Trend Analysis of Historical and Downscaled Future Precipitation Data in Sutlej Basin, India

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Abstract: *The present study aims for detecting trends in precipitation on annual and seasonal time scales for three hydro-metrological stations namely, Kasol, Sunni and Rampur located in Sutlej river basin, India. The trend in precipitation has been analyzed for periods 1971-2100 using statistics of Mann-Kendall test while magnitude of the trend is determined by Sen's non-parametric estimator of slope respectively. The historical daily records of precipitation data available from 1971-2005 (35 years) and downscaled daily precipitation data grouped into three different time periods: 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) have been used for this purpose. Statistical downscaling method has been applied to downscale and generate future scenarios of precipitation at station scale from large scale climate variables obtained from CGCM3 model for A1B and A2 scenario respectively.*

The results, determining trend in precipitation have shown spatial and temporal differences. The statistically insignificant decreasing trend in annual precipitation has been found at Kasol and Sunni for historical records (1971-2005) while increasing trend has been observed for Rampur respectively. The downscaled annual precipitation has shown a rising as well as a falling trend at different stations under scenario A1B and A2 for future periods (2020s, 2050s and 2080s). The falling trend in precipitation for scenario A1B has been found at Kasol, Sunni and Rampur for period 2050s, 2080s and 2020s respectively. For scenario A2, decreasing trend in precipitation has been noticed at Sunni for period 2020s. Besides this, an overall rising trend in precipitation has been shown for both scenarios A1B and A2 for periods; 2020s, 2050s and 2080 at each stations.

Keywords: *Climate change, Men-Kendall test, Sen's slope, Statistical downscaling, CGCM3*

1. Introduction:

The increased concentrations of greenhouse gases in atmosphere has attributed to global warming and further to climate change (IPCC, 2007). The change in patterns of precipitation and temperature caused by global warming has been studied and discussed in several regions of the world. Precipitation is an important climate variable as it determines types and distribution of natural vegetations and availability of water to meets the needs of agriculture, industrial and hydro-electric power sectors. The spatial and temporal variability in trends of precipitation has been studied for inter-annual and inter-seasonal periods during the past few decades all across Asia. Decreasing trend in mean annual precipitation has been reported in Russian and East and North China followed by coastal and arid plains of Pakistan [1]. However, increasing trend in mean annual precipitation has been detected over Western China, Changjiang Valley and the South-Eastern coast of China, Bangladesh and the western coasts of the Philippines.

Many research studies have so far been performed in India in order to detect long term trend in precipitation on country, basin and regional scale [2]. No significant trend in annual and monsoonal precipitation has been detected on country scale whereas increasing as well as decreasing trends in precipitation have been observed on basin and regional scales. Singh *et al.* [3] have examined spatial and temporal characteristics of annual and seasonal precipitation on basin scale over period 1871-2001. An upward trend in annual precipitation has been detected in the Indus basin from 1954, Ganga basin from 1993, Brahmaputra basin from 1988, Krishna basin from 1953 and Cauvery basin from 1929 onwards. Likewise, increase in trend of precipitation has also been reported at some other regions of the country. Patra *et al.,* [4] have studied long term trend in annual, seasonal and monthly precipitation in Orissa for period 1871-2006. They have found insignificant decrease in

trend of annual as well as monsoon precipitation whereas increase during post-monsoon season. Orissa Rohtak and Kurukshetra of Haryana, Delhi, peripheries of the Rajasthan desert, west Madhya Pradesh and coastal Orissa have witnessed increase in trend of precipitation [5-9]. The studies of Alvi and Koteswaram [10] have shown increase in trend of precipitation for the west coast of India. Rupa Kumar *et al.* [11] have observed increase in trend of monsoon seasonal rainfall along the west coast, north Andhra Pradesh and north-west India.

On contrary, downward trends in precipitation have been observed in the basins of Sabarmati, Mahi, Narmada, Tapi, Godavari and Mahanadi [3], along with east Madhya Pradesh and adjoining areas, north-east India [12], parts of Gujarat [11], south Kerala [13-14] and central north Indian divisions [15].

