




Temperature and Precipitation trends in Kashmir valley, North Western Himalayas

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Received: 24 September 2017 / Accepted: 8 January 2018 / Published online: 22 January 2018
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Abstract

Climate change has emerged as an important issue ever to confront mankind. This concern emerges from the fact that our day-to-day activities are leading to impacts on the Earth's atmosphere that has the potential to significantly alter the planet's shield and radiation balance. Developing countries particularly whose income is particularly derived from agricultural activities are at the forefront of bearing repercussions due to changing climate. The present study is an effort to analyze the changing trends of precipitation and temperature variables in Kashmir valley along different elevation zones in the north western part of India. As the Kashmir valley has a rich repository of glaciers with its annual share of precipitation, slight change in the temperature and precipitation regime has far reaching environmental and economic consequences. The results from Indian Meteorological Department (IMD) data of the period 1980–2014 reveals that the annual mean temperature of Kashmir valley has increased significantly. Accelerated warming has been observed during 1980–2014, with intense warming in the recent years (2001–2014). During the period 1980–2014, steeper increase, in annual mean maximum temperature than annual mean minimum temperature, has been observed. In addition, mean maximum temperature in plain regions has shown higher rate of increase when compared with mountainous areas. In case of mean minimum temperature, mountainous regions have shown higher rate of increase. Analysis of precipitation data for the same period shows a decreasing trend with mountainous regions having the highest rate of decrease which can be quite hazardous for the fragile mountain environment of the Kashmir valley housing a large number of glaciers.

1 Introduction

Climate plays a decisive role in the lives and livelihoods of the people and the socio-economic development as a whole. The warming of climate system is showing its impacts on almost all spheres of life with predominant effects on the environment, water resources, industrial production, agricultural activities, and human lives (Shi and Xu 2008; Yao and Chen 2015). IPCC (2013) ascertains that the global climate has shown a warming trend of about 0.89 °C for the period

spanning from 1901 to 2012 and mainly attributed the anthropogenic factors as the primary cause. Generally, climate studies have been performed on global scales (Pielke et al. 2000), but in order to understand the complexities, the scale needs to be narrowed down to the local level. The complexities become increasingly important over mountainous regions when we take topographical factors into consideration, because of their unparalleled impact on the local climatic conditions.

Numerous studies suggest an increased rate of warming, particularly in the minimum temperatures over most of the mountainous regions which among others include Himalayas and Tibetan Plateau as compared to the nearby low land areas (Rangwala and Miller 2012). The rate of warming around the globe has been increasing steadily but seems to have heightened since the last five decades, and highest rates of increase were recorded in the last two decades (Bhutiyani et al. 2010; Easterling et al. 1997; Qiang et al. 2004; Oerlemans 1994; De and Mukhopadhyay 1998; Schaer et al. 2004). Conforming to the global trends in the rate of warming, high elevated areas particularly Alps, Rockies, Himalayas, and Andes have shown that these

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highlands have also warmed significantly, as revealed by various studies done in these areas (Beniston et al. 1997; Beniston 2003; Diaz and Bradley 1997; Bhutiyani et al. 2010; Wibig and Glowicki 2002; Rebetz 2004; Diaz et al. 2003; Villaba et al. 2003; Vuille et al. 2003; Dimri and Dash 2012). The ongoing debate about the current and future climate change impacts have gained impetus due to the fragile ecosystems of the Himalayan region which is also extremely vulnerable to natural hazards (Cruz et al. 2007). The concerns of the changing climate arise from the fact that Himalayas encompass the potential of floods, droughts, and landslides (Barnett et al. 2005), simultaneously affecting the human health, biodiversity, agricultural production, sustenance of livelihood, and food security (Xu et al. 2009; Rasool et al. 2016). Although some studies suggest that pre-monsoon or spring (March to May) and summer cooling have been reported in some portions of Himalayan and Indus basins (Yadav et al. 2004; Fowler and Archer 2006), but most of the studies suggest significant increasing annual temperatures in the last century (Shafiq et al. 2016; Pant and Borgaonkar 1984; Bhutiyani et al. 2007; Seko and Takahashi 1991; Sharma et al. 2000; Bhutiyani et al. 2010).

The Himalayas influence climate at both major and micro-scales, and in turn, the climate at all these scales (global, regional, and local) impacts the Himalayan climate itself (Dimri and Niyogi 2013). Mountainous regions of the world show a characteristic feature of uneven topography and heterogeneous land use and display a large variability in the climatic conditions over a comparatively smaller gradient (Bhutiyani et al. 2007). The studies done on Himalayan mountains are very few when compared to studies on high-elevation regions round the globe such as by Diaz and Bradley (1997), Beniston et al. (1997), Beniston (2003), Diaz et al. (2003), and Rebetz (2004) mainly due to inaccessible terrain and poor database (Bhutiyani 2012). There are several studies conducted on Himalayan climate like Bhutiyani et al. (2007) who found the warming rate of 0.16 °C/decade in the last century. Dash et al. (2007) reported that the western part of Indian Himalayas has seen a 0.9 °C warming over the last century (1901–2003); they further observed that majority of this warming is related to increments in recent decades especially after 1972. Further, Dimri and Dash (2012) analyzed the winter month's temperature from 1975 to 2006 and showed a warming rate over western Himalayas with greatest observed increase in mean maximum temperature (1.1–2.5 °C). Warming has been observed during monsoon and postmonsoon seasons by Archer and Fowler (2004) and Jhaharia and Singh (2011). Due to complexity in the topography and vast spatial expanse of the Himalayas, its sub-regions respond differently to the small variations in the climate system (Chevuturi et al. 2016).

