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Statistical Evidence of Climate Variability in The Upper Jhelum Catchment.

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Abstract:

Kashmir forms a typical highland tectonic valley knotting the Pir-Panjals from the south-west with the Main Himalayan range from the north eastern side. Alike other mountainous regions of the world Kashmir valley has been affected by the changing climate as well. The disastrous impacts of the changing climate will not only affect the local population of the valley but will also have serious implications in the downstream areas on socio-economic and hydrological fronts. This study attempts to analyse a thirty five year old observed instrumental time series dataset of three IMD stations (Pahalgam, Qazigund and Kokernag) all of which are located in the southern part of Kashmir valley and placed at different altitudes. The data (temperature and precipitation), classified into annual and seasonal (winter, spring, summer and autumn) is subjected to non-parametric Mann Kendall's trend test to detect trends and the Theil-Sen's slope estimator to find the magnitude thereof. For a parametric analysis, simple linear regression was also carried out on the time-series. Furthermore, the coefficient of variation of the dataset is also calculated to verify the dispersion in the data. The study is an attempt to find and compare differences in the climate variability on a local scale and also to establish the impact of altitude and local factors on the micro-climatic scenario of a particular place within a climate complex. The study reveals and establishes that there exists a warming trend in both the minimum and maximum temperature (annual and seasonal) in all the three stations, however the magnitude and significance of this change bears a signature of their altitudal variation.

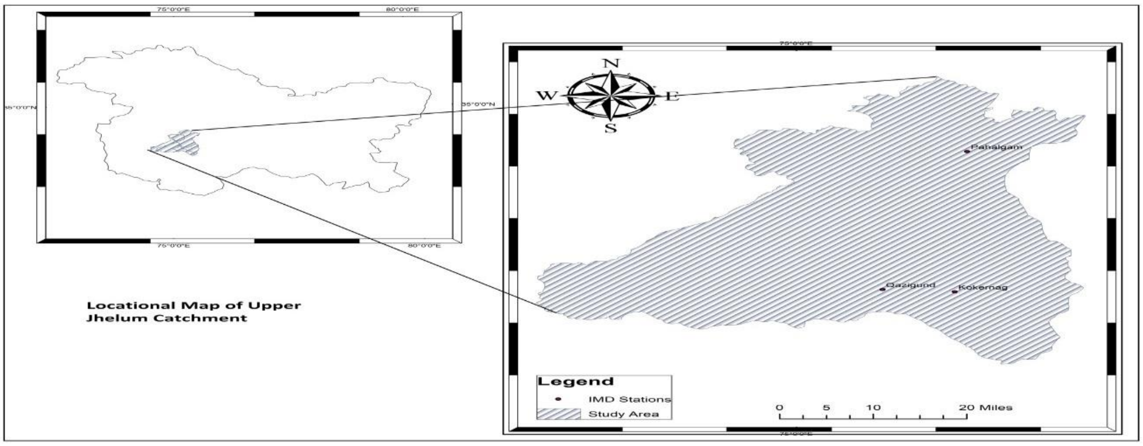
Key-words: *Climate variability, Highland, Downstream, Climate complex, Magnitude*

Introduction

The temperature of the earth has risen about 0.84ºC since 1880 (Stocker et al., 2013). Intergovernmental Panel on Climate Change (IPCC) 2014 report states that the climate warming is unequivocal and that since the 1950s many of the observed changes are unprecedented. The report further states that the atmosphere and oceans have warmed, the amounts of snow and ice have diminished, and sea levels risen. Specific to Northern hemisphere the report states with a high confidence that the period from 1983 to 2012 was very likely the warmest 30-year period of the last 800 years. There has been little detailed research on observed climate change in the mountains, and generalizations have been made from scattered (diverse) studies carried out at sites widely separated in space and time (IPCC 2007a; Nogues-Bravo et al. 2007). Addressing the bearings of climate change in the high-mountain cryosphere and respective downstream regions, as well as responses to these impacts, has increasingly been the perennial focus of research activities in current climate change and glacier response discourse (e.g. Huss et al. 2017; Milner et al. 2017; Vuille et al. 2018). Studies aim at providing evidential understanding and enhancing of processes and triggers related to these impacts, the degree of their adverse effects, and the perception of these problems from the perspective of those affected. In similar, the Intergovernmental Panel on Climate Change (IPCC) has laid special emphasis in its sixth assessment cycle (AR6) responding to awareness gaps on climate change impacts in the high-mountain cryosphere, further stirring the research action seen on this critical theme.

