Recent Variability and Trends in Temperatures over India

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ABSTRACT

Present paper focuses on the variability and trends in annual, seasonal and monthly maximum and minimum temperature and other temperature parameters over India as a whole and over different homogeneous region designated as Western Himalaya (WH), North west (NW), North central (NC), Northeast (NE), Interior Peninsula (IP), East coast (EC) and West Coast (WC) during the period of 1975 to 2007. Analysis on the variability and trends in temperature is also presented over widely spaced 23 stations in different subdivision over India. Using the percentile values (extreme temperature indices), the number of hot and cold days in daily maximum temperature and number of hot and cold nights in daily minimum temperature were calculated for every month, season and year during the entire period of study. Annual mean temperature over India as a whole is observed to be 24.5°C with inter-annual variability of 1.1%. Diurnal temperature range (DTR) is found to vary by 1.73% over the India as a whole. The DTR during post monsoon season is most variable compared to other seasons over country. Variation in minimum temperature is higher than the maximum temperature over the country as a whole and in its homogeneous regions. Highest variability in annual mean maximum and minimum temperature is observed in WH region and most significant and accelerated increase in day and night temperature is also observed at the rate of 0.62°C and 0.40°C / decade in WH region. Annual mean maximum temperature is also significantly increasing in WH, NW and in WC regions while annual mean minimum temperature showed positive and significant trend in WH, NW, NC, NE and WC. Annual frequency of hot days showed comparatively increasing at higher rate in the subdivisions situated in peninsular and southern part of country. Significant and fastest increase in hot days is found during monsoon season at the rate of 2.1 days / decade. Occurrence of hot nights is observed to be significantly increasing annually at more accelerated rate in northern India. Annual frequency of cold night over the country as whole clearly showed significant decreasing trend at the rate of 9.0 days / decade. All the seasons in country as whole showed significant declining trends in frequency of cold nights and steeper decline is found in monsoon season.

Keywords: *Maximum temperature, minimum temperature, hot days, cold days.*

1. Introduction

There is general consensus within the scientific community that global surface temperatures have been increasing in recent decades. In 2007, the intergovernmental panel on climate change report mentioned that there is rise in temperature by 0.74 °C in twentieth century and also projected a warming of 0.2°C/decade. Recent studies have also shown that the anthropogenic forcing due to land-use and land-cover changes (LULCC) may also significantly modify the temperature trends (Bonan, 1997; Gallo et al., 1999; Chase et al., 2000; Feddema et al., 2005; Christy et al., 2006; Wichansky et al., 2008; Betts et al., 2007). It is also found that LULC changes have contributed in warming over Western India by 0.06°C/decade (Nayak and Mandal, 2012) which is quite consistent with the result of the present study. Regional surface temperature trends may have different warming rates or even cooling trends relating to land cover/land use changes (Kalnay and Cai, 2003; Findell et al., 2009; McCarthy et al., 2010) such as

urbanization and irrigation (Kueppers et al., 2007; Puma and Cook, 2010). The urban heat island effect can also have a significant impact on warming trends (Oke, 1973; Karl et al., 1988). The cause of increased heating in urban area may be from the trapping of the reflected solar radiation by the narrow arrangement of buildings which is ultimately absorbed by the walls of the buildings. Other factors such as increased atmospheric pollutants, production of waste heat from air-conditioning, refrigeration systems and industrial processes also contribute to a higher minimum temperature. Several researchers have assessed the trends in surface temperature at global and regional level. Rupakumar and Hingane (1988) investigated long term variation of seasonal and annual surface temperature at major industrial and non industrial cities and concluded that non industrial cities did not show any significant trends whereas the industrial cities either showed a cooling tendency after 1950. Kothawale and Rupakumar (2005) observed that surface temperature trend over India as a whole in the period 1901-2003 showed significant warming and accelerated warming in the period 1971-2003.IPCC report also state that after the year 1998, the next nine warmest years are in the decade during 2001-2010. Dhorde et al. (2009) found inconsistent climate response to urbanisation in four mega cities of India. Kothawale et al. (2010) has studied the temperature extreme for pre-monsoon and showed that in general the frequency of occurrence of hot days and hot nights is observed to be increasing and cold days and cold nights have shown wide spread decreasing trend over the seven homogeneous regions of India. Dash and Mamgain (2011) indicated a significant decrease in the frequency of occurrence of cold nights in the winter months in homogeneous regions in the north except in the western Himalaya and maximum warming in the west coast compared to other regions.

In the present paper, an attempt has been made to investigate the annual, seasonal and monthly trends and intra-annual variability over the country as a whole and in its seven homogeneous zones in maximum temperature and minimum temperature. The trends in mean temperature and diurnal temperature range (DTR) have also been studied. Study is also performed on sub-divisional level to investigate the monthly, seasonal and annual trends and variability in maximum, minimum and highest maximum, lowest minimum temperature at wide spread representative stations in 23 different subdivisions over India during the period of 1975 to 2007. Using the percentile values as a threshold (extreme temperature indices), the hot/cold days as well as hot/cold nights are used to estimate the frequencies of extreme temperature events. Location of meteorological stations in different subdivisions of India under present study is shown in Fig.-1 and different homogeneous region over the country is shown in Fig.-2.

Fig.1 Location of all the representative stations under study.

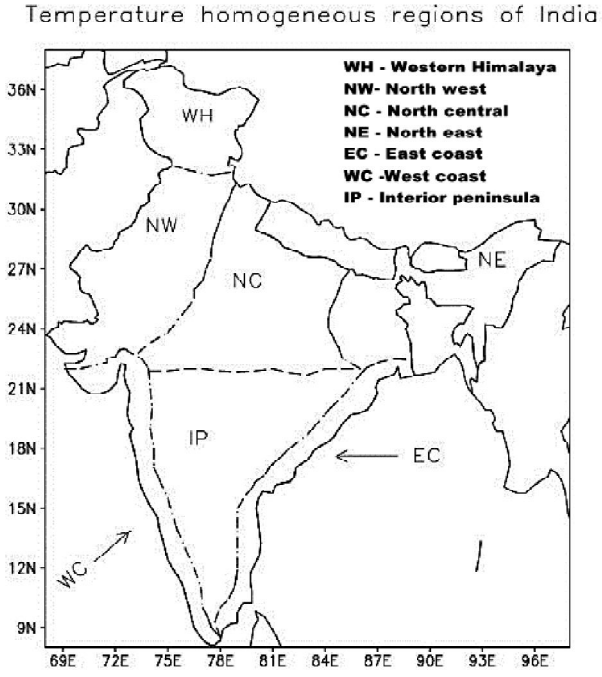


Fig.2 Homogeneous Regions of India.

2. Data and Methodology

The monthly temperature data from 1975 to 2007 of homogeneous temperature regions (western Himalaya (WH), North West (NW), North Central (NC), North East (NE), Interior peninsula (IP), East coast (EC) and West coast (WC) were obtained from IITM (www.tropmet.res.in). The methodology for preparing the datasets is also available on the website of IITM. The monthly temperature data series of maximum and minimum temperature is averaged out separately to get data series of seasonal and annual mean maximum and minimum temperatures. DTR time series is prepared for each homogeneous zone and also over India as whole by subtracting maximum and minimum temperature of each month. Based on climatic features of the months, India Meteorological Department has defined four seasons: Winter (January and February), Pre-monsoon (March–May), Monsoon (June–September) and Post-monsoon (October–December).

The daily temperature series of widespread 23 meteorological stations in different subdivisions over India from the year 1975-2007 were obtained from India Meteorological Department (IMD). Data and quality is checked by appropriate quality control methods. Data quality assessment is an important requirement before the calculation of trends since any erroneous outlier can have a serious impact on the trends. All the daily temperature values for individual stations/months that differ from their corresponding long-term means by more than four times their standard deviation were listed (Alexander et al., 2006) and manually examined to check the outliers. If the daily temperatures were nearly uniform for 3 days before and after a given day with missing temperature data and the weather condition on that missing date is also normal, then the missing value is substituted by the mean of the temperatures on the preceding and the following days of the missing date. All erroneous values were set to missing data.

Highest maximum and lowest minimum temperature of each month is averaged to get seasonal mean values for each station. Highest maximum temperature and lowest minimum temperature is calculated for each year to get the time series of annual mean values for each station and India as a whole.

The arbitrary threshold values are generally used where the climate is less variable (Kothawale and Rupa Kumar, 2005). Hence, in this study, extreme temperature indices are calculated based on the 10^{th} and 90^{th} percentiles. The 10^{th} and 90^{th} percentile values of daily temperatures based on the period 1975–2007 have been computed for each season. Using these percentile values (extreme temperature indices), the number of hot and cold days in daily maximum temperature and number of hot and cold nights in daily minimum temperature were detected for each season and year in the entire data period. The hot/cold days as well as hot/cold nights are used to estimate the frequencies of extreme temperature events. In brief the extreme temperature events are as: Hot days = Days with maximum temperatures above 90^{th} percentile Cold days = Days with maximum temperatures below 10^{th}percentile Hot nights = Nights with minimum temperatures above 90^{th} percentile Cold nights = Nights with minimum temperatures below 10^{th}percentile.

Averaging the seasonal and annual frequencies of each station of extreme temperature events have been constructed for the country as a whole. At large spatial aggregated scale, the different time series for seven homogeneous zones and over country as whole have been examined to observe the trends and inter-annual coefficient of variation (%) which is defined as the ratio of the standard deviation to the mean. Similarly, different time series of the stations in 23 subdivisions are also examined for the trends and variability during the period of present study. The Mann–Kendall nonparametric test is applied in order to detect trends. The magnitude of the trends was estimated using Sen's Slope (Sen, 1968).

3. Results and Discussion

3.1 Spatial and temporal variability

3.1.1 Mean temperature

Annual mean temperature of India as a whole is found to be 24.5^0C in the period of present study. WH region have lowest annual mean temperature 12.3^0C while over EC region, it is highest up to 28.2^0C.In the other homogeneous zones like NW, NC, NE and over WC, it is observed as 25.4^0C, 24.5^0C, 23.6^0Cand 26.3^0C respectively. It is clearly noticed that inter-annual variability in annual mean temperature over India as a whole was 1.1% and largest variability is noticed in the month of February (5.75%) and least in August (1.22%) shown in Table-2c.The WH region showed highest variability while lowest in IP region. Variability in average mean temperature in first half of the year is slightly more than second half of the year in the country as a

whole. Seasonally, winter mean temperature is highly variable in all the homogeneous zones and over India as a whole and least variable in monsoon season. Largest variability is observed in WH (45%) in winter and lowest in the pre-monsoon in EC (0.92%) (Table-2c).

3.1.2 Diurnal temperature range (DTR)

Mean DTR over India as a whole is 12.1^{0}C and it is largest during winter (14.7^{0}C) and lowest during monsoon season (8.8^{0}C). Largest DTR is observed over NC region (15.7 ^{0}C) during pre-monsoon while lowest in WC (6.4^{0}C) in monsoon season. Lowest diurnal range is observed during the monsoon season in the entire homogeneous zone except over WH where lowest diurnal range is occurred in winter. Diurnal temperature range is observed to be largest in post-monsoon season in NW region while in NC and NE it is noticed in pre-monsoon season. All the other regions, in peninsular and southern India, DTR were highest in winter. Inter-annual variability in DTR over India as a whole is noticed 1.73% whereas month wise largest variability is observed during the month of December (6.51%) and least in April (3.22%) and seasonally diurnal temperature range in post monsoon season is highly varied in the country. Monthly analysis showed that the diurnal range over India as a whole is highest in the month of March(14.7^{0}C), while in NW (16.5^{0}C) November, NC (16.4^{0}C) April, NE (13.9^{0}C) and IP (15.2^{0}C) March, EC (10.4^{0}C) and WC (13.7^{0}C) February showed highest diurnal range. Most variable DTR is observed in WH in the month of December (19.25%), while in NW, NC and NE, the largest variability is observed in the month of July. The highest variability is noticed in the month of November in IP (9.65%) and WC (8.00%) while in February in EC (9.24%) showed largest variability in DTR (Table-2d).