Since the late 1800s, when climate data began to be recorded and analyzed, only in recent decades especially after 1970 that a significant change in various variables of climate has

been shown. Any small variation in the temperature and precipitation can prove detrimental to the already fragile environs of Kashmir Himalayas, which is an amalgamation of many glaciers, water resources, and forests. Keeping all this in consideration, the present study focuses on the recent trends or variability of temperature and precipitation in Kashmir valley which forms a significant part of the northwestern Himalayas. The region is a low lying basin surrounded by mighty Himalayas. The mountain areas act as a roadblock to circulation patterns of the atmosphere for both the summer monsoon (Kumar et al. 2004, 2006) and winter monsoon (Dimri et al. 2016). The winter climate of the northwestern Himalayas is determined to a large extent by the western disturbances from October to May (Dimri et al. 2015) and by southwest monsoon from July to September (Bhutiyani et al. 2016). This study thus attains much significance as almost no such studies have been conducted on the climate of Kashmir valley which can show the changes in various variables of climate over various topographic zones. Thus, this study assesses an elaborate analysis of recent climate over the Kashmir valley as a whole and at the same time attempt to understand the topographic variations of climate. The study also attempts to comprehend these variations in light of changing climatic scenario both at the national and international levels.

2 Study area

Geologically younger, but an integral Kashmir valley forms a part of the main Himalayan range. The physical limits of the Kashmir valley coincide with the drainage basin of Jhelum River. Kashmir is a meso-geographical region with an area of around 15,948 km². Topographically, the valley depicts an elliptical bowl-shaped character, encapsulated between mighty Pir-Panjal range in its south and southwest and the great Himalayan range in the north and east. The mountain ranges rise to the height of about 5550 m in the northeast and dip down to a height of 2770 m in south. The valley of Kashmir (Fig. 1) stretches between 32° 22' to 34° 43' N latitude and 73° 52' to 75° 42' E longitudes (Hussain 1987). Within the Himalayas, the Kashmir valley has a discrete geographical and distinct physiographic personality. The valley can be divided into four broad physiographic divisions: the mountains, the foot hills, the Karewa's, and the valley floor. The location of Kashmir at a high altitude in the northwest nook of the sub-continent, enclosed within the high mountain ranges, gives it a distinctive character with its own climatic peculiarities. Within the valley, interesting variations in weather are witnessed, largely owing to the variations in altitudinal aspects. The mountain ranges work as the separating wall in the way of summer monsoon originating from the Indian Ocean and winter air masses coming from central Siberia. The westerly trough moves at the higher altitude, enters the

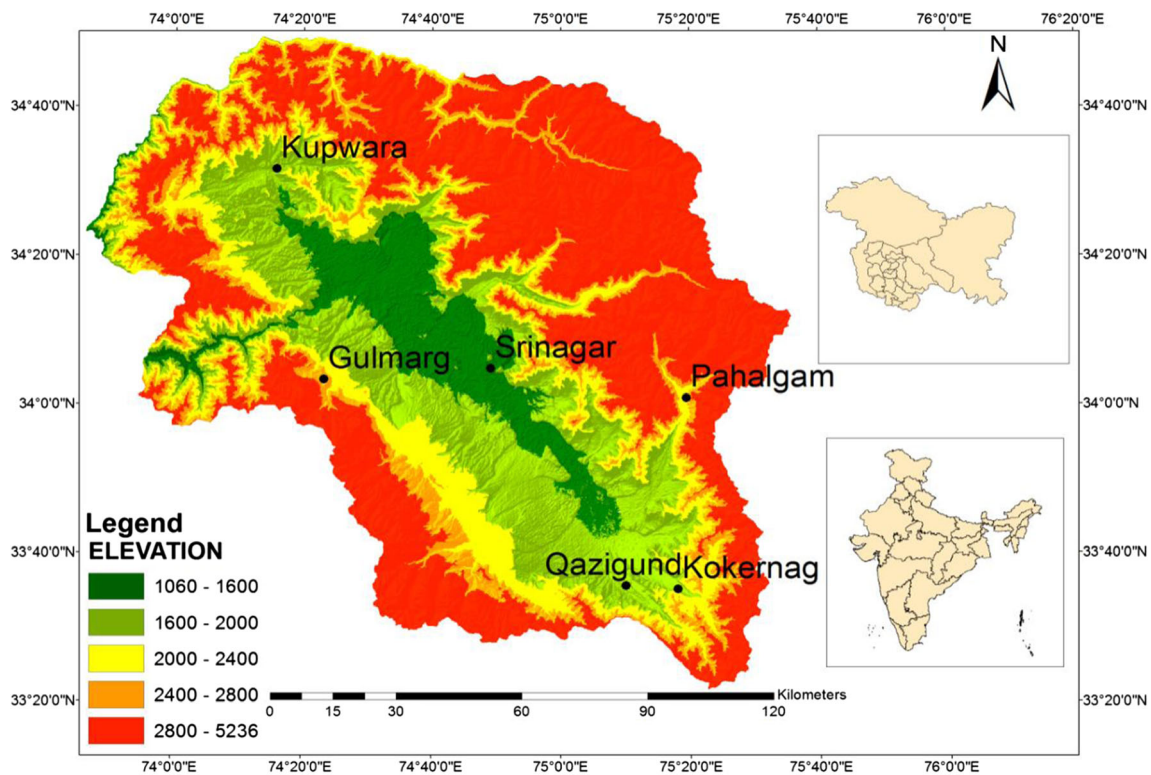


Fig. 1 Digital elevation map of the study area with location of Indian Meteorological Department stations

valley from west and northwest during winter, and their influx is less obstructed by greater Himalayas. The micro-level variations here render the climate extremely rigorous over tops of surrounding mountains whereas relatively mild and temperate over valley region. The climate of Kashmir is governed by altitude, insolation, and amount of rainfall. With an average altitude of 1545 m, the valley experiences temperatures varying from -9°C in winter months to 38°C in summer months. Winters are generally severe while the month of July becomes oppressively warm. Spring, though wet, is pleasant with fresh green tints. The summer is hot with the roses and flowers in full bloom, while the autumn is dry and invigorating. The average mean maximum and minimum temperatures of Kashmir valley are 19.27 and 7.29°C , respectively, while as the average rainfall is 84 cm (Hussain 1987).

