MAUSAM, **66**, 1 (January 2015), 145-154

L E T T E R S

551.583 : 551.524.36 (540.25)

TEMPERATURE VARIABILITY AND TREND OVER RAJASTHAN

1. Man has needed and used energy at an increasing rate for his sustenance and well - being ever he came on the Earth a million years ago. Primitive man required energy primarily in the form of food, then fire for cooking as well as for keeping himself warm. With the passage of time cultivation and agriculture came in his life. Till this time it would not be wrong to say that the Sun was supplying all the energy needs of man either directly or indirectly. Industrial revolution which began with the discovery of the steam engine (1700 AD) brought about a great change. Man began to use a new source of energy, *i.e*., coal in large quantities. A little later, the internal combustion engine was invented (1870 AD) and began to use extensively fossil fuels, oil and natural gas etc. In the recent past few years, it has become obvious that fossil fuel resources are fast depleting and that of fossil fuel era is gradually coming to end. It is worth noting that while man's large scale use of commercial energy (coal, oil and natural gas, hydroelectric power and nuclear power) has led to a better quality of life, it has also created many problems. Perhaps the most serious of these are the harmful effect on the environment. The combustion of fossil fuels has caused serious air pollution problem in many areas because of the localised release of large amounts of harmful gases, *i.e.*, CO_2, CO, water vapour, methane, SO_2, chloro-floro-carbon (CFC) etc. known as green house gases (GHGs) into the atmosphere. It has also resulted in the phenomenon of global warming which is now a matter of great concern. Similarly the release of large amounts of waste heat from power plants has caused thermal pollution leading to the destruction of many forms of flora-fauna. Climate change is now-a-day a great concern for many scientist, researchers and policy makers as the implications of the climate change perceived are detrimental and adverse to the survival of the mankind. Our day to day life in which we use the fossil fuel, refrigerator, coolant, pesticide etc. from which the extract of the gases like carbon dioxide, carbon mono-oxide, methane and halogen released .The few impacts of climate changes are global warming, melting of glaciers, rise in sea levels, sub merging of coastal areas, decrease in pH value of water less than 7, *i.e.*, increases acidity, floods and increase in frequency of heavy rainfall. The present state of our understanding suggests that even though climate change can be by natural caused like, change in orientation of the earth axis, variation in the solar radiation reaching the surface of Earth, variation in the distance between the Sun and the Earth, massive volcanic eruption, change in the rotational speed of the Earth etc. (Seetharam, 2008). The temperature variability now seen as purely due to manmade activities like large scale emission of GHGs from industry into atmosphere and combustion associated with the daily human activities. Many scientific and governmental conventions and conferences sought reduction in the GHGs emissions both from developed and developing countries so as to retard these climate changeses. The Inter governmental Panel on Climate Change (IPCC) in its third assessment report mentioned the average global temperature has increased by about 0.6 °C in last centuary. The IPCC working group I on climate change in its fourth report (IPCC, 2007) concluded that most of the average temperature increases over the past 50 years are due to the observed increase in anthropogenic green house gas concentration at the global and continental scale. The climate change is unequivocal. In the present scenario, the climate change over Rajasthan state comprises ten districts headquarter, *i.e.*, Ajmer, Barmer, Bikaner, Churu, Jaipur, Jaisalmer, Jodhpur, Kota, Sriganganagar and Udaipur have been taken up to find out presence of any noticeable trend in decade wise maximum mean temperature, minimum mean temperature and rainfall in accounts.