3.1.3 Maximum temperature

Maximum temperature over the country as a whole is observed to be 31.3^{0}C .The highest mean maximum temperature during all the homogeneous zones and India as a whole during the period of study occurred during the month May except over WH and WC where it was noticed in the month of July and April respectively. Highest mean maximum temperature among the entire homogeneous zone is found over NW India (39.5^{0}C) in the month of May. Similarly, in the subdivisions, annual mean maximum temperature was largest in west Rajasthan (34.2^{0}C) and Kutch (34.2^{0}C) and lowest mean maximum temperature is observed in Sikkim (18.7^{0}C) and Kumaun (Uttarakhand) (18.8^{0}C).

.3.1.4 Highest maximum temperature

Mean annual highest maximum temperature in the period of 1975-2007 is observed to be highest in West Rajasthan (46.0^{0}C) over NW region and lowest at the station in Sikkim (29.3^{0}C) over NE. Mean annual highest maximum temperature is observed above 45^{0}C over NW region at the station in Delhi and west Rajasthan. Most of the stations in NW and NC India have mean annual highest maximum temperature in between 40^{0}C to 45^{0}C during the period of the present study. Variability of highest temperature in first half of the year is comparatively higher than the latter half of the year. Highest temperature is also highly varied in winter season and least in monsoon season in almost all the subdivisions in north while at the stations in IP, EC and WC region, maximum variability is observed in pre monsoon season. Annual highest maximum temperature is highly variable in Sikkim (9.03%), Coastal Andhra Pradesh (CAP) (5.36%) and least variable in Madhya Maharashtra (1.73%).

3.1.5 Minimum temperature

The lowest mean minimum temperature is found in the month of January over India as a whole. All homogeneous zones have highest mean minimum temperature in monsoon season (JJAS) except EC region. Pre-monsoon season of EC region showed hottest night in the month of May. Over most of subdivisions except few stations in southern India, highest mean minimum temperature is noticed in monsoon season. The inter-annual variability in mean minimum temperature over India as a whole is 1.57%, largest 6.48% in the month of November and minimum in August 1.01%. All regions except WH region, the largest inter-annual variability is observed in winter season where as in WH region maximum variation in night temperature is observed in post- monsoon season. Monthly analysis showed maximum variability in November in WH (105.88%) and IP (6.58%) while in NC, NW and NE region, maximum variation is occurred in February (Table-2b). Maximum inter-annual variation over east and west coast is noticed in December. Average minimum temperature in first half of the year in the entire homogeneous region and over India as a whole showed higher inter annual variability compared to the latter half. WH region showed 50% more variability in the first half of the year which is observed to be highest difference among all the regions.

In the sub divisional analysis, night temperatures also showed maximum inter annual variability as like day temperatures over Himalayan region Kumaun, Uttarakhand (15.37%) and in Sikkim (13.01%). All the subdivisions under study also showed highest variation in minimum temperature observed in winter and lowest in monsoon season. Station in Uttarakhand, east Uttar Pradesh (U.P), Bihar, Gangetic west Bengal, Vidarbha, SIK have maximum variability in the month of January while station at Delhi, east Rajasthan, North east, Sikkim, Tamilnadu have maximum variability in February. Maximum variability in the month of December is observed in west Rajasthan, Kutch, east Madhya Pradesh (M.P), Orissa, Telangana, CAP and NIK. Inter-annual variability (203.6%) in minimum temperature in the month of November at the station in Jammu & Kashmir is highly variable.

3.1.6 Lowest minimum temperature

Mean annual lowest minimum temperature during the study period is lowest in J&K (-7.5 ^{0}C) over WH region and largest at the station in Kerala (19.7^{0}C) over the WC. Highest variability in annual lowest minimum temperature among all subdivision is noticed in Sikkim (116.7%) in the NE region, West Rajasthan (72.5%) and Kutch (71.7%) in NW region and least in Kerala subdivision in WC region (2.9%). Almost all the subdivisions in the present study showed largest inter annual variability in seasonal mean lowest minimum temperature during post monsoon to winter season and least during the pre-monsoon to monsoon season. Lowest temperature in winter is highly variable in all the subdivisions and least in monsoon season; however some stations in WH, NW, IP and NE region showed comparatively greater inter annual variability in mean lowest temperature in pre monsoon season. Monthly analysis showed that the lowest minimum temperatures were highly variable in the month of January in most of the subdivisions except at the station in WH where it occurred in March. Stations in NE and EC showed maximum variability in the month of February in the present study.

3.2 Trends in temperatures

3.2.1 Mean temperature

Annual mean temperature of the India as a whole is noticed significantly increasing at the rate of 0.22^{0}C/decades and significantly increasing in winter 0.28^{0}C/decade and monsoon season 0.16^{0}C/decade over the country as a whole. Significant warming in the month of February, March, July, August, September, November and December is also observed over the country as a whole. Significant increasing trend is observed in all the seasons in WH and WC. WH region is observed to be significantly warming at the highest rate during all the seasons and among the entire zones in the country. Most fastest and significant warming is noticed in winter (0.84^{0}C/decade) in WH region (Table-1c). Similarly most significant warming trend at higher rate is noticed in monsoon and post monsoon season over NE. Significant warming trend is also observed during winter and the pre-monsoon in NW region while winter and monsoon in IP and EC region. No significant trend is seen in NC region.

3.2.2 Diurnal temperature range

Annual mean DTR did not show significant trend over the country as a whole or in any homogeneous zone, while seasonally positive significant trend is observed during pre-monsoon and post-monsoon season in WH region while negative significant trend is noticed over WH during monsoon season and during the pre-monsoon season over NE region. Most significant and positive trend is seen in February and March at the rate of 0.82^{0}C/decade in WH region (Table-1d).

3.2.3 Maximum temperature

Annual mean maximum temperature showed significant increasing trend at the rate of 0.22^{0}C/ decade over India as a whole during the period of study. In the homogeneous zone, except NC, and NE region all the other regions showed significant increasing trend in annual mean maximum temperature with most steeper and positive trend at the rate of 0.62^{0}C/decade is seen in WH region (Table-1a).

All the seasons except monsoon season showed significant rising trend in maximum temperature over India as a whole although mean monthly maximum temperature of July and November is found significantly increasing over the country. Maximum temperature over WH and WC is observed to be significantly increasing during all the seasons, while no significant trend is found in any season over NC region. Maximum temperature of WH, NW, IP, EC and WC region is significantly increasing in winter and steeper increase is observed over WH region at the rate of ~1.1^{0}C/ decade. Day temperatures in the pre-monsoon is most significantly increasing over WH, NW and WC region while most significant warming in monsoon season is seen over WH and WC region only.

Significant warming in day temperature in post monsoon season is only noticed in WH, NW, NE and WC region.

Monthly mean maximum temperatures of the months from August to December along with February, March and April over WH and WC regions showed significant increase in maximum temperature. Significant decreasing trend is only seen at the station in EC in the month of June and October. In WH and NW region first half of the year (winter to the pre-monsoon season) showed greater rate of warming in maximum temperature while in IP, EC and WC, faster rate of warming is noticed during the post-monsoon to winter season (Table-1a).

Annual mean maximum temperature of the country as a whole, based on the maximum temperature of the stations in different subdivisions under study is found to be significantly increasing at the rate of 0.15^0C/decade. Most accelerated significant increase in annual mean maximum temperature at the rate of 0.45^0C /10 year is observed at the station in east Rajasthan in NW region, along with it the station in Kumaun region in Uttarakhand (WH), West M.P (NC), and Vidarbha, Telangana (IP), Orissa, Tamilnadu (EC), Madhya

TABLE-1
Sen estimator of slope (°C/Year)

Maximum Temperature

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	0.015	0.046	0.015	-0.007	-0.007	**0.039**	0.030	**0.033**
FEB	0.045	**0.150**	0.050	0.040	0.029	0.033	0.031	0.036
MAR	0.026	**0.119**	0.050	0.019	-0.008	0.023	0.021	0.031
APR	0.023	0.083	0.046	0.023	-0.012	0.000	0.000	0.018
MAY	0.000	0.068	0.012	-0.022	0.013	0.000	0.000	0.017
JUN	0.000	0.014	0.000	-0.010	-0.008	0.010	-0.010	0.020
JUL	0.015	0.028	0.030	0.000	0.013	0.015	0.017	0.011
AUG	0.020	0.038	0.032	0.016	0.019	0.009	0.012	0.017
SEP	0.016	0.043	0.026	0.014	0.013	0.007	0.008	0.018
OCT	0.000	0.046	0.013	0.000	0.011	*-0.011*	-0.010	0.000
NOV	0.030	**0.075**	**0.046**	0.019	0.021	0.025	0.017	0.031
DEC	0.029	0.084	0.025	0.017	0.028	0.038	0.018	0.020
JF	0.025	**0.106**	0.038	0.011	0.000	0.037	0.029	**0.036**
MAM	0.018	0.089	0.040	0.007	0.000	0.007	0.008	0.017
JJAS	0.014	0.029	0.022	0.006	0.010	0.010	0.008	0.013
OND	0.020	**0.063**	0.028	0.014	0.018	0.020	0.007	0.017
ANNUAL	**0.022**	**0.062**	**0.031**	0.010	0.010	0.013	0.014	**0.022**

(a)

Minimum Temperature

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	0.018	0.046	0.029	0.008	0.012	0.009	0.000	0.020
FEB	**0.038**	**0.075**	0.045	0.053	0.050	0.000	0.000	0.020
MAR	0.028	0.050	0.042	0.033	0.020	0.010	0.020	0.020
APR	0.024	0.043	0.031	0.025	0.020	0.000	0.008	0.020
MAY	0.019	0.050	0.023	0.012	0.024	0.010	0.007	0.016
JUN	0.013	**0.049**	0.007	0.016	0.011	0.015	0.009	0.014
JUL	**0.021**	0.043	0.013	0.018	**0.022**	0.020	0.018	0.017
AUG	**0.014**	0.038	0.006	**0.017**	**0.025**	0.011	0.006	0.012
SEP	**0.021**	0.050	0.019	0.023	0.018	**0.018**	0.012	0.021
OCT	0.009	0.012	0.002	0.012	0.019	0.013	0.012	0.008
NOV	0.020	0.025	0.020	0.027	0.020	-0.015	0.000	0.000
DEC	0.010	0.015	0.031	0.020	0.020	-0.017	*-0.011*	0.000
JF	**0.031**	0.055	0.039	0.033	0.034	0.000	0.000	0.020
MAM	**0.022**	0.050	0.036	**0.026**	0.021	0.008	0.012	0.020
JJAS	**0.018**	**0.049**	0.007	0.020	**0.020**	**0.018**	0.012	**0.018**
OND	0.012	0.010	0.014	0.016	0.018	0.000	0.000	0.009
ANNUAL	**0.020**	**0.040**	0.021	**0.022**	**0.021**	0.007	0.005	0.014

(b)

Mean Temperature

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	0.017	0.055	0.025	0.000	0.000	0.021	0.017	0.028
FEB	0.040	**0.111**	0.051	0.044	0.040	0.018	0.013	**0.031**
MAR	0.028	0.086	0.051	0.029	0.008	0.014	0.022	0.026
APR	0.021	0.065	0.040	0.025	0.009	0.000	0.005	0.017
MAY	0.010	0.057	0.013	-0.007	0.017	0.004	0.005	0.016
JUN	0.006	0.030	0.000	0.002	0.000	0.013	0.000	0.017
JUL	0.018	0.035	0.026	0.011	0.019	0.014	0.021	0.016
AUG	0.016	**0.035**	0.021	0.019	0.018	0.011	0.009	0.013
SEP	0.018	0.046	0.025	0.014	0.016	0.013	0.009	**0.018**
OCT	0.008	0.023	0.008	0.004	0.014	0.000	0.000	0.006
NOV	0.026	**0.057**	0.033	0.029	0.020	0.007	0.002	0.016
DEC	0.020	**0.045**	0.027	0.018	0.023	0.008	0.000	0.013
JF	**0.028**	**0.084**	0.039	0.019	0.019	0.020	0.017	**0.030**
MAM	0.020	**0.067**	0.034	0.017	0.013	0.009	0.010	0.019
JJAS	0.016	**0.038**	0.017	0.013	0.016	0.013	0.011	0.016
OND	0.018	**0.042**	0.020	0.017	0.018	0.008	0.003	**0.015**
ANNUAL	**0.020**	**0.054**	**0.028**	**0.018**	0.017	0.011	0.011	**0.018**

