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Letters to the Editor

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RECENT TRENDS IN TEMPERATURE (COLD WAVE CONDITION) AND RAINFALL OVER GANGTOK CITY

1. Gangtok is the capital city of Sikkim, the erstwhile Himalayan Kingdom, and now the 22nd State of India (after 1975), located in the lap of Eastern Himalayas between Latitude 27° N and 28° N and Longitude 88° E and 89° E is wholly mountainous, with hilly terrains of altitudes ranging from 300 m to 6000 m and has a population of about 5.2 lakhs (2001 Census). However, Sikkim is under increasing biotic pressure and a number of plants and animals are under threat of extinction due to deforestation, habitat destruction, and over exploitation of the sites. Some plant species are already listed place in the Red Data Book (Rai, 2001). In Sikkim, particularly after 1975, there has been exceptionally rapid creation of infrastructures in terms of construction of residential and non-residential buildings, expansion of towns and bazaars including markets, construction of road and bridges, irrigation channels, power lines etc. besides development of small and big hydroelectric projects. With the increase in population, the construction of residential buildings/houses, have been on the increase even in rural areas (Basnett, 2001). The urban population of the city has considerably increased from 35000 (1981 Census) to 50000 (2001 Census). Here an attempt has been made to study the impact of urbanization on temperature and rainfall over Gangtok city based on the data for the period from 1973 to 2002 recorded at M.O. Gangtok.

2. Urbanization increases air temperature, dust particles, cloudiness and precipitation whereas it decreases relative humidity, radiation, albedo and wind speed. These in turn affect the water balance parameters like evapo-transpiration, soil moisture storage, run off etc. (Mavi, 1986). Significant increase in the frequency, persistency and spatial coverage of heat waves/severe heat waves and cold waves/severe cold waves has been observed during the recent decade 1991-2000 in comparison to that during the earlier two decades. These changes might be the regional impact of the observed general increase in the global warming during the recent decade (1991-2000), which is the warmest decade in the past 140 years, the warmest years in succession being 1998, 1999, 1997, 1995, 1990, 1996 and 1991 (WMO, 2001). Other possible reasons behind these changes are local factors such as deforestation, urbanization etc. However, the magnitudes of the changes in the characteristics of cold waves were relatively less than that of heat waves (Pai *et al*., 2004). Recent findings by Mukhopadhyay *et al.* (1999) have however confirmed that there is a clear signal of urbanization in these warming, that there is a steeper rise in the minimum temperature also in urban locations (De, 2001). Precipitation intensity is expected to increase during global warming because of greater moisture holding capacity of a warmer atmosphere (Houghton, 1997). The trend shown by the various meteorological parameters are not uniform for all the Indian cities. In general radiation values, bright sunshine hours, wind speeds and total cloud amounts are decreasing whereas relative humidity, rainfall amounts are increasing. Percentage number of days of maximum/minimum temperatures with a threshold values of >35° C / <10° C are decreasing/increasing respectively over north India (Prakasa Rao *et al*., 2004). Late studies have shown that the frequency of heavy rains during the southwest monsoon show increasing trend over certain parts of the country. On the other hand, decreasing trend is seen during winter, pre-monsoon and post-monsoon months. Dynamical and anthropogenic causes have been attributed for this variation (De, 2001). Basu & Basu (2001) have found an increasing trend in total monsoon rainfall at Calcutta during the period 1961-96 and the percentage trend vary from 66% to 145% without any periodicity.

