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TEMPERATURE VARIATION OVER DEHRADUN IN DOON VALLEY OF OUTER HIMALAYAS IN INDIA (1967-2007)

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ABSTRACT

Long-term climatic variability is paramount for the estimation of its impact on human activities and for predicting the future climate change. The knowledge of the extent of such change will help to answer the questions posed by society about adaptation strategies. Several attempts in literature have been made to study the temperature variability in India and abroad. However, very few studies on temperature variability have been undertaken in Himalayan region due to remoteness, inhospitable terrain, inaccessibility and sparse meteorological network. Therefore, the present study has been undertaken to study the long-term temperature variability by utilizing daily time series data collected over the period 1967-2007 for Dehradun located in Doon Valley of the outer Himalayas in India. The temperature time series has demonstrated a warming trend in annual mean, maximum and minimum temperature. The ratio between the temperature of hottest and coldest months was found to be 2.36. The analysis also revealed that higher temperature ranges were observed during summer and winter months and lower during rainy (monsoon) months. The frequency of hot nights has escalated by 0.072 nights per year while it has declined in the case of hot and cold days and cold nights by 0.094 and 0.319 days and 0.205 nights per year, respectively. This implies that the extreme events are diverging and hence the gap between the maximum and minimum temperatures will escalate in future at Dehradun. The results obtained from this study may be extremely beneficial for farmers, agricultural research workers, water resource managers and town planners of the Doon valley.

Keywords: climatic variability, anomalies of temperature, human activities, climate change, adaptation strategies, local studies, Doon Valley, Outer Himalayas.

Introduction

In recent times, climate of the earth is more fluctuating than it was in the remote past. Therefore, long-term climatic variability is paramount for the estimation of its impact on human activities and for predicting the future climate. Climate change and global warming arising from anthropogenic-driven emissions of greenhouse gases and land-use and land-cover change have emerged as one of the most important environmental issues in the last two decades (Arora et al., 2005; Singh et al., 2008). Several attempts in literature have been made to study the temperature variability in world and as well as in India (Ventura et al., 2002; Gadgil and Dhorde, 2005; Das et al., 2008; Dhorde et al., 2009; Rehman, 2009; Sadiq and

Qureshi, 2010; Tigga and Hema Malini, 2011: Jain and Kumar, 2012). Records from land stations and ships indicate that the global mean surface temperature has warmed up by approximately 0.6±0.2°C since 1850 and it is expected that, by 2100, the increase in temperature could be 1.4-5.8°C. Available records show that the 1990s have been the warmest decade of the millennium in the Northern Hemisphere and 1998 was the warmest year. Temperature variations influence hydrological cycle, water resources, flood and drought frequencies, natural ecosystems, agriculture, architecture, power generation and its use, including electrical power for heating and cooling; melting of snow and the effects of freezing and icing on transportation systems; flowering and harvesting dates; and society and economy (Ramos, 2001; Ventura et al., 2008; Rehman, 2009).

Moreover, rapid temperature changes affect the seasons causing variation in their duration. Climatic records put together with long-term records of flowering and nesting times show clear warming trends. Further, cold and frost season become squeezed while hot days/nights and heat waves have become more frequent (Rohli and Viga, 2008). Changes like shorter winters leads a mismatches between the key elements of an ecosystem, such as feeding periods for young birds and availability of worms or insects for their food. Also, temperature plays an indispensable role in sowing time, germination, incidence of disease, crop quality, and duration of crop and development of different growth phases of plants as a source of energy (Wang, 1960; Pyke, 2004). There is a steep rise in the water shortage curve when plotted against rise in temperature. Moreover, a disruption of water supply through climate change can result in social and economic losses that often take years to recover (Haris et al., 2010). All these changes are happening in response to change in temperatures of just over 0.74°C over the last century. Likewise, we are bound to see various disruptions in response to the several degrees increase, which is expected by the end of 21st century. The future climate change, in general, will have its impact globally and will be felt severely in developing countries with agrarian economies and particularly in mountain ecosystems. However, very few studies on temperature variability have been undertaken in Himalayan region due to remoteness, inhospitable terrain, inaccessibility and sparse meteorological network. Samui and Gupta (1992) for two hill stations in Sikkam, Attri et al., (1995) for Gangtok and Murthy et al., (2004) for Ranichauri in Uttrakhand are worth mentioning studies in the literature from Himalayan region. Therefore, to fill the research gap, an attempt in the present research has been made to study the long-term temperature variability by utilizing daily time series data collected over the period 1967-2007 for Dehradun located in Doon Valley of the outer Himalayan region in India. The variation of monthly and annual temperature, estimation of warming and cooling rates using regression least square fit modeling and estimation of frequencies of occurrence of hot and cold days and nights constitute the analyses.