(c)

Diurnal temperature range

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	0.000	-0.015	-0.009	-0.014	-0.018	0.032	0.015	0.011
FEB	0.010	0.082	0.008	-0.012	-0.012	0.029	0.032	0.020
MAR	0.000	0.082	0.000	-0.023	-0.044	0.009	0.000	0.013
APR	0.000	0.059	0.012	0.000	-0.038	-0.004	-0.009	0.000
MAY	-0.008	0.031	-0.009	-0.027	-0.009	-0.010	0.000	0.000
JUN	-0.017	-0.040	-0.009	-0.026	-0.025	-0.005	-0.016	0.005
JUL	-0.006	-0.013	0.015	-0.017	-0.008	-0.006	0.000	-0.007
AUG	0.004	0.004	0.026	-0.004	-0.009	0.000	0.000	0.004
SEP	-0.008	-0.017	0.010	-0.008	0.000	-0.008	0.000	-0.004
OCT	-0.018	0.057	0.000	-0.018	0.000	-0.031	-0.024	-0.005
NOV	0.018	0.044	0.033	0.008	-0.005	0.033	0.018	0.027
DEC	0.017	0.087	-0.002	0.000	0.008	0.038	0.029	0.025
JF	0.000	0.022	-0.003	-0.012	-0.022	0.025	0.019	0.007
MAM	-0.006	0.049	0.001	-0.014	-0.025	0.000	-0.003	0.002
JJAS	-0.005	-0.015	0.017	-0.013	-0.011	-0.003	-0.003	-0.001
OND	0.012	0.058	0.021	0.002	0.000	0.017	0.007	0.013
ANNUAL	0.001	0.021	0.012	-0.012	-0.010	0.007	0.005	0.005

(d)

Underlined-significant at 5% significance level ,Shaded –significant at 1% significance level,
Bold -significant at 0.1% significance level

TABLE-2
Coefficent of Variation (%)

`Maximum Temperature

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	2.52	23.92	3.31	3.99	3.50	2.52	**2.06**	1.90
FEB	**4.08**	**26.19**	**5.40**	**5.00**	**4.46**	**4.08**	2.01	**2.29**
MAR	3.22	17.15	4.86	4.43	3.27	3.22	1.41	2.17
APR	2.21	9.71	3.58	2.74	2.97	2.21	1.38	1.35
MAY	1.83	9.16	2.75	2.45	2.18	1.83	2.06	1.76
JUN	2.47	3.35	2.69	3.61	2.60	2.47	2.16	2.23
JUL	1.92	3.22	3.14	3.13	1.48	1.92	1.77	1.66
AUG	1.20	3.06	2.59	1.62	1.44	1.20	1.32	1.73
SEP	1.47	3.63	2.81	2.53	1.50	1.47	1.47	1.56
OCT	1.78	5.80	3.12	2.61	1.86	1.78	1.38	2.00
NOV	1.79	8.34	2.92	2.44	1.81	1.79	1.56	1.70
DEC	2.25	16.70	4.14	3.36	2.81	2.25	1.46	1.38
JF	**2.73**	**19.39**	**3.67**	**3.55**	**3.10**	**2.15**	**1.78**	**1.83**
MAM	1.56	8.82	2.59	2.07	1.81	1.29	1.02	1.15
JJAS	1.13	1.99	1.94	1.68	1.06	1.49	1.13	1.41
OND	1.52	7.06	2.74	2.25	1.52	1.67	1.05	1.21
Annual	0.98	4.88	1.65	1.06	1.03	0.86	0.72	0.93

(a)

Minimum Temperature

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	**5.58**	-37.70	10.24	8.46	6.18	5.85	3.74	3.53
FEB	5.52	-70.24	**10.57**	**9.20**	**7.45**	4.53	3.35	3.37
MAR	3.85	60.13	6.00	5.72	4.91	2.23	2.07	2.62
APR	2.88	15.23	4.70	3.76	3.28	1.99	1.43	2.30
MAY	2.39	11.55	3.60	3.26	2.68	2.07	1.60	1.57
JUN	1.54	6.58	2.31	2.12	1.64	1.86	1.65	1.32
JUL	1.35	5.80	1.84	1.68	1.47	1.42	1.52	1.41
AUG	1.01	4.90	1.47	1.16	1.54	1.14	1.05	1.37
SEP	1.59	8.90	2.37	1.85	1.64	1.31	0.96	1.49
OCT	2.60	16.10	4.75	4.02	3.26	2.02	1.14	1.90
NOV	6.48	**105.88**	8.17	8.41	5.90	**6.58**	3.30	**4.83**
DEC	5.56	-52.46	8.84	7.50	6.04	6.50	**3.88**	3.54
JF	**4.52**	-42.87	**9.36**	**6.59**	**5.41**	**4.32**	**3.04**	**2.84**
MAM	2.27	13.53	3.41	2.94	2.47	1.62	1.24	1.74
JJAS	1.11	4.39	1.41	1.27	1.25	1.22	1.05	1.19
OND	3.47	**52.41**	5.28	4.61	3.21	3.56	2.01	2.69
Annual	1.57	9.66	2.31	1.99	1.71	1.16	1.10	1.27

(b)

Mean Temperature

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	4.47	**69.48**	4.79	4.47	3.43	**3.10**	**2.20**	2.01
FEB	**5.74**	46.76	**6.39**	**5.74**	**5.06**	2.11	1.70	2.19
MAR	4.65	21.23	4.95	4.65	3.36	1.92	1.32	2.25
APR	2.93	10.45	3.82	2.93	2.69	1.75	1.29	1.59
MAY	2.53	9.54	2.94	2.53	2.13	2.24	1.78	1.50
JUN	2.83	3.69	2.38	2.83	1.97	2.63	1.85	1.77
JUL	2.26	3.41	2.47	2.26	1.35	1.74	1.60	1.47
AUG	1.22	3.05	1.98	1.22	1.32	1.11	1.12	1.50
SEP	1.81	4.62	2.36	1.81	1.42	1.27	1.11	1.30
OCT	2.43	5.69	3.10	2.43	2.01	1.45	0.86	1.47
NOV	3.89	10.55	3.59	3.89	2.79	3.06	1.91	**2.31**
DEC	2.76	22.02	4.01	2.76	2.90	2.79	1.92	1.42
JF	**2.97**	**45.11**	**4.87**	**3.93**	**3.39**	**2.19**	**1.72**	**1.75**
MAM	1.73	9.59	2.78	2.23	1.77	1.25	0.92	1.32
JJAS	1.07	2.50	1.60	1.27	1.02	1.26	1.02	1.27
OND	1.84	7.44	2.90	2.45	1.80	1.97	1.21	1.45
Annual	1.10	5.60	1.76	1.18	1.13	0.84	0.75	1.00

(c)

Diurnal Temperature Range

	AI	WH	NW	NC	NE	IP	EC	WC
JAN	3.88	**16.57**	3.38	6.04	6.22	6.65	7.74	4.79
FEB	**5.87**	16.00	6.35	6.51	5.68	7.85	**9.24**	5.51
MAR	4.09	13.57	6.36	5.34	6.21	4.97	5.60	3.04
APR	3.22	10.05	4.63	3.98	6.84	3.27	3.43	3.27
MAY	3.37	9.59	4.16	5.09	5.30	5.08	5.06	5.04
JUN	6.13	7.08	5.64	8.97	8.24	7.70	5.80	6.29
JUL	6.12	8.91	8.49	**10.85**	5.12	6.38	4.35	5.40
AUG	3.54	7.65	8.12	6.44	5.11	4.18	4.01	5.03
SEP	5.30	6.69	7.21	9.27	4.67	7.21	5.33	6.41
OCT	5.16	9.75	7.14	7.72	**6.99**	8.31	7.03	7.40
NOV	6.20	11.18	7.46	6.27	6.50	**9.65**	8.44	**8.60**
DEC	6.51	19.25	**7.70**	7.85	6.15	7.72	8.28	6.06
JF	**3.81**	**12.13**	3.88	5.13	**4.68**	**6.06**	**7.06**	4.42
MAM	2.06	8.23	3.20	3.16	4.57	2.89	3.49	1.97
JJAS	3.62	4.11	4.83	**5.84**	4.01	4.27	3.35	3.85
OND	3.99	10.02	**5.60**	5.08	3.91	5.25	5.02	**4.75**
Annual	1.73	5.13	2.49	2.81	2.86	2.30	2.65	1.74

(d)

Bold letter- Highest vaue , underlined- Lowest value

Maharashtra and Kerala in (WC) showed significant warming in annual mean maximum temperature.

On seasonal scale, seasonal mean maximum temperature during winter is noticed significant increase in Telangana in (IP), Tamilnadu, Orissa (EC) and Kerela(WC) while in the pre-monsoon, west Rajasthan (NW), Tamilnadu (EC) and Kerela (WC) showed significant warming and at the station in Kutch (NW), significant cooling trend is observed at the rate of 0.33^0C /10 year. Monsoon season of the station in J&K (WH), North East (NE), Tamil nadu (EC) and Kerala (WC) showed significant increasing trend in mean maximum temperature during the period of present study. Post monsoon season of the station in East Rajasthan (NW), Vidarbha (IP), Tamilnadu (EC) and Kerala (WC) showed increasing trend while the station in east U.P and Gangetic west Bengal showed significant decreasing trend at the rate of 0.25^0C, 0.18^0C/10 year respectively.

Monthly trend in mean maximum temperature clearly indicate the significant increasing trend in most of the months in Tamilnadu and Kerala and decreasing trend in most of the month in Bihar (Table-3a). Highest rate of significant cooling in day temperature is observed in January (-1.3^{0}C/10 year) in Bihar. Similarly, station in Sikkim showed a decreasing trend in most of the months but significant only in April and June. It is conspicuously observed that average maximum temperature in first half of year over the country showed significant and faster rate of increase than in later half and also with average maximum temperature of winter and post monsoon taken together.

3.2.4 Highest maximum temperature

Annual highest maximum temperature over the country as a whole is found to be increasing at the rate of 0.03^{0}C/10 year (insignificant). It is seen significant increasing at the station in J&K(WH), Telangana (IP) and in Kerala(WC) and at the largest rate in Telangana (IP region) (0.57^{0}C/10 year). On the other hand significant decreasing trend is observed at the station in Sikkim.

Significant increasing trend at the rate of 0.54^{0}C/ 10 year is noticed in winter season over the country as a whole. Seasonal mean highest temperature in winter is found to be significantly increasing at the station in Uttarakhand (WH) , east Rajasthan(NW), west M.P., Telangana, NIK, SIK (IP) and Kerala, Madhya Maharashtra (WC), largest rate of increase is seen at east Rajasthan (0.84^{0}C/decade) in NW region. Mean highest temperature in the pre-monsoon season is observed to be significantly increasing at Delhi, Rajasthan (NW region) Madhya Maharashtra, Kerala (WC), Vidarbha, Telangana (IP), Kumaun region of Uttarakhand and J&K (WH). The J&K Subdivision (WH) showed fastest and significant increase at the rate of 0.95 ^{0}C/10 year. Significant increasing trend during the monsoon season is seen mainly at the station in J&K (WH) , North east(NE), Tamilnadu (EC) and Kerala(WC) while significant decreasing trend in Sikkim (NE). Similarly positive significant trend during post monsoon is noticed at the station in J&K (WH), east Rajasthan (NW), Northeast (NE), Tamilnadu (EC) and Kerala (WC). Monthly highest temperature is observed to be increasing in most of stations in month of December and January and decreasing in the month of June.