3 Data and methodology

3.1 Data

One of the best ways of understanding the climate of an area is to analyze observational climatic data of that particular area for a specific time period. Generally, a trend analysis of climatic data for a minimum period of 35 years is adequate enough to observe changes or variability in various climatic variables at different timescales, which is important in

establishing long-term impacts of climate change. Recent long-term monthly meteorological data for the period 1980–2014 was obtained from India Meteorological Department (IMD) Srinagar and Indian Institute of Tropical Meteorology (IITM) Pune for six ground-based meteorological stations (Table 1) spanning over the study region. These datasets were used to compute inter-annual and intra-annual climatic fluctuations over the selected area of study. The four seasons considered are spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (December, January and February). The data was checked and cross-examined using the double mass curve analysis (Tabari et al. 2011) in order to maintain the homogeneity and consistency, because changes in observation procedures or in surrounding conditions (Peterson et al. 1998) might occur due to instrumentation error. Furthermore, an autocorrelation analysis was applied for both temperature and precipitation time series of each station individually (Costa and Soares 2009; Peterson et al. 1998) before using the same. Thus, data pertaining to temperature and precipitation was obtained for the following stations in consonance with the topographical conditions within which they lie.

3.2 Methodology

The major motive behind the application of a trend analysis is to estimate the general behavior of the variable

Table 1 List of meteorological stations used in the study

S. no.	Station	Physiography	Latitude (north)	Longitude (east)	Elevation (mts)	Time span
1.	Srinagar	Flood plain	34° 05'	74° 50'	1588	1980–2014
2.	Qazigund	Foot hills	33° 35'	75° 05'	1690	1980–2014
3.	Pahalgam	Mountain	34° 02'	75° 20'	2310	1980–2014
4.	Gulmarg	Mountain	34° 03'	74° 24'	2705	1980–2014
5.	Kupwara	Karewa's	34° 25'	74° 18'	1609	1980–2014
6.	Kokemag	Karewa's	33° 40'	75° 17'	1910	1980–2014

under consideration as a function of time to confirm the presence of certain suspected trends and then assess those detected trends. Climatologists use several methods for estimating the trends and their significance. In this study, for detecting the monthly, annual, and seasonal trends, climatic data was thoroughly analyzed and subjected to various statistical procedures. For inter-annual analysis, the monthly datasets were used to derive the mean annual values calculated using simple average or mean. Mann-Kendall statistical test (Mann 1945; Kendall 1975), which is a non-parametric test, has been used for detecting trends within the datasets. This test has been extensively used in various climate studies for testing monotonic trends and abrupt time series changes, being that non-parametric in nature can evade the problem roused by data skew (Kadiolgu 1997; Smadi and Zghoul 2006). The null hypothesis in the test is that there is no significant trend within the data series. When the null hypothesis is rejected, it is an indication of trend being significant within the data series which may be either positive or negative, as described by its score. The Mann-Kendall test is not dependent on the distribution of the dataset and does not vary with the outliers (Chevuturi et al. 2016). In this method, H₀ represents distribution of random variables and H₁ represents possibility of bi-directional changes. The test statistic S is given by

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^n \text{sgn}(x_k - x_i)$$

in which x_k and x_i are the sequential data values, n is the number of values, and

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

In particular, the test statistic is nearly normally distributed, if the sample size is larger than 10. The simple linear regression test has been used for estimating the rate of trend (slope) in the data where an independent variable is plotted against the dependent variable (Meals et al. 2011). Temperature and precipitation are used as dependent variables against time which

acts as an independent variable to estimate the rate of the trend. The rate of trend (slope) is given by

$$Y = bX + A$$

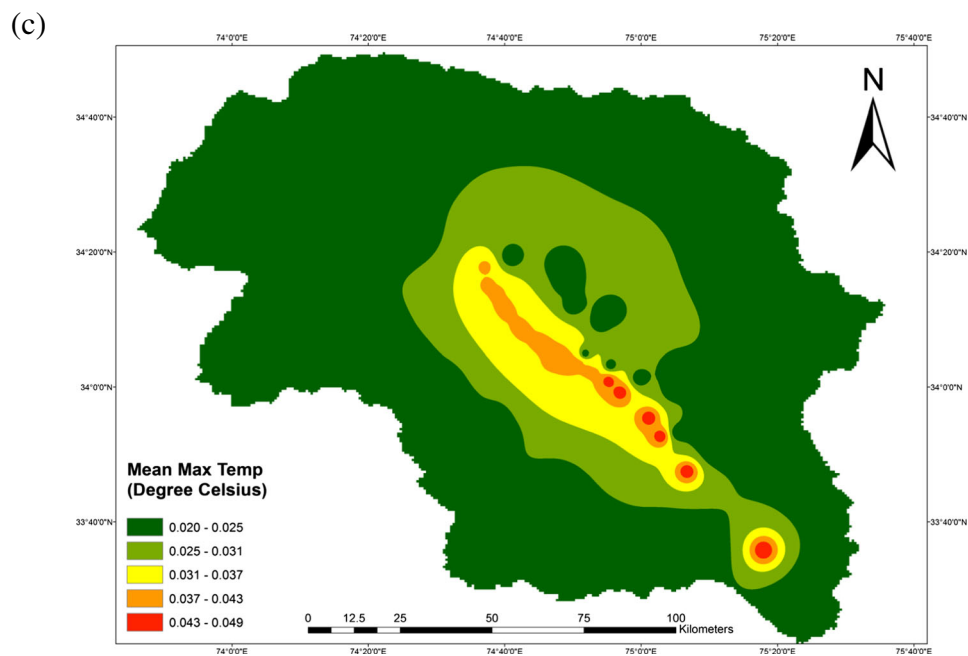
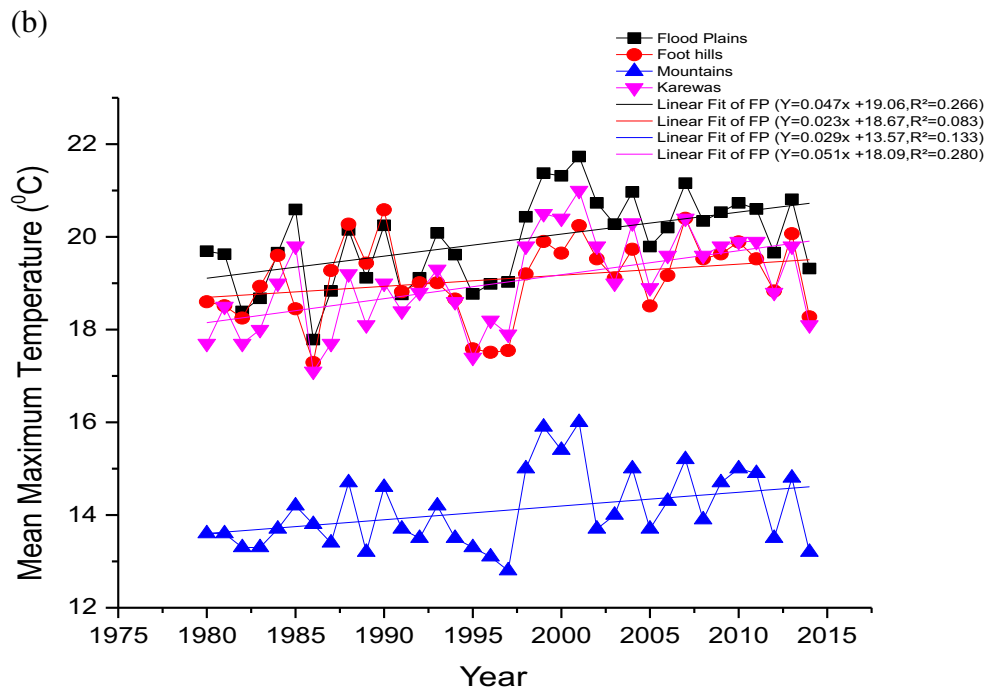
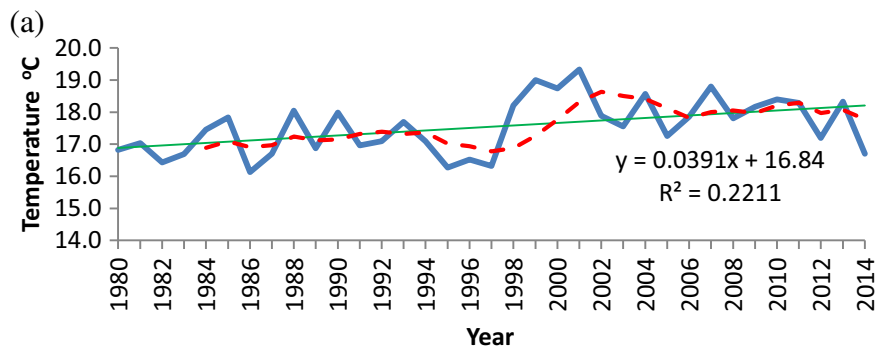
where Y is the dependent variable, b is the slope of the line, and A is the Y intercept.