3. Meteorological data recorded at M.O. Gangtok (Latitude 27° 20′ N, Longitude 88° 37′ E and altitude 1765 m above mean sea level) for the period 1973-2002 have been considered for the study, as according to WMO (WMO, 1983) atleast 30 years' data are required for computation of climatic averages. The meteorological data considered include monthly, seasonal and annual mean values of maximum temperature, minimum temperature, average temperature, diurnal range of temperature. The average of maximum & minimum temperatures *i.e.*, $(T_{max} + T_{min})/2$ has been considered as average temperature. Also the monthly, seasonal and annual total rainfall, for the said period, has been studied. Further, the frequency of cold waves and severe cold waves have been incorporated in order to corroborate the significant rise in minimum temperature during 1993-2002 and also the annual average temperature, the annual mean minimum temperature, and annual total rainfall for the period subjected to Simple Harmonic analysis to find the cyclic variation in the parameters, if any. In order to find the recent trends, the time series of all the aforesaid parameters have been subjected to linear trend analysis by using least square technique. The empirical trend line is given as $Y_c = a + b X_i$, Where, Y_c , is the fitted values of

TABLE 1

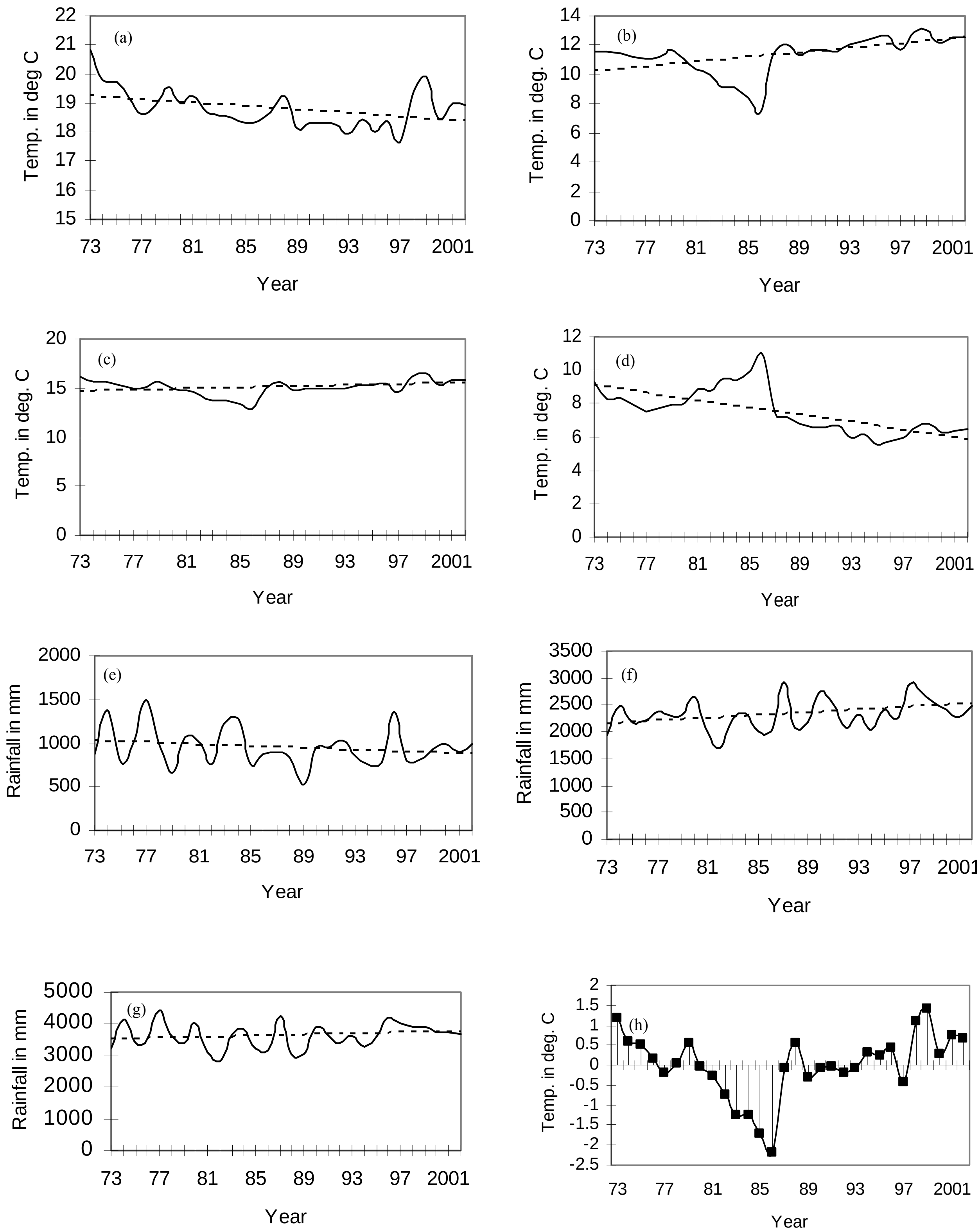
Linear trend in temperature (°C/decade) & rainfall (mm/decade) at M.O. Gangtok