Outside the polar region Himalaya is having the largest snow and ice cover thus sometimes referred to as "The third pole" (Schild, 2008) and "The water tower of Asia" (Xu et al., 2009). The Himalaya is assumed to be undergoing rapid climate change, with serious environmental, social and economic consequences for more than two billion people. However, data on the extent of climate change or its impact on the region remains elusive as several cooling as well as warming trends have been observed within different mountain ranges owing to the complex physiographic disposition of Himalaya (Shekhar et al., 2010, Dimri et al. 2012, Gusian et al. 2014, Singh et al. 2015 & Negi, et al. 2018). The temperature of the north western Himalayas has risen by 1.6 °C warming (0.16° C /decade) in the last century (Bhutiyani et al., 2007). Specific to the western Indian Himalaya the temperature has risen by 0.9 °C over 102 years (1901-2003) with much of this observed trend increasing after the year 1972 (Dash et al., 2007). Over the western Himalayas winter (Dec-Feb) monthly temperature data from 1975-2006, also been found to have a warming trend, the greatest recorded observed increase being in Average Maximum Temperature Tmax (1.1-2.5 °C) (Dimri and Dash, 2011). Increasing trends in Tmax and seasonal average of daily maximum temperature for all but monsoon season over the lower Indus basin in the northwest Indian Himalaya has also been reported (Singh et al., (2008). Similarly increasing trends in winter temperature during 1961-2000 in the upper Indus basin at the rates of 0.07-0.51 °C/decade in annual mean temperature and 0.1-0.55 °C/decade in Tmax have also been documented (Fowler and Archer, 2005). The warming has been found more profound in case of minimum temperature than the maximum temperature (Bhutiyani et al., 2007; Shekhar et al., 2010; Dimri and Dash 2012; Singh et al., 2015; Negi et al., 2018).

Study Area:



The study area lies at the southern terminus of the longitudinal valley of Kashmir nestled in the great north-western complex of the Himalayas stretching between 32.17ºN latitude to 37.6ºN longitude. It constitutes an important relief feature of tremendous geographic significance. The climate of Kashmir extends to the Upper Jhelum catchment as well. The climate of Kashmir falls under Sub-Mediterranean type with the four seasons based on mean temperature and Precipitation, however Koul and Qadri (1979) maintain that the climate of Kashmir is highly variable and did not conform to any definite type. However, the valley of Kashmir has been described to have a continental climate characterized with marked seasonality. In fact, the genesis of Kashmir weather is intrinsically linked with the mechanism of weather in Indian subcontinent in general. Nevertheless, the valley, being surrounded by Himalayan ranges, has modified the subtropical climate. Kashmir valley has experienced an increasing trend in maximum, minimum and mean temperatures as reported in a number of studies (Bhat, et al. 2007) witnessing fairly long period of winter and spring . From the global research insights, it is evident that trends on hemispheric and continental level have got positive correlation with those prevailing in the valley of Kashmir (Bhat et al. 2007).

Data and Methodology

Historical instrumental data of three meteorological stations viz: Pahalgam, Qazigund and Kokernag was used. Data pertaining to classical meteorological variables of mean monthly temperature and precipitation regimes for 37 years (1980-2017) has been obtained for all monitoring stations across the Kashmir valley to analyse the trends and the variability patterns thereof. The data was categorised into seasonal and annual data. The seasons taken into consideration are Winter (December, January and February), Spring (March, April and May), Summer (June, July and August) and Autumn (September, October and November). In order to analyse the secular trend and its magnitude, statistical nonparametric tests (Mann-Kendall & Sen's Slope Estimator) have been used.