Furthermore, the non-parametric distribution free Cusum test was applied for determining the occurrence of step change points of temperature and precipitation. This method tests whether the means in two parts of a record are different (for an unknown time of change). In addition, a surface interpolation technique (ordinary kriging) has been used to prepare the spatial interpolation data maps of mean maximum temperature, mean minimum temperature, and precipitation regime over the Kashmir valley from six-point meteorological stations using ArcGIS framework. Kriging is an advanced geostatistical procedure for interpolation which generates values at grid points based on the available station data observed at known locations. The data from six meteorological stations and using the topographic map of the study area supplemented by digital elevation model, with more than 100 point locations over Kashmir valley representing different topographies like flood plains, foothills, mountains and Karewa's, were generated which in turn given the value (mean maximum, mean minimum, and precipitation) representing the respective topography were used to generate the spatial interpolation maps.

4 Results and discussions

In the following paragraphs, first we have discussed changes in mean maximum temperature and mean minimum

Fig. 2 **a** Mean annual maximum temperature (Kashmir valley) in degree Celsius (blue represents the mean annual maximum temperature, green line represents linear fitting, and red represents 5 years moving average). **b** Mean max temperature at different topographic zones (black—flood plains, red—foot hills, blue—mountains, and pink—Karewa's) in degree Celsius. **c** Spatial interpolation map showing annual rate of change of mean maximum temperature over different topographic zones in Kashmir valley from 1980 to 2014



temperature followed by precipitation. These changes have been analyzed both at the spatial and elevation levels as well.