Site Description

Dehradun, belonging to western part of Uttarakhand state in India, is located in a valley at the foothills of outer Himalaya and lies between 30°15' and 30°25' north

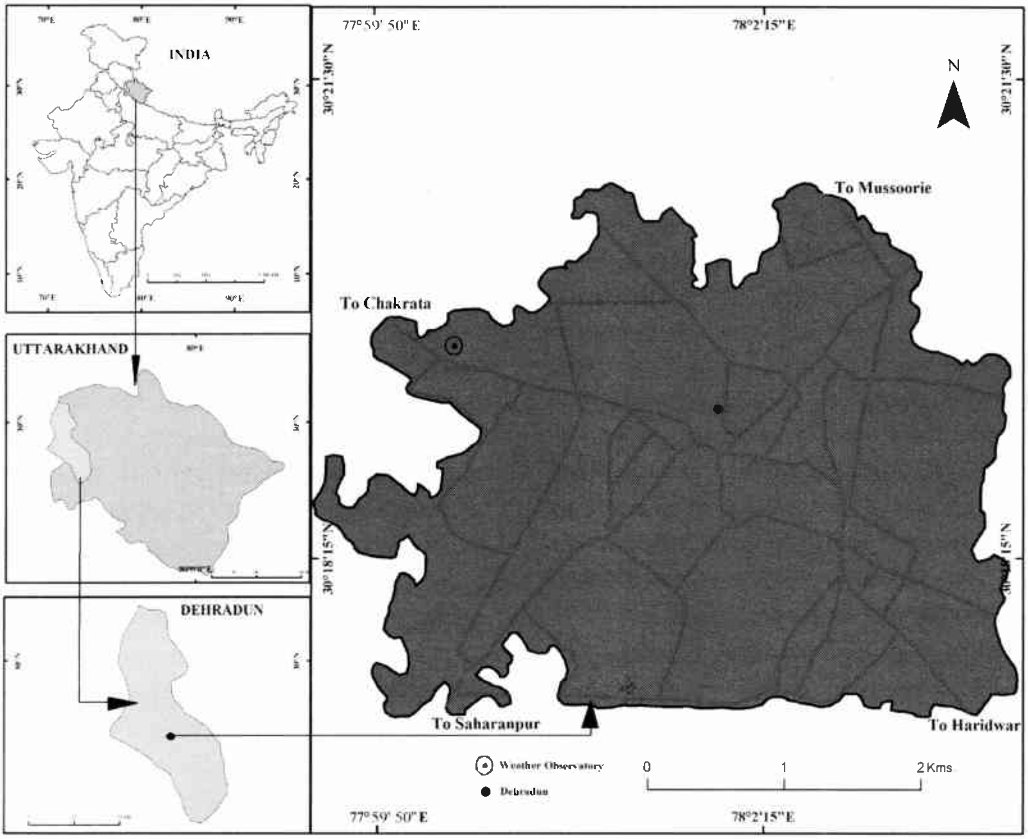

Fig. 1: Extent of Dehradun city and location of meteorological station considered in this study

latitudes and 78°00' and 78°10" east longitudes (Fig. 1). It is well known for its salubrious climate and natural beauty. Also, the wafting fragrance of rice, tea, mango and litchi gardens add to the beauty of Doon Valley. It is surrounded by river Song on the east, river Tons on the west, Himalayan ranges on the north and Sal forests in the south. The high hills in the east and north and Siwaliks in the south offer an interesting topographical setting to the city. During the summer months, the temperature ranges between 36°C and 16.7°C. The winter months are colder with the maximum and minimum temperatures touching 23.4°C and 5.2°C respectively. Dehradun experiences heavy to moderate showers during late June to mid August. Most of the annual rainfall of about 2000 mm in the city is received during the months from June to September, July and August being the rainiest months in the season. Dehradun has been emerging as an important business, educational and cultural destination in north India after becoming the capital of newly carved out state of Uttarakhand since 1999. The population of the city is increasing rapidly and it has registered about 40% growth during the last decade.