Mann-Kendall (MK) Test

Behaviour of annual, seasonal and monthly state time series data of temperature and rainfall has been studied by subjecting them to standard statistical non-parametric Mann-Kendall test while as Sen's method which uses linear model has been used to estimate the slope of the trend (change per unit time) (Sen, 1968). The tests being non - parametric in nature obliterate the limitations imposed upon by the assumptions of a normal datasets. The Mann-Kendall test consists of comparing each value of the time-series with the others remaining, always in sequential order. The number of times that the remaining terms are greater than that under analysis is counted.

The Mann-Kendall trend statistics is calculated as:

$$s = \sum_{i=2}^{n} \sum_{j=2}^{i=1} sgn(Xi - Xj)$$

Where, S = Mann-Kendall Trend Statistics *n* = Number of Data Points

Xj, *Xk* = Generic sequential data values

The function sign (x_i-x_j) assumes the following values:

$$sgn(Xi - Xj) = \begin{Bmatrix} +1, if\ (Xi - Xj) > 0 \\ 0, if\ (Xi - Xj) = 0 \\ -1, if\ (Xi - Xj) < 0 \end{Bmatrix}$$

Under the hypothesis of independent and randomly distributed variables when n≥8, the statistic S is approximately normally distributed with zero mean and the variance Var(S) as follows

$$Var(S) = 1/18[n(n-1)(2n+5)]$$

Where *n* is the length of the time series.

The standardized test statistic Z is given by:

$$z = \begin{Bmatrix} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} & if\ S < 0 \end{Bmatrix}$$

The presence of a statistically significant trend is evaluated using the Z value. This statistic is used to test the null hypothesis such that no trend exists. A positive Z indicates an increasing trend in the time-series, while a negative Z indicates a decreasing trend.

A trend is said to be significant:

At 0.1, if the value of the standardized test statistic, z $\geq$ 1.645

At 0.05, if the value of the standardized test statistic, z $\geq$ 1.96

At 0.01, if the value of the standardized test statistic, z $\geq$ 2.576

Sen's Slope Estimator

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used. It can be in cases where the trend can be assumed to be linear.

$$b = median\left[\frac{(Xi - Xj}{(i-j)}\right] \qquad \text{for all } j<k$$

Where b is the slope between data points *Xi* and *Xj* measured at times *i* and *j* respectively.

Results and Discussion:

Mean Maximum Temperature:

Annual time series of the mean maximum temperature shows an increasing trend for all the three meteorological stations of the upper Jhelum Catchment. The trends for Kokernag (z=2.506) and Pahalgam (z=2.547) are statistically significant. The spring season shows the highest positive shift in the mean maximum temperatures. All the three IMD stations show statistically significant increasing trends.

