a significant trend in a time series that is, in fact, random more often than specified by the significance level (Kulkarni and Van Storch, 1995). For this, Von Storch and Navarra (1995) suggest that the time series should be 'pre-whitened' to eliminate the effect of serial correlation before applying the Mann-Kendall test. This study incorporates this suggestion, and thus possible statistically significant trends in a precipitation observations (x_1, x_2. . . x_n) are examined using the following procedures:

a) Compute the lag-1 serial correlation coefficient (designated by r_1).
b) If the calculated r_1 is not significant at the 5% level, then the Mann-Kendall test is applied to original values of the time series.
c) If the calculated r_1 is significant, prior to application of the Mann-Kendall test, then the 'pre-whitened' time series may be obtained as

$x_2-r_1x_1$, $x_3-r_1x_2$, ...$x_n-r_1x_{n-1}$

3.2. Mann Kendall Test:

Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic and in hydrologic time series. There are two advantages of using this test. First, it is a non parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari et al., 2011). Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set. According to this test, the null hypothesis H0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H1, which assumes that there is a trend (Onoz and Bayazit, 2012).

The computational procedure for the Mann Kendall test considers the time series of n data points and x_k and x_j as two subsets of data where k = 1,2,3,…, n-1 and j = k+1, k+2, k+3, …, n. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic *S* is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, *S* is decremented by 1. The net result of all such increments and decrements yields the final value of *S* .

The MK test is based on the test statistic S defined as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad (1)$$

where

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases}$$

If n < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two tailed test is used. At certain probability level H0 is rejected in favor of H1 if the absolute value of S equals or exceeds a specified value $S\alpha/2$,where $S\alpha/2$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend. For n $\geq$ 10, the statistic *S* is approximately normally distributed with the mean and variance as follows:

$$E[S] = 0$$

$$Var[S]=n(n-1)(2n+5)-\sum_t t(t-1)(2t+5)/18 \quad (3)$$

where t is extent of any given tie (number of x's involved in a given tie), and $\sum t$ denotes the sum of the terms t(t-1)(2t+5), which are evaluated and summed for each tie of the t number in the data. The standard normal variable Z is computed by

$$Z = \begin{cases} \left\{ \dfrac{S-1}{[Var(S)]^{1/2}} \right\} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \left\{ \dfrac{S+1}{[Var(S)]^{1/2}} \right\} & \text{if } S < 0 \end{cases} \quad (4)$$

The test statistic Z is used a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H0. If | Z| is greater than $Z\alpha/2$, where α represents the chosen significance level (eg: 5% with Z 0.025 = 1.96) then the null hypothesis is invalid implying that the trend is significant.

3.3. Sen's Slope Estimator:

As defined by Theil (1950), the Theil–Sen estimator of a set of two-dimensional points (x_i,y_i) is the median *m* of the slopes $(y_j - y_i)/(x_j - x_i)$ determined by all pairs of sample points. Sen (1968) extended this definition to handle the case in which two data points have the same *x*-coordinate. In Sen's definition, one takes the median of the slopes defined only from pairs of points having distinct *x*-coordinates.

4. Results and Discussion:

Trend analysis of Satluj river basin has been done in the present study with more than 40 years of rainfall, temperature and discharge data. Mann-Kendall test has been used for the determination of the trend.

There are 19 rainfall stations distributed over the basin whose data was available for analysis. Table 1 shows the list of stations with data availability and the trend observed. Figure 1 shows the spatial distribution of rainfall trend over the basin. It is observed that there is in general no trend in majority of stations except two stations Rakcham (3131m) and Kahu (526m) which are exhibiting increasing trend in the rainfall. Figure 3 illustrates the Z statistics of the individual stations. It is observed that Z values of Rakcham are quite high indicating a large increase in rainfall amounts over the years. The estimated Sen's slope for Rakcham and Kahu are 0.49 and 0.40 respectively.

Table1: *List of stations and the exhibited trend.*

Station	Longitude	Latitude	Altitude	Data length (years)	Trend
Kaza	78.1044	32.1763	3541	27	No trend
Namgia	78.6563	31.8101	2843	32	No trend
Rakcham	78.3543	31.3919	3131	27	Rising
Kalpa	78.2554	31.5440	2731	28	No trend
Berthin	76.6486	31.4197	668	50	No trend
Bhartgarh	76.6000	31.1000	284	41	No trend
Daslehra	76.5489	31.4156	562	47	No trend
Ganguwal	76.1000	31.4000	1220	41	No trend
Ghanauli	76.5894	31.0258	293	41	No trend
Kahu	76.7811	31.2119	526	43	Rising
Lohand	76.5706	31.1753	288	41	No trend
Naina Devi	76.5356	31.2989	985	37	No trend
Nangal	76.3725	31.3972	369	51	No trend
Rampur	77.6278	31.4400	987	47	No trend
Suni	77.1147	31.2453	701	39	No trend
Kasol	77.3167	31.5000	2614	50	No trend
Kotla	77.2500	31.5000	2824	41	No trend
Swarghat	76.7500	31.3333	1220	35	No trend
Bhakra	76.4347	31.4156	554	45	No trend