Materials and Methods

The daily maximum and minimum

temperature data recorded at New Forest, Forest Research Institute, Dehradun in Doon Valley of Uttarakhand for the period from 1967 to 2007 were collected from the published records. The elevation of the meteorological observatory is about 640 m above mean sea level. This observatory corresponds to class 'A' meteorological observatory of Indian Meteorological Department, Pune. Climatic elements like wind speed, direction, bright sunshine hours, evaporation, vapour pressure, dew condensation, soil temperature at various depths, in addition to the usual rainfall, temperature and humidity are being compiled and published annually since 1967. IMD is only reliable, competent and official source in India for meteorological data.

From the daily time series temperature data (1967-2007) the monthly and annual means of temperature with their standard deviation (SD) and Coefficient of variation (CV) were derived by simple statistical methods to find out the possible changes in monthly and annual temperature for the hilly Dehradun city of Uttarakhand. The magnitudes of the trends of increasing and decreasing temperatures were derived from the slope of the regression line using the least square method. The temperature range was obtained by taking the difference between the monthly maximum and minimum temperatures of the daily mean values.

For better understanding of the observed trends in temperature, anomalies of mean maximum temperature, mean minimum temperature and mean annual temperature were also computed. Anomalies are more accurate than absolute temperature to describe climatic variability. To analyze anomalies in maximum, minimum and annual temperature, the average annual maximum, annual minimum and annual mean temperatures were calculated. Folland et al., (1999) suggested 30 years as a standard period for calculating the average used to analyze the anomalies. For the present purpose, the relative anomalies and comparison were made with the results obtained using the average from the whole data set. The temperature anomalies obtained were plotted against time and the linear trends observed were represented graphically. The linear trend value, represented by the slope of a simple least-square regression line with time as the independent variable shows the magnitude of rise or fall in temperature.

The number of hot and cold days and nights were estimated using daily maximum and minimum temperatures recorded during different years. The hot days are classified as hot if maximum daily temperature Tmax becomes ≥35°C, the hot nights are defined when daily minimum temperature Tmin becomes >20°C , the cold days are defined as cold when Tmax becomes ≤20°C and finally the cold nights are said to be cold when Tmin becomes ≤15°C (Rehman, 2009).

Results and Discussion

Monthly Temperature Variability

The long-term monthly mean temperatures were calculated using the daily values during the years 1967-2007 and are shown in Table 1 and Fig. 2. Figure 2 also displays the monthly maximum and minimum of the daily mean values over the entire period of data collection. The monthly mean minimum temperature of 11.8°C was observed in the month of January while a maximum of 27.8°C in June. This means that the ratio between the temperatures of hottest and coldest months was 2.36.

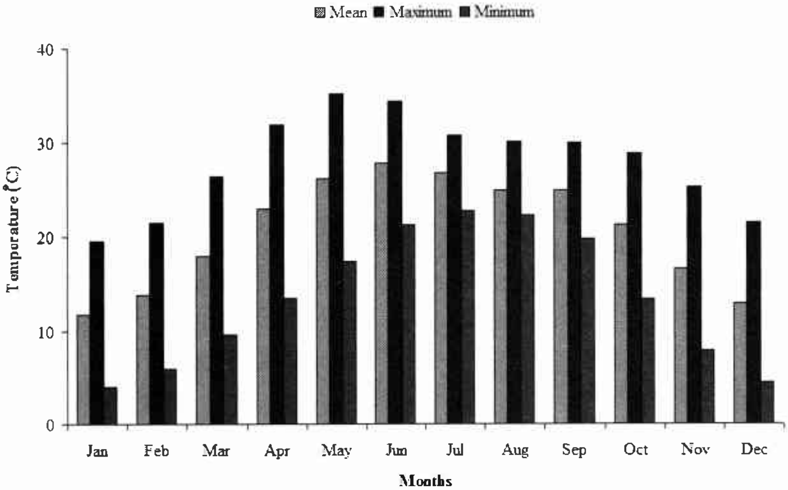

Fig.2: Monthly variation of temperature at Dehradun during 1967-2007.

Table 1: Mean and long-term change of monthly, seasonal and annual temperature at Dehradun during 1967-2007.

