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L E T T E R S

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ANALYSIS OF TEMPERATURE AND PRECIPITATION FOR ASSESSMENT OF CLIMATE CHANGE DURING 20^TH CENTURY IN BEAS RIVER BASIN

1. The mountainous regions are essential sources of freshwater across the globe. Particularly, a significant number of large Asian rivers receive large amounts of snow and glacier melt from the Hindukush-Karakoram-Himalayan (HKH) mountain ranges. The Himalayan mountains are young, weak and flexible in their geological structure and are relatively more sensitive to climate change. The mountain act as a barrier due to its giant size and lofty peaks in atmospheric circulation for both the summer monsoon and the winter westerlies and is playing a significant role as a major climatic control (Eriksson *et al*., 2009). The climate gets influenced by several factors which operate relentlessly within the climatic system at timescales ranging from hours to hundreds of millions of years. In these modern days, understanding of changing climates is crucial in the assessment of vulnerability and risk for evolving management policies at global as well as local scale.

Climate change can be identified by studying changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Although climate change occurs naturally over relatively long periods, the global climate is now changing at a much more rapid rate primarily due to excessive anthropogenic emissions of greenhouse gases (ICLEI, 2013). The impacts of climate change are superimposed on a variety of environmental, *viz*., hazards, water resources, land, air quality, etc. (Javidfakhr, 2017; IHCAP, 2016; Smiatek, *et al*., 2014), ecological like animals, plants and vegetation, etc. (Gopalakrishnan *et al*., 2011; Raha *et al*., 2012), economical including hydroelectricity, land-use changes, construction, transport, etc. (Hamududu and Killingtveit, 2012**)** and social issues, for example, food security, public security, health, etc. (Shelat, 2017; Kumar *et al*., 2011; ICIMOD, 2010**)** and many of them already recognized as severe (Ives & Messerli, 1989).

The special report on the impacts of global warming at 1.5 °C (IPCC, 2018) estimated that human activities have caused approximately 1.0 °C of global warming above pre-industrial levels, with a likely range of 0.8 °C to 1.2 °C. There have been observed changes both positive and negative in surface temperature and precipitation events throughout the world (Abatzoglou *et al*., 2020; UNESCO, 2020; Mall *et al*., 2006; Fauchereau *et al*., 2003; Trenberth, 1990). Several studies have indicated abrupt inter-seasonal, inter-annual and spatial variability in precipitation trends across Hindukush-Karakoram-Himalaya (HKH) region and Indo-Gangetic plain region (IGPR). It was observed that the warming in the greater Himalayas has been much greater than the global average (Pachauri & Meyer, 2014; Eriksson *et al*., 2009; Jianchu *et al*., 2007; Shrestha *et al*., 1999).

The Himalaya is sensitive to climate change and so are its glaciers and rivers. The hydro-meteorological variables in the Himalayan basins have changed a lot in the past and are constantly changing under the current climatic changes. The rising temperatures are causing the net shrinkage and retreat of glaciers affecting water availability, biodiversity, agricultural productions, economies and ecosystem functioning. The river Beas is one of the important rivers of India that originates in the lap of the Himalaya and nourishes a large population from its waters. Waters of the river Beas and its tributaries are being used for irrigation, hydroelectricity, recreation, domestic water supply, etc. The basin is subjected to various climate-induced hazards (sudden landslides, glacial lake outbursts, debris flow and flash floods) emanating from the frozen masses. Glaciers in the Beas basin have been reported to be in the retreating phase and in future, this will result in water scarcity for the people living in the mountain region and in the downstream area who depend on glaciers and snow as a source of freshwater. Hence, the study was conducted for assessing long-term fluctuations of hydro-meteorological variables such as temperature and precipitation over the Beas river basin of western Himalaya.

2. *Description of the study area* : *Location* : The study area, Beas River Basin (BRB) lies between 31°09'-32°22' N latitudes and 77°05'-74°58' E longitudes covering an area about 19,100 km². The river Beas originates in Beas Kund near Rohtang Pass of the Pir Panjal range at an altitude of 14,308 feet above mean sea level (amsl). The entire basin is spreading in parts of nine districts, *viz*., Chamba, Hamirpur, Kangra, Kinnaur, Kullu, Lahaul and Spiti, Mandi, Shimla and Una in Himachal Pradesh and six districts namely Hoshiarpur, Gurdaspur, Amritsar, Kapurthala, Jalandhar and Firozpur in Punjab states of India (Fig. 1).

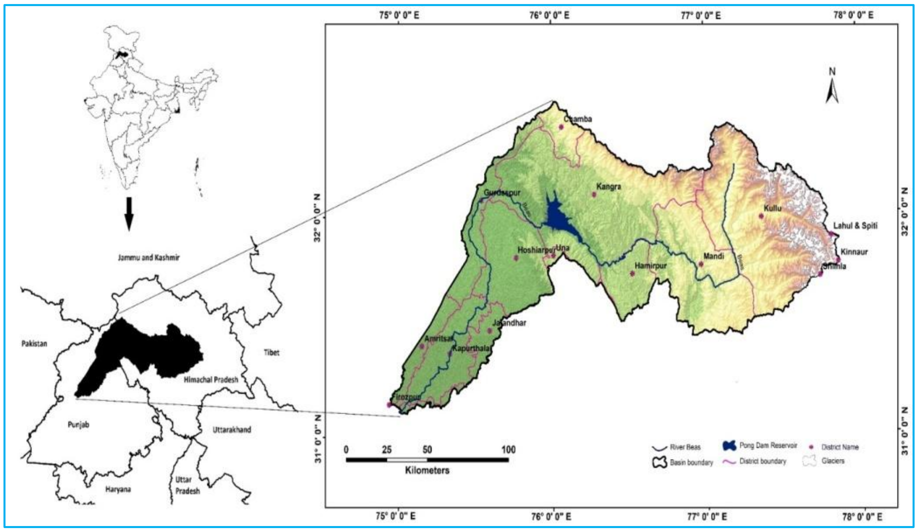


Fig. 1. The study area : Beas Basin

Physiography : There is a big difference in relief, climate, soil, altitude, demographics, culture, beliefs and society in the upper and lower Beas basin. The upper Beas river basin is mainly dominated by mountainous relief and the lower Beas river basin is occupied with alluvial depositional plains. The elevation ranges between 200 m and 6500 m. Physiographically, the Beas basin is very diverse. It can be classified into (*i*) The Greater Himalayan Ranges (above 4500 m amsl), (*ii*) The Middle Himalayan Ranges (1500-4500 m amsl), (*iii*) The Shiwaliks (600-1500 m amsl), (*iv*) The Kandi Region (300-400 m amsl), (*v*) The Alluvial Plains (below 300 m amsl). As noted by (Khullar, 2006 and Manku, 1998), Beas basin presents an ideal representation of all three stages of a river system. It has a steep gradient of 24 m/km in its upper portion and gentle gradient of 1.5 m/km in lower portion.