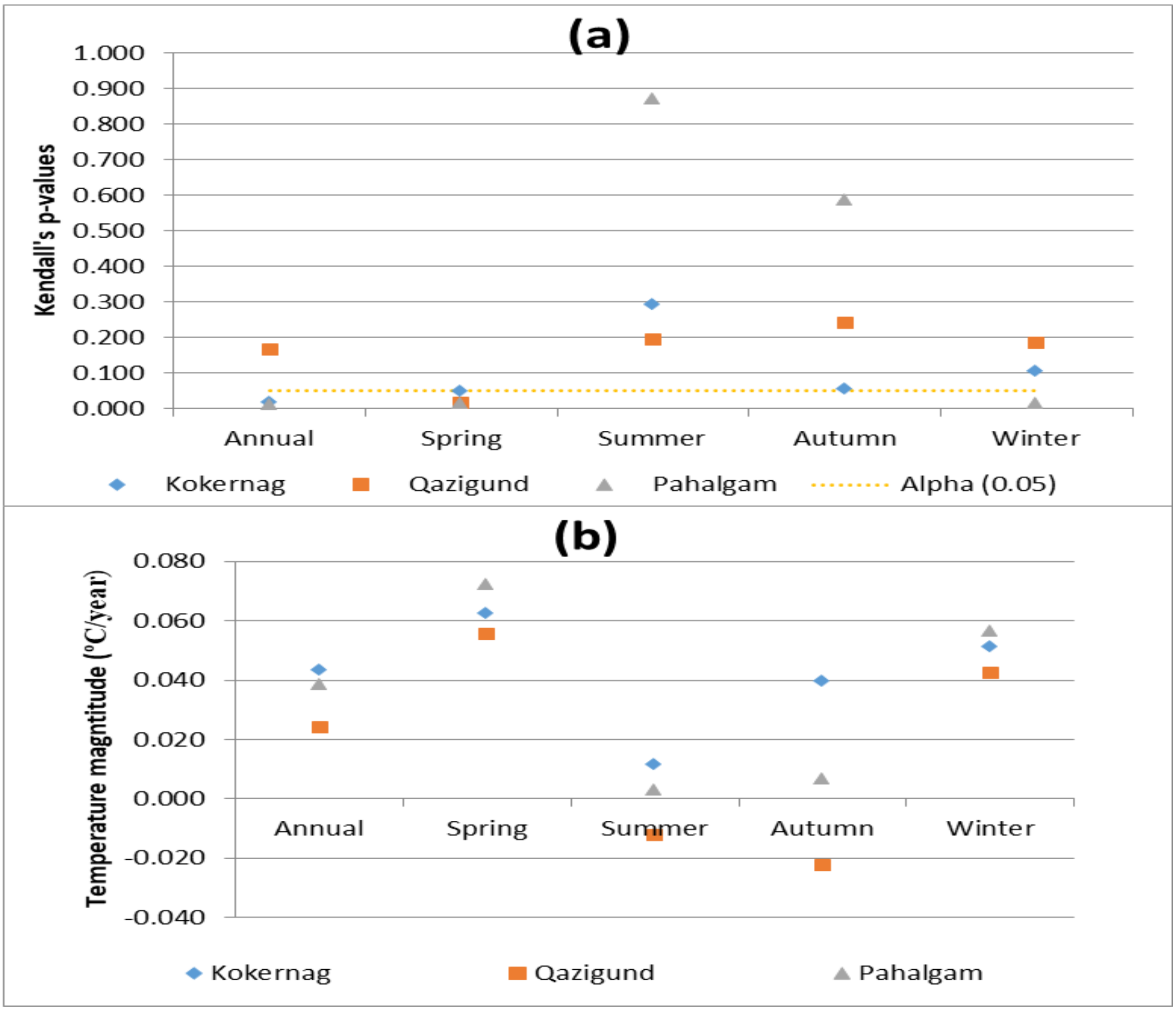


Fig.1 Annual and seasonal trends for mean maximum temperature during the period of 1980-2017 (a) Kendall test p values (b) magnitudes of the trends for the meteorological stations.

The spring temperatures have been increasing at a rate of 0.061°CYear^{-1} in Kokernag (z=1.907), 0.056°CYear^{-1} in Qazigund (z=2.356) and 0.072°CYear^{-1} in Pahalgam (z=2.465). The summer and autumn temperatures show increasing trends at Kokernag and Pahalgam. Only the autumn trend in Kokernag (z=1.921) is statistically significant where the temperature is estimated to have been rising by 0.038 CYear^{-1}. Though statistically insignificant, the summer and autumn trends corresponding to the Qazigund station are downward (Fig. 1.). The recorded winter mean maximum temperatures have also been spiking over the years. The trends for the winter season in all the IMD stations are upward.

The winter temperatures at Kokernag (z=2.397) increase about 0.054°CYear^{-1} and 0.068°CYear^{-1} in Pahalgam (Table 1).

