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Temperature Variability Analysis of Gulmarg, Pahalgam, Srinagar, Qazigund and Kokernag of Kashmir Valley, J&K, India

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ABSTRACT

Present study focuses on examination of temperature and snowfall variability over Gulmarg, Srinagar, Kokarnag, Qazigund and Pahalgam of Kashmir Valley in India during past 41 years (1970–2011). Trends in temperature over the study area is also explored. Minimum and maximum temperature shows increasing trends. Trends in minimum temperature are statistically significant. It is reported that average temperature over Gulmurg shows decreasing trend with slope -0.17 except for the month of February and January. Pahalgam shows a significant increasing trend with slope +2.29 in average temperaute. Srinagar and Quazigund show decreasing trends of average temperature with slopes -0.16 and -0.14 respectively while Kokarnag shows increasing temperature analysis with slope +1.73. These decreasing trends in average temperature are consistent with decadal increasing trends of about 1.2 ◦C and 0.8 ◦C in minimum temperature over Pahalgam and Gulmarg, respectively. Results reported in this study show a decrease of about 24.16% ± 9.86% per degree increase in minimum temperature over Gulmurg. Changing characteristics of temperature, humidity and snow fall in the context of anthropogenic warming present major challenges to the tourism, flora and fauna, and socioeconomic aspects of the Valley.

I. INTRODUCTION

Climate is a critical factor in the lives and livelihoods of the people and socioeconomic development as a whole. Climate has shown warming of 0.89 [0.69 to 1.08] °C over the period of 1901–2012 which is mainly attributed to anthropogenic activities (IPCC 2013). Further, it has projected that the global mean surface temperature and sea level may increase by 0.3°C to 1.7°C and 0.26 to 0.54 m for RCP2.6, 1.1°C to 2.6°C and 0.32 to 0.62m for Representative Concentration Pathways (RCP) 4.5, 1.4°C to 3.1°C and 0.33 to 0.62 m for RCP6.0 and 2.6°C to 4.8°C and 0.45 to 0.81 m for RCP 8.5 respectively by 2181-2100. The newer findings indicate that warming is more pronounced than expected. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India (Sathaye, Shukla & Ravindranath, 2006). Increasing temperature trends of the order of 0.60°C during last 112 years (IMD 2012) and increase in heavy rainfall events and decrease in low and medium rainfall events (Goswami et al. 2006) over India have been observed. Changes in rainfall and temperatures have also been reported by Dash et al. (2009), Arora et al. (2005), De et al. (2005), Guhathakurta and Rajeevan (2008), MoEF (2010), Jones and Briffa (1992), Kothawale et al. (2010), Tyagi and Goswami (2009) and others. Jammu and Kashmir has to face the challenge of sustaining its rapid economic growth in the era of rapidly changing global climate. The problem has emanated from accumulated greenhouse gas emissions in the atmosphere, anthropogenically generated through long-term and intensive local industrial growth and high consumption lifestyles in developed countries. Though, there is need to continuously engage National and the International community to collectively and cooperatively deal with this threat, J&K needs a strong regional strategy to firstly, adapt to climate change and secondly, to further enhance the ecological sustainability of its development path. This path is based on its unique resource endowments, the overriding priority of economic and social development and poverty eradication, and its adherence to its civilization legacy that places a high value on the environment and the maintenance of ecological balance. In its journey to developmental pathway, the valley has a wider spectrum of choices precisely because it is at an early stage of development. The regional/national vision is to create a prosperous, but not wasteful society, an economy that is self-sustaining in terms of its ability to unleash the creative energies of our people and is mindful of our responsibilities to both present and future generations.

Global warming /Climate change, rapidly increasing population, depletion of natural habitats and resources are important global challenges having direct impacts on livelihoods and raising concerns for food security, water supply, health and energy. To address these issues, there is need to mobilize the capabilities to facilitate the mounting societal demand for in changing climate, fully knowing that climate has both physical aspects which can shape the availability of natural resources, such as in particular renewable energies, as well as informational aspects that may be used, at least potentially, to support socio-economic decision-making. Governments and global research communities have strongly indicated their desire that the earth must be preserved for posterity. United Nations Framework Convention on Climate Change (UNFCCC) is playing a major a role in mitigating greenhouse gases emissions by bringing developed and developing countries at some common platform so that climate change can be kept at reasonable safe level. But reasonable agreement is still elusive in spite of 18 annual meetings of Conference of Parties. Government of India (J&K) has taken a number of policy and technological initiatives for safeguarding the earth and resources and addressing climate change implications. There is also need for the sensitization at the grassroot levels and major initiatives at the national level to develop a culture for greener environment, a well-coordinated environment protection protocol between the government and citizens and the passion for protection and conservation on the whole.