Similarly, increasing as well as decreasing trends in precipitation have been found over the Himalayan region [16-18].The North- East region along with Eastern and Central parts of the Tibetan Plateau has reveled increasing trends while the Western Tibetan region shows decreasing trend. North-Western Himalayan region (northern Pakistan) has experienced an increasing trend while Nepal exhibited no long-term trend in precipitation [19]. Indian Himalayas, particularly Western Himalaya has exhibited no trend in mean annual precipitation [20]. Increasing trend in post-monsoonal precipitation has been detected over Uttarakhand whereas a decrease in winter [21]. Kumar *et al.* [22] has found rise in trend of mean annual precipitation but fall in monsoonal precipitation over Himachal Pradesh. The modelled projections have shown a decrease of about 20% in monsoon precipitation in most parts of Pakistan and in south-eastern Afghanistan by the end of the century. The Tibetan plateau will exhibit increase (10–30%) in mean annual precipitation by 2080 (IPCC, 2007). Rupa Kumar *et al*. (2006) observed projected increase of 20 to 30% in precipitation for the western Himalayan region by the end of 21st century.

The magnitude determining trend in precipitation has not been found uniform in nature over a region as intensity and amount of precipitation is locally controlled. Hence, it has been required to access the impact of climate change on precipitation at the regional and local level. The historical records as well as modelled values of precipitation can be used to evaluate the patterns of behavior that the climate has exhibited in the past and will show in the future in order to determine whether recent climate behaviors are normal or anomalous (Xu *et al.,* 2008). The future time series of precipitation data can be generated from Global Climate Models (GCMs). The outputs of GCMs can not be directly used in climate change impact studies at regional and local scales due to their coarse spatial resolution. Downscaling is method which involves projection of weather variables (precipitation, temperature) at local scale based on large scale predictors simulated by a GCM (Maurer and Hidalgo, 2007). Based on literature review, downscaling can be grouped into two broad categories; statistical and dynamic (Fowler *et al.*, 2007).

The Sutlej basin is drained by the Sutlej river. It is a perennial river that is fed by the Himalayan glaciers during summer, precipitation during monsoon season and ground water flow during winter season. The basin is sensitive to climate change and increase in mean annual temperature has been found in lower and middle elevation ranges of the basin (Jain *et al.*, 2009). However, precipitation distribution for the Sutlej basin is poorly known as limited studies have so far been carried out.

Keeping the above in the mind, the main objective of the present paper is to detect trends in precipitation on annual and seasonal basis for historical as well as future periods in Sutlej river basin, India. The future time series of precipitation data is generated under A1B and A2 scenarios from large scale predictors obtained from third generation Canadian Coupled Global Climate Model (CGCM3). The remaining part of this paper has been arranged as follows; study area has been described and shown in section 2. The types of data and their sources have been discussed in section 3. Methodology has been described in section 4. Results have been shown in section 5. Finally, conclusion drawn from this study has been presented in section 6.

2. Study area:

The present study has been carried out in a part of Sutlej river basin that is confined in the hilly State of Himachal Pradesh, India. It has covered parts of Simala, Kullu, Manali, Bilaspur and Solan districts of Himachal Pradesh. This has a spread of 2457 km^2 and lies between 31°05’00”N and 31°39’26”N latitudes and 76°51’11”E and 77°45’17”E longitudes (Figure 1). The basin is drained by the Sutlej river that is the largest North-West flowing river of the Indus river systems. The altitude in the basin ranges in between 502m to 5128m. The elevation and slope aspects control temperature and also have strong impact on spatial and temporal distribution of precipitation in a mountainous region.