Water resources : The river Beas is one of the smallest tributaries of the river Indus. Several tributaries namely Parbati, Sainj, Suketi, Tirthan Bain, Banganga, Luni, Uhal, Banner, Chakki, Gaj, Harla, Mamuni, Patlikuhlal, etc. fed the river to drain nearly 470 km length before meeting the river Sutlej at Harike Wetlands. The largest surface water body, *i.e*., Pong reservoir has bifurcated the basin into two parts as upper BRB and lower BRB. There are 11 dams (7 in Himachal Pradesh and 4 in Punjab) and 16 powerhouses constructed in the BRB. Prominent dams of upper BRB in Himachal Pradesh are Pong dam on Beas river (district Kangra), Malana-II dam on Malana Nallah (district Kullu), Bassi dam on Beas river (district Mandi), Parbati-II dam on Parbati river (district Kullu), Parbati-III dam on Sainj river **(**districtKullu), Larji dam on Beas river (district Mandi), Pandoh dam on Beas river (district Mandi). In lower BRB all the dams are located in Hoshiarpur district of Punjab including Janauri dam on Janauri Khad river, Dholbaha dam on Dholbaha Khad river, Sal dam on Damsal river, Thana dam on Khwaja River (Sharma & Paithankar, 2014).

Climate : On the basis of Koeppen's climatic classification, the study area falls in 'Cwg' and 'Cfa' categories which are warm temperate monsoon climate with dry winters and humid sub-tropical climate respectively. Beas basin has a huge variation in the climatic conditions due to variation in altitude (200-6500 m asl). The upper BRB, a hilly and mountainous region experiences a pleasant and cool climate throughout the year with heavy snow fall during the winter months. However, the lower basin is a highly monotonous alluvial plain with extremely warm temperatures during summers. Physiographically, it is semi-arid and hot in plains, sub-humid and less hot in valleys and foothills, warm and temperate in hilly and mountains, cool and temperate in middle Himalaya and cold alpine and glacial in Lahaul and Spiti region of Beas basin.

Population : BRB supports large population of northern India mainly the lower parts are much denser. The lower basin falling in Punjab state had relatively much dense population owing to its supportive relief, agricultural intensification and economic development as compare to rugged, hilly and inaccessible regions of upper basin. According to Census (2011), Amritsar is recorded the highest population density with 956 persons/km² followed by Jalandhar (861 persons/km²). On the other hand, upper parts of the basin like Lahaul & Spiti and Kinnaur are the most sparsely populated with population density of only 2 and 13 persons/km² respectively.

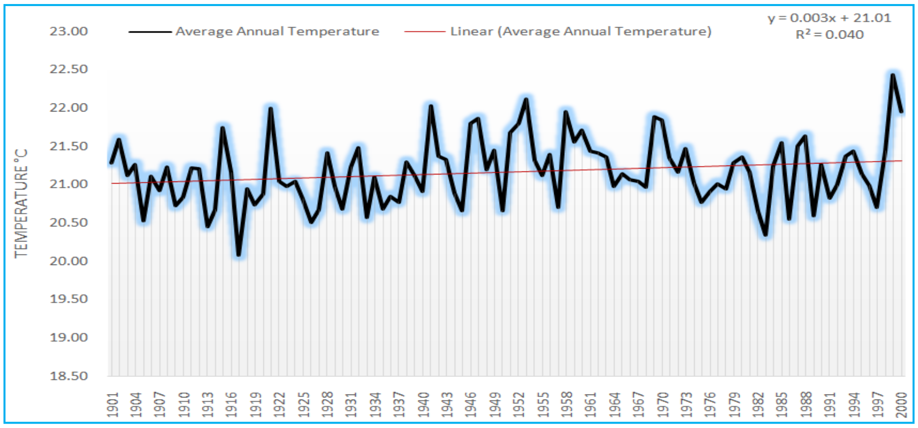


Fig. 2. Annual fluctuations in average annual temperature over Beas Basin

3. The Beas River Basin delineated with the help of Survey of India (SOI) Open Series Map (OSM) toposheets and ASTER-GDEM using ArcGIS software. The basin area is spreading in a total number of 51 toposheets on a 1:50,000 scale. DEM was downloaded from https://earthexplorer.usgs.gov/ and used for the present research work. Monthly precipitation and temperature data from 1901 to 2000 was obtained from the Indian Meteorological Department (IMD) for all the districts falling under Beas river basin. In case of missing values, we have used data obtained from other organizations such as Punjab State Council for Science and Technology (PSCST), India Water Portal (IWP), Economic and Statistical Organization of Punjab (ESOPB) and Himachal Pradesh Council for Science Technology and Environment (HIMCOSTE). The spatial database was created for generating temperature and precipitation variability maps for each district falling in the basin area using ArcGIS 10.4 software.

We have collected monthly mean values of temperature and precipitation (averaged over districts) for all the districts of Beas basin. These monthly mean values of temperature and precipitation were used to calculate mean annual temperature and average annual rainfall at district level. The long-term average of the total of 100 years was considered as the normals of the data. Trends in temperature and precipitation were evaluated using linear trend analysis, coefficient of correlation (*r*), Probable Error (PE), Standard Error (SE), Coefficient of Determination and Frequency analysis. All the datasets were computed on annual (1901-2000) and decadal (1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1990 and 2000) scale for each district falling in the basin region. Besides, the data were grouped into three tri-decades (1901-1930, 1931-1960, 1961-1990) for assessing the fluctuations after every 30 years' duration. IBM-SPSS software was used for calculating statistical measures like normal (long period) average, standard deviation, coefficient of variation, etc.