II. DATA AND METHODOLOGY

One of the best ways of understanding how climate may change in future is to examine how it has changed in the past based upon long-term observational records. Recent long-term meteorological data for 1951-2010 period were obtained from National Data Centre of India Meteorological Department (IMD) located at Pune where all quality controlled climatological data are archived. Climatological trend analysis for a 60-year period is of sufficient duration to reflect natural climatic variability on a multi-decadal timescale, which is important in considering long-term impacts of climate change. There are more than 500 surface meteorological stations and more than 2500 rainfall stations maintained by Central and state Governments in IMD’s network. To obtain sufficient number of stations for calculating state averages, exceptions are made for stations in the Jammu and Kashmir where stations having 35 years or more with 75% data availability during 1951-2010 are also considered. The number of meteorological stations data are used for analyzing surface temperature and

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rainfall trends are 282 and 1451 respectively. It is important to note that state averages of temperature and rainfall are calculated as simple arithmetic means of number of stations in the state. In addition to mean maximum temperature and mean minimum temperature, mean temperature (average of maximum and minimum temperature) and diurnal temperature range (difference of maximum and minimum temperature) for each month of the year were also computed. From the monthly values, annual (January December) and seasonal (Winter: December, January, February; Summer: March-May; Monsoon: June-September; Post monsoon: October-November) time series of mean maximum temperature, mean minimum temperature, mean temperature, mean diurnal temperature range and rainfall were prepared. State annual, seasonal and monthly time series of maximum temperature, minimum temperature, mean temperature, diurnal temperature range (DTR) and rainfall were computed by averaging the stations series in the respective state. Total 282 surface meteorological stations are used for preparing state temperature series. Similarly, 1451 rainfall stations spread across all over the country were used for preparing state average rainfall series. Behaviour of annual, seasonal and monthly state time series of temperature and rainfall is studied by subjecting them to non-parametric Mann-Kendall test and increasing or decreasing slope of trends in the time series is determined by using Sen's method (Sen, 1968). 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.

III. GENERAL STATISTICS OF METEOROLOGICAL PARAMETERS

The general statistical analysis may be performed to take a general overview of the data collected. The statistical parameters which are usually considered to look for gross data errors/outliers are:

- Minimum and maximum
- Mean
- Standard deviation
- Coefficient of variation

The trend analysis may be performed to determine the existence and magnitude of any statistically significant trend in meteorological parameters over the time period considered. The Mann-Kendall (MK) test has been used in this study for detection of trend. This is a non-parametric test, which makes no assumption for probability distribution of the variate and is less affected by missing values or outliers. However, MK test is a statistical yes/no type hypothesis testing procedure and, therefore, another index, Sen slope has been used to quantify the magnitude of such trend. Being non-parametric, Sen slope also enjoys the same advantages mentioned earlier for the MK test. Mann-Kendall test The Kendalls statistic S is given by :

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) 1$$

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Where,

$$sgn(xj - xi) = \begin{cases} 1 if x_i > x_j \\ 0 if x_i = x_j \\ -1 if x_i < x_j \end{cases} \qquad 2$$

for a time series x_k, k = 1, 2, ..., n.

When n ≥ 10, S becomes approximately normally distributed with mean = 0 and variance as:

$$\sigma^2 = \frac{(n)(n-1)(2n+5) - \sum_t (t)(t-1)(2t+5)}{18} \qquad 3$$

Where, t is the extent (number of x involved) of any given tie and Σt denotes the summation over all ties. Then Zc follows the standard normal distribution where:

$$Z_c = \begin{cases} \frac{s-1}{\sigma_s}, S > 0 \\ 0, S = 0 \\ \frac{s+1}{\sigma_s}, S < 0 \end{cases} \qquad 4$$

The null hypothesis that there is no trend is rejected when:

$$|Z_c| > Z_{1-\frac{\alpha}{2}}$$

Where, Z is the standard normal variate and α is the level of significance for the test.