Month	Maximum temperature (°C)	Minimum temperature (°C)	Mean temperature (°C)	SD	CV (%)
January	19.6	4.0	11.8	0.8	6.4
February	21.5	5.9	13.8	1.2	8.4
March	26.4	9.5	18.0	1.4	7.8
April	31.9	13.5	23.0	2.3	10.0
May	35.2	17.4	26.2	1.2	4.6
June	34.4	21.2	27.8	0.9	3.3
July	30.8	22.7	26.7	0.5	2.0
August	30.1	22.3	24.9	0.9	3.7
September	29.9	19.8	24.9	0.9	3.5
October	28.8	13.3	21.2	1.1	5.4
November	25.3	7.8	16.6	0.8	4.7
December	21.5	4.5	13.0	0.6	5.0
Annual	28.0	13.6	20.8	0.5	2.2

SD and CV are computed for mean temperature.

Higher values of mean temperatures were observed from April to October relative to rest of the year, as seen in Fig. 2. The highest monthly maximum temperature of 35.2°C was observed in the month of May, whereas lowest 19.6°C was observed in January. In this case the ratio between the hottest and coldest temperature months was 1.80. This means that the monthly maximum temperature ratio is less wide than the monthly mean temperature ratio. The maximum and minimum values for the monthly minimum temperature were found to be 22.7°C and 4°C in the months of July and January, respectively. In this case the ratio between hottest and coldest months was observed to be 5.69. This reflects that monthly minimum temperature ratio is much wide than the monthly maximum and mean temperature at Dehradun. However, much lower values of 1.59, 2.38 and 1.84 of the ratio between hottest and coldest months for monthly maximum, minimum and mean temperature was observed for Ranchi in India (Tigga and Hema Malini, 2011).

A wide range of temperature between monthly maximum and minimum temperature was observed at Dehradun (Fig. 3). While analyzing the entire record, the highest range of 18.4°C was obtained for the month of April and the lowest of 7.8°C in August. The analysis also revealed that higher temperature ranges were observed during summer and winter months and lower during rainy (monsoon) months, as it is evident from Fig. 3. These results were found to be in agreement with the results obtained for Ranchi in India (Tigga and Hema Malini, 2011).

Annual Temperature variability

The annual mean, maximum and minimum temperatures have been exhibited in Fig. 4 along with the linear regression line. The annual mean temperature trend line demonstrated an increment of 0.01°C per year with coefficient of determination at 9%. Relatively lower annual mean temperature was observed in the years 1997 and 1989 and an abnormal increase in 2006