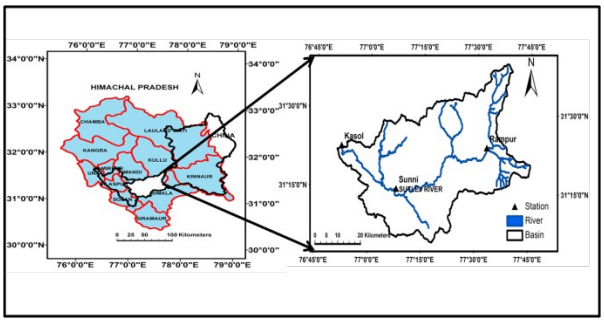


Figure : Location map

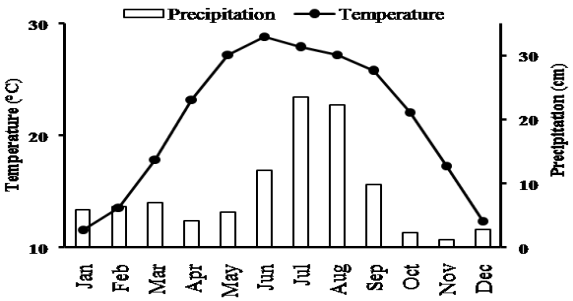


Figure : Climatic characteristics in study region

The climatic characteristics of the study area have been shown in Figure 2. The mean annual temperature and precipitation has been recorded 21.23°C and 103cm respectively. The maximum amount of precipitation is received in the months of June, July, August and September from the South-West monsoon. It contributes more than 65% of total precipitation in the study region. 14.63% precipitation has been recorded during winter season (December, January, February) and it mainly occurs due to western disturbances.

3. Data Sets:

The precipitation data used in this study has been procured from Bhakra Beas Management Board (BBMB). It has been collected for three stations namely, Kasol, Sunni and Rampur on daily time steps for the periods 1971-2005. The details about station locations and major characteristics of precipitation data is given in Table 1. For analysis, annual and seasonal time series of precipitation data are prepared for the given period.

Table 1: Location details of the stations considered for the study in Sutlej basin

Station Name	Latitude	Longitude	Elevation(m)	Annual Precipitation (cm)	Seasonal Precipitation (cm)			
				Mean	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
Kasol	31°21'25"	76°52'42"	662	132.26	14.82	85.65	17.14	14.65
Sunni	31°14'15"	77°06'30"	655	101.47	17.98	54.43	13.16	15.90
Rampur	31°27'15"	77°38'40"	976	76.34	17.35	34.04	10.17	14.80

4. Methodology:

The large scale atmospheric variables called predictors are grouped into two category; observed predictors (National Centre for Environmental Prediction/ National Centre for Atmospheric Research reanalysis data sets) and modelled predictors (GCMs simulated data). In the present study, predictor variables for NCEP/NCAR and GCM have been directly downloaded from the Data Access Integration (DAI) website (http://loki.qc.ec.gc.ca/DAI/predictors-e.html). The GCM selected in this study is third generation Canadian Coupled Global Climate Model (CGCM3). The NCEP/NCAR reanalysis data is available from 1961 to 2003 (43 years) and this data is interpolated to CGCM3 grid resolution (3.75° latitude × 3.75° longitude). The predictor variables of CGCM3 are available for period 1961-2100 (A2 scenario) and 2001-2100 (A1B scenario).

The methodology adopted in the present study has been discussed in details under sections 4.1. and 4.2. respectively.

4.1. Mann-Kendal test and Sen' slope method:

Man-Kendall test, a non-parametric test has been used for detecting trends in the time series of precipitation data. It has widely been used for detecting trends in hydrologic and climatologic time series (Yue and Wang, 2004; Mavromatis and Stathis, 2011). MK test has advantage over other non-parametric tests as it does not

require data to be normally distributed and is robust against outliers (Hess *et al*., 2001).

The computational procedure for the MK test has been described in Adamowski and Bougadis (2003). 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:

$$Sign(T) = \begin{cases} 1 \ \ for \ \ T_j > T_i \\ 0 \ \ for \ \ T_j = T_i \\ 1 \ for \ \ T_j < T_i \end{cases}$$

……(1)

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

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

……..(2)

The variance for the S-statistic is defined by:

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

….. (3)

In which t_i denotes the number of ties to extent i. The summation term in Eq. (1) is only used if data series contains the "tied" values. The test statistic, Z*s*, can be calculated as

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

…… (4)

In which Z_s follows a standard normal distribution. Eq. 4 is useful for record lengths greater than 10 and if the number of tied data is low (Kendall, 1955). 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, H_0: 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.