4. *Annual variations in temperature and precipitation over Beas basin* : *Annual temperature trends* : There is no specific pattern noted in temporal fluctuations in mean annual temperature over the study area. Considerable departures both positive and negative were observed during the span of 100 years but overall the temperature represents a slight increasing linear trend (Fig. 2). A huge range of 2.36 °C was observed in mean annual temperature between the warmest and the coldest year. The long-term average temperature was calculated as 21.17 °C. The year 1999 was the warmest year with mean annual temperature of 22.44 °C witnessing a positive departure of 1.2 °C from long-term average. On the other hand, 1917 was the coldest year of the century with mean annual temperature of 20.08 °C witnessing a negative departure of -1.09 °C from long-term average. The average temperature recorded from 1901-50 was 21.06 °C and 21.21 °C during 1951-2000. Overall, the study area experienced warmer temperatures (nearly 0.21 °C) during second half of the 20th century.

During 1901, Lahaul & Spiti was the coldest place with mean annual temperature of only 8.87 °C and Firozpur was the hottest place with mean annual temperature of 25.67 °C. During 2000 Lahaul & Spiti and Firozpur remained the coldest and hottest places of the basin with mean annual temperature of 9.98 °C and 25.9 °C, respectively. Although, the spatial patterns of temperature distribution remained almost similar at the end of the 20th century but there was noticeable increase found in average monthly and mean annual temperature throughout the basin. It is to be noted that warming is more pronounced in the upper parts of the basin. As against all other variables increase in mean annual temperature was minimum over Firozpur (the warmest

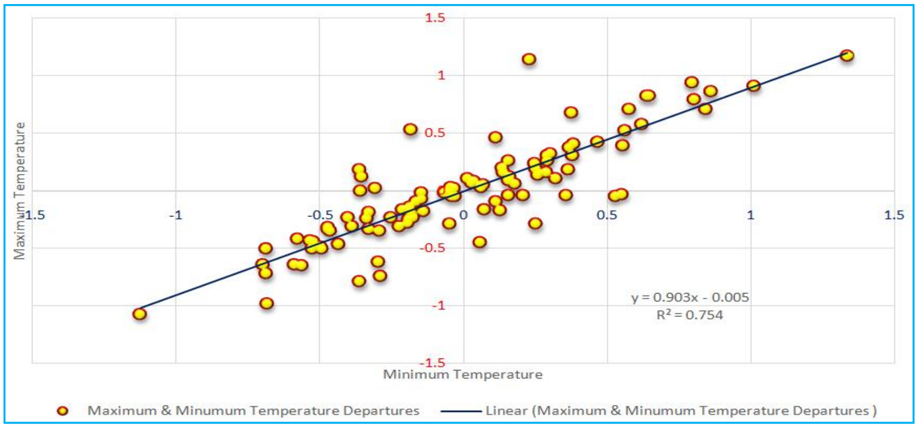


Fig. 3. Annual departures of maximum & minimum from LTA temperatures

district of the basin) and maximum over Lahaul & Spiti (the coldest district of the basin). It shows that temperature was found to be increasing throughout the basin but places with lower mean annual temperature are experiencing rapid warming than places with higher mean annual temperature.

A highly positive correlation is found between the two extreme variables (*T*max and *T*min) of the temperature which was analyzed using the scatter diagram (Fig. 3)**.** Overall in the study area, the Diurnal Temperature Range (DTR) is found to be decreasing from 12.54 °C (1901) to 12.4 °C (2000). Maximum diurnal temperature range was found during 1970 and lowest noted during 1962. Diurnal temperature range has shown a sudden decline during 1951-1960 and a considerable inclination in the next decade. Spatial distribution maps show maximum fall in diurnal temperature range in the upper BRB, for example, Lahaul & Spiti (-0.22), Chamba (-0.21) and Kullu (-0.20) districts of HP and minimum fall in the Firozpur (-0.06), Kapurthala (-0.09) and Jalandhar (-0.09) districts of Punjab. The results revealed that the upper BRB is experiencing temperature increase with much more intensity as compared to the lower basin. A detailed description of spatio-temporal variations in diurnal temperature range is shown in Table 1**.** On a decadal scale, diurnal temperature range for the whole basin keeps on increasing for the first five decades of the twentieth century and the second half shows undulating behaviour.

TABLE 1

Spatial variability in minimum and maximum diurnal temperature range over Beas basin

S. No.	District	Minimum annual average DTR		Maximum annual average DTR	
		Year	Range	Year	Range
1.	Amritsar	1982	13.08	1970	14.19
2.	Chamba	1962	11.83	1970	13.31
3.	Firozpur	1982	13.65	1970	14.66
4.	Gurdaspur	1982	12.87	1970	14.07
5.	Hamirpur	1961	12.47	1970	14.10
6.	Hoshiarpur	1962	12.90	1970	14.27
7.	Jalandhar	1961	13.07	1970	14.37
8.	Kangra	1962	12.38	1970	13.87
9.	Kapurthala	1962	13.11	1970	14.31
10.	Kinnaur	1961	8.18	1970	10.55
11.	Kullu	1961	9.92	1970	11.87
12.	Lahul & Spiti	1960	10.59	1970	11.72
13.	Mandi	1961	11.81	1970	13.64
14.	Shimla	1961	10.72	1970	12.84
15.	Una	1961	12.82	1970	14.34

Annual precipitation trends : During the study period of 100 years 54 years received precipitation less than the long-term average whereas, 46 years were observed with more precipitation than the long-term average (Fig. 4). Annual departures of precipitation from long-term average vary between -316.24 mm (1918) and 449.43 mm (1976). The minimum value of average annual precipitation recorded is 400 mm (1918), 428 mm (1952) and 461 mm (1987) and maximum of average annual precipitation observed as 1166 mm (1976), 1163 mm (1978) and 1067 mm (1980). The overall trend of precipitation data is indicating an increasing trend (Fig. 5). Overall data from 1901-2000 explains that there is a considerable increase of precipitation observed during