2. The available meteorological data for the period 1971-2010 in respect of monthly maximum temperature, monthly minimum temperature and monthly rainfall has been collected from the M.C., Jaipur, India Meteorological Department (IMD). A few missing values in the data so selected have been substituted with long period average values (1971-2000). IMD established observatories are operated by the IMD trained staff indicated in Rajasthan map (Fig. 1), *i.e.*, Ajmer (26° 27′ N, 74° 37′ E), Barmer (25° 45′ N, 71° 23' E) , Bikaner (28° 00′ N , 73° 18′ E), Churu (28° 15′ N, 74° 55′ E), Jaipur (26° 49′ N, 75° 48′ E), Jaisalmer (26° 55′ N, 70° 54′ E), Jodhpur (26° 18′ N, 73° 01′ E), Kota (25° 09′ N, 75° 51′ E), Sriganganagar (29° 55′ N, 73° 53′ E) and Udaipur (24° 37′ N, 73° 53′ E). Daily maximum and minimum temperature data were colleted from MC Jaipur IMD for the period of 1971-2010. For the given period, the mean temperature of the years was calculated by averaging the mean yearly maximum and minimum temperature values. Normal values of different temperature has been obtained based on 30 years data from 1971-2000 by the MC Jaipur IMD. Information on the number of industries since 1st January, 1971 to 31st December, 2010 has been collected from Udog Bhawan (Office of Commissioner of Industries) Govt. of

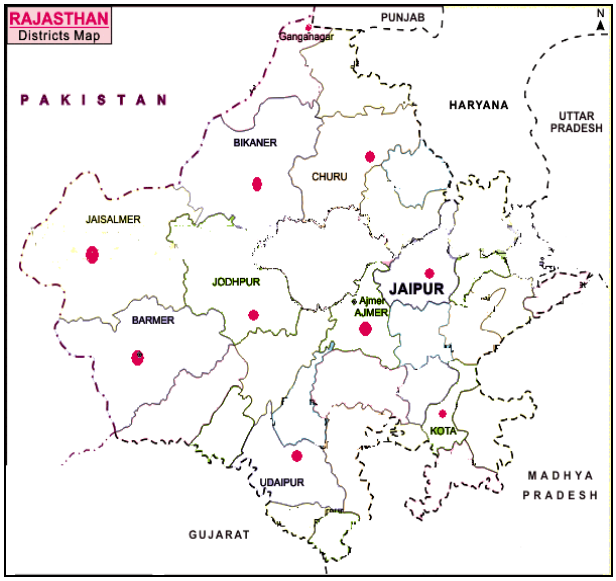

Fig. 1. Rajasthan map indicating IMD observatories

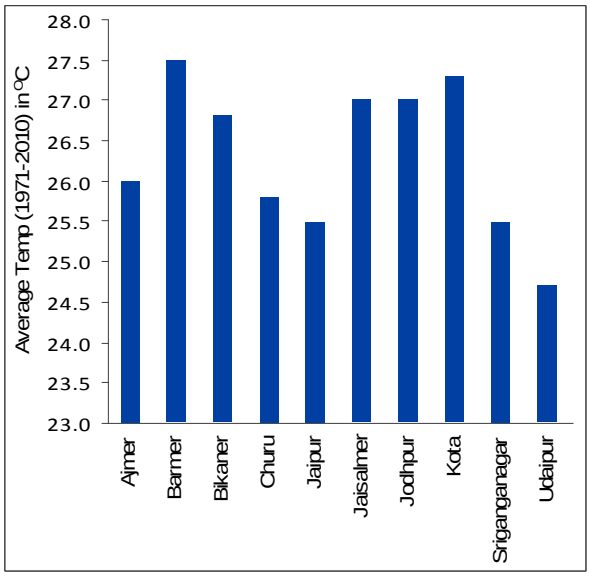

Fig. 3. Average temp (1971-2010)