4.1 Temperature

4.1.1 Maximum temperature

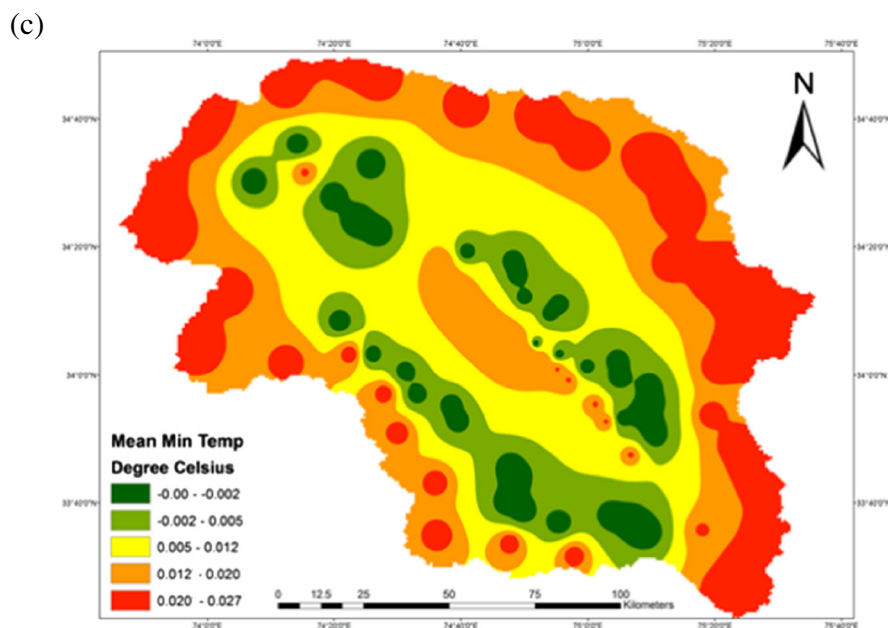
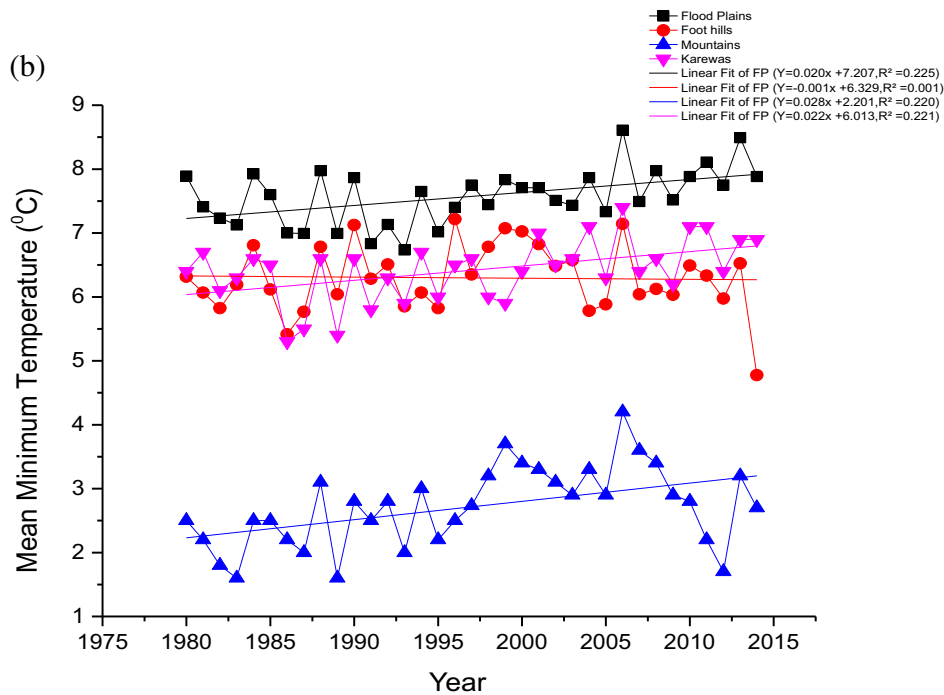
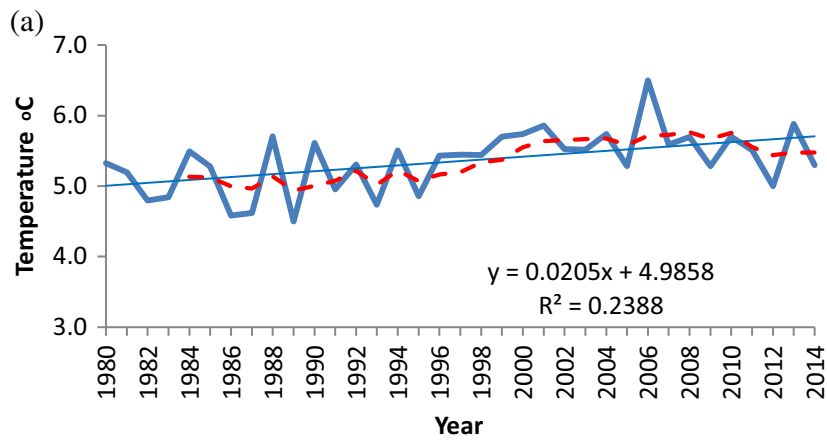
The analysis of the monthly and annual trends in temperature was conducted for the period 1980–2014. The non-parametric Mann-Kendall statistical test shows a significantly increasing trend in the annual mean maximum temperature in the whole Kashmir valley during the 35-year period ($p < 0.01$) at a rate of $0.03\text{ }^{\circ}\text{C}/\text{year}$ (Fig. 2a). It also indicates significant step jump at 1997 ($p < 0.01$) which shows that there is a significant variation in data with later years having higher data than initial years of the study period. Though there seem to be phases of increased and decreased annual temperatures, however this step jump, in particular in mean maximum temperature, is intriguing and needs further elaboration. The perusal of Table 2 reveals that except summer, all other seasons are showing statistically significant increasing trend. The increasing trend in winter can prove to be detrimental for the glacio-fluvial environment of the valley. To have an in-depth insight into the changes in micro-climate, in situ data pertaining to temperature collected from the six stations falling under different topographical conditions has been analyzed. It has been

Fig. 3 **a** Mean annual minimum temperature (Kashmir valley) in degree Celsius (blue line represents linear fitting, and red represents 5 years moving average). **b** Mean minimum temperatures at different topographic zones in Kashmir valley (black—flood plains, red—foot hills, blue—mountains, and pink—Karewa's) in degree Celsius. **c** Spatial interpolation map showing annual rate of change of mean minimum temperature in different topographic zones over Kashmir valley from 1980 to 2014

observed that the mean maximum temperature of different topographic zones, i.e., Karewa's (represented by Kupwara and Kokernag meteorological stations) shows an annual rate of increase by $0.05\text{ }^{\circ}\text{C}/\text{year}$ followed by flood plains (represented by Srinagar) at $0.04\text{ }^{\circ}\text{C}/\text{year}$, foot hills (represented by Qazigund) at $0.02\text{ }^{\circ}\text{C}/\text{year}$, and mountains (represented by Gulmarg and Pahalgam) at $0.02\text{ }^{\circ}\text{C}/\text{year}$, respectively (Fig. 2b). A spatial interpolation map using Kriging technique was generated for mean maximum temperature using ArcGIS 10.2 platform to show the temperature variations along different elevation zones and is shown in Fig. 2c. The lower rate of increase in elevated mountainous regions may be attributed to the huge expanse of snow and glacier, vegetation diversity, and high ecosystem stability in the mountain areas, exerting a buffer action on global climate change (Li et al. 2012). Statistically, significant step jump in different topographical zones has been observed in 1997 ($p < 0.01$) which clearly shows that mean maximum temperatures have shown an increase during the recent years.