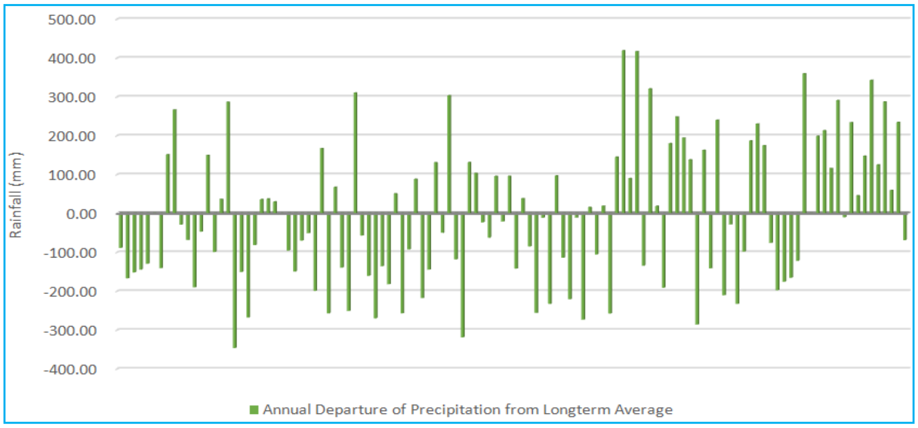


Fig. 4. Average departure of rainfall from long-term average (1901-2017)

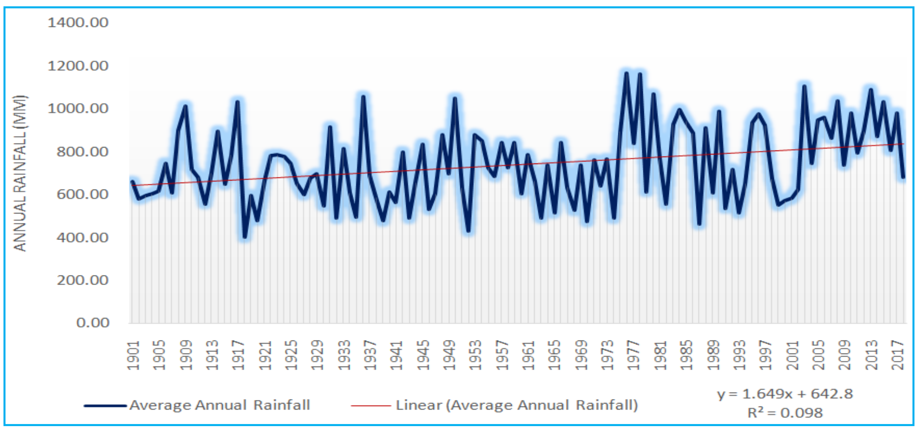


Fig. 5. Trends in average annual rainfall over Beas Basin (1901-2017)

the second half of the 20th century. During 1901-1950, a total number of 32 years received less precipitation from long-term average in comparison to the period 1951-2000 in which 22 years are noted with lesser precipitation than long-term average.

There has been a huge variability observed in average annual precipitation from one part of the basin to another owing to considerable heterogeneity in its altitudinal zones, topographical characteristics, vegetation, etc. The Kinnaur district has received the maximum amount of precipitation during 20th century with long-term average precipitation of 969.83 mm followed by Kullu (952.14 mm) and Shimla (942.29 mm). In addition to these districts, all other high precipitation districts are the part of upper Beas basin. Whereas, all the low precipitation receiving areas such as Firozpur (321.26 mm) Amritsar (471.31 mm) and Kapurthala (495.53 mm) districts are part of the lower basin. A range of 648.57 mm of precipitation is noted between Kinnaur and Firozpur districts located at northern and southern ends of the basin respectively.

Spatially it is observed that the northern, north-eastern, central and south-eastern parts of the basin receive higher amounts of precipitation whereas north-western, southern and south-western parts of the basin receive comparatively lesser precipitation (Fig. 6). On the whole, the study area has shown an increasing trend of precipitation except Kinnaur, Lahaul & Spiti and Firozpur district regions. The upper BRB falling in mountainous terrain of Himachal Pradesh received much more precipitation as compared to the lower BRB which lies in the Punjab plains.

Decadal temperature and precipitation variations over Beas basin : The decadal average temperature and precipitation data of the study area is given in Table 2. The decade of 1911-20 was the coolest with an average temperature of 20.91 °C and 1951-60 was the warmest decade (21.5 °C). The decade of 1951-60 experienced eight years with average temperatures more than long-term average as against to 1921-30 with eight years having average temperatures less than long-term average. It is to be noted that all the decades after 1970 had equal number (5 each) of years with temperatures more and less