To find out the effect of auto-correlation on MK test results, the modified MK test with effective sample size (ESS) approach, as suggested in, was attempted on detrended series. In this method, the variance, σ_s^2, is modified as:

$$\sigma_s^{2} = \sigma_s^{2} \frac{n}{n^*} \qquad 5$$

Where, n is the effective sample size calculated as [34]:

$$n^* = \frac{n}{1 + 2\frac{\rho_1^{n+1} - n.\rho_1^2 + (n-1)\rho_1}{n(\rho_1 - 1)(21)}} \qquad 6$$

where, ρ_1 is the lag-1 auto-correlation coefficient, as given in [35], computed trend as:

$$x_k^* = x_k - \beta.(k-1), \qquad k=1,2,\dots,n$$

where, ρ_1 can be determined by:

$$\rho_1 = \frac{\sum_{i=1}^{n-1}(x_i^* - x^*)(x_{+1i}^* - x^*)}{\sum_{i=1}^{n} {}_*^2} \qquad 7.$$

IV. RESULTS AND DISCUSSION

The results of trend analysis are presented in Figures 1 to 6 where statistically significant trends for Max./Min. Temperatures year wise are presented in different colours. The annual,

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seasonal and monthly trend values of mean maximum temperature, minimum temperature, mean temperature, diurnal temperature range and rainfall for 1951-2010 are given in Tables I where increasing (+) and decreasing (-) trends significant at 95% level of significance are shown in bold and marked with '*' sign.

The observed data sets of mean monthly maximum and minimum temperatures and total monthly precipitation for the period 1978 to 2010 were used for calibration purposes, that is, to establish the regression equations. The validation of these regression equations was carried out using the monthly predictand data sets for the years 2010 to 2014. The results of validation are shown in Figures (1--5) shows the comparison between observed and predicted values of monthly Max./Min. temperature and precipitation using Mankadal Test (MK) for Data of Gulmarg. Figures 1-5, show that there is an excellent comparison between observed monthly mean maximum and minimum temperatures and those predicted by using regression equations of Table 2, for the validation period of 2011 to 2014.The regression relationships developed above, were used to predict the monthly precipitation, monthly mean maximum and minimum temperatures at Gulmarg meteorological observatory over the entire 21st century. 100 year monthly projections of local weather parameters at Pahalgam are shown in Figures 3-5.

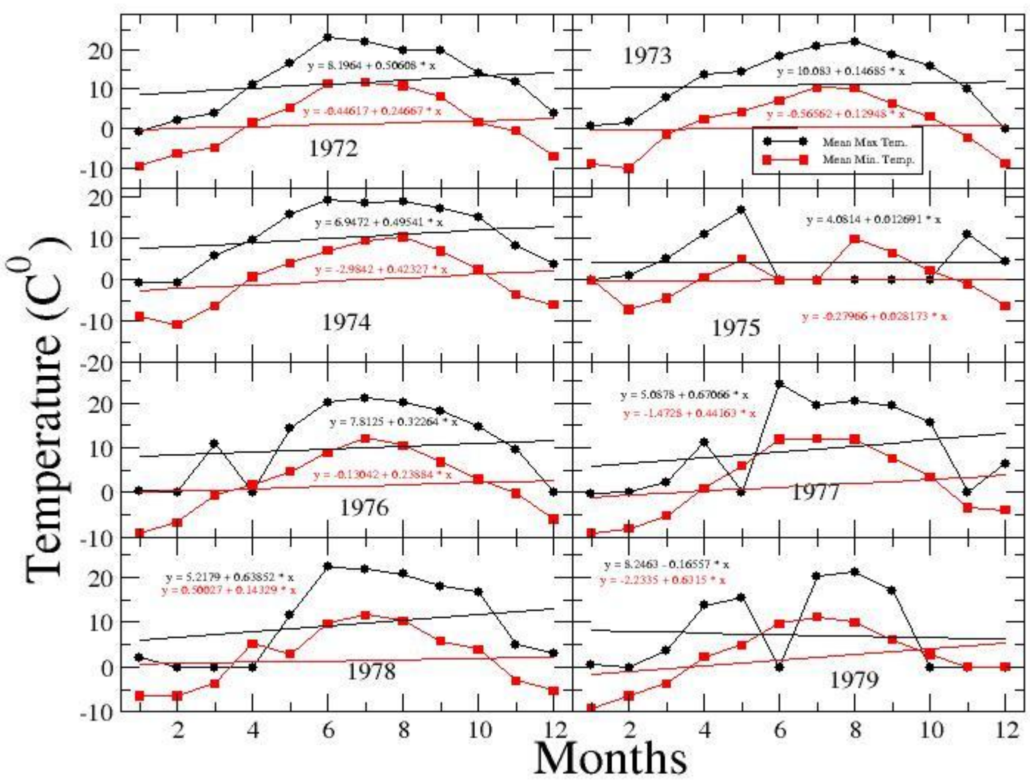

Fig. 1 Time series of temperature (minimum and maximum) for different months over Gulmarg from 1972-1979.