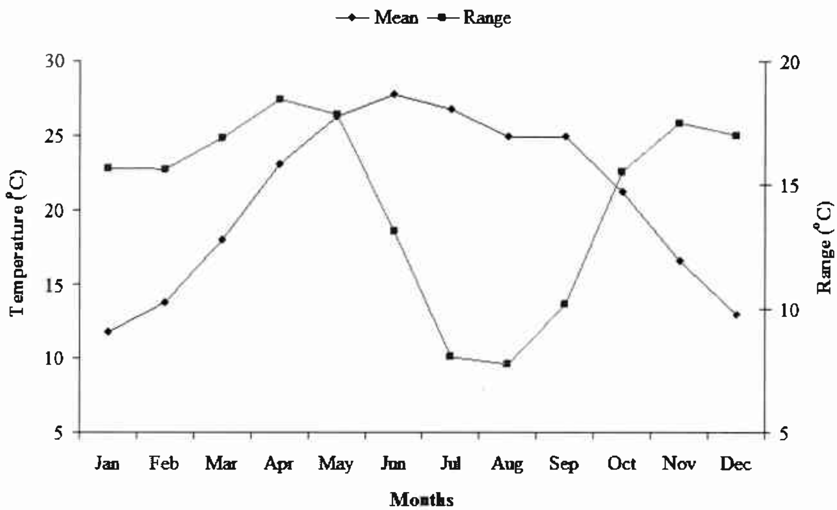

Fig. 3: Monthly mean temperature and range at Dehradun during 1967-2007

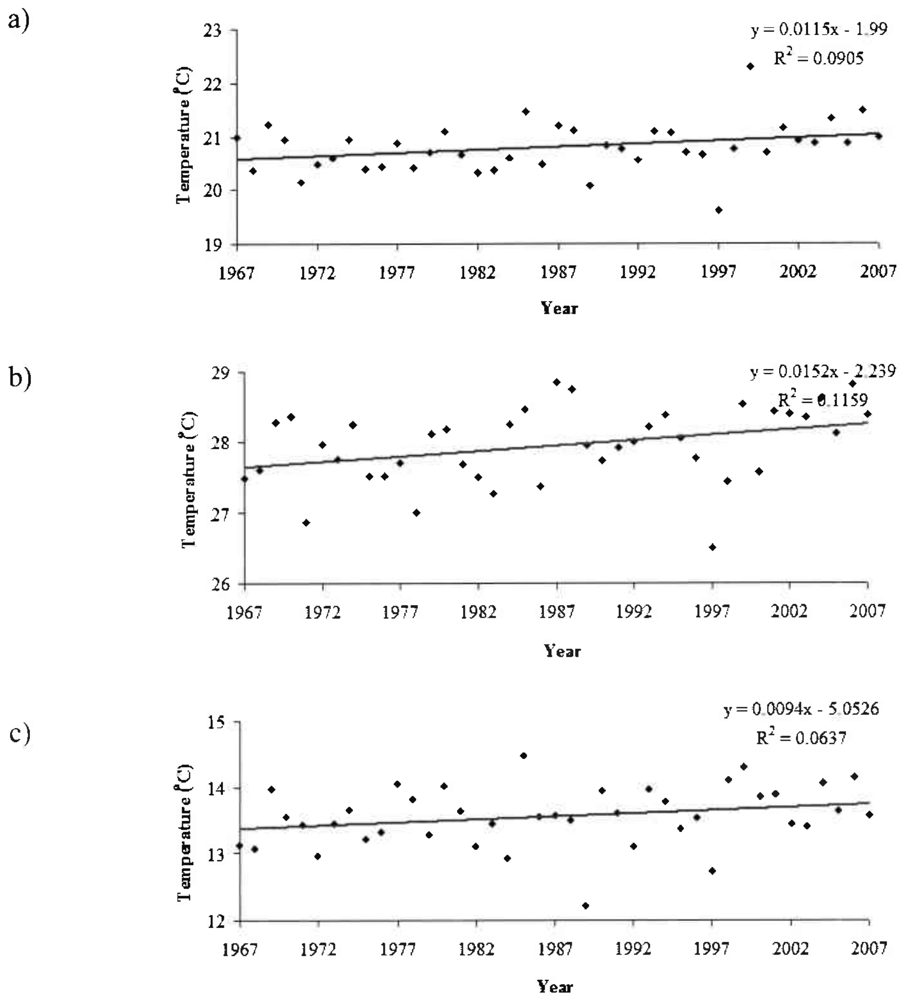

Fig. 4: Annual variation of (a) mean, (b) maximum and (c) minimum temperature with their linear regression model at Dehradun during 1967-2007.

during the reported period at Dehradun. An overall increase of 0.5°C was found between 1967-2007 that is from 20.5°C to 21.0°C as estimated by least square regression line shown in Fig. 4. Also, annual maximum and minimum temperature series exhibited an increasing trend. The linear regression lines with coefficient of determination of 11% and 6% indicate an increase of 0.01°C and 0.009°C per year corresponding to annual maximum and minimum temperatures, respectively. The trend of the annual maximum temperature is 1.1 times compared to that of the annual minimum temperature.

Variability in anomalies of temperature

The annual mean, maximum and minimum temperature anomalies form the mean of these variables for the entire period 1967-