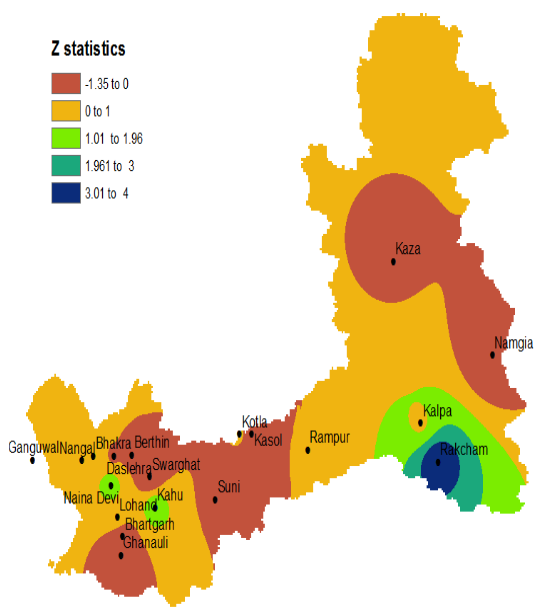

Figure 1: *Spatial trends exhibited by rainfall stations in the Satluj river basin.*

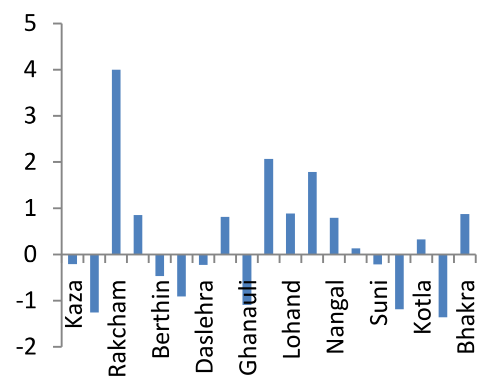

Figure2: *Z statistics of different rainfall stations in the Satluj river basin.*

There are 5 discharge stations distributed over the basin whose data was available for analysis. Table 2 shows the list of stations with data availability and the trend observed. Figure 3 shows the spatial distribution of rainfall trend over the basin. It is observed that 2 stations out of 5 stations Rampur (987m) and Suni (701m) are exhibiting decreasing trend in the discharge. Figure 4 illustrates the Z statistics of the individual stations. It is observed that Z values of majority of stations are negative except 1 station Kahu. Sen's slope for Rampur and Suni are -0.1975 and -0.1510 respectively.

Table2: *List of stations and the exhibited trend.*

Station	Longitude	Latitude	Altitude	Data Length (Years)	Trend
Kahu	76.7811	31.2119	526	40	No- trend
Rampur	77.6278	31.4400	987	49	Falling Trend
Suni	77.1147	31.2453	701	49	Falling Trend
Kasol	77.3167	31.5000	2614	47	No- trend
Bhakra	76.4347	31.4156	554	43	No- trend

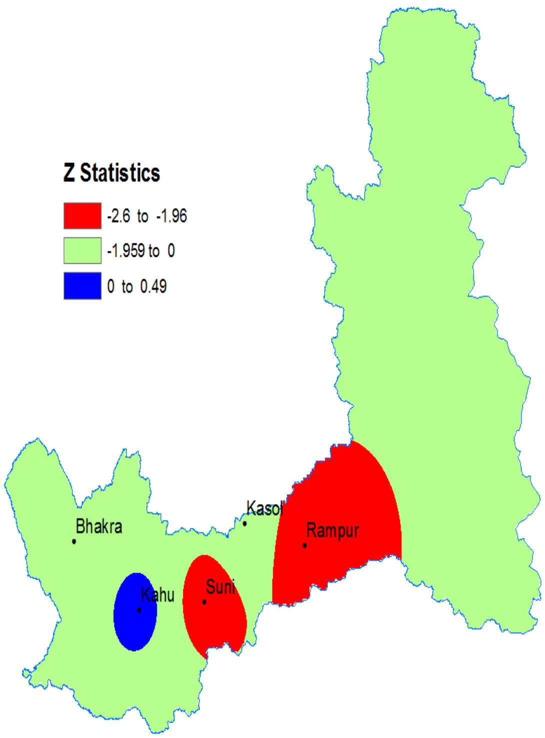

Figure 3: *Spatial trends exhibited by discharge stations in the Satluj river basin.*