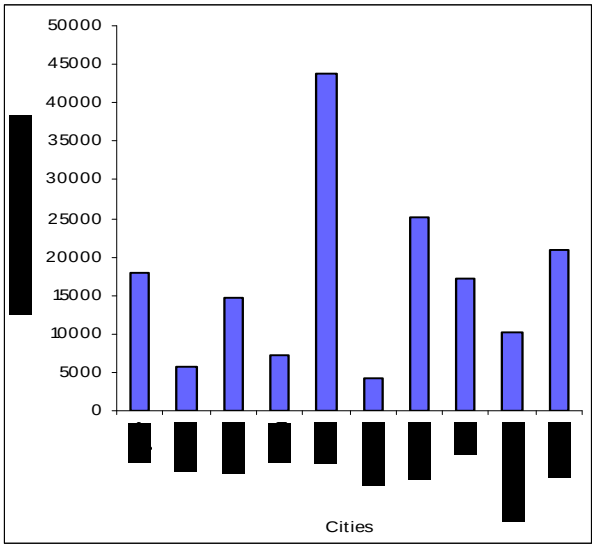

Fig. 2. Rajasthan Registered No of Industries (1971-2010)

Rajasthan. The profile of large scale and micro, small and medium scale industries for all the ten cities have shown in Fig. 2. Whether it is a large scale or micro, small and medium scale industry, air and water get polluted. At present number of working industries for Ajmer 8 large scale and 17902 micro, small and medium scale, for Barmer 3 large scale and 5698 micro, small and medium scale, for Bikaner 2 large scale and 14710 micro, small and medium scale, for Churu only 7315 micro, small and medium scale, for Jaipur 32 large scale and 43693 micro, small and medium scale, for Jaisalmer only 4213 micro, small and medium scale, for Jodhpur 10 large scale and 25176 micro, small and medium scale, for Kota 8 large scale and 17107 micro, small and medium scale, for Sriganganagar 5 large scale and 10132 micro, small and medium scale and for Udaipur 16 large scale and 20861 micro, small and medium scale industries established. In this study the coldest month for Ajmer, Barmer, Bikaner, Churu, Jaipur, Jaisalmer, Jodhpur, Kota, Sriganganagar and Udaipur found January with its mean minimum temperature 7.2 °C, 10.2 °C, 5.7 °C, 4.4 °C, 7.9 °C, 6.9 °C, 8.9 °C, 10.6 °C, 5.3 °C and 7.0 °C. In the same way May found the hottest month for Ajmer, Barmer, Bikaner, Jaipur, Jaisalmer, Jodhpur, Kota and Udaipur with its mean maximum temperature 40.4 °C, 41.8 °C, 41.8 °C, 40.1 °C, 41.6 °C, 41.5 °C, 42.2 °C and 39.6 °C. June found the hottest month for Churu and Srigaganagar with its mean maximum temperature 41.3 °C and 41.8 °C. The normal minimum temperature of January for these cities were found to be 8.2 °C, 10.4 °C, 6.5 °C, 4.6 °C, 8.4 °C, 7.6 °C, 9.6 °C, 11.2 °C, 5.8 °C and 7.0 °C. Normal maximum temperature of May and June for these cities were found to be 40.5 °C, 41.7 °C, 41.9 °C, 41.7 °C, 40.3 °C, 41.4 °C, 41.2 °C, 42.1 °C, 41.5 °C and 39.8 °C respectively.

Earth's climate has been changing both on global and regional scales. People in general believe that weather pattern changing and they believe summers in their areas are getting hotter and lengthening and winter shorter and warmer which is a direct consequence of the global warming (Das *et al.*, 2008). Authors have arranged the mean maximum temperature, mean minimum temperature and average temperature decade wise for all the ten cities. Tables 1-10 are arranged. The minimum temperature of

TABLE 1

Ajmer decade wise temperature and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 32.5 °C)	Mean min temp in °C (Normal = 19.0 °C)	Mean temp in °C (Normal = 25.8°C)	R/F in mm per year
1971-80	32.3	17.5	25.4	620
1981-90	32.8	19.1	26.0	434
1991-2000	32.5	20.2	26.3	574
2001-2010	32.8	20.9	26.8	527
Correlation coefficient	-0.88	-0.32	-0.34	