Annual				
Station	**Kendall's z-statistics**	**Sen's slope**	**Trend**	**CV**
Qazigund	1.29*	0.022	Increasing (*)	-0.78
Kokernag	2.70**	0.044	Increasing (*)	-0.65
Pahalgam	1.71+	0.044	Increasing (*)	-0.55
Spring				
Qazigund	2.25	0.049	Increasing	0.09
Srinagar	2.09*	0.054	Increasing (*)	0.27
Pahalgam	1.70+	0.048	Increasing	0.12
Summer				
Qazigund	-1.04	-0.011	Increasing	0.04
Srinagar	0.33	0.005	Increasing	0.09
Pahalgam	-0.63	-0.007	Increasing	0.07
Autumn				
Qazigund	-1.28	-0.026	Increasing	0.19
Kokernag	1.69+	0.036	Increasing	0.16
Pahalgam	1.46	0.028	Increasing	0.14
Winter				
Qazigund	2.21*	0.064l	Increasing (*)	-0.78
Kokernag	2.71**	0.071	Increasing (*)	-0.65
Pahalgam	3.72**	0.079	Increasing (*)	-0.55

Table 1. Mann Kendall & Sen Slope Estimator of Mean Maximum Temperature for all meteorological (IMD) stations in Kashmir Valley. (Significance levels + = 0.1, * = 0.05 and ** = 0.01)

Mean Minimum Temperature: The annual and intra-annual mean minimum temperature depict increasing trends in the three IMD stations located in Upper Jhelum Catchment (Fig. 2). The annual time-series at Pahalgam (z=4.236) has a statistically significant increasing trend at the rate of 0.041°CYear^{-1}. The Spring mean minimum temperature at Kokernag (z=1.73) and Pahalgam (z=2.588) are statistically significant increasing trends. The spring minimum temperatures are rising by 0.023°CYear^{-1} in Kokernag, while as the trend at Pahalgam has a magnitude of 0.03°CYear^{-1} (Table 2).