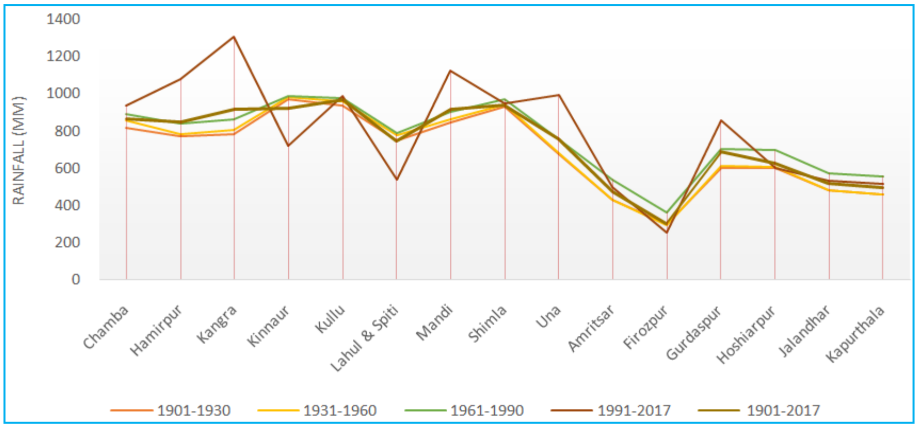
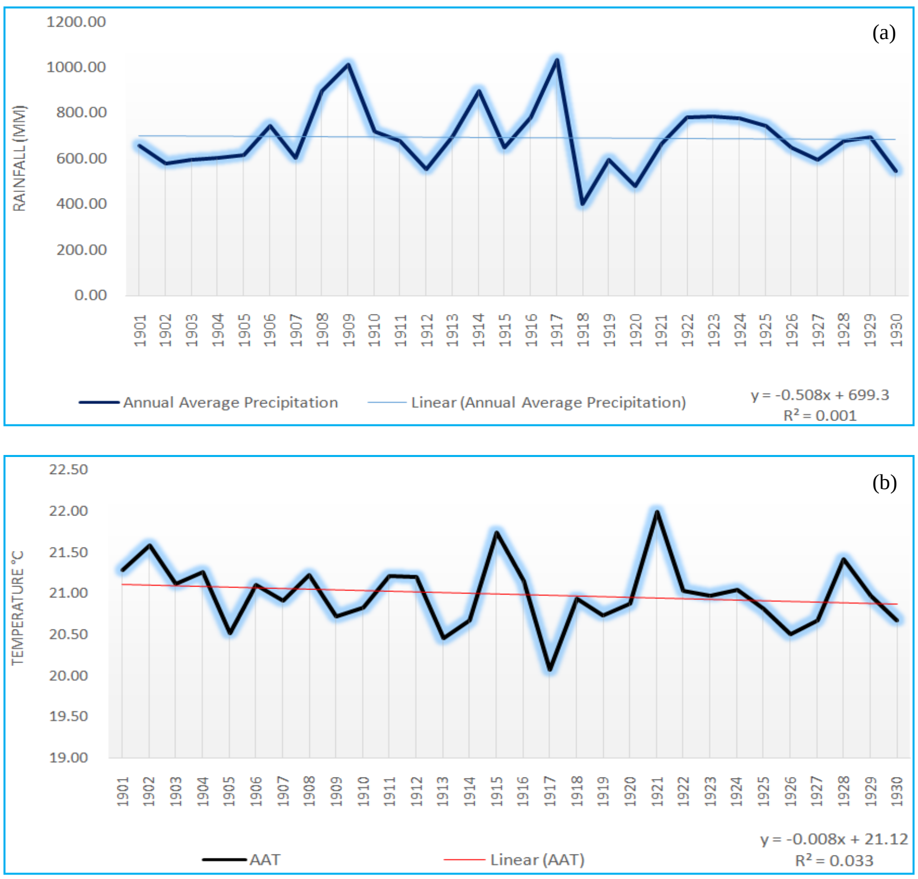
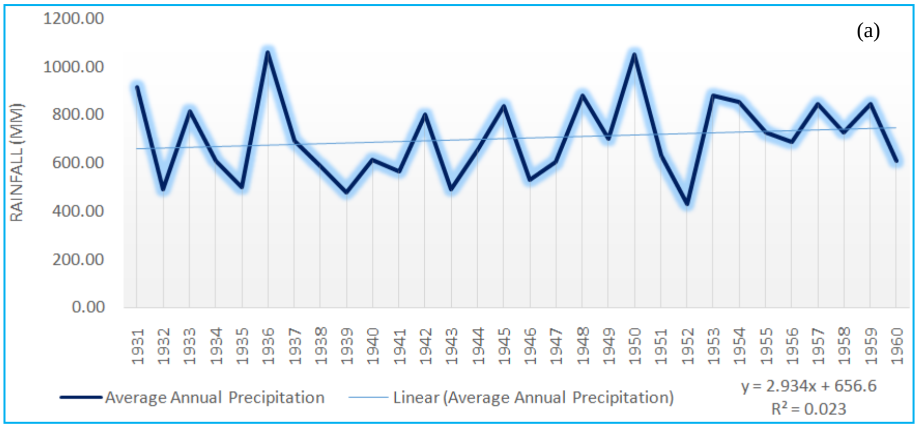


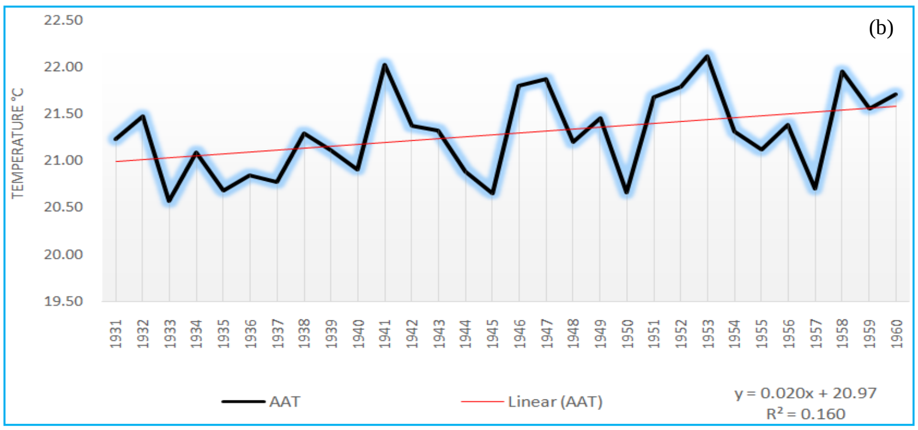
Fig. 6. Tri-decadal district-wise rainfall in Beas Basin



Figs. 7(a&b). (a) Annual average rainfall over Beas Basin (1901-1930) and (b) Mean temperature in Beas basin : 1901-1930

than long-term average of the basin. In context to the decadal fluctuations in precipitation from the decade of 1901-1910 to 1990-2000, a considerable increase in precipitation observed during the second half of the twentieth century. During 1901-1950, 35 years received precipitation less than long-term average as compared to the second half receiving less precipitation only in 27 years. Maximum precipitation of 840.20 mm observed during 1971-80 followed by 803.68 mm during 1981-1990. On the other hand, minimum precipitation has been observed during 1911-20 with an annual average precipitation of 677.59 mm followed 640.52 mm and 674.81 mm during 1961-70 and 1931-40 respectively.





Figs. 8(a&b). (a) Annual average rainfall over Beas Basin (1931-1960) and (b) Mean temperature in Beas basin: 1931-1960

TABLE 2

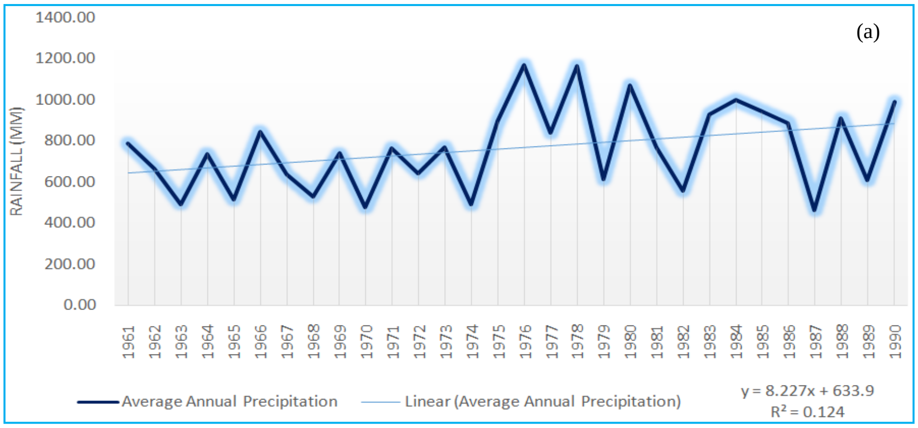
Decadal temperature & rainfall trends (1901-2000)