TABLE 2

Barmer decade wise temp and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 34.6 °C)	Mean min temp in °C (Normal = 20.7 °C)	Mean temp in °C (Normal = 27.7°C)	R/F in mm per year
1971-80	34.3	20.5	27.5	357
1981-90	34.4	20.4	27.6	234
1991-2000	35.0	20.5	27.7	224
2001-2010	34.9	21.0	28.1	296
Correlation coefficient	-0.48	0.21	-0.07	

TABLE 3

Bikaner decade wise temp and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 33.9 °C)	Mean min temp in °C (Normal = 18.7 °C)	Mean temp in °C (Normal = 26.0 °C)	R/F in mm per year
1971-80	33.9	18.5	26.2	202
1981-90	34.0	19.2	26.6	339
1991-2000	34.1	19.8	27.0	306
2001-2010	34.5	20.3	27.4	219
Correlation coefficient	-0.86	-0.35	-0.53	

TABLE 4

Churu decade wise temperature and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 33.6 °C)	Mean min temp in °C (Normal = 17.3 °C)	Mean temp in °C (Normal = 25.5°C)	R/F in mm per year
1971-80	33.2	16.6	25.8	328
1981-90	33.2	17.8	25.9	367
1991-2000	33.7	17.8	25.7	600
2001-2010	34.6	18.6	26.5	356
Correlation coefficient	0.12	0.18	-0.46	

TABLE 5

Jaipur decade wise temperature and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 31.9 °C)	Mean min temp in °C (Normal = 18.8 °C)	Mean temp in °C (Normal = 25.4 °C)	R/F in mm per year
1971-80	31.7	18.4	25.5	479
1981-90	32.0	18.8	25.4	618
1991-2000	32.0	19.5	25.7	598
2001-2010	32.7	19.5	26.1	485
Correlation coefficient	-0.24	0.18	0.48	

TABLE 6

Jaisalmer decade wise temp and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 33.8 °C)	Mean min temp in °C (Normal = 18.7 °C)	Mean temp in °C (Normal = 26.3 °C)	R/F in mm per year
1971-80	34.1	18.3	26.2	213
1981-90	33.9	19.4	26.7	211
1991-2000	34.1	20.2	27.2	259
2001-2010	34.4	20.6	27.5	217
Correlation coefficient	-0.47	-0.53	-0.39	

the most of the cities have increased much for the last three decades due to use of domestic gas for cooking, continuous use of transport like trains, busses, auto mobile and continuous running of industries.

Rain dissolves and removes the GHGs particles from atmosphere and global warming can be reduced. The decades which got more and more rain per year has shown the falling tendency in temperature a reciprocal relation. By the definition of correlation coefficient, it is showing the positive value for the two quantity which are increasing or decreasing proportionately. In our study most of the cases, it is negative (more rain less rise in temperature) value and for some cases (less rain, more rise The in temperature) it is positive and is significant. For Ajmer, Barmer, Bikaner, Jaisalmer, Jodhpur,

TABLE 7

Jodhpur decade wise temp and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 34.1 °C)	Mean min temp in °C (Normal = 19.6 °C)	Mean temp in °C (Normal = 26.9 °C)	R/F in mm per year
1971-80	33.9	19.2	26.6	456
1981-90	34.1	19.6	26.9	294
1991-2000	34.0	19.6	26.8	374
2001-2010	34.2	20.5	27.3	363
Correlation coefficient	-0.59	-0.99	-0.85	

TABLE 8

Kota decade wise temperature rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 32.7 °C)	Mean min temp in °C (Normal = 21.3 °C)	Mean temp in °C (Normal = 27.0 °C)	R/F in mm per year
1971-80	33.1	21.7	27.4	182
1981-90	32.8	21.8	27.3	566
1991-2000	32.8	21.7	27.2	765
2001-2010	33.4	22.0	27.8	689
Correlation coefficient	-0.12	0.39	0.05	