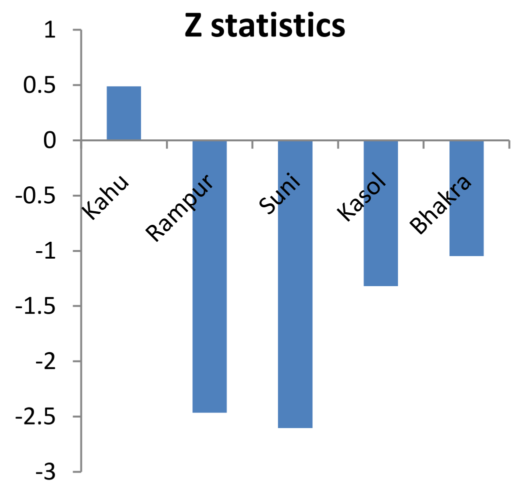

Figure 4*: Z statistics of different discharge stations in the Satluj river basin.*

There are 8 stations distributed over the basin whose temperature data was available for analysis. Though the data length is short we have used this data length however, this limitation needs to be overcome and the analysis is to be performed on larger database. Table 3 shows the list of stations with data availability and the trend observed. Figure 5 shows the spatial distribution of rainfall trend over the basin. It is observed that 3 stations out of 8 stations Namigia (2843m), Rakcham (3131m) and Kalpa (2731m) are exhibiting increasing trend in the temperature. Whereas 1 station Bhakra (554m) is exhibiting decreasing trend in temperature. Figure 6 illustrates the Z statistics of the individual stations. It is observed that Z values of majority of stations are positive negative except for 2 stations Suni and Bhakra.

Table3: *List of stations and the exhibited trend.*

Station	Longitude	Latitude	Altitude	Data length (years)	Trend
Kaza	78.1044	32.1763	3541	22	No trend
Namgia	78.6563	31.8101	2843	22	Rising
Rakcham	78.3543	31.3919	3131	21	Rising
Kalpa	78.2554	31.5440	2731	22	Rising
Rampur	77.6278	31.4400	987	26	No trend
Suni	77.1147	31.2453	701	21	No trend
Kasol	77.3167	31.5000	2614	21	No trend
Bhakra	76.4347	31.4156	554	26	Falling

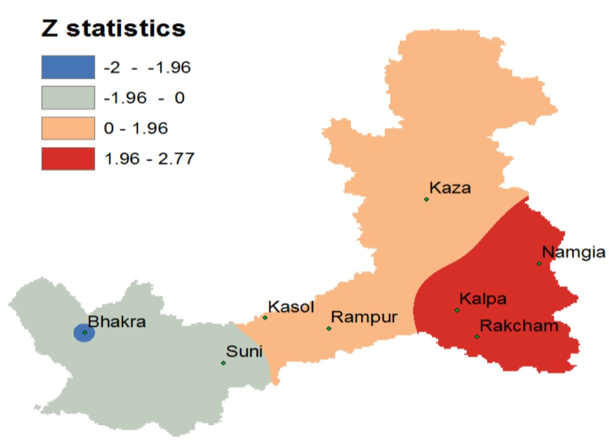

Figure 5: *Spatial trends exhibited by temperature stations in the Satluj river basin.*

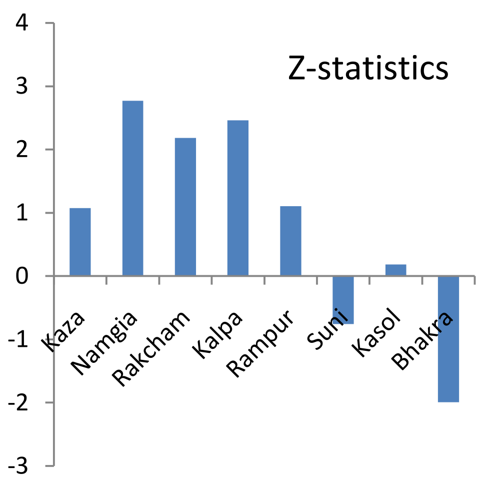

Figure 6: *Z statistics of different temperature stations in the Satluj river basin.*

5. Conclusion:

In general, there was conformity in the results obtained from the Mann-Kendall test and the linear trend line most of the stations. The Mann Kendall test demonstrates that in the case of rainfall no trend is noticeable for the 17 rainfall stations; however an increasing trend is seen for 2 stations. For discharge 2 stations are exhibiting falling trend out of 5 stations. For the temperature data, the Mann Kendall test indicates that no trend exists for 4 stations whereas out of the other 4 stations 3 are exhibiting an increasing trend and remaining 1 station shows decreasing trend.

It is critical to understand here that these estimates should be analyzed from a global perspective and no conclusions should be drawn for the local level. In other words, the trend in temperature and precipitation seen for each state could imply that the changes are more pronounced for certain locations and less for others, or the changes in temperature and precipitation patterns could be affected seasonally. However, study of the area may reveal other aspects which will be helpful in controlling flood causing havoc in this particular area.

7. Acknowledgements:

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