Sen's slope method is used to compute magnitude of trend line. This is defined as the median of all combination of data pairs for the whole data set. It is given as follows (Xu *et al*., 2008):

$$Q = Median\left(\frac{x_j - x_i}{j - i}\right)$$

for i =1, 2….,N …….(5)

where, x_i and x_j are data values at time i and j respectively. Q is a estimate of the trend magnitude. A positive value of Q indicates an upward (increasing) trend and a negative value of Q indicates a downward (decreasing) trend in time series.

4.2. Downscaling:

Statistical Downscaling Model (SDSM) version 4.2 has been used to downscale and generate future precipitation from predictors of CGCM3 model after calibration and validation. The functions and major characteristics of the model have been described in literature (Wilby and Dawson, 2007). The Model has been calibrated using observed station scale daily precipitation and predictors of NCEP/NCAR reanalysis data sets. The calibration period has been taken 20 years (1963-1982) for Kasol and 16 years for Sunni and Rampur stations respectively. The future projection in precipitation has been made under A1B and A2 scenarios and daily time series of precipitation data has been generated for 100 years (2001-2100).

5. Results :

In this section, the annual and seasonal trends in precipitation has been discussed for historical (1971-2005) and future periods. The future period is divided into three time slices; 2020s (2011-40), 2050s (2041-2070) and 2080 (2071-2100).

5.1. Annual and seasonal trend in precipitation during 1971-2005:

The MK test has been applied to analyze nature of trend in annual and seasonal precipitation at various stations for historical records of 35 years (1971-2005) within the study area. The magnitude of trend direction has been determined by the slope computed by Sen's slope estimator method. In this study, null hypothesis has been tested at 5% level of significance as a condition for rejecting null hypothesis of no significance trend.

The results of annual trends in precipitation data has been shown in Figure 3 for historical periods (1971-2005). Statistically, insignificant decreasing trend in precipitation has been reported at Kasol and Sunni for

historical periods (1971-2005) at the rate of 0.19mm/year and 0.37mm/year respectively. On contrary, statistically insignificant increasing trend in precipitation at rate of 0.16mm/year has been found at Rampur for the historical periods.

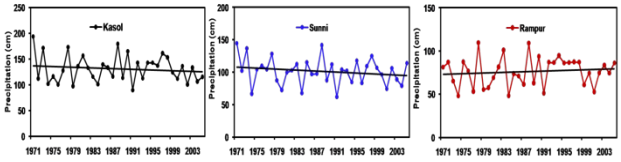


Figure : Trends in mean annual precipitation for historical periods (1971-2005)

Table 2: Seasonal trend analysis of precipitation for historical period performed at all stations

Station	Season	MK Test (Z_S)	Sen's Slope (Q) estimate mm/year	Remarks
Kasol	Winter	-0.44	-0.35	Decreasing
	Spring	0.68	0.62	Increasing
	Summer	-0.62	-2.97	Decreasing
	Autumn	0.26	0.61	Increasing
Sunni	Winter	-1.05	-0.88	Decreasing
	Spring	0.71	0.64	Increasing
	Summer	-0.80	-2.04	Decreasing
	Autumn	0.23	0.35	Increasing
Rampur	Winter	-0.23	-0.27	Decreasing
	Spring	0.00	0.00	No trend
	Summer	1.05	2.42	Increasing
	Autumn	0.06	0.24	Increasing

Similarly, the results of MK tests showing seasonal trends in precipitation have been givrn in Table 2. No statistically significant trend in precipitation has been found at 95% confidence level. In winter (December, January, February) season, statistically insignificant decreasing trends in precipitation has been observed at Kasol (0.35mm/year), Sunni (0.88mm/year) and Rampur (0.27mm/year). Insignificant increasing trend in precipitation has been noticed at Kasol and Sunni whereas Rampur has shown no trend during spring (March, April, May) season. In summer (June, July, August) season statistically insignificant decreasing trend in precipitation has been reported at Kasol and Sunni. On contrary, Rampur has shown insignificant increasing trend in precipitation. The magnitude of trend is 2.90mm/year, 2.04mm/year and 2.40mm/year respectively. Statistically insignificant increasing trend at 5% significance level has been observed at all the three stations during autumn (September, October, November) season.

5.2. Annual and seasonal trend analysis in precipitation for future periods:

The plausible ensembles of future time series of precipitation data have been generated at each station under A1B and A2 scenarios from predictors of CGCM3 model for period of 100 years (2001-2100). The MK test has been applied on future data which is divided into three distinct time slices; 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) at an equal interval of 30 years.