TABLE 9

Sriganganagar decade wise temp & rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 32.7 °C)	Mean min temp in °C (Normal = 17.7 °C)	Mean temp in °C (Normal = 25.2 °C)	R/F in mm per year
1971-80	32.8	17.4	25.6	197
1981-90	32.6	17.8	25.2	313
1991-2000	32.3	17.5	25.2	307
2001-2010	33.6	18.5	26.0	267
Correlation coefficient	-0.33	0.20	-0.54	

TABLE 10

Udaipur decade wise temp and rain with correlation coefficient

Decade	Mean max temp in °C (Normal = 31.8 °C)	Mean min temp in °C (Normal = 17.2 °C)	Mean temp in °C (Normal = 24.5 °C)	R/F in mm per year
1971-80	31.7	17.8	24.7	543
1981-90	31.7	16.0	24.3	599
1991-2000	32.0	17.4	24.7	635
2001-2010	32.5	18.3	25.4	564
Correlation coefficient	-0.04	-0.46	-0.37	

Sriganganagar and Udaipur, the more rain, more likely dissolved the sub particulate matter thus increasing the transparency of the atmosphere and lesser the green house effect. Based on data for 1901-87 Rupakumar *et al*. (1994) found a rising trend in minimum temperature at some cities of India and attributed it mainly to rise in the maximum temperature. However, all temperature parameters are considered in the present study and show that, so far Rajasthan is concern, the temperature has increased in the last three decades for Ajmer, Barmer, Bikaner, Churu, Jaipur, Jaisalmer and Udaipur. The warmest year for Ajmer was 2002 with average temperature 27.9 °C and the ever highest and lowest temperature during 1971-2010 recorded were 46.4 °C on 9 May, 1987 and 1.3 °C on 8 February, 1980, for Barmer it was 2004 with average temperature 29.8 °C and the ever highest and lowest temperature during 1971-2010 recorded were 49.9 °C on 7 May, 1995 and 2.0 °C on 2 January, 1981, for Bikaner it was 2004 with average temperature 28.5 °C and the ever highest and lowest temperature during 1971-2010 recorded were 48.6 °C on 27 May, 1998 and -0.8 °C on 14 December, 1986, for Churu it was 2002 with average temperature 27.2 °C and the ever highest and lowest temperature during 1971-2010 recorded were 49.9 °C on 26 May, 1998 and -0.3 °C on 7 January, 2001, for Jaipur it was 2002 with average temperature 27.1 °C and the ever highest and lowest temperature during 1971-2010 recorded were 49.0 °C on 23 May, 1994 and 1.3 °C on 1 January, 1991, Jaisalmer were 1999 and 2000 with average temperature 27.5 °C and the ever highest and lowest temperature during 1971-2010 recorded were 49.2 °C on 4 June, 1991 and 1.0 °C on 19 December, 1986, for Jodhpur it was 2009 with average temperature 28.7 °C and the ever highest and lowest temperature during 1971-2010 recorded were 48.4 °C on 20 May, 1998 and 0.6 °C on 21 February, 1984, for Kota it were 2002, 2004 and 2010 with average temperature 28.3 °C and the ever highest and lowest temperature during 1971-2010 recorded were 48.5 °C on 28 April, 1984 and 5.9 °C on 12 January, 2009, for Sriganganagar it was 2002 with average temperature 26.7 °C and the ever highest and lowest temperature during 1971-2010 recorded were 49.3 °C on 27 May, 2010 and -0.1 °C on 8 January, 2006 and 21 January, 2008 and for Udaipur it was 2002 with average temperature 25.9 °C and the ever highest and lowest temperature during 1971-2010 recorded were 46.4 °C on 31 May, 1983 and -0.1 °C on 22 February, 1984, 11 January, 1989 to 13 January, 1989.