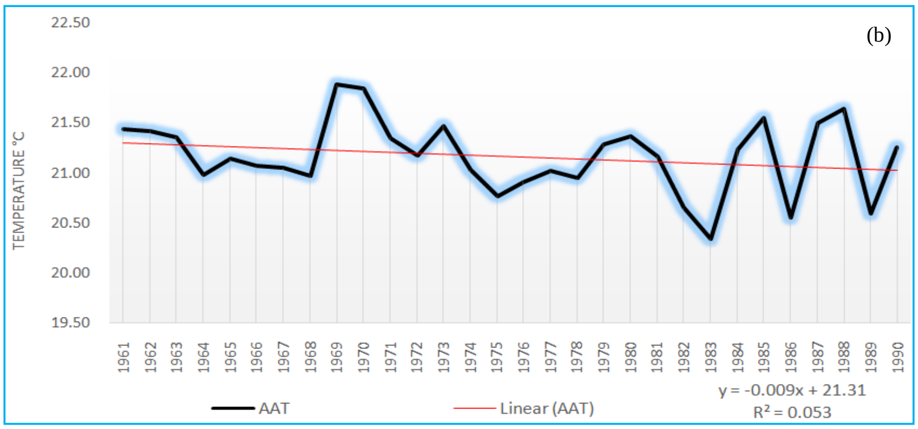
	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000
Temperature	21.06	20.91	21.01	21	21.32	21.53	21.31	21.13	21.04	21.33
Rainfall	703.93	677.59	692.90	674.81	710.22	721.44	640.52	840.20	803.68	704.65

Tri-decadal temperature and precipitation variations over Beas basin : Climate is defined as the average state of weather for at least 30 years therefore analysis at the tri-decadal scale was taken into account temperature and precipitation for 30 years from 1901-30, 1931-60 and 1961-90 was studied to identify the fluctuations and trends in a systematic manner.

Temperature and precipitation trends during 1901-1930 : In 1901-30, Beas basin had an Average temperature of 21 °C. During this period of 30 years 16 had mean annual temperature less than tri-decadal average. Upper BRB was noted with much lesser annual temperatures than lower BRB. Lahaul & Spiti had the lowest temperatures of only 8.66 °C followed by Kinnaur (12.46 °C) and Firozpur (25.26 °C) recorded warmest temperatures. The whole basin recorded a range of 1.92 °C between 1901 to 1930. During this period the average precipitation was recorded as 691.5 mm. The maximum precipitation was received by Kinnaur (973.9 mm) whereas, the lowest precipitation was in Firozpur (298.2 mm). The temporal fluctuations in mean annual temperature and average annual precipitation during 1901-1930 is shown in Figs. 7(a&b).

Temperature and precipitation trends during 1931-1960 : It is noted that from 1931-60 all the districts of the study area have witnessed an increase in the temperature. Maximum changes in the average temperature have been noted in the upper BRB with maximum temperature





Figs. 9(a&b). (a) Annual average rainfall over Beas Basin (1961-1990) and (b) Mean temperature in Beas Basin : 1961-1990

change of 0.34 °C in the districts of Mandi and Kullu followed by Shimla with an increase of 0.33 °C. Minimum temperature increase has been noted in the districts of Amritsar (0.23 °C) followed by Firozpur (0.25 °C). The average precipitation was 702.2 mm during this tri-decade. The maximum precipitation was recorded in Kinnaur (980.7 mm) and minimum was in Firozpur (295.1 mm). The temporal fluctuations in mean annual temperature and average annual precipitation during 1931-1960 is shown in Figs. 8(a&b).

Temperature and precipitation trends during 1961-1990 : During 1931-60 to 1961-90 a fall in temperature has been noted with maximum fall of temperature in the lower BRB. Maximum and minimum fall in temperature has been noted in Firozpur (-0.21 °C) and Kinnaur (-0.01) districts respectively. During the period, the spatial pattern of maximum and minimum precipitation remained similar to the previous tri-decades of 1901-30 and 1931-60 but received relatively more precipitation. The average precipitation during this period was 818.7 mm. The temporal fluctuations in mean annual temperature and average annual precipitation during 1901-1930 is shown in Figs. 9(a&b).

Correlation analysis : So far we have discussed about the spatio-temporal trends and fluctuations in temperature and precipitation independent of each other. In order to visualize the extent, nature and significance of association (if any) between temperature and precipitation variability over Beas basin correlation analysis has also been carried out using Pearsonian Coefficient of Correlation (r). It was calculated using Raw Score Method (RSM) using the equations (1, 2 and 3);

Coefficient of Correlation (r)

$$= \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[n\sum x^2\right]\left[n\sum y^2 - \left(\sum y\right)^2\right]}} \tag{1}$$

$$\text{Probable Error (PE)} = 0.6745\left(\frac{1-r^2}{\sqrt{N}}\right) \tag{2}$$