The results of MK test showing annual trends in precipitation data for future periods have been shown in Figure 4. Generally, statistically insignificant increasing trend in precipitation has been observed for all stations under scenario A1B and A2 for CGCM3 model during 2020s, 2050s and 2080s. The downward trend of precipitation can be seen under scenario A1B for 2050s at Kasol, under A2 and A1B scenario for 2020s and 2080s at Sunni, and under A1B scenario for 2020s at Rampur respectively. The magnitude of increasing trend for precipitation has been computed between 0.08 mm/year to 3.17 mm/year for A1B scenario and 0.16 mm/year to 1.85 mm/year for A2 scenario.

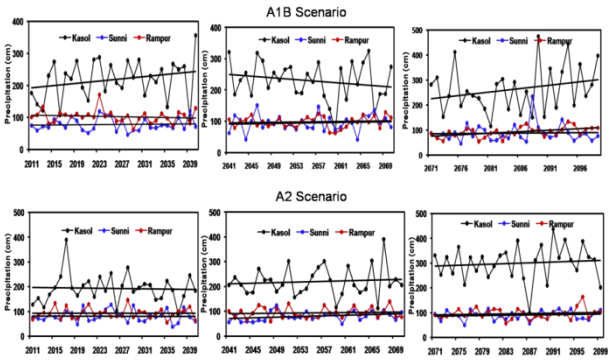


Figure 4: Trend in annual precipitation in future under A1B and A2 scenario

The results of MK test showing seasonal trend analysis of precipitation have been given in Table 3. During winter statistically significant downward trend in precipitation has been seen at Kasol during 2020s and 2080s under A2 scenario at 95% confidence level. The rate of change has been found 3.09mm/year and 1.64mm/year respectively. No statistically significant

trend in precipitation has been computed at Sunni and Rampur under both the scenarios for the future periods at 5% level of significance as values of Zs are less than 1.96. So, there is a probability of decline in winter precipitation at Kasol in future whereas for remaining stations it is undetermined.

In spring, rise in trend of precipitation at 5% level of significance has been found at Sunni under A1B scenario during 2080s and at Rampur under A2 scenario during 2020s. Kasol has shown statistically insignificant trends in precipitation for the future periods under both the scenarios. The precipitation has revealed statistically significant downward trend at rate of 6.20mm/year at Rampur under A2 scenario during 2080s. The statistically significant increasing trend in precipitation has been observed at Kasol (2080s), Sunni (2050s and 2080s) and Rampur (2080s) during summer season under A2 scenario. The magnitude of change is 33.37mm/year at Kasol, 7.08mm/year and 5.99mm/year at Sunni and 4.11mm/year at Rampur respectively. At Rampur, statistically significant fall in trend of precipitation (7.50mm/year) has been seen under A2 scenario during 2020s. During autumn, statistically significant rising trend in precipitation has been found under A1B scenario at Sunni (2050s) and Rampur (2080s) whereas no significant trend has been detected at Kasol respectively.

Table 3: Seasonal trend analysis of precipitation for future periods performed at all stations (* indicates that values are statistically significant at 5% level of significance)

Station	Season	Periods	Scenario	MK Test (Z_S)	Sen's Slope (Q) estimate mm/year	Remarks
Kasol	Winter	2020s	A1B	-1.28	-1.62	Decreasing
			A2	-2.36*	-3.09	Decreasing
		2050s	A1B	-0.07	-0.04	Decreasing
			A2	-1.00	-1.17	Decreasing
		2080s	A1B	-1.14	-0.99	Decreasing
			A2	-2.25*	-1.64	Decreasing
	Spring	2020s	A1B	0.43	0.60	Increasing
			A2	-0.57	-0.50	Decreasing
		2050s	A1B	-1.36	-1.42	Decreasing
			A2	-1.53	-1.35	Decreasing
		2080s	A1B	1.68	1.33	Increasing
			A2	-0.29	-0.19	Decreasing
	Summer	2020s	A1B	1.75	22.01	Increasing
			A2	0.21	3.10	Increasing
		2050s	A1B	-0.54	-7.10	Decreasing
			A2	-0.04	-1.13	Decreasing
		2080s	A1B	1.28	24.29	Increasing
			A2	2.14*	33.37	Increasing
	Autumn	2020s	A1B	-0.75	-2.47	Decreasing
			A2	0.93	1.03	Increasing
		2050s	A1B	-1.03	-4.68	Decreasing
			A2	1.28	1.69	Increasing
		2080s	A1B	0.50	1.49	Increasing
			A2	-0.93	-2.36	Decreasing
Sunni	Winter	2020s	A1B	0.36	0.54	Increasing
			A2	-1.11	-2.53	Decreasing
		2050s	A1B	0.18	0.54	Increasing
			A2	-0.21	-0.23	Decreasing
		2080s	A1B	1.46	2.76	Increasing