Table 2 Seasonal Mann-Kendall trend statistics of temperature and precipitation at different stations in Kashmir valley with significant observations in italics from 1980 to 2014. The values in the parenthesis represent the level of significance

Meteorological Station	Meteorological parameters		Winter	Spring	Summer	Autumn
Kashmir valley	T ($^{\circ}\text{C}$)	Max	<i>0.05 (0.05)</i>	<i>0.07 (0.05)</i>	0.01	<i>0.02 (0.1)</i>
		Min	0.01	<i>0.02 (0.05)</i>	0.01	<i>0.02 (0.01)</i>
	P (mm)	-0.9	<i>-5.5 (0.05)</i>	-1.0	0.5	
Srinagar	T ($^{\circ}\text{C}$)	Max	<i>0.07 (0.01)</i>	<i>0.07 (0.05)</i>	0.01	<i>0.03 (0.05)</i>
		Min	0.00	<i>0.02 (0.1)</i>	0.01	<i>0.03 (0.05)</i>
	P (mm)	-0.15	<i>-3.3 (0.05)</i>	-0.6	0.50	
Qazigund	T ($^{\circ}\text{C}$)	Max	<i>0.05 (0.05)</i>	<i>0.06 (0.01)</i>	0.01	-0.01
		Min	0.00	0.00	0.00	-0.00
	P (mm)	-1.17	<i>-6.1 (0.05)</i>	-0.5	1.50	
Pahalgam	T ($^{\circ}\text{C}$)	Max	<i>0.05 (0.01)</i>	<i>0.08 (0.01)</i>	0.01	0.01
		Min	<i>0.06 (0.01)</i>	<i>0.03 (0.05)</i>	<i>0.04 (0.05)</i>	<i>0.02 (0.05)</i>
	P (mm)	0.78	<i>-4.8 (0.05)</i>	0.44	1.14	
Gulmarg	T ($^{\circ}\text{C}$)	Max	0.00	0.05	0.01	0.00
		Min	0.01	0.03	0.00	0.02
	P (mm)	-4.0	<i>-10.4 (0.01)</i>	<i>-2.8 (0.05)</i>	-0.95	
Kupwara	T ($^{\circ}\text{C}$)	Max	<i>0.05 (0.05)</i>	<i>0.08 (0.05)</i>	<i>0.03 (0.05)</i>	<i>0.06 (0.01)</i>
		Min	-0.00	<i>0.03 (0.01)</i>	<i>0.02 (0.05)</i>	<i>0.04 (0.01)</i>
	P (mm)	-0.05	<i>-5.5 (0.05)</i>	-1.8	-0.2	
Kokernag	T ($^{\circ}\text{C}$)	Max	0.06	<i>0.07 (0.05)</i>	0.01	<i>0.05 (0.05)</i>
		Min	0.01	<i>0.02 (0.1)</i>	0.00	0.02
	P (mm)	-0.78	<i>-3.1 (0.05)</i>	-1.2	1.11	



4.1.2 Minimum temperature

Corresponding trends in annual mean minimum temperature reveal that the same have been increasing at a rate of about $0.02\text{ }^{\circ}\text{C}/\text{year}$, with the Mann-Kendall test showing a statistically increasing trend ($p < 0.01$) (Fig. 3a); the year of change has been 1998, which shows a significant step jump ($p < 0.01$) with the data for the later years being higher than the initial years of the study period. Further, with mean minimum temperature only, in spring and autumn seasons are showing statistically significant increasing trends. These results show that at the regional level, climate has slowly but surely shown a consistently increasing trend particularly in case of temperatures. The rate of change is consistent with rising average global temperatures ($0.13\text{ }^{\circ}\text{C}/\text{decade}$) and similarly rising temperatures in Northern Hemisphere ($0.07\text{ }^{\circ}\text{C}/\text{decade}$, 1901–2005) and ($0.23\text{ }^{\circ}\text{C}/\text{decade}$, 1979–2005) (Brohan et al. 2006; IPCC 2007; Wang et al. 2008; Yao and Chen 2015). The increase in the mean minimum temperatures at different elevations among various topographic zones has witnessed a visible change in the last 15 years or so (Fig. 3b). These changes have been quite prominent during the years 1997 and 2000 which have shown a significant step jump. Mean minimum temperature at different topographic zones shows relatively homogenous increase of $0.02\text{ }^{\circ}\text{C}/\text{year}$ with highest rate of increase over the mountainous regions ($0.02\text{ }^{\circ}\text{C}/\text{year}$) with flood plains and Karewa's showing the same rate of increase while decreasing rate has been observed over foothills ($-0.01\text{ }^{\circ}\text{C}/\text{year}$). The rate of change along different elevation zones is shown in Fig. 3c, applying the same technique of spatial interpolation. In this case, higher elevation zones are showing higher increase in minimum temperatures than the lower elevation which is in contrast with earlier discussed maximum temperature changes. The Fig. 3c also reveals that mean minimum temperatures have been showing rather a discontinuous trend in different topographic zones. It also reveals that a narrow patch of land along lower elevations is showing a relatively higher rate of increase in mean minimum temperature mainly due to the anthropogenic impact as most of the population lives in this area with their economic activities concentrated along the river courses of lower elevations.

4.2 Precipitation

The annual rainfall data was analyzed using certain statistical procedures. The results, when studied, showed a consistent decrease in the annual precipitation at an alarming rate of about $-7.9\text{ mm}/\text{year}$ which was statistically significant ($p < 0.1$). The step change occurred in 1996 with no significant trend ($p = 0.10$) (Fig. 4a). The rainfall data, when analyzed, seasonally shows that it is decreasing at the rates of -9.12 , -5.58 , and $-1.09\text{ mm}/\text{year}$ for the winter, spring, and summer seasons, respectively. Only the autumn rainfall

follows an almost consistent uniform increasing trend at the rate of $0.5\text{ mm}/\text{year}$ (Table 2). The decrease in the spring precipitation is statistically significant ($p = 0.05$). Discernible changes have been recorded in precipitation in the different topographic zones over the recent decades (Fig. 4b). While the mountainous parts of the valley have shown a considerable rate of decrease in precipitation ($10.3\text{ mm}/\text{year}$) with decreasing trend, the flood plains have shown a relatively less rate of decrease ($3.6\text{ mm}/\text{year}$) with foothills and Karewa's having moderate rate of decrease (6.3 and $5.8\text{ mm}/\text{year}$), respectively (Fig. 4b, c). The results of the non-parametric statistical test reveal that the precipitation in the entire Kashmir valley and mountain areas exhibited decreasing trends at 0.01 significance level. Mann-Kendall test also shows no statistically significant trend for foothills ($p = 0.10$). The step change in the precipitation data over different topographical zones shows that significant step change ($p < 0.01$) took place over the mountainous region during 1998. This precipitation in mountainous zones of Kashmir valley is mainly in the form of snowfall which has shown decreasing trend after 1998. Step change has occurred in the year 1994 in the Karewa zone but with no significant trend at a significance level of 0.1, with foothill and plain zones also following the same; however, the step changes occurred in the year 1997.