Period	Max temp.	MKR statistics	Min temp.	MKR statistics	Average temp.	MKR statistics	Diurnal range of temp.	MKR statistics	Total rainfall	MKR statistics
Jan	-0.38	-0.2046	0.69	0.2874 (S*)	0.15	0.0529	-1.09	-0.3195 (S)	4.7	0.1126
Feb	-0.45	-0.2138 (S’)	0.65	0.1310	0.15	0.0069	-1.16	-0.3977 (S*)	-8.9	-0.1310
Mar	-0.86	-0.4161 (S*)	0.51	0.2506 (S)	-0.20	-0.0805	-1.37	-0.5034 (S*)	32.0	0.2322 (S’)
Apr	-0.40	-0.2598 (S)	0.45	0.1724	0.02	0.0023	-1.01	-0.5678 (S*)	-12.8	-0.0069
May	-0.07	-0.0483	0.86	0.4115 (S*)	0.42	0.2322 (S’)	-0.94	-0.5908 (S*)	-49.0	-0.2322 (S’)
Jun	-0.26	-0.3471 (S*)	0.81	0.4575 (S*)	0.28	0.2368 (S’)	-1.05	-0.4621 (S*)	59.5	0.0575
Jul	-0.18	-0.1356	0.73	0.4391 (S*)	0.23	0.2919 (S)	-0.92	-0.4897 (S*)	-5.1	-0.0391
Aug	-0.33	-0.3425 (S*)	0.64	0.5034 (S*)	0.16	0.1080	-0.95	-0.4483 (S*)	52.2	0.2184 (S’)
Sep	-0.24	-0.2230 (S’)	0.69	0.4483 (S*)	0.24	0.1908	-0.94	-0.4483 (S*)	14.6	0.0391
Oct	-0.26	-0.1770	0.66	0.3333 (S*)	0.21	0.1310	-0.93	-0.3333 (S*)	22.1	0.0575
Nov	-0.37	-0.0253	0.95	0.3839 (S*)	0.28	0.1862	-1.27	-0.3517 (S*)	1.4	0.0391
Dec	-0.16	-0.0207	1.02	0.4529 (S*)	0.44	0.2137 (S’)	-1.13	-0.4391 (S*)	-4.0	-0.1310
Winter	-0.41	-0.2874 (S)	0.66	0.2644 (S)	0.13	0.0069	-1.13	-0.3195 (S)	-3.3	-0.0207
Pre-monsoon	-0.46	-0.3149 (S)	0.66	0.3609 (S*)	0.13	0.0437	-1.12	-0.5632 (S*)	-53.1	-0.0805
Monsoon	-0.22	-0.3379 (S*)	0.69	0.4943 (S*)	0.21	0.2823 (S)	-0.98	-0.5080 (S*)	130.3	0.2276 (S’)
Post-monsoon	-0.25	-0.1310	0.85	0.3379 (S*)	0.29	0.1770	-1.03	-0.4299 (S*)	25.2	0.1172
Annual	-0.29	-0.3609 (S*)	0.79	0.4345 (S*)	0.25	0.1126	-1.06	-0.5080 (S*)	85.6	0.1264

S* = Significant at 0.99-level; S = Significant at 0.95-level; S’ = Significant at 0.90-level;

the variables and X_i is the i^{th} year; and a = $\sum Y/N$ and b = $\sum XY/ \sum X^2$. The increase or decrease in the trend values of the parameters are determined by the value of ‘b’, positive or negative respectively (Basu, 1982). The statistical significance of the trend coefficients has also been tested by powerful Mann-Kendall rank statistics (T), the value of which is given by $T = [4\Sigma n_i \; T = N(N–1)] - 1$; where n_i is the number of values larger than the i^{th} value in the series, subsequent to its position in the series (WMO, 1966). The test statistics t is given by $t = \pm t_g [(4N + 10) / 9N (N – 1)]^{0.5}$, where t_g is the value of t at the probability point in the Gaussian distribution appropriate to the two tailed test.