TABLE 11

Major contributor of GHGs nations, the kind of GHGs, their source of generation and their ill-effects on environment

World countries releasing GHGs		Kind of GHGs release in atmosphere		Source of GHGs		Effect of GHGs on environment	
USA	22%	CO_2 & NO_2 Dust Particle Hydro Carbon SO_2	34- 47 %	Traffic convenience Fuel Industries Forest Fire Fossil Fuel Volcanic Eruption	42%	CO_2 and CO	9-26%
Europe	17.2%		10-17 %		21%	N_2O-NO_2	3-7%
China	17.2%		13%		14%	CFC	36-72%
Russia	6.0%		15%		8%	CH_4	10%
Japan	4.7%		15%		5%	Halon 1301 &	0.0002%
India	4.1%				10%	1211	0.00017%
Australia	1.4%						

Source :IPCC Report , 2007 (Paris)

Karl *et al.* (1993) based on data of 494 stations in the United States found substantial and significant increase in the minimum (night) temperature, Sinha Ray *et al.* (1997) and Sahai (1998) have also found an increasing tendency in mean temperature in some of the cities in India and attributed it partly to rise in minimum temperature. Landsberg (1981) postulated that increase in urbanization would differentially warm the minimum temperature relative to the maximum temperature and attributed it to the heat island effect. In this study authors found that minimum temperature for all the ten cities has increased much with higher percentage. One of the most visible and well accepted evidence in recent years is the gradual increase in the atmospheric pollution and aerosols (Vishnoi, 2011). These aerosols also alter the heat budget of atmosphere. In India some attempts on the effect of industrialization on climate seems to have been earlier studied by Ramana Rao and Ramana Murthy, 1973; Rupakumar and Hingane, 1988 etc.

The growth of number of industries in Rajasthan from 1st January, 1971 to 31st December, 2010 has shown in Fig. 2, for all the ten cities. These industries cover metal, chemical, textile, stone cutting and agro-based etc. each of which release huge amount of gases and particulate matter into air.

3. Developed countries are in the race of getting more and more prosper by their growth of domestic production (GDP) and way of living life luxurious in all possible direction. Developing countries are in the race to gain the status of developed countries and in this race non of single world country seems to ready to reduce the production of GHGs contribution. As per the Inter Governmental Panel on climate change (IPCC, 2007) report and United Nation Frame Work Convention on Climate Change (UNFCCC)-1992, CO_2 enter into our environment through burning of fossils fuel, respiratory process, release by vegetation, volcanic eruption etc. Last 20 years it has increased by 75% of total. Chlro-floro-carbon (CFC) enter into our environment by chemical reaction, fluids used for refrigerants, aerosol, spray, air coolant, fast food container, fire extinguishers and cleaning fluid of electronics components. CFC radicals are having 75 years (Girija and Reddy, 1993) long life in environment, if CFC are converted into HCFC, their life period is 20-25 years only and less harmful. Methane (CH_4) enter in to environment by paddy crops, animal husbandry, natural quagmire, coal mining and burning of waste bio-products, its environmental concentration is very less (0.0002%) but its contribution in global warming is 10% (20 times more effective then CO_2). Life period of a methane molecule in environment is 11 years and entering $52.5*10^7$ tons every year. Nitrous oxide (N_2O) enter into our environment through fertilizer, waste bio-products and burning of fossil fuel. Since 1750-2000 it has increased 17% in environment and its global warming contribution is 6% (It is 320 times effective then CO_2). Life period of a nitrous oxide molecules is 150 years. Halon 1301 & 1211 are electrically non conducting agent used in firefighting equipment and aviation safety. It is a cleaning agent for electronic equipments. Both are effectively destroy the ozone molecules in ozone layer. Their concentration in environment are 2 PPM & 1.7 PPM but both are 16000 times effective then CO_2. These molecules survive for 25 years and 110 years in environment. Major contributor of GHGs nations, the kind of GHGs, their source of generation and their ill-effects on environment are summarized in Table 11.

Although the area of Rajasthan is negligible compare to global surface area, even then it has tried to find out the variability in temperature as it is global phenomenon. It appears to be a slow and steady increase in the mean

yearly maximum and minimum temperature for the years as a whole during 1971-2010. It was decided to classified the period 1971-2010 into decades and then compiled the mean maximum, mean minimum and average temperature.