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4.3 Interrelationship between temperature and precipitation

The variability in climate between observed changes in precipitation and temperature of a specific region can be interrelated with one another (IPCC 2007). During warm seasons, higher temperatures are accompanied by lower amounts of precipitation over continental areas and vice versa (IPCC 2007). Further, the Pearson correlation coefficient (PCC) is a statistical measure of the strength of a linear relationship between any two paired datasets represented by r . In this case, thus PCC was employed to measure the linear dependence between average precipitation and average temperature besides its relationship with mean maximum and mean minimum temperatures also. PCC varies between $+1$ to -1 , where “ $+1$ ” represents perfect positive relationship and “ -1 ” represents perfect negative relationship while 0 represents no linear relationship. The relationship can be either positive or negative.

Figure 5 distinctly shows that there is a kind of hidden controlled relationship that exists between temperature and

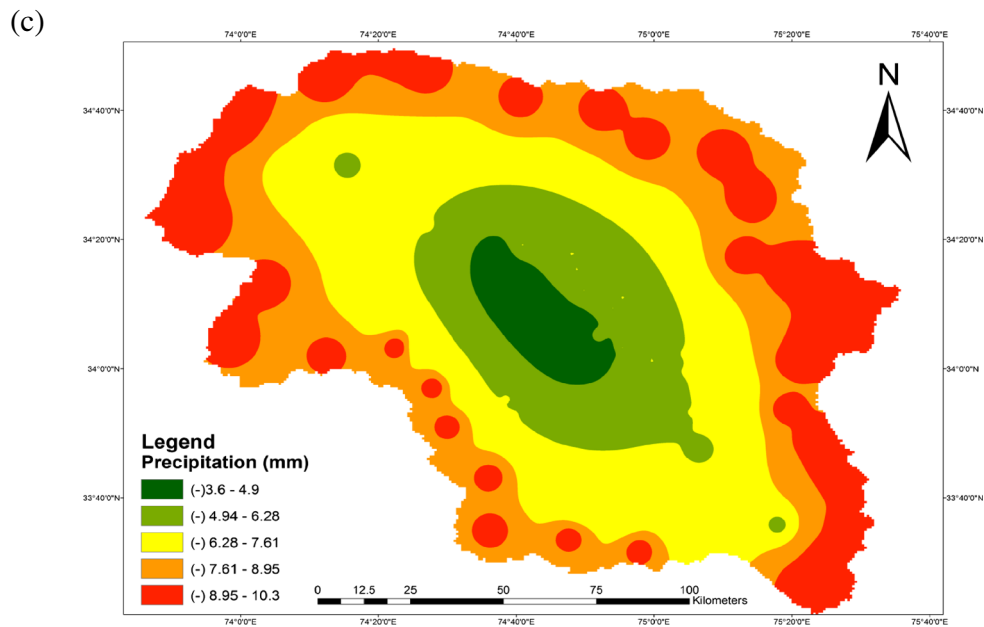
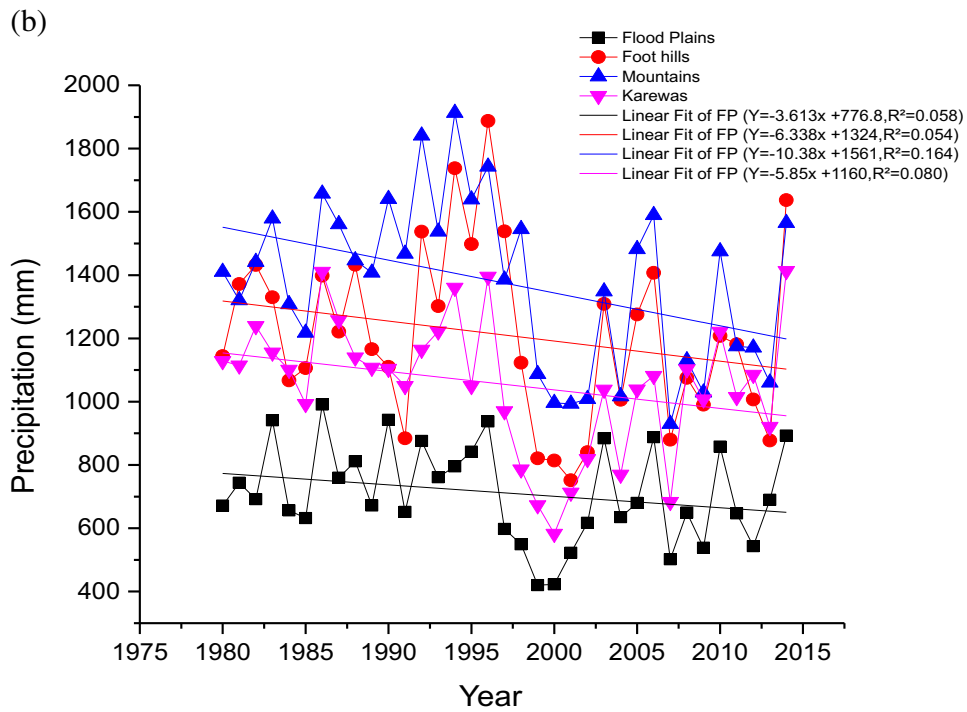
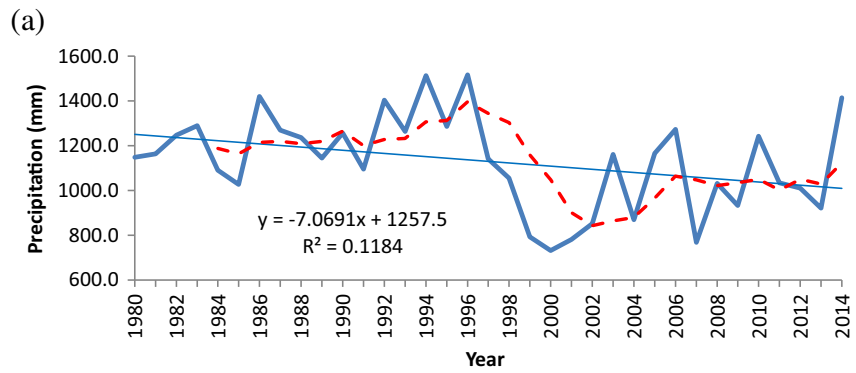
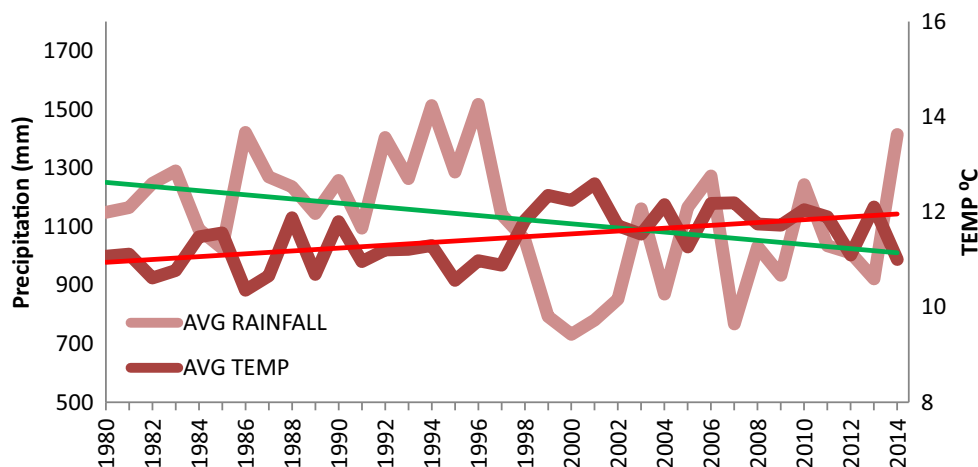