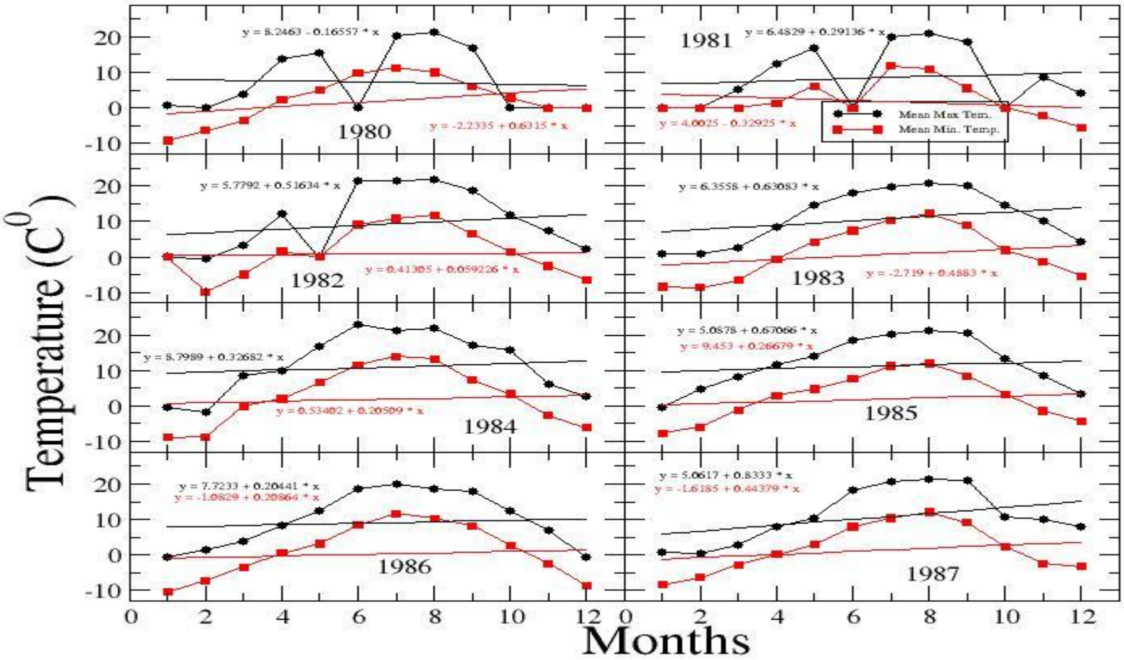

Fig. 2 Time series of temperature (minimum and maximum) for different months over Gulmarg from 1980-1987.

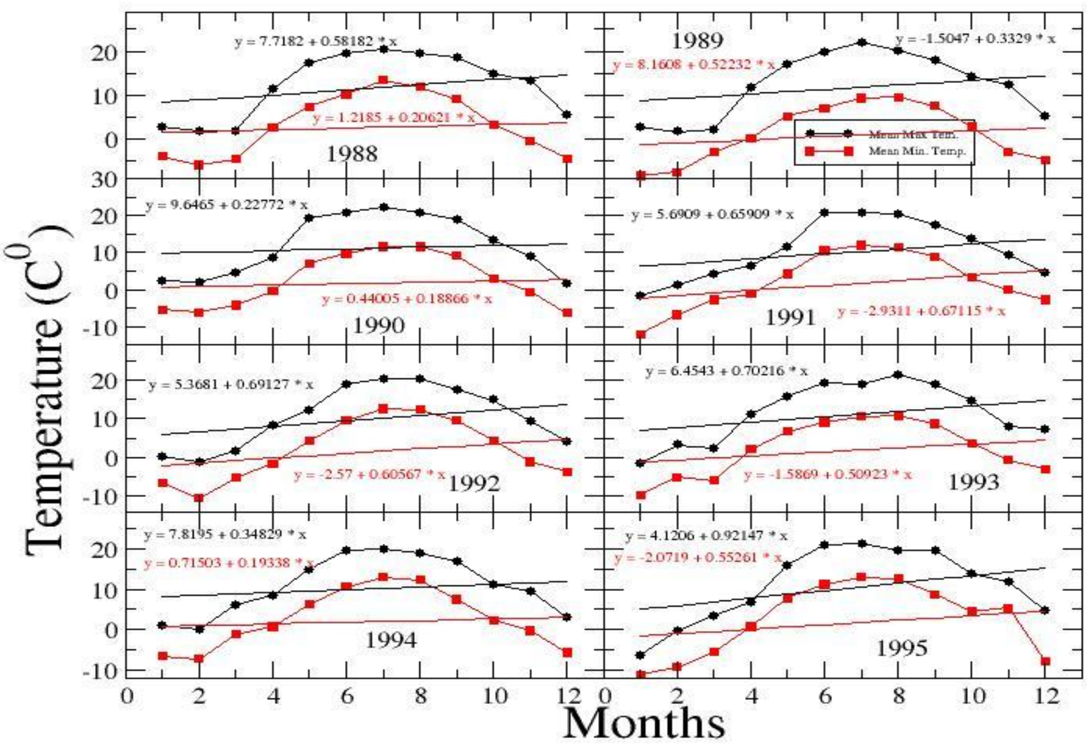

Fig. 3 Time series of temperature (minimum and maximum) for different months over Gulmarg from 1981-1995