$$\text{Standard Error (SE)} = \frac{1-r^2}{\sqrt{N}} \tag{3}$$

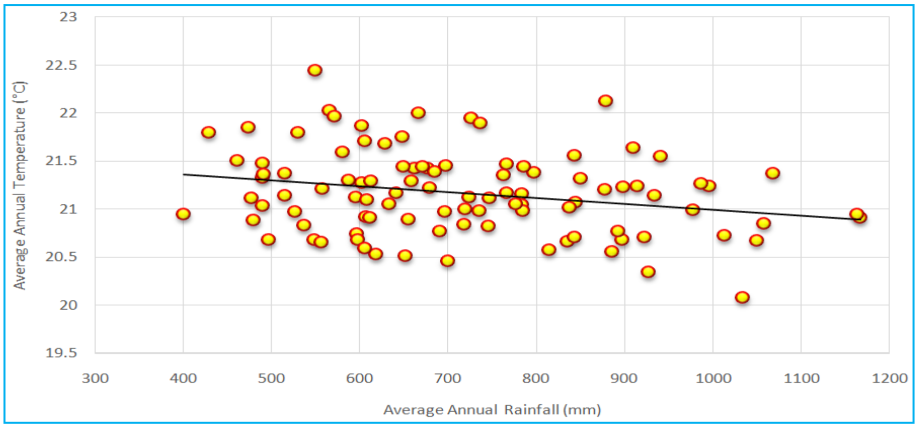
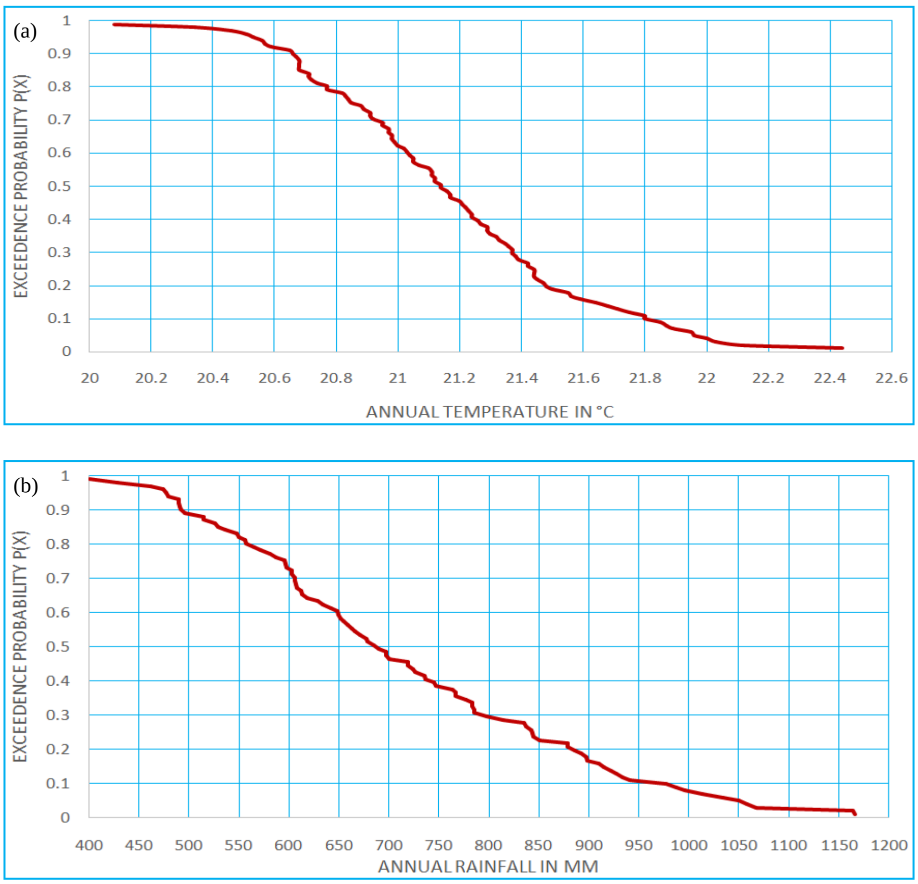


Fig. 10. Temperature and rainfall correlation



Figs. 11(a&b). (a) Probability plot of mean annual temperature, Beas Basin and (b) Probability plot of average annual rainfall, Beas Basin

where, r = coefficient of correlation, n = number of the observation in X and Y series,

$\sum x$ = Sum of all the X observations, $\sum y$ = Sum of all the Y observations.

Temperature and precipitation variability was found to have a very low degree of negative correlation with a coefficient of correlation of only -0.24. The cause and effect relationship between temperature and precipitation was explained using coefficient of determination (r^2). A very week correlation matrix can be seen in the scatter

TABLE 3

Exceedence probability at various rainfall values

S. No.	Average annual rainfall (mm)	Exceedence probability	Dependable rainfalls percentage	Frequency of recurrence in years
1.	400	0.99	99	115.83
2.	450	0.98	98	114.66
3.	500	0.90	90	105.3
4.	550	0.85	85	99.45
5.	600	0.76	76	88.92
6.	650	0.63	63	73.71
7.	700	0.52	52	60.84
8.	750	0.44	44	51.48
9.	800	0.36	36	42.12
10.	850	0.290	29	33.93
11.	900	0.21	21	24.57
12.	950	0.15	15	17.55
13.	1000	0.1	10	11.7
14.	1050	0.06	6	7.02
15.	1100	0.03	3	3.51

plot (Fig. 10). It was found that there is almost no relationship between increasing temperature and precipitation anomalies over the study area. Only 5.76 percent changes in average annual precipitation are explained by the changes in mean annual temperature and 94.24 percent changes in average annual precipitation was found to be independent of temperature changes. Although an increasing linear trend has been noted in both mean annual temperature and average annual precipitation during 20th century but the changes in both the variables during the study period were found to be independent of each other. The values of probable error (PE) and standard error (SE) was much higher than the value of '*r*' confirming no significance of the correlation between temperature and precipitation.

Frequency analysis : Recurrence interval or return period and exceedance probability (reciprocal of return period) has also been worked out for the study area using the 100 years of annual precipitation data with the help of Weibul's equation (4&5). Mean annual temperature and associated exceedance probabilities are given in the graph [Fig. 11(a)]. It is noted that the study area has nearly 50 percent of the exceedence probability to experience mean annual temperature more than or equal to 21.16 °C long-term average. It may explain that we can expect mean annual temperature of 21.16 °C or more in 50 years out of every 100 years over the Beas basin. The annual temperature corresponding to the exceedence probabilities of 0.75 and 0.50 are read as 20.85 °C and 21.15 °C respectively.

$$\text{Return period} = T_r = \frac{n+1}{m} \tag{4}$$

$$\text{Exceedence Probability} = P(x_m) = \frac{1}{T_r} \tag{5}$$

where, n = total number of observations, m = rank of the observation.

In context to precipitation, average annual precipitation and respective exceedance probabilities are presented in the graph [Fig. 11(b)]. Minimum precipitation has the maximum exceedence probability with the minimum value for the return period and the maximum precipitation has the minimum exceedence probability with a maximum value of recurrence interval or return period. It is noted that the study area has nearly 45% of the exceedence probability of receiving precipitation more than or equal to 720 mm (716 mm long-term average). It may explain that we can expect precipitation of 720 mm or more in 45 years out of every 100 years over the Beas basin. The annual precipitation corresponding to the exceedence probabilities of 0.75 and 0.50 are read as 580 and 680 mm respectively, therefore, the 75% and 50% dependable precipitations are 580 and 680 mm. In other words, we can expect average annual precipitation of 580 m or more in 80 years out of 100 years and a precipitation of 680 mm or more in 53 years out of 100 years in the study area (Table 3).