Fig. 5 Graphical relationship between annual rainfall and temperature in Kashmir valley from 1980 to 2014. (The thick lines represent the annual temperature and annual rainfall, while the thin lines represent the trend line, green for rainfall, and red for temperature.)



precipitation which has been investigated further. Table 3 reveals that correlation of annual data for the study period was negative, and a significant association is found between precipitation vis-a-vis maximum temperatures and minimum temperatures. The correlation of annual rainfall and average temperature gave significant PCC as $r = -0.66$ ($p = 0.01$), and when data was analyzed between average rainfall and mean temperature (both maximum and minimum) over the Kashmir valley, the PCC was found to be $r = -0.74$ ($p = 0.01$) and $r = -0.35$ ($p = 0.05$), respectively. The results of the correlation analysis confirm the identified trends of reduction in rainfall and an increase in temperature in the study area.

Further, it was investigated whether there exists any kind of interrelationship during step jump years 1996–1997. For this analysis, the whole time series data of both temperature and precipitation was divided into two time periods (1980–1997 and 1998–2014, one before step jump year and other after step jump year). It was found that average temperatures during first period are relatively uniform with little variability ($y = 0.007x - 3.519$) while this trend is not followed afterwards as it increased after step jump years ($y = 0.016x - 20.36$). Precipitation showed the unique relationship with temperature as it shows an increase before 1996–1997 ($y = 13.21x - 25,021$) when temperatures were almost homogenous. But negative trend ($y = -0.909x + 2872$) has been observed in precipitation after the step jump years, when temperatures showed relatively strong increase as compared to earlier years. These changes in meteorological variables could be partly due to the heterogeneous topography of the Himalayas of which Kashmir valley is an integral part, where local scale micro-

climate plays an important role accompanied by interplay of some global phenomenon.

5 Conclusions

This study recognizes that both the temperature and the precipitation of the Kashmir valley have generally exhibited a significant variability over all topographic zones for the study period (1980–2014). The recognition of these trends was confirmed by the non-parametric Mann-Kendall test for both temperature and precipitation. It is also critical to understand here that the changing trends in these climatic parameters are varying across different topographical regions across the study area, which is thus important for studying various topographical climatic conditions. This is estimated by the fact that the mean maximum temperature of different topographic zones, i.e., Karewa's, shows an annual rate of increase (0.05 °C/year) followed by flood plains (0.04 °C/year), foot hills (0.02 °C/year), and mountains (0.02 °C/year), respectively. However, mean minimum temperature at different topographic zones showed relatively homogenous increase of around 0.02 °C/year with the highest rate of increase in mountains (0.02 °C/year) with flood plains and Karewa's showing the same rate of increase while the lowest rate of increase is in foothill zones (-0.01 °C/year).

For precipitation, mountainous parts of valley have shown a drastic decrease in precipitation (10.3 mm/year) while flood plains have shown relatively less rate of decrease of 3.6 mm/year with foothills and Karewa's having moderate rate of decrease 6.3 and 5.8 mm/year, respectively.

Table 3 Pearson correlation coefficient (PCC) between precipitation and temperature

	Average temperature	Mean maximum temp	Mean min temperature
Average precipitation	-0.66^*	-0.74^*	-0.35^{**}

* $P < 0.01$; ** $P < 0.05$ (significant at these levels)

There are various uncertainties in the climatic variability analysis, especially in the mountainous regions, which might arise from the input data and regional characteristics (Yao and Chen 2015). The variability of climate depends upon observation data of different meteorological stations located in the Kashmir valley. Further, the uncertainty in climatic analysis may arise due to concentration of meteorological stations along the length and breadth of study area which can also distort the climatic studies. This variability of trends at various stations points to the need that more detailed studies are required on the climate of this region at micro-level owing to the significance of Kashmir Himalayas having huge glacial area which feed a huge chunk of population. The study aims to convey the message that climate is steadily but surely changing and timely measures can help in minimizing the vulnerability of fragile ecosystem of Kashmir Himalayas to the damages caused by climate change.

Acknowledgements The acknowledgements are due to Indian Meteorological Department (IMD), Srinagar for necessary meteorological data. Thanks are also to Mr. Hartmut Graßl, editor-in-chief of the journal and anonymous reviewers for their valuable suggestions and comments.

Funding information The authors would like to express their gratitude to University Grants Commission (UGC), Govt. of India for fellowship in the form of NET-JRF to the first author.

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