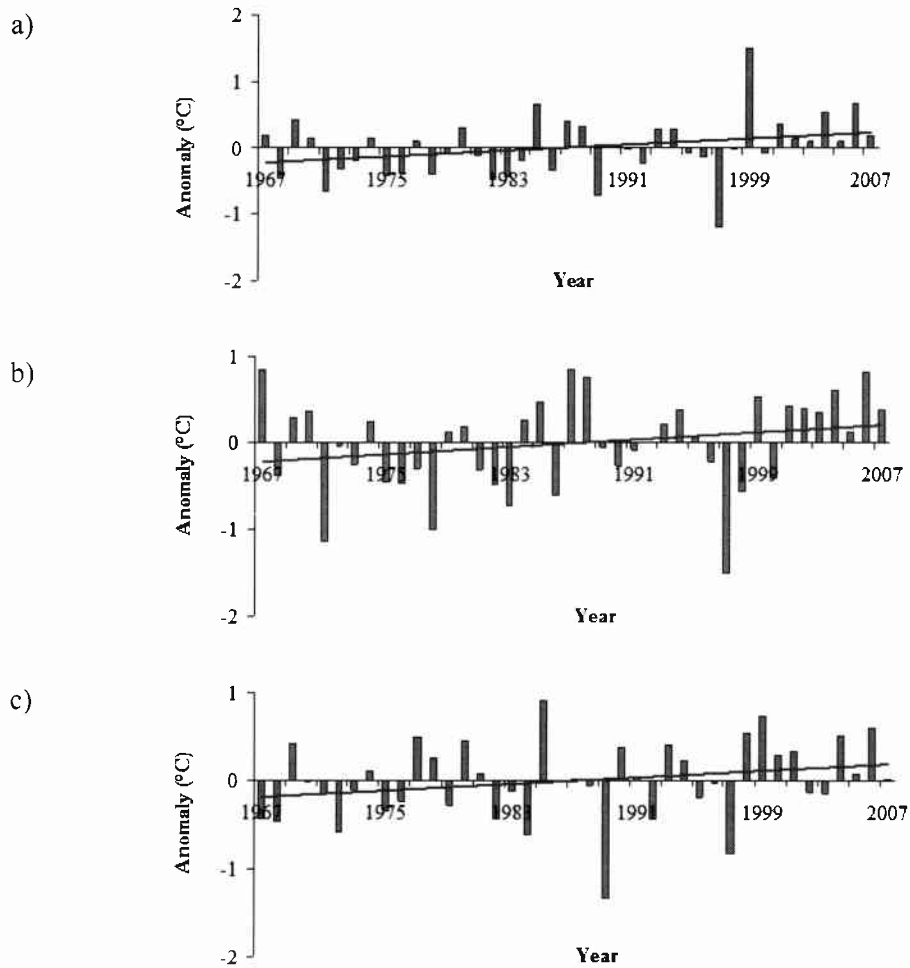

Fig. 5: Variation in anomalies of annual (a) mean, (b) maximum and (c) minimum temperature at Dehradun during 1967-2007.

2007 have been demonstrated in Fig. 5. It is evident from the plot of annual mean temperature that intermittent cold and warm spells were experienced at Dehradun during the reported period, while continuous hot spells were observed at the beginning of the 21st century and it can be attributed to urbanization process. The highest annual mean temperature of 22.3°C was recorded in the year 1999 while the lowest of 19.6°C was observed in 1997. Further investigation was made by dividing the whole period into two spans of 21 and 20 years from 1967 to 1987 and 1988 to 2007, respectively. The frequency of below and above average temperature was counted during both the periods individually. This analysis revealed warming trends during later span (1988-2007) with 60% instances of above average temperatures while 62% cold spells occurred during earlier span (1967-1987). The ratio between the frequencies of hot to cold spells have been calculated as 1:1.62 and 1.5:1 for 1967-1987 and 1988-2007 time periods, respectively indicating warming trend during the latter period. The annual maximum temperature anomalies showed 38% hot events and 62% cold events during 1967-1987 while 60% hot events, 35% cold events and 5% neither hot nor cold were registered during 1988-2007. The annual minimum temperature anomalies exhibited 38% above average and 62% below average during 1967-1987 and 60% above average and 40% below average during 1988-2007. All of these facts are leading towards a conclusion that the temperature at Dehradun is increasing with time. The analysis also revealed that the maximum and minimum anomalies of annual maximum temperature were 0.85°C and -1.50°C in the years 1987 and 1997, respectively. Furthermore, about 48.7% anomalies were found to be both below average and above average while about 2.4% demonstrated neither increasing nor decreasing trend in the maximum temperature at Dehradun during 1967-2007. In case of the annual minimum temperature, about 48.7% anomalies were