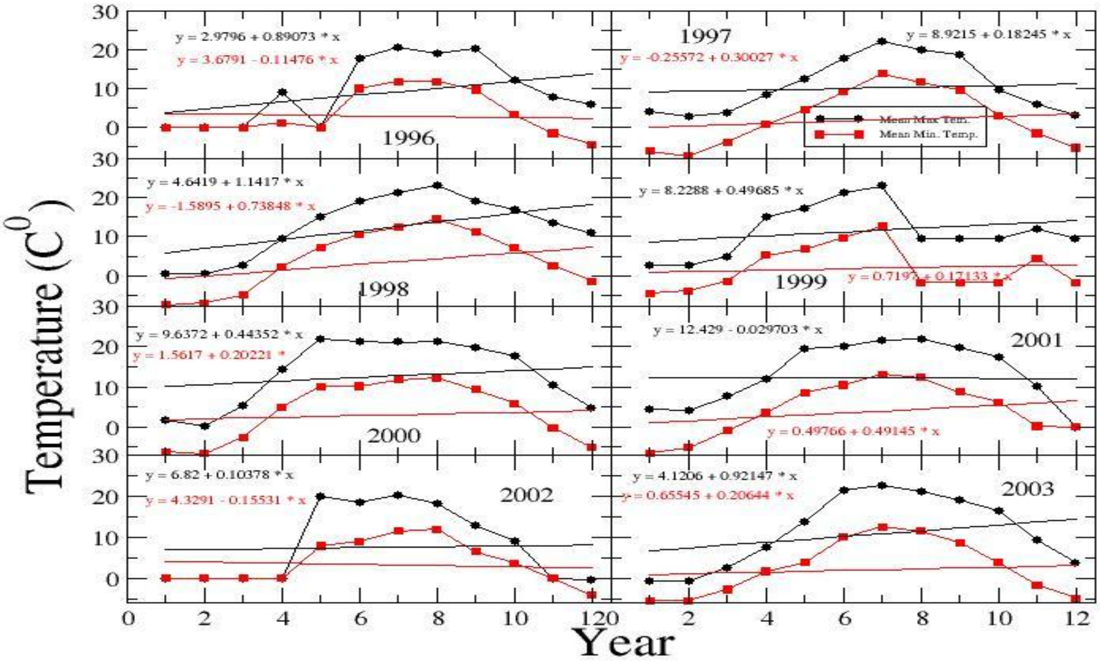

Fig. 4 Time series of temperature (minimum and maximum) for different months over Gulmarg from 1996-2003.