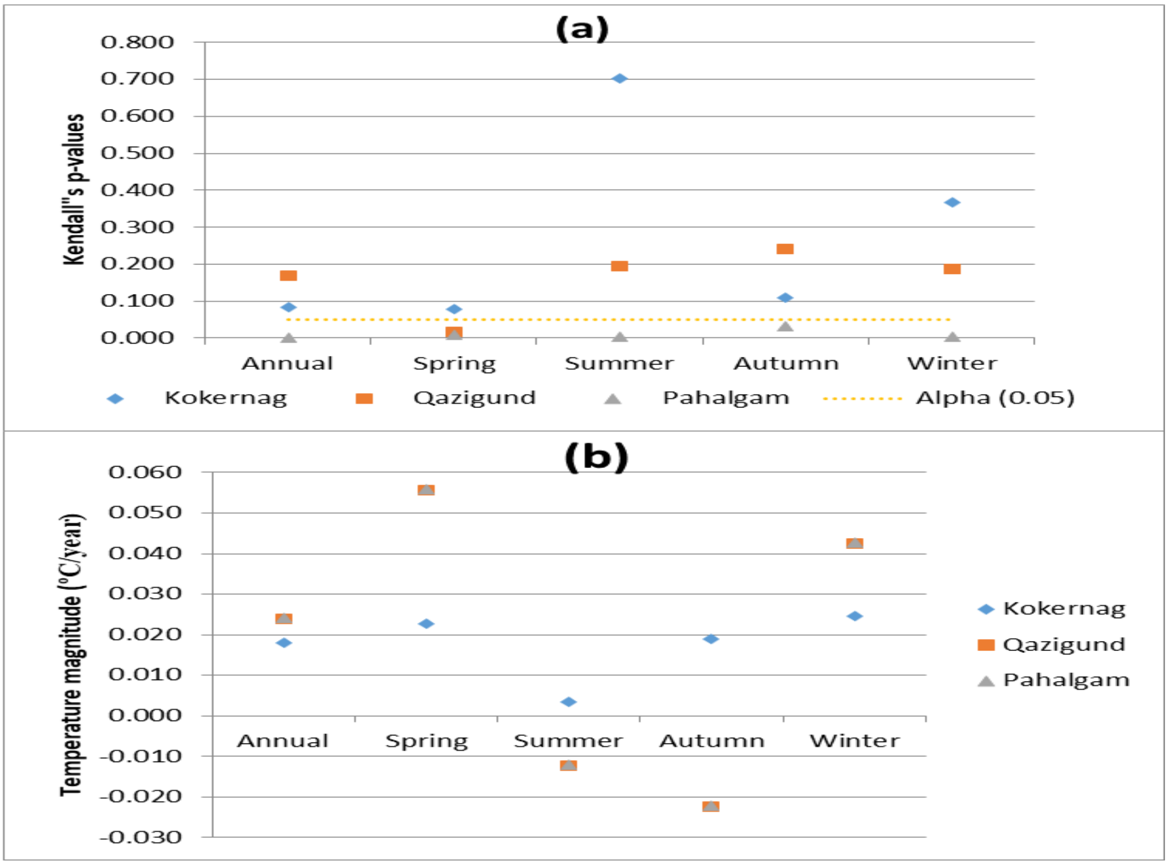


Fig. 2. Annual and seasonal trends for mean minimum temperature during the period of 1980-2017(a) Kendall test p values (b) magnitudes of the trends for the meteorological stations.

The summer and autumn average minimum temperatures also tend towards a positive scale. However, only the trends in the Pahalgam station are statistically significant. The summer mean minimum temperature in Pahalgam (z=2.847) is rising with an increment of 0.05°CYear^{-1} while as the autumn trend line (z=2.138) has a magnitude of 0.062°CYear^{-1}. The trends in other stations though increasing are not statistically significant.

Annual				
Station	**Kendall's z-statistic**	**Sen's slope**	**Trend**	**CV**
Qazigund	0.63	0.006	Increasing	0.04
Srinagar	3.07**	0.020	Increasing (*)	0.05
Pahalgam	3.12**	0.040	Increasing (*)	0.05
Spring				

Qazigund	1.23	0.009	Increasing	0.07
Srinagar	2.53*	0.024	Increasing (*)	0.09
Pahalgam	2.43*	0.030	Increasing (*)	0.09
Summer				
Qazigund	0.64	0.010	Increasing	0.03
Srinagar	1.80+	0.022	Increasing (*)	0.04
Pahalgam	2.02*	0.033	Increasing (*)	0.03
Autumn				
Qazigund	-0.68	-0.006	Increasing	0.09
Kokernag	1.24	0.015	Increasing	0.06
Pahalgam	2.34*	0.030	Increasing (*)	0.06
Winter				
Qazigund	0.73	0.0176	Increasing	0.18
Kokernag	1.22	0.030	Increasing	0.28
Pahalgam	1.30	0.023	Increasing	0.17

Table 2. Mann Kendall & Sen Slope Estimator of Mean Minimum Temperature for all meteorological (IMD) stations in Kashmir Valley. (Significance levels + = 0.1, * = 0.05 and ** = 0.01)

Precipitation:

The total annual precipitation in all the three IMD stations has decreasing but statistically insignificant trends. The seasonal trends are also decreasing and statistically insignificant (Fig. 3). However, the spring rainfall at Qazigund decreases by 5.3mm Year^{-1} (Table 3)

Furthermore, the three IMD stations exhibit climatic variability that seem to be somewhat determined by their position, more so by their behaviour. Situated in a climatologically similar region, the three stations are placed at different altitudes. The Qazigund station is positioned at an altitude of 1697 masl, Kokernag at 1874 masl and the Pahalgam station is at an altitude of 2177 masl. Although the exact mechanism is unclear but there seems to be some control of the altitude on the degree of climate variability of these three stations