3.2.5 Minimum temperature

Annual mean minimum temperature over India as a whole is observed to be significantly increasing at the rate of 0.20^{0}C/10 years. Positive and significant trend is observed over all regions except IP and EC (Table-1b). Most significant and steeper warming trend in night temperature is seen in western and eastern Himalayan region.

Seasonal mean minimum temperature over the country as a whole is significantly increasing during winter, pre-monsoon and monsoon seasons (Table-1b). Significant warming trend in night temperatures during winter is noticed in all the homogeneous regions except IP and EC, highest over WH region (0.55^{0}C /decade) while during pre-monsoon, significant increasing trend is observed over all the regions except IP. Only NW did not show any significant trend in monsoon season. No significant trend is noticed during the post-monsoon season Average minimum temperature in the first half of the year over the country and in WH, NW NC,NE and in WC showed significant increasing trend at the rate more than twice the rate in later half.

In the individual months, the largest rate of increase in night temperature is noticed in the month of February 0.38^{0}C/decade over the country as a whole. The months July, August, and September also showed significant warming in night temperature over the country as a whole (Table 1b). Except the months October and November, rest of the months showed significant increasing trend over WH region. The mean minimum temperature of February is noticed significantly increasing over all the homogeneous regions in the northern India (WH, NW, NC and NE).

Analysing the sub-divisional annual mean minimum temperature, significant increase is found over the country at the rate of 0.29 ^{0}C/10 year. Except at the station in Bihar, most of the subdivisions in northern India showed significant increasing trend. Stations in Uttarakhand (WH), Delhi, Rajasthan, Kutch in NW, east M.P, Gangetic West Bengal along with Northeast and Sikkim in NE showed significant increasing trend in annual mean minimum temperature.

Season wise, the mean minimum temperature during winter is observed to be significantly increasing in Uttarakhand in WH, Madhya Pradesh (NC), Gangetic West Bengal and Sikkim in NE and most accelerated increase in noticed in Delhi, Kutch, west Rajasthan in NW region. Similarly at the station in Garhwal, Uttarakhand in WH, Delhi, Rajasthan, Kutch (NW), east M.P. (NC), Gangetic West Bengal and Sikkim (NE) and over southern India the station in Madhya Maharashtra (WC) with

TABLE-3A
Sen estimator of slope (°C/Year) of Maximum Temperature

SUBDIVISIONS	STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JF	MAM	JJAS	OND	ANNUAL
JAMMU&KASHMIR	KUPWARA	-0.037	0.065	0.132	0.032	0.073	0.036	0.075	0.029	0.008	0.000	0.063	-0.010	0.019	0.074	0.030	0.037	0.035
GARHWAL	DEHRADUN	-0.019	0.020	0.063	0.030	-0.024	-0.030	-0.008	0.007	-0.004	-0.005	-0.006	0.000	0.000	0.025	-0.006	0.000	0.006
KUMAUN	MUKTESHWAR	0.067	0.055	0.095	0.050	0.005	0.000	0.014	0.000	0.006	-0.015	0.013	0.010	0.056	0.037	0.009	0.005	0.028
DELHI	DELHI	-0.053	0.028	0.033	0.045	0.011	-0.002	0.040	0.044	0.000	-0.027	0.016	-0.021	-0.020	0.029	0.016	-0.014	0.006
EAST RAJASTHAN	JAIPUR	0.014	0.058	0.075	0.058	0.021	0.012	0.043	0.036	0.041	0.011	0.056	0.033	0.032	0.052	0.031	0.033	0.045
WEST RAJASTHAN	JAISALMER	0.018	0.036	0.069	0.041	0.032	-0.030	0.055	0.000	0.054	0.038	-0.005	0.032	0.031	0.052	0.020	0.008	-0.017
KUTCH	BHUJ	0.000	0.033	0.007	-0.038	-0.055	-0.055	-0.018	-0.009	-0.008	-0.033	0.025	-0.006	0.018	-0.033	-0.027	0.000	-0.014
WEST M.P	INDOOR	0.025	0.041	0.033	0.009	0.004	0.014	0.000	0.025	-0.009	0.000	0.064	0.061	0.022	0.018	0.000	0.040	0.026
EAST M.P	JABALPUR	-0.043	-0.012	-0.017	-0.025	-0.020	0.000	0.005	-0.016	-0.002	-0.029	-0.008	0.000	-0.020	-0.013	-0.010	-0.011	-0.006
EAST U.P	VARANASI	-0.035	0.000	0.008	0.014	-0.023	-0.053	0.000	0.000	0.009	-0.034	-0.017	-0.025	-0.013	-0.006	-0.013	-0.025	-0.016
BIHAR	GAYA	**-0.134**	-0.056	-0.073	-0.089	-0.079	-0.083	-0.033	-0.026	-0.050	-0.089	-0.061	-0.060	-0.035	0.000	0.000	-0.025	-0.025
ORISSA	BHUNESHWAR	0.040	0.036	0.020	0.000	0.009	-0.022	0.019	0.022	0.002	-0.016	0.000	0.041	0.036	0.016	0.008	0.010	0.017
GANGETIC WEST BENGAL	KOLKATA	-0.025	0.000	-0.003	-0.023	0.009	0.000	-0.008	0.000	0.000	-0.033	-0.020	0.000	-0.014	-0.009	0.000	-0.018	-0.008
NORTH EAST	GAUHATI	0.013	-0.008	-0.020	0.000	0.062	0.017	0.038	0.024	0.025	0.053	0.039	0.056	0.007	0.022	0.022	0.033	0.008
SIKKIM	GANGTOK	0.000	-0.016	-0.058	-0.037	0.000	-0.033	-0.014	-0.010	-0.011	-0.008	0.000	0.030	-0.013	-0.021	-0.012	0.004	-0.012
MADHYA MAHARASTRA	PUNE	0.026	0.021	0.025	0.017	0.000	0.017	0.000	0.005	0.009	0.004	0.030	0.047	0.025	0.011	0.003	0.021	0.014
VIDARABHA	NAGPUR	0.045	0.038	0.005	0.011	0.011	0.004	-0.006	0.012	0.014	0.004	0.053	0.079	0.044	0.006	0.005	0.040	0.028
TELANGANA	HYDERABAD	0.057	0.052	0.037	0.000	0.011	0.009	0.023	0.017	0.022	-0.010	0.067	0.041	0.056	0.017	0.029	0.026	0.029
COASTAL ANDHRA PRADESH	VISHAKHAPAT TNAM	0.044	0.011	0.024	0.000	-0.013	-0.017	0.030	0.017	0.033	0.007	0.037	0.029	0.035	0.000	0.017	0.020	0.013
TAMILNADU	CHENNAI	**0.056**	**0.047**	**0.043**	0.023	0.026	0.000	0.047	0.047	0.040	0.019	0.033	**0.049**	**0.050**	0.028	**0.043**	**0.037**	**0.037**
NORTH INTERIOR KARNATAKA	GADAG	0.021	0.015	0.004	0.000	0.000	0.013	0.024	0.025	0.018	-0.025	0.022	0.018	0.019	0.000	0.017	0.000	0.006
SOUTH INTERIOR KARNATAKA	HASAN	0.038	0.015	0.006	-0.012	-0.015	0.053	0.030	0.023	0.000	-0.027	0.012	0.022	0.032	0.000	0.016	0.000	0.007
KERALA	TRIVENDRUM	**0.047**	**0.050**	**0.047**	0.020	0.025	0.044	0.029	0.044	0.038	0.036	**0.044**	0.046	**0.048**	0.032	**0.036**	**0.039**	**0.038**

Undelined- significant at **5%** significance level , Shaded- significant at **1%** significance level , Bold - significant at **0.1%** significance level

TABLE-3B
Sen estimator of slope (°C/Year) of Minimum Temperature

SUBDIVISIONS	STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JF	MAM	JJAS	OND	ANNUAL
JAMMU&KASHMIR	KUPWARA	-0.032	0.042	0.041	0.000	0.021	0.042	0.010	0.010	0.060	0.014	-0.050	-0.022	0.004	0.018	0.030	-0.022	0.000
GARHWAL	DEHRADUN	0.047	**0.088**	**0.107**	**0.100**	0.067	0.042	**0.060**	**0.056**	0.060	0.044	0.037	0.050	0.067	**0.078**	0.056	0.046	**0.056**
KUMAUN	MUKTESHWAR	0.067	0.049	0.089	0.006	0.033	0.036	0.042	0.043	0.044	0.038	0.050	0.035	0.056	0.033	0.042	0.036	0.043
DELHI	DELHI	0.000	0.079	0.075	0.072	0.067	0.028	**0.060**	**0.052**	0.050	0.033	0.000	0.042	0.047	**0.071**	**0.050**	0.024	**0.050**
EAST RAJASTHAN	JAIPUR	-0.004	0.043	0.050	0.056	0.060	0.027	0.024	0.017	0.035	0.029	0.004	0.004	0.016	0.060	0.033	0.018	0.041
WEST RAJASTHAN	JAISALMER	0.087	0.089	**0.100**	0.047	0.027	0.000	0.008	0.000	0.037	0.050	**0.110**	0.127	0.089	**0.057**	0.012	**0.095**	**0.061**
KUTCH	BHUJ	**0.150**	0.093	**0.106**	0.052	0.026	0.000	0.000	0.006	0.050	0.100	0.126	0.133	**0.120**	**0.060**	0.012	0.110	0.067
WEST M.P	INDOOR	0.015	0.047	0.046	0.006	0.017	0.019	0.013	0.000	0.008	-0.028	-0.002	0.003	0.038	0.018	0.008	0.000	-0.009
EAST M.P	JABALPUR	0.015	0.059	0.057	0.043	0.035	0.045	0.018	0.017	0.018	0.050	0.033	0.015	0.041	0.045	0.022	0.033	**0.039**
EAST U.P	VARANASI	-0.039	0.023	0.000	-0.009	0.000	0.000	0.022	0.024	0.039	-0.002	-0.017	0.000	-0.009	0.000	0.020	-0.004	-0.006
BIHAR	GAYA	-0.050	-0.021	-0.030	-0.055	-0.027	-0.041	-0.040	-0.054	-0.050	-0.071	-0.092	-0.006	-0.036	-0.050	-0.041	-0.061	-0.050
ORRISA	BHUNESHWAR	0.000	0.000	0.014	0.014	0.015	0.015	0.025	0.014	0.018	0.014	-0.031	-0.011	0.000	0.013	0.017	-0.002	0.008
GANGETIC WEST BANGAL	KOLKATA	0.025	**0.054**	0.045	0.032	0.033	0.018	0.020	0.015	0.019	0.020	0.037	**0.058**	0.038	**0.036**	0.018	0.033	**0.033**
NORTH EAST	GAUHATI	0.043	0.050	0.031	0.029	**0.054**	0.033	**0.038**	**0.029**	**0.033**	0.047	0.036	0.050	0.038	0.038	**0.033**	0.044	**0.040**
SIKKIM	GANGTOK	**0.080**	0.094	0.080	0.067	**0.080**	**0.054**	**0.056**	**0.058**	**0.056**	**0.077**	0.080	**0.094**	**0.079**	**0.069**	**0.053**	**0.069**	**0.069**
MADHYA MAHARASTRA	PUNE	0.011	0.029	0.022	0.020	0.024	0.014	0.014	0.009	0.017	-0.014	-0.027	-0.008	0.020	0.024	0.014	-0.005	0.011
VIDHRAVA	NAGPUR	0.005	0.017	0.033	-0.008	-0.021	0.000	0.008	0.006	0.008	0.004	0.000	0.000	0.000	0.000	0.006	0.000	0.000
TELANGANA	HYDERABAD	0.000	-0.010	0.019	0.000	-0.006	0.000	0.003	-0.007	0.008	0.000	-0.011	-0.052	-0.013	0.000	0.000	-0.022	-0.009
COASTAL ANDHRA PRADESH	VISHAKHAPATNAM	-0.026	-0.042	0.006	-0.013	0.009	0.021	0.031	0.022	0.024	0.029	-0.023	-0.090	-0.035	0.000	0.027	-0.025	-0.005
TAMILNADU	CHENNAI	0.030	0.013	0.022	0.013	0.000	0.009	0.031	0.025	0.011	0.000	0.000	-0.006	0.023	0.013	0.020	-0.004	0.011
NORTH INTERIOR KARNATAKA	GADAG	-0.017	-0.033	-0.014	0.002	0.000	0.013	0.007	0.000	0.000	0.000	-0.014	-0.036	-0.023	0.000	0.004	-0.017	-0.012
SOUTH INTERIOR KARNATAKA	HASAN	0.076	0.050	0.000	0.058	0.080	0.054	0.025	0.019	0.027	0.048	0.058	0.066	0.060	0.020	0.031	0.069	0.060
KERALA	TRIVENDRUM	0.020	0.006	0.000	-0.020	0.000	0.012	0.009	0.008	0.007	0.000	0.000	-0.021	0.014	0.000	0.007	0.000	0.000