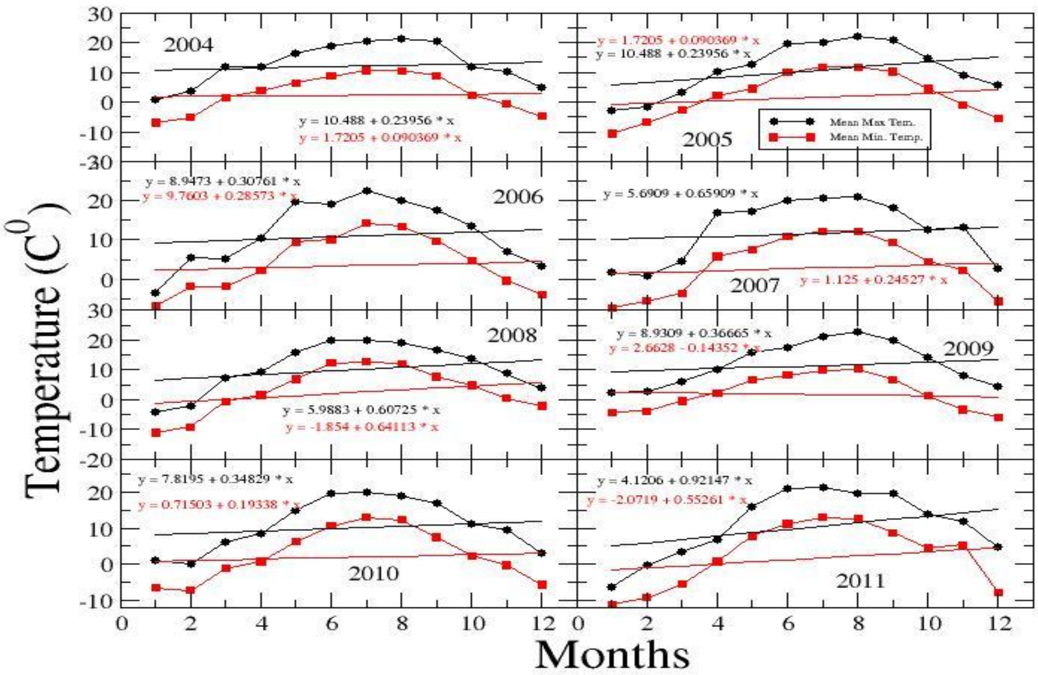

Fig. 5 Time series of temperature (minimum and maximum) for different months over Gulmarg from 2004-2011.

The averaged annual mean maximum temperature time series has shown increasing trends over many years in valley except 1979 with slope of Max. Temp. -0.1655, 1980 with slope of Max. temp. -0.1665, 1996 with slope for Min. temp. -0.1147, 2001 with slope of Max. temp. -0.0297, 2002 with slope for Min. temp. -0.155 and 2009 with slope for Min. Temp. -0.143. Among all 1980 is most significant in decreasing trend analysis of Max. temperature. The highest increase in annual mean maximum/minimum temperatures was observed over 1993 with slope for Max. Temp. 0.702, 1995 with slope for Max. Temp 0.9214, 1996 with slope for Miax. Temp 0.8907, 1998 with slope for Max. Temp. 1.141 and 2003 with slope for Max. Temp 0.9214. Among all 1998 is most significant in increasing trend analysis of Max. temperature.

Table I, shows decreasing trend in average annual mean maximum temperature. The highest increase in annual mean maximum temperatures was observed over Winter (+0.01 C/year). The highest increase in annual mean minimum temperature was observed annually (-0.01 C/year) followed by summer sesson (-0.02^0 C/year). Annual mean minimum temperature trends are significantly decreasing over Monsoon and Post monsoon (-0.03^o C/year). The highest increase in annual mean temperature was obtained Monsoon and Post Monsoon (+0.03^o C/year). Summer session has shown significant decreasing trends in annual mean temperature while no trends were observed in Winter. Annual and Seasonal rainfall trends show increasing trends annually (+2.13^o C/year). Post monsoon has shown significant decreasing trends in Summer (-1.07^o C/year). Table II shows the monthly temperature/rainfall based upon different temp/rainfall stations from 1951-2010 monthly. It can be observed that both Pahalgam and Gulmarg shows very high interannual variability during different months.

Table I. *Annual and Seasonal mean maximum/ minimum temperature trends based on meteorological Data analysis for 1951-2011of Kashmir Valley. Increasing (+) and decreasing (-) trends significant at 95% are shown in bold and marked with '*'sign (Kashmir Valley).*

	Annual	Winter	Summer	Monsoon	Post monsoon
Mean Maximum Temperature Trends in oC per year	-0.01	+0.01	-0.01	**-0.04***	-0.01
Mean Minimum Temperature Trends in ^{o}C per year	-0.01	No trend	-0.02	**-0.03***	**-0.03***
Annual and Seasonal mean temperature trends	-0.01	No trend	-0.02	**-0.02***	**-0.02***
Annual and Seasonal mean diurnal temperature range	**+0.02***	**+0.02***	**+0.03***	No trend	**+0.03***
Annual and Seasonal rainfall trends	+2.13	**+1.88***	-1.07	-0.16	-0.37

Table II. *Trends in monthly temperature/rainfall based on different rainfall stations for 1951-2010. Increasing (+) and decreasing (-) trends significant at 95% are shown in bold and marked with '*' sign. No trend is indicated by abbreviation NT (Kashmir Valley).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct.	Nov.	Dec.
Monthly mean maximum temperature trends	+0.02	NT	-0.01	-0.01	-0.03	-0.06*	-0.04*	-0.02*	-0.03*	-0.01	NT	NT
Monthly mean minimum temperature trends	-0.02	-0.01	-0.02	-0.03*	-0.04*	-0.05*	-0.03*	-0.03*	-0.03*	-0.04*	-0.03*	-0.01
Monthly mean temperature trends	NT	NT	-0.02	-0.02	-0.03*	-0.05*	-0.03*	-0.03*	-0.04*	-0.03*	-0.01	NT
Monthly mean diurnal temperature range	+0.03	* 0.01	+0.01	0.03*	0.02*	-0.01	-0.01	NT	+0.01	+0.04*	+0.03*	+0.02
Monthly rainfall	+0.78	-0.16	-0.86	-0.20	-0.35	-0.02	+0.09	-0.36	-0.20	-0.35	-0.21	-0.63

Fig. 6 Time series of average temperature over study area during different years.