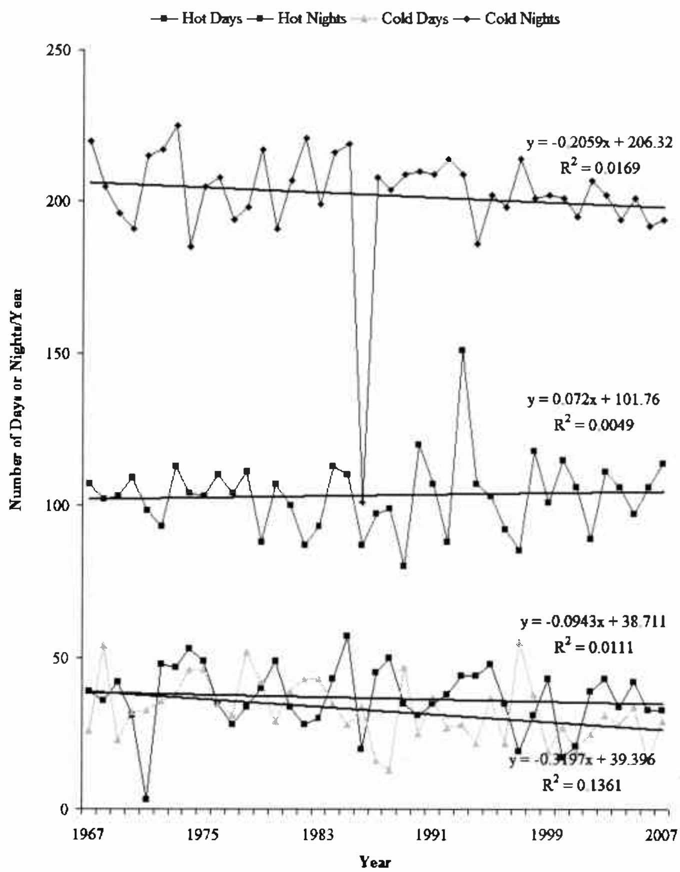

Fig. 6: Number of annual hot and cold days and nights at Dehradun during 1967-2007.

observed to be hot while 51.3% were cold. However, maximum and minimum anomalies of annual minimum temperature were 0.91°C and -1.34°C in 1985 and 1989, respectively.

Hot and Cold Days and Hot and Cold Nights Variability

The number of hot (daily maximum temperature ≥35°C) and cold (daily maximum temperature (≤20°C) day's variability in different years also imparts information on the increasing and decreasing effect of warming on local, regional and global scales. Similarly the variability in annual number of hot (daily minimum temperature ≥20°C) and cold (daily minimum temperature ≤15°C) nights also yields an increasing or decreasing trend in the daily minimum temperatures. The annual frequencies in terms of number of hot and cold days and nights over the study period were estimated and have been depicted in Fig.6. The frequency of hot nights over Dehradun has increased right from 1967 to 2007 (Fig. 6). The frequency of hot nights registered a hike of 0.073 nights per year. Conversely, the frequency of hot and cold days and cold nights had declined over the reported period, though it is small. The frequency of hot and cold days waned by 0.085 and 0.317 days per year, respectively while cold nights declined by 0.195 nights per year. This implies that the extreme events are diverging and hence the gap between the maximum and minimum temperatures will escalate in future at Dehradun.

CONCLUSIONS

The global situation of climate change has been well described by IPCC reports. However, local studies are important to understand the impact and priorities due to climate change. The analysis of temperature data collected at Dehradun confirmed global warming effect with an annual rise of 0.01°C per year. An overall increase of 0.5°C was observed (20.5°C to 21°C) during the reported period. The monthly mean minimum temperature of 11.8°C was observed in the month of January while a maximum of 27.8°C in June. Higher values of mean temperatures were observed from April to October relative to rest of the year. Higher temperature ranges were observed during summer and winter months and lower during rainy (monsoon) months. Annual mean temperature demonstrated intermittent cold and warm spells at Dehradun during the reported period. The ratio between the frequencies of hot to cold spells have been calculated as 1:1.62 and 1.5:1 for 1967-1987 and 1988-2007 time periods, respectively indicating warming trend during the latter period. The warming in the latter period and specifically at the start of 21st century can be attributed to urbanization process initiated at Dehradun after becoming the capital of newly carved out state of Uttarakhand. Also, an increase in the annual frequency of occurrence of hot nights was observed while a reverse trend in case of hot and cold days and cold nights was observed. An increase in the frequency of occurrence of hot nights is not a healthy signature for crop production and water resources in the region. Finally, to understand the climatic variability in totality, it is suggested that similar analysis is urgently required to examine the trend of other climatological variables at Dehradun and in the Himalayan region.

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