Undelined- significant at 5% significance level , Shaded- significant at 1% significance level , Bold - significant at 0.1% significance level

Tamilnadu (EC) also showed significant increasing trend inthe pre-monsoon season. Night temperatures at the station in Uttarakhand (WH), Delhi (NW), east M.P (NC), Orrisa, Gangetic west Bengal, Northeast, Sikkim (NE) while in southern India, Madhya Maharashtra (WC) and Tamilnadu (EC) showed significant warming trend in Monsoon season (Table 3b). The station in west Rajasthan and Kutch in NW region showed much steeper and significant warming trend at the rate of 0.95 ^{0}C and 1.1^{0}C/10 year respectively in post monsoon season along with Uttarakhand (WH), North east, Gangetic west Bengal and Sikkim in (NE) while at the station in Bihar, there is a significant decreasing trend in the season at the rate of 0.61 ^{0}C/10 year.None of stations in southern India showed any significant trend in post monsoon season. All the seasons at the station of Sikkim (NE) showed significant increase in night temperature. In most of the months in year at the stations in Sikkim, Gangetic West Bengal, east M.P., Kutch and Uttarakhand showed a significant rising trends in night temperatures. Minimum temperature in NW region showed faster rate of increase during post monsoon to winter season.

3.2.6 Lowest minimum temperature

Annual lowest temperature over the country as a whole did not showed any significant trend however stations in west Rajasthan (1.55^{0}C), Kutch (1.69^{0}C) in NW region along with Northeast (0.61^{0}C), and Sikkim 0.57^{0}C/decade in NE region showed significant increasing trend in the annual lowest temperature. Cooling trend in annual lowest temperature is observed at the station in Bihar, east U.P, Orissa in northern India while coastal Andhra Pradesh (CAP), NIK and Kerala in southern part of country but significant only at Bihar, CAP and NIK subdivision.

Mean lowest temperature over country as a whole showed significantly increasing trend only in winter and post monsoon at the rate of 0.35^{0}C and 0.16^{0}C/decade respectively. Seasonal mean lowest temperature is significantly increasing during all the season at the station in Northeast and Sikkim in NE with Uttarakhand in WH region. It is also found increasing significantly at the station in west Rajasthan and Kutch in NW in all the seasons except in Monsoon season. The most steeper and significant rate of increase is observed is seen in winter, pre-monsoon post monsoon season in west Rajasthan and Kutch in NW region. Seasonal mean lowest temperature is also seen significant increasing trend at Delhi and Uttarakhand in all season except post monsoon season.

Monthly lowest temperature is found significant increasing in all the months of the year in Sikkim and except August, September and October in Uttarakhand (Garhwal). Most of subdivisions in northern India had significant increasing trend in the month of February, March and December. Monthly/ seasonal mean lowest temperature did not show any significant trend in most of the subdivisions in Southern India.

4. Trends in temperature indices

4.1 Frequency of hot days

Annual number of occurrence of hot days over India is observed to be increasing significantly at the rate of 5.5 days/decade (Figure3a). Annual over any homogeneous regions (Table-1b). frequency of hot days is increasing significantly with higher rate in the subdivisions located in southern part of the country which is quite consistent with the trends in maximum temperature. In Kerala (WC) subdivision, there is annual significant increase of 23.3 days/decade is found, while in Tamilnadu (EC), it is significantly increasing at the rate of 14.5days/ decade. Similarly in Telangana and Vidarbha (IP), rate of increase in annual frequency of hot days is found 7.5days/decade and 14 days/decade respectively. The highest increase in annual frequency of hot days over north India is noticed at the station in J&K and east Rajasthan at the rate of 13.8 days and 10.6 days/decade respectively while west M.P, Orissa showed significant increase at the rate of 9.1days and 5.1days/decade (Table-4a).

Trend analysis is performed for all the season over the country, Analysis indicates significant increase in hot days only during winter, monsoon and post monsoon season at the rate of 1.1, 2.1 and 1.6 days/decade respectively (Figure-3). During winter season, significant increase in frequency of hot days is noticed in Madhya Maharashtra, Telangana, CAP, Tamilnadu, NIK, SIK and Kerala situated over southern part of country at the rate ranging from 2.4 days to 3.3 days/decade while in north, significant increasing rate ranging from 1.4 days to 1.9 days/decade is observed over Uttarakhand, east Rajasthan and Orrisa. The pre-monsoon season, being the hottest season, only J&K and stations in east and west Rajasthan showed significant increasing trend at the rate of 4.0 days, 2.3 days and 2.7 days/decade respectively. Occurrence of hot days in monsoon season is significantly increasing only at the station in J&K and North east at the rate of 5.9days and

3.9days/decade respectively and at the stations in southern India significant increase is observed at the station in Tamilnadu (5.0days), NIK (3.1days) and in Kerala (6.7days/decade). Significant decrease is noticed in Sikkim at the rate of 3.4days/ decade. During post monsoon season significant increase in number of hot days is found in J&K and North east as well as in Tamilnadu and Kerala. Majority of stations showed negative trend in occurrence of hot days during post monsoon season but not statistically significant like Delhi, Kutch in NW, east U.P, east M.P, Bihar in NC, Gangetic West Bengal and Sikkim in NE. In the month of January, most of the stations showed significant increasing trend in occurrence of hot days (Table-4a).

4.2 Frequency of cold days

Annual frequency of cold day over India as a whole is decreasing significantlyat the rate of 2.2 days/decade (Fig.-4b). Annual frequency is also significantly increasing only at the station in east U.P. and Gangetic West Bengal at the rate of 6.3days and 5.3days/decade. On the other hand the stations in southern India, Tamilnadu, Kerala and Telangana showed significant sharp decline in frequency of cold days at the rate of 12.5days, 10.0 days and 7.5days/decade is noticed. Over the subdivisions in north and central India, largest significant decline is seen in east Rajasthan 7.6 days/decade along with Kumaun of Uttarakhand and west M.P. showed significant decrease in annual frequency of cold days (Table-4b).

As far as seasons over all India is concerned, analysis showed no significant trend (Fig.-4), but some stations showed significant trend in different seasons, frequency of cold days are significantly decreasing during winter in Kerala and during pre-monsoon season in Tamilnadu. Cold days are significantly decreasing during monsoon season in Kerala and Tamilnadu both, while significant

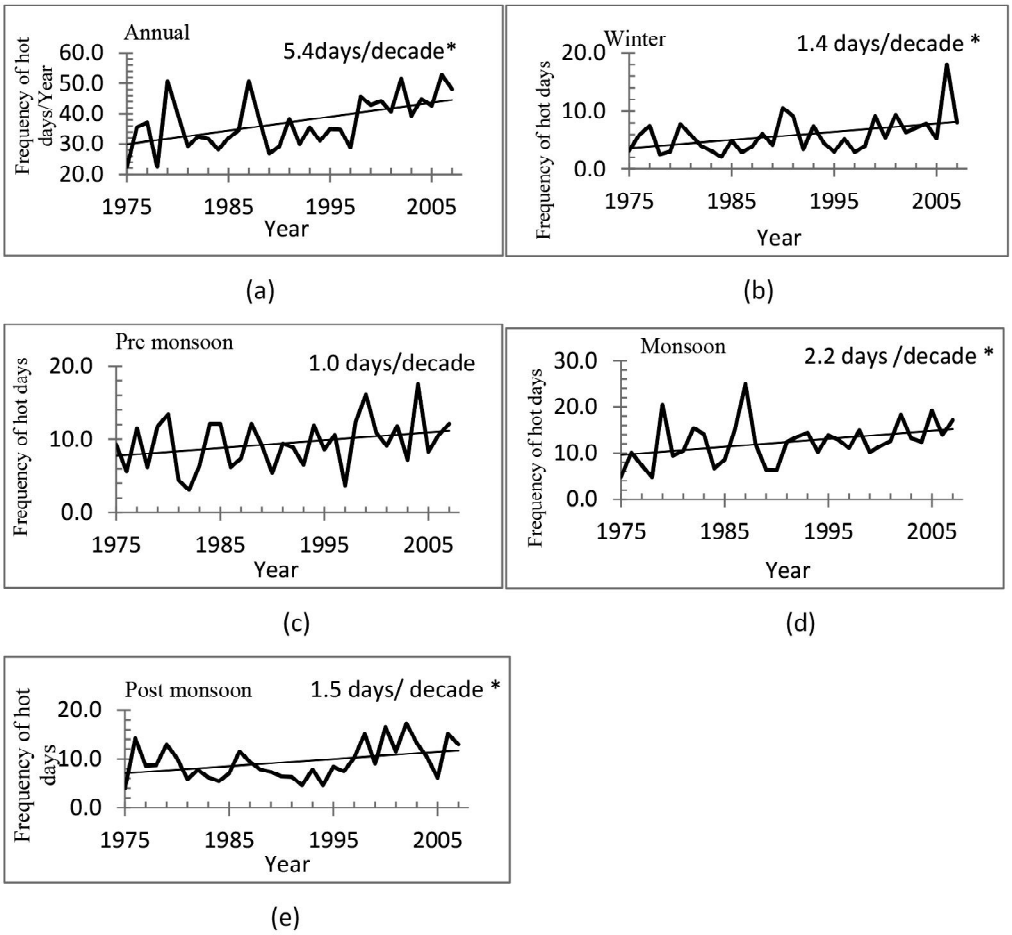


Fig.3 Trends in frequency of hot days over country as a whole (a) Annual (b) winter season (c) the pre-monsoon season (d) monsoon seasons (e) post monsoon season.

increase is observed in west Bengal. Post monsoon season in Kerala, Vidhabha, Madhya Maharashtra, west M.P. and north east showed significant decreasing trend while, significant increasing only at Gangetic West Bengal in the season.

Frequency of cold days in the month of January is significantly increasing in Delhi, Bihar and Gangetic west Bengal. Similarly, it is important to note that Kutch in NW India showed significant increase in cold days in the month of May (Table-4b).

4. 3 Frequency of hot nights

Most significant and major change is noticed in the occurrence of hot night over the country. On average there are 10% night in the year are hot night in the country and it is significantly increasing at the rate of 12.9 days/decade (Fig.-5a). Occurrence of hot nights is observed to be significantly increasing annually with accelerated rate mostly in northern India at the stations in Sikkim, North east and Gangetic west Bengal in NE region and Uttarakhand in WH region. The stations in Rajasthan, Kutch, M.P, Orissa and Delhi also showed significant increasing trend in frequency of hot night (Table-5a). In southern India, significant increase is seen only in Madhya Maharashtra, Tamilnadu and south interior Karnataka. Significant decrease in annual frequency of hot night is only observed in Bihar.