It can be observed that both Pahalgam and Kokarnag show very high interannual variability during different years. Almost all four Station recorded maximum average temperature 500^{0}C during 1982 and minimum average temperature -10^0 C during 2009. These regions experienced a minima of average temperature about 100 mm during March 2000 and 2010. There are multiple peaks and valleys of average temperature over study area. These peaks in average temperature are consistent with corresponding valleys in temperature (minimum and maximum). This shows that increase in temperature causes a reduction in snowfall. This result is consistent with results of Mir et al. (2015) who reported a significant decrease in snowfall in the context of increased temperature. A trend analysis is performed for quantitative exploration of average temperature/snowfall in the context of warming. Statistics are presented in Tables 1 and 2. Average temperature over Pahalgam shows increasing trend except for the months of February and January. Pahalgam shows a significant increasing trend in average temperature. This has reduced the snow fall in Pahalgam. This reduction in snowfall (December to March) over Pahalgam is observed with an increase of about 0.7 ^{0}C in Min. temperature and 1.9 ^{0}C in Max temperature per decade. However, an in significant decreasing trend of about 15 mm per decade is observed for the season (December–January–February–March) from Table 1. These decreases in seasonal snowfall is observed with an

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increase of about 1.2 ^{0}C in T min and 0.8 ^{0}C in T max per decade. Insignificant increasing trends during February and January were observed for the Pahalgam region. Gulmarg shows statistically significant decadal reduction in snowfall of about 12 mm during December. This is consistent with increase of about 0.7 ^{0}C in Min. temperature and of about 0.4 ^{0}C in Max. temperature. It is also observed that insignificant average temperature decreasing trends is observed over Srinagar and Quazigund as indicated in **Fig. 6**. A maximum decrease of about 0.1 ^{0}C in average temperature is observed during the period from 1770-2011.

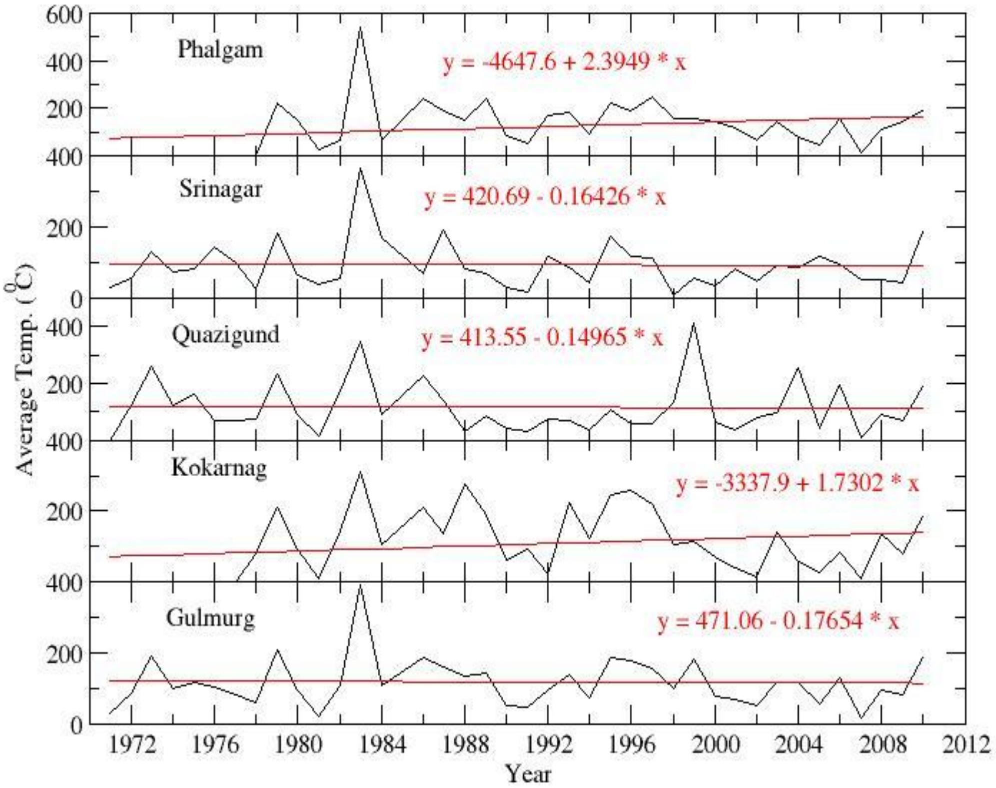

Fig. 6 Time series of Average temperature over study area during different years.