4. The results of the analysis of the trend coefficients along with the values of Mann-Kendall rank statistics (T) are depicted in Table 1. The mean maximum temperature of M.O. Gangtok shows decreasing trend for all the months, all the seasons and the year as a whole. The negative trend coefficients are statistically highly



Figs. 1(a-h). Annual (a) Mean Maximum, (b) Mean Minimum, (c) Average and (d) Diurnal range of temperature & trends (dotted lines) and total rainfall (e) Pre-monsoon, (f) Monsoon, (g) Annual rainfall & trend (dotted lines) and (h) departure of annual average temperature from normal (1973-2002) at M.O. Gangtok

TABLE 2

Inter-decadal departure & trends in temperature (°C) and rainfall (mm) at M.O. Gangtok

Decade	Max (°C)	Min (°C)	Average temp (°C)	Diurnal range (°C)	Rainfall (mm)
1973-82	0.55	-0.20	0.18	0.74	-55.5
Students' *t*-test values	2.6297 (S)	-1.1254	1.0398	41810 (S*)	-0.3532
Trend – MKR rank statistics	-0.5111 (S)	-0.6444 (S*)	-0.8222 (S*)	-0.2222	-0.2444
1983-92	-0.35	-0.94	-0.65	0.58	-100.3
Students' *t*-test values	-3.6111 (S*)	-1.7736	-2.3315 (S)	1.1162	-0.7674
Trend – MKR rank statistics	-0.3333	0.5111 (S)	0.3333	-0.7333 (S*)	-0.1555
1993-2002	-0.19	1.13	0.47	-1.34	156.0
Students' *t*-test values	0.8547	8.4858 (S*)	2.7206 (S)	-10.6683 (S*)	1.9373 (S')
Trend – MKR rank statistics	0.3778	0.2444	0.3778	0.5111 (S)	0.0667
Normal (1973-2002)	18.81	11.31	15.06	7.51	3615.8

S* = Significant at 0.99-level; S = Significant at 0.95-level; S' = Significant at 0.90-level

significant at 0.99 level for the month of March, June, August, the monsoon season and the year as whole; significant at 0.95-level for the winter and pre-monsoon season; and less significant *i.e.*, at 0.90-level for the month of February and September. The decreasing trend is found maximum in March *i.e.*, -0.86° C/decade. The mean minimum temperature however shows increasing trend for all the months, all the seasons and the year as a whole. The trend coefficients are statistically highly significant at 0.99-level for all the months, seasons and the year as whole, except in the months of January and the winter seasons in which the trend coefficients are statistically significant at 0.95-level, for March at 0.90-level, and statistically insignificant for the month of February. The trend coefficient is maximum in December *i.e.*, 1.02° C/decade, followed by November *i.e.*, 0.95° C/decade. The average temperature shows increasing trend for all the months, all the seasons and the year as a whole except in the month of March in which it has a decreasing trend. The trend coefficients are statistically significant at 0.95-level for the months of July and the monsoon season only, and less significant *i.e.*, at 0.90-level for the months of May, June and December only, otherwise the trend coefficients are statistically insignificant for rest of the months, seasons and the year as a whole. The trend coefficient is maximum in the month of December *i.e.*, 0.44° C/decade followed by May *i.e.*, 0.42° C/decade.The diurnal range of temperature shows decreasing trend for all the months, all the seasons and the year as a whole. The trend coefficients are statistically highly significant at 0.99-level for all the months, seasons and the year as whole, except in the months of January and the winter seasons in which the trend coefficients are statistically significant at 0.95-level. The negative trend coefficient is found maximum in March *i.e.*, -1.37° C/decade, followed by November *i.e.*, -1.27° C/decade.