One very interesting and common warmest years for 60% cities were 2002 and 30% of cities were 2004. The coolest years for 50% of cities were 1997 and 20% were 1983. 2001-2010 found as 100% warmest decade for all the ten cities. Last 2 to 3 decade for all these cities are showing successive warmer decades and authors found that minimum temperature has increased much with higher percentage. According to IPCC, 2007 report since 1997, last 11 years were continuously observed as the hottest. Last 50 years it has observed that cold days and nights are reducing as compare to hot days and nights.

Change in carbon-dioxide concentration has linearly increasing. When carbon-dioxide concentration is increasing so rapidly and linearly, global warming has to rise. Now it is time for world community to think and act seriously to save the environment by reducing GHGs. More and more plantation and protection of deforestation is require. Implementation of renewable sources of energy like wind, solar, tidal, hydroelectric and geothermal, otherwise nature will be unable to stop the natural disasters.

Acknowledgment

The authors are thankful to Dr. L. S. Rathor, Director General of Meteorology and Dr. O. P. Singh Dy. DGM, RMC, New Delhi for their encouragement and support. Authors are also thankful to Shri S. S. Singh, Scientist 'F', Meteorological Center, Jaipur for providing the important data. Authors are also express heartily thanks to unknown referee for his valuable suggestions which have helped immensely to improve both presentation and scientific aspects of the present paper.

Reference

Das, H. P., Dhotre, A. K. and Rase, D. M., 2008, "Temperature Variability & Trends over Pune", *Mausam*, **59**, 3, 291-296.

IPCC Report, 2007.

Karl, T. R., Jones, P. D., Knight, R. W., Kukla, G., Plummer, N., Razuvayev, V., Gallo, K. P., Lindseay, J., Charison, R. J. and Peterson, T. C. , 1993, "A new perspective on recent global warming: Asymmetric trends of daily ma ximum and minimum temperatures", *Bulletin of American Met. Soc.*, **74**, 6, 1007-1023.

Landsberg, H. E., 1981, "The urban climate", *Academic Press*, p285.

Girija, Raja Ram and Reddy, B. M., 1993, "Atmospheric Research from Antarctica", The Indian Institute of Geomagnetism, National Physical Laboratory, 1-104.

Ramana Rao, T. and Ramana Murthy, V, Bh., 1973, "Effect of steel mills on rainfall at distinctly located station", *Indian J. Met. & Geophys.*, **24**, 15-26.

Rupakumar, K. and Hingane, L. S., 1988, "Long term variation of surface and temperature at major cities in India", *Climate Change*, **13**, 287-307.

Rupakumar, K., Krishna Kumar, K. and Pant, G. B., 1994, "Diurnal asymmetry of surface temperature trends over India", *Geophysical Research Letters*, **21** ,8, 677-680.

Sahai, A. K., 1998, "Climate change : A case study over India", *Theor . Appl. Climatol*., **61**, 9-18.

Seetha Ram, K., 2008, "Climate change scenario over Gangtok", *Mausam*, **59**, 3, 361-366.

Sinha Ray, K. C., Mukhopadhyay, R. K. and Chowdhury, S. K., 1997, "Trends in maximum and minimum temperature and sea level pressure over India", Presented in INTROMET – 97, New Delhi 1997.

UNFCCC, 1992.

Vishnoi, B. N., 2011, "Wind analysis for Western Rajasthan for Generation of electricity through wind mills", *Mausam*, **62**, 1, 1-10.

B. N. VISHNOI
R. C. GUPTA*
ANAND NAGAR
KALU RAM SHARMA

Weather Radar Station, IMD, Jaisalmer, India
**Meteorological Centre, Jaipur, India*
(*Received 10 December 2012, Modified 23 July, 2014*)
e mail : wrsjsm@yahoo.co.in