			A2	-0.82	-1.67	Decreasing
	Spring	2020s	A1B	-0.79	-0.16	Decreasing
			A2	-0.57	-0.14	Decreasing
		2050s	A1B	-0.89	-0.12	Decreasing
			A2	-0.82	-0.17	Decreasing
		2080s	A1B	2.71*	0.33	Increasing
			A2	0.71	0.14	Increasing
	Summer	2020s	A1B	0.04	0.06	Increasing
			A2	-0.32	-1.22	Decreasing
		2050s	A1B	-0.36	-0.21	Decreasing
			A2	2.71*	7.08	Increasing
		2080s	A1B	0.54	0.51	Increasing
			A2	2.50*	5.99	Increasing
	Autumn	2020s	A1B	0.36	0.32	Increasing
			A2	0.46	1.08	Increasing
		2050s	A1B	2.03*	4.65	Increasing
			A2	-0.11	-0.11	Decreasing
		2080s	A1B	-1.61	-2.28	Decreasing
			A2	-0.50	-0.68	Decreasing
Rampur	Winter	2020s	A1B	0.21	0.29	Increasing
			A2	-0.46	-0.64	Decreasing
		2050s	A1B	0.00	0.00	No trend
			A2	-0.29	-0.47	Decreasing
		2080s	A1B	1.14	2.09	Increasing
			A2	1.21	5.42	Increasing
	Spring	2020s	A1B	0.29	0.32	Increasing
			A2	2.82*	7.59	Increasing
		2050s	A1B	-0.46	-0.55	Decreasing
			A2	0.93	2.21	Increasing
		2080s	A1B	0.18	0.09	Increasing
			A2	-2.46*	-6.20	Decreasing
	Summer	2020s	A1B	-0.11	-0.34	Decreasing
			A2	-2.50*	-7.50	Decreasing
		2050s	A1B	0.50	1.45	Increasing
			A2	-1.50	-2.96	Decreasing
		2080s	A1B	1.21	2.76	Increasing
			A2	2.68*	4.11	Increasing
	Autumn	2020s	A1B	-1.28	-2.38	Decreasing
			A2	1.53	2.69	Increasing
		2050s	A1B	0.54	1.32	Increasing
			A2	1.39	2.16	Increasing
		2080s	A1B	2.82*	5.22	Increasing
			A2	-0.61	-0.63	Decreasing

6. Conclusion:

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5. Since, knowledge of future trends in annual and seasonal precipitation has advantage in water resource management and planning at basin scales. The future water availability in the basin in different seasons and years can be estimated based on simulations of GCMs. In the present study, an effort has been made to analyze trends in past and future time series of precipitation data in middle catchment of Sutlej river basin. The future trends in precipitation have been studied for the time periods; 2020s, 2050s and 2080s under A2 and A1B scenarios. No statistically significant trends in annual and seasonal precipitation have been detected during historical periods for all the stations. The future precipitation has also revealed no clear trend in annual time series under A1B and A2 scenarios. The seasonal trend analysis of future precipitation data has shown statistically significant increasing as well as decreasing trend under both the scenarios for the future periods. However, the interpretation of results has become very difficult because the downscaled precipitation has shown poor agreement with observed data during calibration period. The projected precipitation inherited uncertainties due to uncertainties associated with CGCM 3 model and limitations of the SDSM 4.2 in downscaling of precipitation. This may cause of erroneous interpretation of the results.

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