5. Several studies have been reported in the literature to assess the temperature and precipitation variability in the Himalayas as a whole or its various regional divisions. Gautam *et al*. (2013), reported an overwhelmingly warming trend of temperature over the Himalayas, albeit at different rates in different periods depending on the regions and seasons. Dimri & Dash (2012) noted an Increase in maximum temperature between 1.1 and 2.5 °C in the western Himalayan region during 1975-2006. Dash *et al*. (2007) noted a 0.9 °C rise over western Indian Himalaya during the twentieth century with much increases after 1972. In another study, Bhutiyani *et al*. (2007) found 1.6 °C warming (0.16 °C/decade) in the last century over the northwest Indian Himalayan region. Yin, *et al*. (2016) found a decrease in the annual precipitation of the majority of the stations in Beas basin up to the Pandoh dam between 1982-2010.

BRB is a part of the bigger western Himalayan region and the Indo-Gangetic plains and the existing literature speaks about an increasing trend in temperature and precipitation across the Himalayan region in common and the western Himalayan region in the singular. Singh *et al*. (2008) recognized increasing trends in maximum temperature and the seasonal average of daily maximum temperature for all seasons except the monsoon season over the lower Indus basin in the northwest Indian Himalaya. Based on the results of our investigation, it is established that BRB has undergone relatively warmer and moister climates during the last quarter of the 20th century. In an annual timeframe, no significant trend in temperature and precipitation was noted except an insignificant positive linear trend. The exact picture of fluctuations in temperature and precipitation was captured in a tri-decadal approach**,** although these fluctuations were independent of each other. Precipitation increased continuously till 1990, whereas in the case of mean annual temperature a drop observed subsequent 1960.

The probability analysis revealed that the BRB may encounter hotter temperatures along with heavier precipitation during the 21st century. Recognizing the spatial patterns of temperature increase in BRB during the previous century it can be debated that the warming will be more apparent in the upper BRB (a high altitude mountain region) as compare to the lower BRB. The increased temperatures may lead to the excessive melting of the glaciers and modify the river flow in the study area. The form of precipitation may shift from snowfall to rainfall owing to the temperature increase which may amplify the severity of natural hazards in the basin. The snow and glacier melt has a significant contribution for the total runoff in the Beas basin, which varies from 27.5% to 40% as noted in previous studies by Kumar *et al*., 2007; Li *et al*., 2013; Li *et al*., 2015. There are large uncertainties noted in the future hydrological projections under various climate change scenarios. Li *et al*. (2019), applied the Snow Melt - WASMOD model (GSM-WASMOD), to investigate hydrological projections under climate change during the 21st century in the Beas basin. They projected a decreasing glacier discharge due to decrease in glacier extent during the twenty-first century using an integrated glacio-hydrological model under various climate change scenarios.

As far as rainfall contribution to the river runoff is concerned it is likely to increase slightly, especially in the winter and pre-monsoon period, with large uncertainty in the summer period (Li *et al*., 2019). On the other hand, Adebayo *et al*. (2013) noted higher river inflows at Pong Dam during summer months and monsoon months leading to an overall increase in the mean annual runoff for the future in comparison with the historic records using five parameter Hydrological MODel (HyMOD). Aggarwala *et al*. (2016) has applied variable infiltration capacity (VIC) model for hydrological simulation for the period of 1977 to 2006. It is noticed that both temperature and precipitation may increase in future. In this study, an increase in both precipitation and temperature is noted which may lead to disintegration and thinning of the glaciers and reduction in glacier melt contribution to the overall river runoff but the increased precipitation may lead to increased runoff.

It is to be noted that increase in temperature and precipitation is independent of each other because no significant correlation was marked. Consequently, in the absence of correlation and a very insignificant cause-effect relationship, it is difficult to predict precipitation increase with increasing temperature. However, BRB has a good probability to experience more precipitation than long-term average.

6. The study was conducted for assessing the long-term fluctuations of hydro-meteorological variables such as temperature and precipitation over the Beas river basin of western Himalaya. The river Beas is recognized to be one of the famous rivers of India that originates in the lap of the Himalaya and nourishes a large population from its waters. The Himalaya is sensitive to climate change and so are its glacier and rivers. These variables have changed a lot under the current climatic scenario. No definite trend of annual fluctuations in mean annual temperature observed during 1901 to 2000. However, significant temperature deviations noted along the higher elevation regions of the basin. The temperature increased everywhere in the basin yet places with lower mean annual temperature experienced much rapid warming than places with higher mean annual temperature. Both positive and negative departure of temperature observed during 100 years but overall, the temperature represented a slightly increasing linear trend. The last decade of the century experienced the warmest year with a maximum positive departure of 1.2 °C during 1999. On the other side, 1917 was the coldest year of the century with a negative departure of -1.09 °C.

Relatively warmer temperatures were experienced over the Beas basin during the second half of the 20th century. The average temperature of three decades during the second half was more than the long-term average; whereas, during the first half, only one decade was noted higher temperatures than long-term average. Although spatial patterns of temperature distribution remained almost similar until the end of the 20th century, there was a noticeable increase found in mean annual temperature throughout the study area. From the period of 1931-60 to 1961-90, temperature declined with a maximum fall in the lower basin. Diurnal temperature range is shown a rapid decline during 1951-60 and a quick pick-up during the following decade. It is concluded that temperature increase became more apparent at the end of the century.

There has been a considerable increase in precipitation during the second half of the century. The number of years received less precipitation than the long-term average is much less during the second half as compared to the first half. There has been an increase in the precipitation from 1901-1930, to 1931-1960 and a decrease in the next tri-decade 1961-1990. It is observed that the northern, north-eastern, central and south-eastern parts of the basin receive higher amounts of precipitation whereas north-western, southern and south-western parts of the basin receive comparatively lesser precipitation. The study area has about 45% of the exceedence probability of receiving precipitation equal to or more than the long-term average. Beas basin has experienced an increase in mean annual temperature and average annual precipitation during the 20th century but no significant correlation coefficient was noted.

7. The contents and views expressed in this research article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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