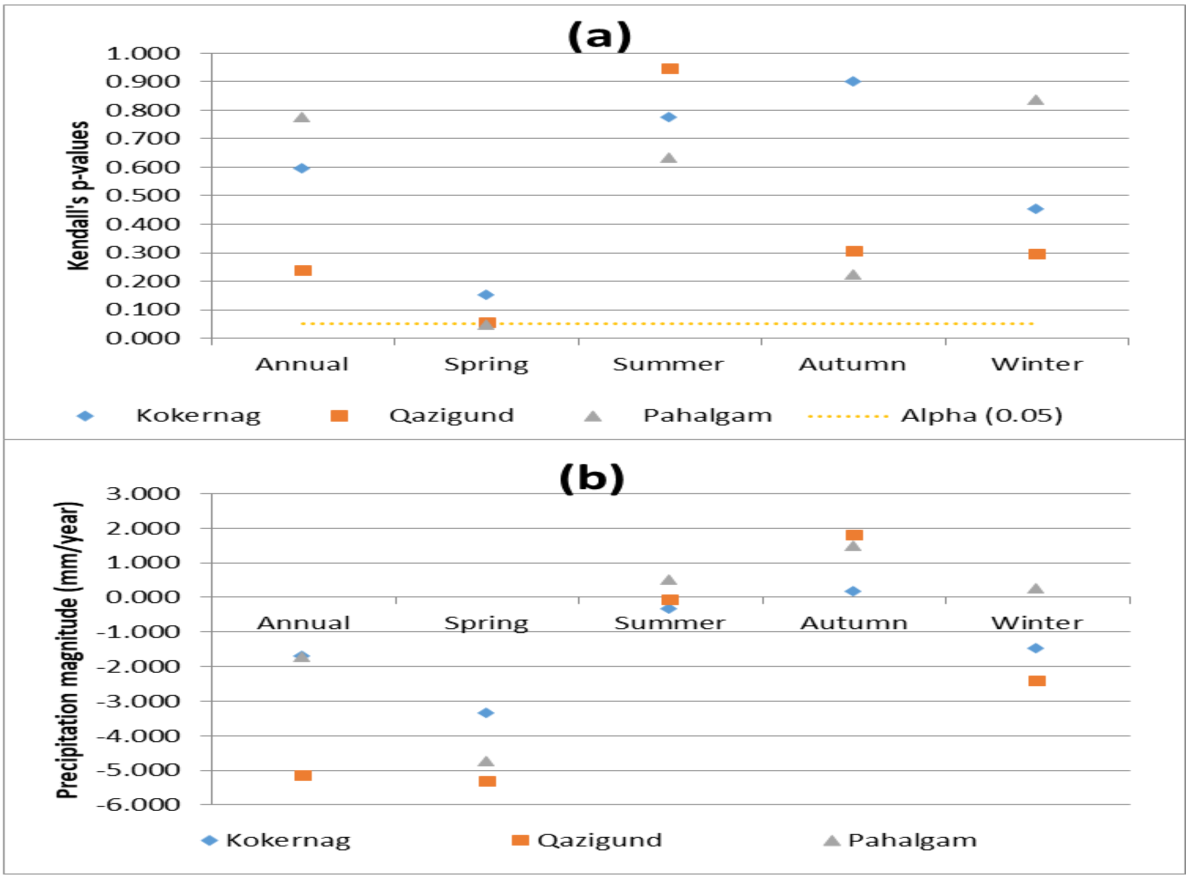


Fig. 3 Annual and seasonal trends for precipitation during the period of 1980-2017 (a) Kendall test p values (b) magnitudes of the trends for the meteorological stations.

The strength of the variation of the climatic elements seems to be positively related to the height of the meteorological station. This could be understood by the fact that trends established in the annual and intra annual temperature regimes are progressively and strongly established towards the higher altitude (i.e. Pahalgam).

Annual				
Station	**Kendall's z-statistic**	**Sen's slope**	**Trend**	**CV**
Qazigund	-1.53	-6.463	Decreasing	0.31
Kokernag	-0.040	-1.373	Decreasing	0.26
Pahalgam	-0.50	-2.583	Decreasing	0.21
Spring				
Qazigund	-1.99*	-4.372	Decreasing (*)	0.60
Kokernag	-0.78	-1.627	Decreasing	0.30
Pahalgam	-1.73	-3.700	Decreasing	0.37
Summer				