Significant increasing trend is observed during all the four seasons of the country as a whole and highest rate of increase is observed in the pre-monsoon (2.6days/decade) and monsoon season 4.4days/decade) (Fig.-5c and 5d). Number of days with significant increase in hotter night in winter is

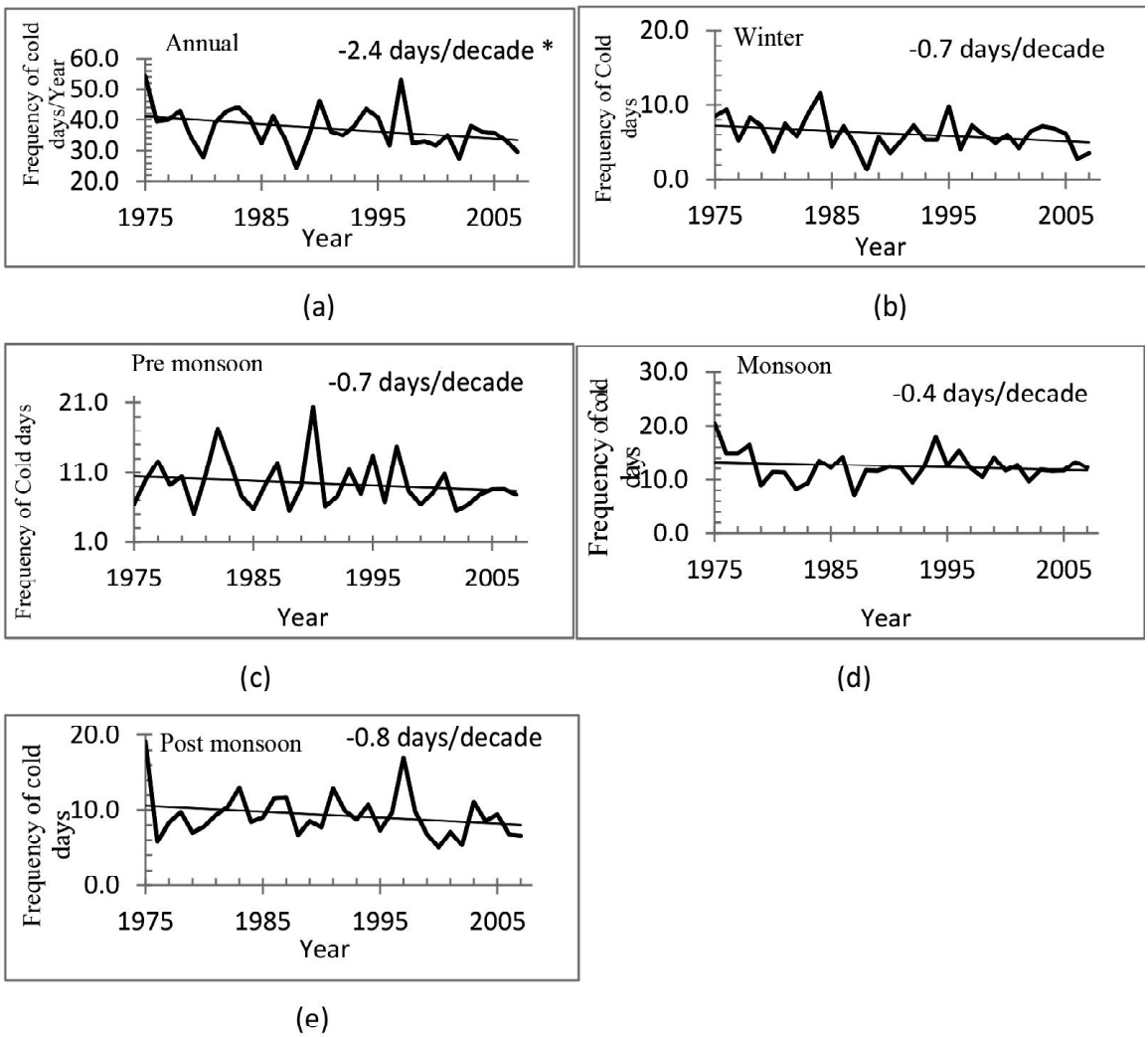


Fig.4 Same as in Figure-2 but for frequency of cold days.

TABLE-4A
Sen estimator of slope (number of hot days/year)

SUB DIVISIONS	STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JF	MAM	JJAS	OND	Annual
JAMMU& KASHMIR	KUPWARA	0.000	0.111	0.143	0.091	0.105	0.000	0.167	0.158	0.111	0.125	0.050	0.000	0.125	0.404	**0.526**	0.200	**1.376**
GARHWAL	DEHRADUN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.066	0.000	0.000	0.000	0.070	0.051	0.019	0.000	0.167
KUMAUN	MUKTESHWAR	0.065	0.045	0.000	0.063	0.000	0.000	0.000	0.000	0.000	-0.069	0.000	0.032	0.167	0.134	0.049	0.000	0.470
DELHI	DELHI	0.000	0.000	0.000	0.035	0.000	-0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.143	-0.083	0.000	-0.049
EAST RAJASTHAN	JAIPUR	0.069	0.060	0.083	0.111	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.067	0.143	0.233	0.236	0.222	1.058
WEST RAJASTHAN	JAISALMER	0.000	0.043	0.035	0.083	0.000	-0.050	0.064	0.000	0.111	0.000	-0.043	0.000	0.087	0.273	0.120	0.000	0.500
KUTCH	BHUJ	0.044	0.000	0.000	-0.067	-0.083	-0.045	0.000	0.000	0.000	0.000	-0.043	0.035	0.074	-0.220	-0.080	-0.125	-0.583
WEST M.P	INDOOR	0.091	0.057	0.000	0.053	0.065	0.000	0.000	0.054	0.000	0.000	0.000	0.140	0.167	0.263	0.123	0.250	0.913
EAST M.P	JABALPUR	-0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.045	0.000	-0.119	0.000	0.111	-0.071	0.143
EAST U.P	VARANASI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.037	-0.083	0.000	0.000	0.000	0.047	-0.158	-0.033
BIHAR	GAYA	-0.067	0.000	-0.051	0.000	0.000	-0.048	0.000	0.000	0.000	0.000	-0.041	0.000	-0.052	0.000	0.000	-0.160	-0.627
ORISSA	BHUNESHWAR	0.132	0.000	0.000	0.000	0.000	-0.021	0.068	0.119	0.063	0.000	0.000	0.000	0.190	0.000	0.264	0.000	0.513
GANGETIC WEST BANGAL	KOLKATA	0.000	0.000	0.000	-0.050	0.000	0.000	0.043	0.032	0.071	0.000	-0.091	0.038	0.000	-0.161	0.160	-0.083	0.000
NORTH EAST	GAUHATI	0.143	-0.044	-0.100	0.000	0.103	0.083	0.106	0.091	0.200	0.125	0.133	0.175	0.000	0.078	0.388	0.577	1.000
SIKKIM	GANGTOK	0.000	0.000	0.000	0.000	0.000	-0.125	-0.016	-0.059	-0.091	0.000	0.000	0.000	0.000	-0.089	-0.340	-0.044	-0.376
MADHYA MAHARASTRA	PUNE	**0.167**	0.077	0.045	0.000	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.286**	0.188	0.158	0.000	0.647
VIDHRBHA	NAGPUR	0.000	0.000	0.000	0.069	0.000	0.000	0.000	0.048	0.000	0.000	0.000	0.100	0.125	0.200	0.200	0.095	0.750
TELANGANA	HYDERABAD	0.172	0.091	0.143	0.111	0.039	0.000	0.072	0.100	0.000	0.000	0.100	0.083	0.333	0.447	0.333	0.250	1.357
COASTAL ANDHRA PRADESH	VISHAKHAPAT TNAM	0.150	0.000	0.129	0.000	0.000	-0.059	0.087	0.038	0.000	0.000	0.156	0.143	0.250	0.170	0.069	0.270	0.745
TAMIL NADU	CHENNAI	**0.250**	0.000	0.050	0.000	0.037	0.000	0.063	0.106	0.125	0.095	0.125	**0.167**	**0.286**	0.174	0.500	**0.571**	**1.456**
NORTH INTERIOR KARNATAKA	GADAG	0.154	0.000	0.000	0.000	0.000	0.000	0.000	**0.167**	0.000	0.000	0.045	0.000	0.250	0.125	0.308	0.000	0.382
SOUTH INTERIOR KARNATAKA	HASAN	0.130	0.000	0.000	-0.125	0.000	0.000	0.095	0.000	0.000	0.000	0.000	0.000	0.245	-0.046	0.333	0.000	0.267
KERALA	TRIVENDRUM	0.071	**0.167**	0.125	0.100	0.118	0.056	0.077	0.182	0.077	**0.235**	0.111	0.125	**0.250**	**0.500**	**0.667**	**0.600**	**2.333**

Underlined- significant at 5% significance level ,Shaded- significant at 1% significance level , Bold - significant at 0.1% significance level

TABLE-4B
Sen estimator of slope (number of cold days/year)

SUB DIVISIONS	STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JF	MAM	JJAS	OND	Annual
JAMMU& KASHMIR	KUPWARA	0.040	0.000	-0.100	0.000	-0.038	0.000	-0.053	0.037	0.043	0.000	0.000	0.000	0.069	-0.160	0.000	-0.067	0.067
GARHWAL	DEHRADUN	0.078	0.000	-0.077	-0.067	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.038	-0.156	0.117	0.000	-0.070
KUMAUN	MUKTESHWAR	-0.063	0.000	-0.067	0.000	0.000	0.000	-0.032	0.000	0.000	0.000	0.000	-0.036	-0.087	-0.143	0.000	-0.071	-0.333
DELHI	DELHI	0.098	0.000	0.000	-0.074	0.000	0.000	-0.089	-0.069	0.000	0.000	0.000	0.000	0.074	-0.143	-0.100	0.000	-0.067
EAST RAJASTHAN	JAIPUR	0.000	0.000	0.000	-0.054	0.000	0.000	-0.050	-0.067	0.000	0.000	-0.095	0.000	-0.100	-0.091	-0.222	-0.156	-0.760
WEST RAJASTHAN	JAISALMER	0.083	0.000	-0.085	-0.043	0.000	0.000	-0.078	-0.071	0.000	0.000	0.000	0.000	0.091	-0.118	-0.200	0.000	-0.479
KUTCH	BHUJ	0.000	0.000	0.000	0.000	0.063	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.176	0.143	0.000	0.250
WEST M.P	INDOOR	-0.047	0.000	0.000	-0.046	0.049	0.000	0.071	0.000	0.000	0.000	-0.152	-0.059	-0.093	0.000	0.000	-0.333	-0.417
EAST M.P	JABALPUR	0.036	0.000	0.000	0.000	0.037	0.000	0.067	0.000	0.000	0.000	-0.077	0.000	0.052	0.125	0.176	-0.077	0.185
EAST U.P	VARANASI	0.083	0.000	0.000	0.000	0.059	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.143	0.125	0.125	0.091	0.632
BIHAR	GAYA	0.162	0.000	0.000	0.000	0.000	0.048	0.000	0.000	0.000	0.057	0.000	0.100	0.098	0.000	0.000	0.232	0.470
ORRISA	BHUNESHWAR	-0.033	0.000	0.000	0.000	0.000	0.063	0.000	0.000	0.035	0.069	0.000	-0.091	-0.074	-0.116	0.087	-0.097	-0.250
GANGETIC WEST BANGAL	KOLKATA	0.080	0.000	0.000	0.000	0.000	0.000	0.087	0.000	0.067	0.130	0.050	0.000	0.083	0.000	0.174	0.211	0.533
NORTH EAST	GAUHATI	0.000	0.000	0.000	0.000	-0.085	-0.077	0.000	0.000	0.000	0.000	0.000	-0.133	0.065	-0.106	-0.077	-0.204	-0.111
SIKKIM	GANGTOK	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	-0.100	0.000	0.084	0.000	-0.093	0.000
MADHYA MAHARASTRA	PUNE	0.000	0.000	-0.095	0.000	0.000	0.000	0.036	0.000	0.000	0.000	-0.095	-0.125	-0.038	-0.067	0.000	-0.273	-0.235
VIDHRBHA	NAGPUR	-0.071	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	-0.091	-0.091	-0.106	0.000	0.046	-0.286	-0.374
TELANGANA	HYDERABAD	0.000	0.000	-0.076	0.000	0.000	0.000	-0.063	0.000	-0.063	0.000	-0.143	-0.048	-0.143	-0.049	-0.182	-0.091	-0.750
COASTAL ANDHRA PRADESH	VISHAKHAPATNAM	-0.095	-0.048	-0.082	0.000	0.000	0.000	0.000	-0.043	-0.100	0.000	-0.053	-0.071	-0.204	0.000	-0.111	-0.174	-0.500
TAMIL NADU	CHENNAI	-0.087	-0.125	-0.138	-0.091	-0.059	0.000	-0.111	-0.125	-0.067	0.000	0.000	-0.048	**-0.269**	-0.348	**-0.357**	-0.109	**-1.250**
NORTH INTERIOR KARNATAKA	GADAG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.077	0.111	-0.083	0.000	0.000	0.000	-0.123	0.000	0.000
SOUTH INTERIOR KARNATAKA	HASAN	0.000	0.000	0.000	0.000	0.000	-0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.066	-0.071	0.000	-0.192
KERALA	TRIVENDRUM	-0.204	**-0.146**	**-0.167**	0.000	0.000	-0.083	-0.077	-0.100	0.000	0.000	-0.045	-0.100	-0.383	-0.143	-0.300	-0.200	-1.043