The trend coefficients of total rainfall at M.O. Gangtok along with the values of Mann-Kendall rank statistics (*T*), depicted in Table 1, shows increasing trend for the months of January, March, June, August, September, October, November, monsoon, post-monsoon and the year as a whole and decreasing trend in rest of the months and seasons. The positive trend coefficients are statistically less significant at 0.90-level for the months of March, June and the monsoon season, and the negative trend coefficient for the month of May is also less significant at 0.90-level, otherwise the trend coefficients are insignificant for rest of the months, seasons and the year as a whole. The rising trend is highest in the monsoon season *i.e.*, 130.3 mm/decade followed by June *i.e.*, 59.5 mm/decade. The negative trend is found highest in the month of May *i.e.*, –49.0 mm/decade.

5. Figs. 1(a-g) depict annual mean values of maximum temperature, minimum temperature, diurnal range of temperature, average temperature, total pre-monsoon rainfall, total monsoon rainfall and annual total rainfall of Gangtok for the period 1973-2002. The trends in the time series of the said parameters are shown by dotted lines and have been found to vary as hereunder: The annual mean maximum temperature : 95% to 109%; the annual mean minimum temperature : 66% to 109%;

TABLE 3

Frequency of cold waves over M.O. Gangtok (1981-2002)

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Frequency	7 + 1*	4 + 3*	8 + 6*	13+4*	21+6*	24+11*	6 + 3*	Nil	2 + 1*	3 + 1*	2 + 1*
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Frequency	1 + 2*	2	Nil	1	Nil	1	1 + 1*	Nil	3	Nil	Nil

* = Frequency of severe cold waves

the annual average temperature : 86% to 111%; the annual diurnal range of temperature : 83% to 143%; total monsoon rainfall : 84% to 126%; and the annual total rainfall : 78% to 125%. Hence the annual mean values of minimum temperature, average temperature and annual total rainfall for the period under study have been subjected to Harmonic analysis with a view to delineate the regular periodic fluctuation in the aforesaid parameters. The best estimates of sine and cosine amplitudes and their standard errors were obtained by the method of least square fit. From the analysis the amplitudes and their standard errors were estimated. Any value of amplitude exceeding twice the standard error limit was accepted as significant at 5% level of significance. The study of periodogram so generated revealed two prominent peaks in the spectrum of annual mean minimum temperature, annual average temperature and annual total rainfall at 1.0 and 27.0 years, significant at 95% confidence level, suggesting a decadal cycle of variation in the parameters. Moreover, peaks, significant at 95% confidence level, were observed in the spectrum, at 1.0, 2.0, 22.5 (except annual total rainfall), 23.3, 25.0, 26.0, 27.0, 28.0, 29.0 & 30.0 years, implying an increasing trend in the parameters, though exhibiting a decadal cycle of variation.

6. The departure from the normal value of the annual average temperature (1973-2002) is depicted in Fig. 1(h). Also the inter-decadal trends *i.e.*, in terms of Mann-Kendall rank statistics (T) and the inter-decadal departures from normal or average values of the said parameters for the period 1973-2002 along with values of student's t-test are depicted in Table 2. It is observed from the table that :

(*i*) During the decade 1973-82, there was a highly significant decreasing trend in the annual average temperature due to highly significant decreasing trend in the annual mean maximum temperature & a highly significant decreasing trend in the annual mean minimum temperature,

(*ii*) During the decade 1983-92, there was a highly significant decreasing trend in the annual diurnal range of temperature and a significant negative departure in the annual average temperature, due to decreasing trend in the annual mean maximum temperature and a significant increasing trend in the annual mean minimum temperature, which implies that this was the coldest decade under the period of study and

(*iii*) During the decade 1993-2002, both the annual mean maximum and mean minimum temperatures show increasing trend, due to which the annual diurnal range of temperature shows increasing trend significant at 95% confidence level, implying that the decade was the warmest. On Harmonic analysis of mean values of minimum temperature, average temperature and annual total rainfall for the respective three decades (Table 2), the spectrum so generated revealed two prominent but less significant peaks, at 1.1 and 9.2 years, suggesting a cyclic variation in the parameter.