Qazigund	-0.28	-0.236	Decreasing	0.43
Kokernag	-0.35	-0.519	Decreasing	0.34
Pahalgam	-1.50	0.500	Decreasing	0.37
Autumn				
Qazigund	-0.45	-0.950	Decreasing	0.73
Kokernag	-0.78	-0.829	Decreasing	0.65
Pahalgam	0.23	0.346	Increasing	0.51
Winter				
Qazigund	-0.77	-1.781	Decreasing	0.40
Srinagar	0.59	0.562	Increasing	0.37
Pahalgam	-1.24	-3.537	Decreasing	0.31

Table 3. Mann Kendall and Sen Slope Estimator of precipitation for all meteorological (IMD) stations in Kashmir Valley. (Significance levels + = 0.1, * = 0.05 and ** = 0.01)

The results indicate that mean maximum annual and intra-annual temperature (except the summer season) at Pahalgam is affected by a warming trend. Similarly the annual and seasonal mean minimum temperatures also show strong statistical evidence of increase. The rainfall patterns do not conform to any significant behaviour. At Kokernag the maximum temperatures tend to be more significantly altered than the minimum temperatures. The annual and the seasonal mean maximum temperature trends (except the summer season) exhibit a rising behaviour. The annual and spring mean minimum temperatures are increasing significantly as well. Furthermore, the rainfall does not show any significant trends. Of all, data from the Qazigund station suggest that it has been least affected by the changing climate, though there are established significant trends in spring and winter mean maximum temperatures/indices. Mean minimum temperatures in the Qazigund station exhibit inconsistent behaviour. Qazigund station also exhibits a significant decreasing trend in the spring precipitation. Apart from depicting a positive altitudinal relationship with the climate variability, the analysis shows the most affected seasons in terms of minimum as well as maximum temperatures are the spring and winter seasons.

Climate exhibits a dominant control over the natural distribution of ecosystems. The impact of climate change in mountainous regions is expected to result in the loss of cooler climatic zones at mountain peaks and the upward shifting of tree line (Gottfried et al. 2012; Engler et al. 2011). The indicators of climate change are quite loud and clear in the Himalaya (Omar and Rashid 2015; Immerzeel et al. 2012). The Himalaya is experiencing a temperature increase that is higher than the global mean of about 0.7 °C in the last century (Bhutiyani et al. 2007). In particular, a strong increase in the mean temperature of about 1.7 °C was recorded in the Himalaya potentially inducing strong impact on the high altitude ecosystems especially changes in the vegetation structure and biodiversity (Aryal et al. 2014). Entire

Himalaya is covered by a vast range of mountains, where as the mountains and the uplands are often considered to comprise some world's extreme environments. However, they are of immense value to mankind as sources of food, minerals and water. Mountains regions are often perceived to be isolated and inhospitable: in reality they are fragile regions whose welfare is related to that of neighbouring lands (Bradley et al. 1991). Specific to Kashmir Himalaya many recent studies have suggested that the glaciers have receded due to climate change (Negi et al., 2009, Ramshoo and Rashid, 2014) while as streamflow and ground water recharge is also expected to be affected (Mir et al., 2021).

Conclusion

The main purpose of this study was to highlight, on the basis of statistical tests, the significant secular changes in the temperature and precipitation and its effect on the glacier environments, through the analysis of historical meteorological records from six stations of IMD in Kashmir valley The trend analysis carried out for the climate data of 37 years (1980-2017) exhibited a warming trend in both mean maximum and mean minimum temperatures. The precipitation trends have also been found to be decreasing. The seasonal analysis of the mean maximum temperature data reveals that the warming is most profound in annual, winter and spring seasons while as it is least in the in the summer and the autumn seasons. The minimum temperatures also rise significantly mostly in spring season. Furthermore, as revealed by the analysis of four glaciers, the rising temperatures and decreasing precipitation there exists a rapid recession process of glaciers in the region. The observed glacier recession and changing climatic patterns, if going with the same magnitude it would further reduce the stream-flows resulting in serious repercussions on water supplies for different uses in the region. Based on the findings from this study considerable attention should be given to integrate multiple lines of evidence to base conclusions, and the need for inclusive frameworks that consider both the key interfaces in Kashmir Himalayas as socio-ecological systems and biophysical factors

Conflict of Interest: The authors declare that there is no conflict of interest.

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