Underlined- significant at **5%** significance level ,Shaded- significant at **1%** significance level , Bold - significant at **0.1%** significance level

Highest and significant decreasing trend in annual frequency is seen at the station in Delhi, west Rajasthan and Kutch in NW region, Uttarakhand (WH) and North east where significant annual decrease of 10days/decade is seen. Station in east M.P., Sikkim, Gangetic West Bengal, Madhya Maharashtra, Tamilnadu also showed significant decreasing trend in annual frequency of cold night. All the seasons in country as whole showed significant decline in frequency of cold nights where steeper decline is found in monsoon season 3.3days/10 year (Fig.-5d). Highest rate of significant decline is observed at the station in Sikkim along with it other stations in Garhwal of Uttarakhand, west Rajasthan, Kutch, east M.P, CAP and Tamilnadu also showed significant decreasing trend but with comparatively slower rate. (Table-5b) .Only station in NIK showed significant increasing trend in occurrence of cold nights in winter. During the pre-monsoon season, none of station in southern India except Madhya Maharashtra showed significant trend in occurrence of cold night, while in northern India station in Uttarakhand, West Rajasthan, Kutch, North east and Sikkim showed significant decline in occurrence of cold nights. During monsoon season comparatively more number of station showed significant decreasing trend, stations in J&K, Uttarakhand, Kutch, Gangetic west Bengal, North east, Sikkim, Madhya Maharashtra, CAP and Tamilnadu showed significant decreasing trend. Many stations showed increasing trend (not significant) in frequency of cold nights is mainly observed in post monsoon season over the country, while significant decrease in frequency of cold nights in post monsoon season is noticed at the station in Garhwal of Uttarakhand, west Rajasthan, Kutch, east M.P., Gangetic West Bengal, North east, Sikkim and in SIK Table-5b.

Uttarakhand (Garhwal), Kutch and Sikkim showed significant decline in frequency of cold night in all the seasons, while in west Rajasthan and North east significant decline is observed in all seasons except monsoon season in west Rajasthan and winter in North east. Monthly analysis of trend showed that most of the month in the year at the station in Uttarakhand, West Rajasthan, Kutch and North east showed significant decline in occurrence of cold night.

On a larger spatially aggregated scale, the

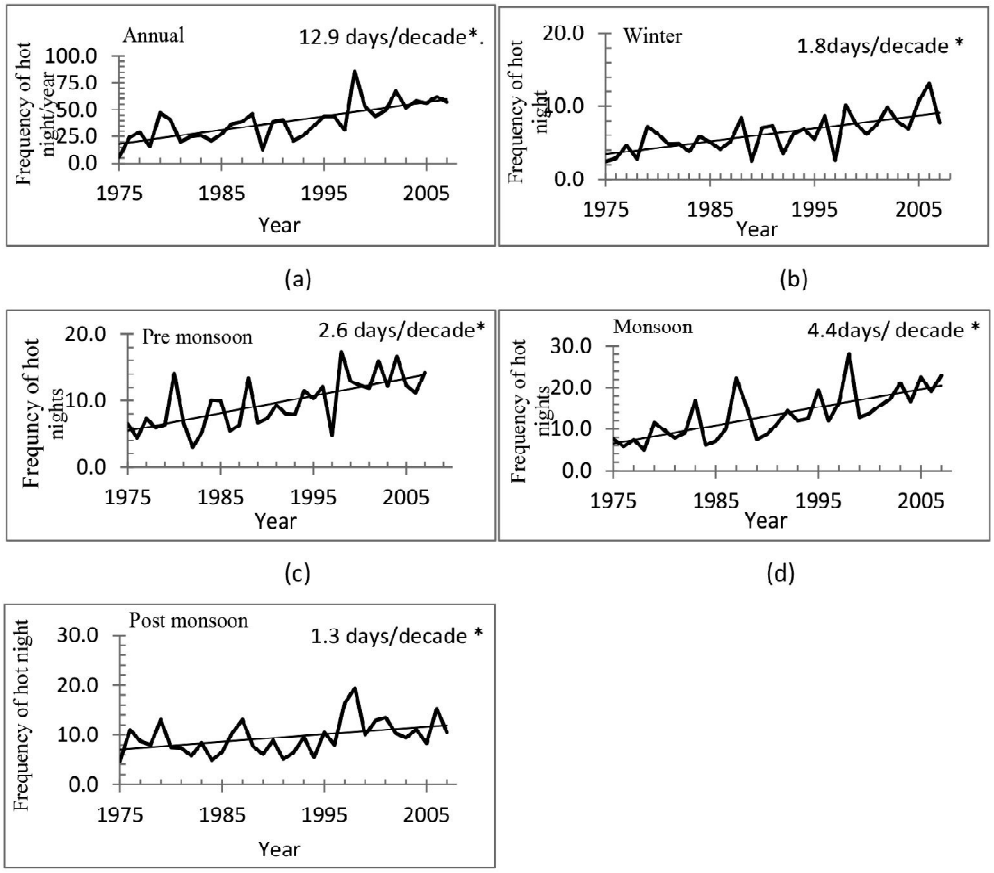


Fig.5 Same as in Fig.-2 except for frequency of hot night.

TABLE-5A
Sen estimator of slope (number of hot night/year)

SUB DIVISIONS	STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JF	MAM	JJAS	OND	ANNUAL
JAMMU& KASHMIR	KUPWARA	0.000	0.000	0.000	-0.098	0.000	0.000	0.000	-0.091	0.063	0.000	-0.130	-0.045	0.067	-0.067	0.056	-0.190	-0.230
GARHWAL	DEHRADUN	0.154	**0.143**	0.130	0.133	0.100	0.040	0.108	**0.250**	0.214	0.173	0.000	0.131	**0.314**	**0.364**	**0.698**	0.369	**1.811**
KUMAUN	MUKTESHWAR	0.125	0.000	0.040	0.045	0.000	0.035	0.091	0.170	**0.179**	0.137	0.140	0.067	0.158	0.125	0.563	0.386	1.574
DELHI	DELHI	0.048	0.111	0.071	0.087	0.054	0.000	0.047	**0.160**	**0.179**	0.000	0.000	0.071	0.156	0.261	**0.609**	0.143	**1.154**
EAST RAJASTHAN	JAIPUR	0.000	0.044	0.036	0.111	0.111	0.000	0.000	0.042	0.100	0.091	0.000	0.000	0.043	**0.333**	0.333	0.132	1.089
WEST RAJASTHAN	JAISALMER	0.118	0.090	0.083	0.000	0.043	0.000	0.080	0.000	0.105	0.000	0.114	0.138	0.190	0.286	0.176	0.296	0.894
KUTCH	BHUJ	**0.167**	0.111	0.000	0.063	0.067	0.000	0.000	0.000	0.111	0.167	0.067	**0.111**	**0.250**	0.238	0.083	0.500	1.367
WEST M.P	INDOOR	0.000	0.095	0.000	0.034	0.049	0.000	0.071	0.035	0.000	0.000	0.000	0.000	0.113	0.200	0.250	-0.133	0.500
EAST M.P	JABALPUR	0.040	0.113	0.103	0.167	0.043	0.100	0.063	0.056	0.057	0.105	0.000	0.000	0.216	0.333	**0.474**	0.077	**1.133**
EAST U.P	VARANASI	0.000	0.065	0.000	0.000	0.000	0.000	0.000	0.125	0.160	0.036	0.000	0.043	0.057	0.000	0.308	0.077	0.519
BIHAR	GAYA	-0.069	0.000	-0.069	-0.129	-0.114	-0.051	0.000	-0.091	0.000	-0.111	-0.063	0.000	-0.118	-0.419	-0.409	-0.382	-1.417
ORRISA	BHUNESHWAR	0.033	0.000	0.078	0.115	0.083	0.000	0.100	0.100	0.143	0.033	0.000	0.000	0.047	0.357	0.400	0.000	0.791
GANGETIC WEST BANGAL	KOLKATA	0.000	0.111	0.154	**0.211**	0.091	0.083	0.125	0.053	0.095	0.000	0.000	0.043	0.158	**0.471**	**0.429**	0.211	**1.250**
NORTH EAST	GAUHATI	0.036	0.000	0.000	0.100	0.200	0.167	0.182	0.160	0.125	0.136	0.167	0.069	0.103	0.429	**0.659**	**0.408**	**1.786**
SIKKIM	GANGTOK	**0.200**	0.000	0.146	0.125	**0.200**	**0.182**	**0.182**	**0.220**	**0.250**	**0.190**	**0.205**	0.106	**0.333**	**0.525**	**1.000**	**0.667**	**2.756**
MADHYA MAHARASTRA	PUNE	0.000	0.000	0.000	0.053	0.074	0.071	0.067	0.091	0.095	0.000	-0.059	0.000	0.000	0.172	0.353	-0.042	0.462
VIDHRBHA	NAGPUR	0.000	0.015	0.050	0.000	0.000	-0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.083	-0.210
TELANGANA	HYDERABAD	0.043	0.000	0.065	0.047	0.000	0.000	0.000	0.000	0.000	0.000	-0.042	0.000	0.000	0.162	0.189	-0.136	0.250
COASTAL ANDHRA PRADESH	VISHAKHAPAT TNAM	0.000	0.067	0.111	0.000	0.085	0.000	0.154	0.167	0.091	0.048	0.000	-0.103	0.100	0.372	0.483	0.000	1.155
TAMIL NADU	CHENNAI	0.038	0.000	0.071	0.000	0.000	0.000	0.067	0.049	0.095	0.113	0.000	0.000	0.000	0.100	0.333	0.091	0.500
NORTH INTERIOR KARNATAKA	GADAG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.000	-0.040	0.000	-0.033	0.000	0.286	-0.067	0.090
SOUTH INTERIOR KARNATAKA	HASAN	0.085	0.162	0.244	0.059	0.054	0.085	0.000	0.000	0.000	0.104	0.111	0.043	0.286	**0.471**	0.214	0.200	1.261
KERALA	TRIVENDRUM	0.111	0.000	0.031	-0.043	0.000	0.070	0.000	0.000	0.056	0.000	0.000	-0.042	0.125	0.077	0.136	-0.036	0.370

Underlined- significant at **5%** significance level ,Shaded- significant at **1%** significance level , Bold - significant at **0.1**% significance level

TABLE-5B
Sen estimator of slope (number of cold night/year)