In hill stations when the normal value of minimum temperature is less than 10° C (2nd November to 31st March over Gangtok) and the daily departure of minimum temperature is -3° C to -4° C it is termed as cold wave and when the departure is equal to or more than –5° C, it is termed as severe cold wave (IMD, 1988). It has been found that 1986 was the coldest year with 11 spells of severe and 24 spells of cold wave conditions over Gangtok preceded by 1985, 1984, 1983 and 1987 wherein the frequencies were 27 (6 severe), 17 (4 severe), 14 (6 severe), and 9 (3 severe) respectively (Table 3). Annually, cold wave is found to occur mostly in the month of February. Cold wave conditions have now become few and far between, which may again be attributed to the cause of rise in minimum temperature over Gangtok. From 1990 onwards, the annual spells of cold waves and severe cold waves were: 1990 – 3 & 1, 1991 – 1 & 1, 1992 – 2 & 1, 1993 – 2 & nil, 1995 – 1 & nil, 1997 – 1 & nil, 1998 – 1 & 1 and 2000 – 3 & nil.

7. Hence the following conclusions may be drawn from the study:

(*i*) Due to significant decreasing trend in the mean maximum temperature in the monsoon season, significant increasing trend in the mean minimum temperature throughout the year as a whole, a significant decreasing trend in the diurnal range of temperature has been found throughout the year, resulting in the increasing trend in the annual average temperature, however less significant, leading to a benign and warmer climate at the hill station due to the warming, and a milder winter, reducing the human discomfort level.

(*ii*) Also cold wave conditions have now become few and far between, which may again be attributed to the cause of rise in minimum temperature over Gangtok. From 1990 onwards the annual spells of cold waves and severe cold waves were: 1990 – 3 & 1, 1991 – 1 & 1, 1992 – 2 & 1, 1993 – 2 & nil, 1995 – 1 & nil, 1997 – 1 & nil, 1998 – 1 & 1 and 2000 - 3 & nil.

(*iii*) The annual mean minimum temperature, annual average temperature and annual total rainfall show prominent peaks at 1.0 and 27.0 years, significant at 95% confidence level, suggesting a decadal cycle of variation in the parameters. Moreover, peaks, significant at 95% confidence level, were observed in the spectrum, at 1.0, 2.0, 22.5 (except annual total rainfall), 23.3, 25.0, 26.0, 27.0, 28.0, 29.0 & 30.0 years, implying an increasing trend in the parameters, though exhibiting a decadal cycle of variation.

(*iv*) From the inter-decadal trends and inter-decadal departures from the normal or average values of the said parameters for the period 1973-2002, it is observed that the decade 1983-92 was the coldest and the decade 1993-2002 was the warmest, during which the mean annual total rainfall shows an increasing trend, significant at 0.90-level. On Harmonic analysis of mean values of minimum temperature, average temperature and annual total rainfall for the respective three decades, the spectrum so generated revealed two prominent but less significant peaks, at 1.1 and 9.2 years, suggesting a cyclic variation in the parameter.

(*v*) Orography, the density of population, the distance between tall buildings, vehicular pollution and the industrial development play an important role in controlling the urban climate. At this stage of development, urban climate studies based on routine climatological data leading to description of meteorological features will be necessary for some more time in tropical areas until sufficient knowledge is available for generalization (Rao *et al*., 2004).

(*vi*) However no remarkable change in rainfall pattern over east Sikkim was found. As such further studies, in greater depth, are necessary in order to assess the recent climate changes and its affect on environment in the higher reaches of the Himalayas, especially at locations like Chungthang, Lachen, Lachung & Yumthang.

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