V. EFEECTS OF CLIMATE-CHANGE ON FLORA AND FAUNA

Anthropogenic climate change is predicted to be a major cause of species extinction in next century. Undesirable alterations in local and regional floras due to global climate change in phytogeographically distinct and ecologically sensitive regions such as Kashmir Himalaya is an alarming problem. Over the years, Kashmir Himalayan region has witnessed burgeoning invasion by alien species. The interactive effects of climate change and invasive species has brought many endemic species of this Himalayan biodiversity hotspot to the endangered status, some of which are even on the brink of extinction. Hence, predicting the climate

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change driven potential extinction of threatened endemic plant species and invasion by alien species attains pivotal importance for biodiversity conservation and ecosystem management. The present work will help predict range size of worst alien species and can also be used to understand population decline of threatened endemic species under changing climate using a Bioclimatic Envelope (or Ecological Niche Modeling) approach. An attempt could be made to track the source populations of invasive species through climate matching approach and identify transport vectors and dispersal corridors. Comparison of changes in phenology and physiology of endemic and invasive species could be used for developing predictive models for future phenological trends and their implications for regional biodiversity patterns. Assessment of the role of mutualistic interactions in fitness of target species and monitoring changes in species interactions along an altitudinal gradient makes remarkable sense in the light of climate change. This is because interactions determine spatial arrangements of species prior to the onset of rapid climate change through space-occupancy effects that limit the rate of expansion of the fast-growing competitors. Various climate change scenarios generated by IPCC could be applied to Kashmir Himalayan region to simulate and model the impact of unit change in temperature and CO_2 concentration on shifting patterns of distribution of endemics and invasive species. The Open Top Chambers, an ideal system for maintaining desired levels of CO_2, temperature and relative humidity, could be used to monitor the plant performance in a changing climate. This would pave way for long-term monitoring of species shifts with specific focus on alpine and sub-alpine systems in the region. The proposed study, a pioneering attempt of great scientific utility, hopefully, would lay firm foundation for advanced studies on the climate change driven shifting patterns of regional plant diversity and distribution. The information yielded is anticipated to play a pivotal role in developing a predictive framework necessary for formulating proactive management plans for the menace of plant invasion and improving conservation status of threatened endemic species in Kashmir Himalaya.

Due to its proximity with the erstwhile Silk Route and promotion as a global tourist destination, the region has and is likely to witness intentional or unintentional introduction of varying floral elements from different phytogeographical regions of the world. Historically, the region has been an important stopping point for the historical trade caravans starting from the far East Asia passing through the Central Asia to reach the Mediterranean coast and vice versa. Such anthropogenic influences, along with wanton axing of virgin conifer forests, unregulated grazing of alpine meadows, pollution of freshwater ecosystems, burgeoning urbanization, etc., have promoted invasion of these disturbed habitats by invasive alien plant species. These problems have been exacerbated by climate change stressors over the years. In the study area described above, extensive field surveys have been carried out to locate populations of rare and endangered endemic species by different workers. These field surveys also focus on the extent of invasion by various alien species in different communities. Various such plants have been identified at the Kashmir University Herbarium (*KASH*) and other places using the relevant reference floras and identified herbarium specimens.

VI. CONCLUSION

Analysis of temperature and snowfall data reveal that there is high inter-annual variability in average temperature, min./max, temperature/snowfall for different months over the study area. Pahalgam shows a significant reduction in snowfall for the peak snowfall month which

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is consistent with increase in temperature. This may affect the economy of the Valley as tourism is one of the major sources of income (Dar et al., 2014). Increase in temperature is attributed to increase in column black carbon as a result of unplanned urbanization. Increased temperature may cause significant snowmelt over Himalayan region (Kulkarni, 2007). Reduction in snowfall combined with increase in temperature, snowmelt and black carbon concentration may result in shrinking of glaciers (Rafiq and Mishra, 2016). Jammu and Kashmir experienced a heavy flood in 2014 which was attributed to heavy precipitation (in the form of rain) and snow melt from high elevated regions including Pahalgam and Gulmarg (Mishra, 2015). Given the inaction in mitigating anthropogenic warming such events may increase in near future. For this reason water resource management and disaster preparedness needs to be implemented at earliest. Further, though geographical distribution of some plant species have been studied, only a few studies have taken into account the impact of climate change. The results of the present study are of great importance in understanding the impact of climate changes on different species of plants and describe appropriate conservation measures for the species.

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