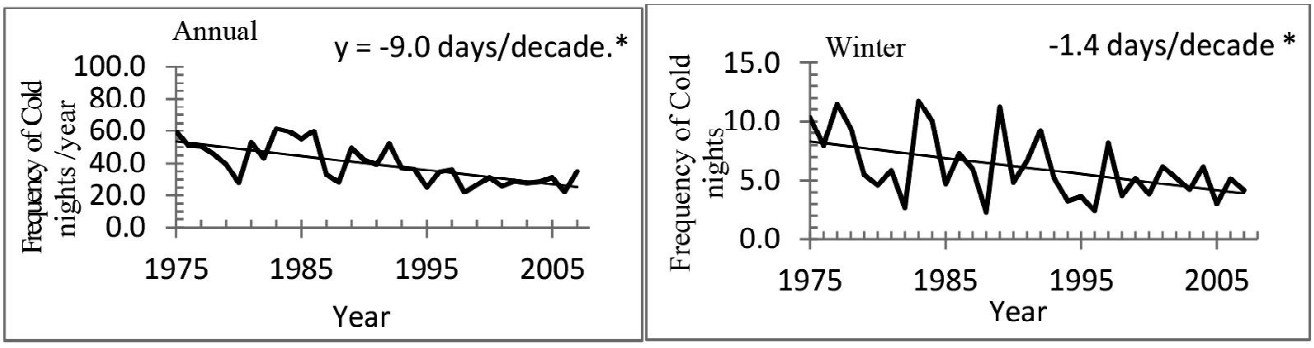
SUB DIVISIONS	STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JF	MAM	JJAS	OND	ANNUAL
JAMMU& KASHMIR	KUPWARA	0.000	0.000	-0.074	-0.083	0.000	-0.130	0.000	-0.091	-0.098	0.000	0.000	0.000	-0.045	-0.143	-0.530	0.059	-0.519
GARHWAL	DEHRADUN	-0.067	-0.128	**-0.143**	-0.133	-0.091	-0.167	**-0.111**	**-0.200**	-0.061	0.000	-0.167	-0.133	-0.185	**-0.400**	**-0.571**	-0.293	**-1.491**
KUMAUN	MUKTESHWAR	-0.050	-0.063	-0.065	-0.061	-0.070	-0.071	-0.059	0.000	-0.111	0.000	0.000	-0.042	-0.125	-0.275	-0.333	-0.151	-0.962
DELHI	DELHI	0.000	-0.083	-0.135	-0.085	-0.098	-0.085	**-0.172**	**-0.100**	0.000	-0.059	0.000	0.000	0.000	**-0.351**	**-0.500**	0.000	-1.182
EAST RAJASTHAN	JAIPUR	0.000	-0.045	-0.118	0.000	0.000	0.000	-0.050	-0.042	0.000	-0.045	0.000	0.000	0.000	-0.167	-0.194	-0.140	-0.675
WEST RAJASTHAN	JAISALMER	-0.070	-0.097	**-0.250**	-0.100	-0.118	0.000	0.000	0.067	-0.059	-0.167	-0.188	-0.174	-0.250	**-0.444**	-0.034	**-0.667**	**-1.569**
KUTCH	BHUJ	**-0.135**	-0.125	-0.158	-0.100	-0.068	0.000	0.000	-0.125	-0.133	-0.043	-0.087	-0.068	**-0.296**	-0.333	-0.364	-0.267	-1.357
WEST M.P	INDOOR	-0.018	0.000	-0.143	0.000	-0.048	-0.082	0.000	0.000	0.000	0.053	0.000	0.000	-0.093	-0.156	-0.073	0.000	-0.333
EAST M.P	JABALPUR	-0.046	-0.077	-0.091	-0.063	0.000	-0.048	0.000	-0.077	-0.073	-0.037	0.000	0.000	-0.185	-0.176	-0.273	-0.353	**-1.000**
EAST U.P	VARANASI	0.031	0.000	0.000	0.035	0.000	-0.032	0.000	-0.043	0.000	0.000	0.000	0.000	0.068	0.115	-0.130	0.103	0.000
BIHAR	GAYA	0.125	0.000	0.077	0.059	0.000	0.071	0.061	0.143	0.083	0.108	0.000	0.000	0.200	0.226	0.500	0.105	0.895
ORRISA	BHUNESHWAR	0.000	0.048	0.000	0.000	0.000	-0.091	-0.100	-0.067	-0.061	0.000	0.000	0.000	0.069	0.000	-0.353	0.019	-0.437
WEST BANGAL	KOLKATA	-0.083	-0.040	-0.067	0.000	-0.067	0.000	-0.067	-0.091	-0.083	-0.077	-0.080	**-0.200**	-0.100	-0.188	-0.286	**-0.417**	**-1.000**
NORTH EAST	GAUHATI	-0.039	-0.066	-0.111	0.000	**-0.149**	-0.077	-0.146	**-0.178**	-0.143	-0.072	-0.043	-0.128	-0.143	**-0.316**	**-0.712**	**-0.412**	**-1.533**
SIKKIM	GANGTOK	-0.046	**-0.080**	-0.077	0.000	0.000	-0.046	0.000	0.000	0.000	-0.049	0.000	0.000	**-0.156**	-0.182	**-0.167**	-0.100	**-0.692**
MADHYA MAHARASTRA	PUNE	0.000	0.000	-0.077	0.000	-0.083	-0.069	-0.091	0.000	-0.050	0.043	0.000	0.000	0.000	-0.214	-0.286	-0.067	-0.533
VIDHRBHA	NAGPUR	0.000	0.000	-0.059	0.000	0.000	-0.040	-0.091	0.000	0.000	0.038	0.000	0.000	0.000	0.000	-0.250	0.000	-0.240
TELANGANA	HYDERABAD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.111	0.067
COASTAL ANDHRA PRADESH	VISHAKHAPATNAM	0.000	0.074	0.057	0.000	0.000	-0.154	-0.083	0.000	-0.143	-0.061	0.000	0.000	0.289	0.125	-0.400	0.108	0.000
TAMIL NADU	CHENNAI	-0.083	0.000	0.000	0.000	0.000	0.000	-0.082	-0.085	0.000	0.056	0.000	0.000	-0.200	-0.083	-0.222	0.058	-0.429
NORTH INTERIOR KARNATAKA	GADAG	0.100	0.053	0.045	0.000	0.000	0.000	0.000	0.056	0.000	0.000	0.000	0.000	0.226	0.113	-0.053	0.063	0.446
SOUTH INTERIOR KARNATAKA	HASAN	0.000	0.000	-0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.143	0.000	0.000	0.000	0.000	-0.167	-0.357
KERALA	TRIVENDRUM	0.000	0.000	0.000	0.071	0.000	0.000	-0.087	0.000	0.000	0.000	0.000	0.167	-0.119	0.143	-0.125	0.205	0.150

Underlined- significant at 5% significance level ,Shaded- significant at 1% significance level , Bold - significant at 0.1% significance level

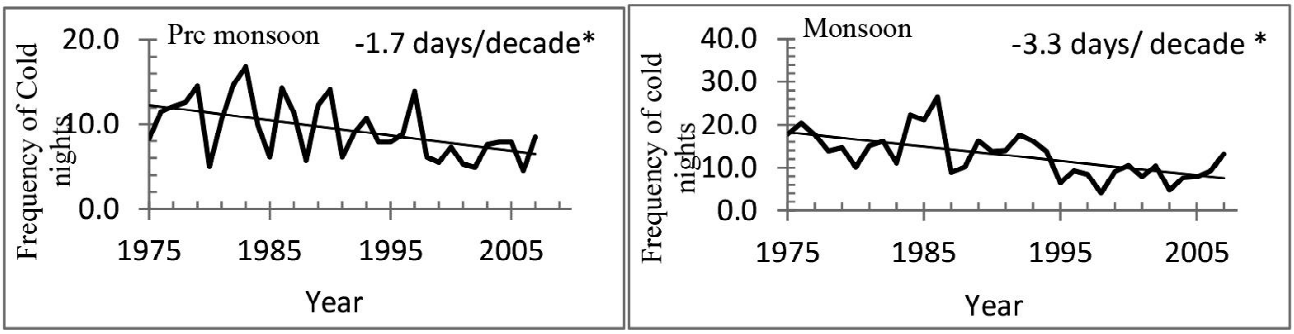
observed at the station in Uttarakhand, west Rajasthan, Kutch, east M.P., Gangetic West Bengal and Sikkim in northern India and only SIK in southern India. The fastest and significant increase in the pre-monsoon season is seen at the station in Sikkim, Northeast, Gangetic west Bengal and in Garhwal region of Uttarakhand with SIK in southern India. The stations in Delhi, Rajasthan, Kutch, and east M. P., Oriassa, Madhya Maharashtra and CAP also showed significant increasing trend in frequency of hot nights in the pre-monsoon season. Monsoon season of the station in Uttarakhand, Delhi and east Rajasthan in northern India, east M.P in central India, Gangetic West Bengal, North east and Sikkim in NE region and in southern India Madhya Maharashtra, CAP and Tamilnadu showed significant increase in frequency of hot nights. Highest rate of increase is observed in Sikkim 10days/decade in monsoon season. Post monsoon season in Uttarakhand, west Rajasthan, Kutch, North east and Sikkim along with SIK showed significant rising trend in frequency of hot nights, while in Bihar, significant decreasing trend is noticed. Most of the months in the year at the station in Uttarakhand, Gangetic west Bengal and Sikkim and SIK showed significant increase in occurrence of hot nights (Table-5a).

4.4 Frequency of cold nights

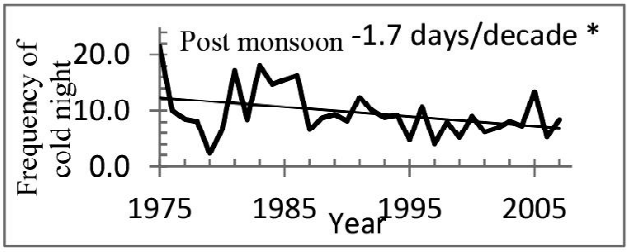
Annual frequency of cold night over the country as whole clearly showed significant decreasing trend at the rate of 9.0 days /decade (Fig.-6a).



(a)(b)



(c)(d)



(e)

Fig.6 Same as in Fig.2 except for frequency of cold night.

temperature trends in India are found to be quite consistent with the hemispheric trends. Further, the trends were also influenced by the variability in rainfall in the monsoon and post-monsoon seasons. The rise in mean temperature in WH has been primarily due to rapid increases of both maximum and minimum temperatures. The possible cause of faster increase in temperature in Himalayan region is the deforestation, major change in land use and due to blowing of dust and particles of incomplete combustion of fossil fuels, bio fuels and biomass along with the winds towards higher altitude increasing the temperature of the region. Thick haze and smoke, originating from burning biomass north east India and air pollution from large industrial cities in northwest India, changing the temperature trend in the regions.

5. Conclusions

1. Inter-annual variability in mean temperature over India as a whole is found to be 1.1% with largest variability is noticed in the month of February (5.75%) and least in August (1.22%) during the period of present study. Most significant and widespread positive trend in mean temperature is observed during all the seasons over WH and WC and fastest rate of increase is noticed during winter (0.84^{0}C/decade) over WH region.

2. The largest inter-annual variability in day and night temperatures in most of the regions and over country as a whole is observed during winter season. Variability in night temperature is comparatively higher than the day temperature over country as a whole and over all homogeneous regions. Most significant warming in day temperature is only seen during winter and post monsoon season while night temperature during winter, pre-monsoon and monsoon season over India as a whole. The most accelerated and significant warming in day and night temperature is observed over WH region. The inter-annual variability in highest and lowest temperature is observed highest during winter and post monsoon season in most of places. Annual lowest and highest temperature over the country as a whole did not show any significant trend.

3. Annual number of occurrence of hot days over India as a whole is noticed wide spread increasing significantly at the rate of 5.5 days/ decade while frequency of cold day is decreasing nearly significant at the rate of 2.2 days/decade. Stations in southern India showed significant sharp decrease in frequency of cold days and increase in hot days. Seasonally, none of the seasons over the country showed any significant trend in frequency of cold days.

4. Occurrence of hot nights over the country showed the most steeper and wide spread significant increasing trend at the rate of 12.9 days/ decade and it is observed to be significantly increasing annually at more accelerated rate in northern India mainly in WH and NE regions. Significant increasing trend is observed in all the four seasons of the country as a whole and highest rate of increase is observed in the pre-monsoon and monsoon season

5. Annual frequency of cold night over the country as whole clearly showed significantly decreasing trend at the rate of 9.0 days/decade. There were significant decline in frequency of cold nights during all the seasons in country as whole where steeper decline is found during monsoon season 3.3 days/decade.

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