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L E T T E R S

551.58 : 551.510 (540.15 : 540.21)

A STUDY ON TRENDS IN METEOROLOGICAL PARAMETERS OVER PUNJAB AND HARYANA

1. State of Punjab lies roughly 29° 30' N latitudes, 73° E and 77° E longitudes. It is bounded by Pakistan on its west Sirsa, Hissar, Jind and Kurukshtra district of Haryana and Ganganagar districts of Rajasthan on its south. Himachal Pradesh on east and Jammu and Kashmir on its north. The area of the state which is mostly plain is about roughly 50, 300 sq km. Climate of Punjab are tropical steppe, semi arid, hot and subtropical monsoon, mild winter and hot summer.

State of Haryana lies in the area bounded by 27° 39', 31° N latitudes and 74° 30' E longitudes forms the eastern part of the Table l and between the Sutlej and Yamuna to the South and to north of Rajasthan desert. The state has the Yamuna on its eastern border and on the north Himachal Pradesh, while it's adjoining Rajasthan desert on the south and southwest and Punjab on the northwest. There are three main physical divisions in the state namely, the Himalayan sub montaneareas which stretches from the Yamuna to the Salt Range, the arid South-western plains and the western portion of the state. The whole of Haryana consists of a vast alluvial plain except in the northeast region which falls under Himalayan submontane region. There is no other mountain system of importance in the state but a few unimportant outliers of the Aravalli system passes across Gurgaon district in the extreme southeast and terminate in the Ridge at Delhi. The districts Karnal, Ambala and a portion of Kurukshtra district lying between Karnal and Ambala and Chandigarh fall under the climatic type sub-tropical monsoon, Mild winter, dry winter, hot summer. Only Sirsa district has got climatic type: Tropical desert, Arid, hot and Hissar district has a climatic type varying between (Tropical Steppe, Semi-arid).

IPCC fourth report indicated 0.74 °C rise of global surface temperature over 100 years linear trend 1906 - 2005 (IPCC, 2007) larger than corresponding trend of 0.6 (1901-2000) given in third assessment report (IPCC, 2001). Eleven of the last twelve year 1995 - 2006 rank among the twelve warmest years in the instrumental record of global surface temperatures since 1850 (IPCC, 2007). It has also mentioned in this report that global average sea level has risen since 1961 at an average rate of 1.8 mm/year and at 3.1 mm/year since 1993. Mountain glacier and snow cover on an average have decline in both the hemisphere (IPCC, 2007). In India annual mean temperature averaged over the country as a whole during 2010 was (+0.93 °C) above the 1961 - 1990 averages (Annoymous, 2010). It is slightly higher than that of year 2009 thus making year 2010 as the warmest year on record since 1901 (Annoymous, 2010). Other warmest year on record are 2009 - (0.92), 2002 - (0.71), 2006 - (0.6), 2003 - (0.560), 2007-(0.553), 2004 - (0.515), 1998 - (0.514), 1941- (0.448), 1999 - (0.445), 2001- (0.429) and 1987 - (0.413) (Annoymous, 2010).

Temperature trends over India have been studied by a number of researchers (Sen Roy and Prasad, 1991; Srivastava *et al*., 1992; Rupa Kumar *et al*., 1994; De and Rajeevan, 1997; Sinha Ray *et al*., 1997; Sahai, 1998; Kothawale and Rupa Kumar, 2005) and the trends in maximum and minimum temperatures are similar to what have been reported world over (Karl *et al*., 1993; Easterling *et al*., 1997; Jones *et al*., 1999; IPCC, 2001; Giorgi, 2002 and Jones & Moberg 2003). According to Kothawale and Rupa Kumar (2005), all India mean annual temperature has significantly increased by 0.05 °C/year during 1971 - 2003. Roy and Balling (2005) have found significant increase in maximum and minimum temperature over the Deccan plateau and in general decrease in DTR over Northwest Kashmir in summer. Based upon three stations (Shimla, Srinagar and Leh), Bhutiyani *et al*. (2007) have found significant rise in air temperature by 1.6 °C during the last century in the northwest Himalayan region. Recent studies on effect of urbanization on climate by Kalnay and Cai, (2003), Zhou *et al*. (2004) and Zhang *et al*. (2005) have attributed surface temperature warming to land-use change. Kalnay and Cai (2003) have estimated that land cover changes have caused surface warming of 0.27 °C per century. De *et al*. (2001) have noted increase in atmospheric aerosols over many Indian cities leading to sharp decline in atmospheric visibility during winter season. All these studies highlight the role of urbanization, deforestation and land-use change on climate change.

In this paper, an attempt have been made to see the trends in meteorological parameters (temperature, rainfall, rainy days, diurnal range of temperature) for six stations in Punjab and Haryana for the period (1980-2010). Amritsar, Patiala and Ludhiana has been taken as representative for Met. sub-division Punjab and Hissar, Ambala and Chandigarh for Haryana depending upon quality, accuracy and completeness of the data. Stations used for study alongwith their data period is shown in Table 1.

TABLE 1

Details of the stations

Name of the station	Latitude (°N)	Longitudes (°E)	Altitudes (meters)	Data period
Amritsar	31° 38'	74° 52'	234.4	1980-2010
Ludhiana	30° 52'	75° 52'	254.73	1980-2010
Patiala	30° 21'	76° 27'	250.0	1980-2010
Ambala	30° 23'	76° 46'	272.48	1980-2010
Hissar	29° 10'	75° 44'	213.70	1980-2010
Chandigarh	30° 40'	76° 42'	347	1980

2. Annual mean, max/min, mean temperatures and season wise temperatures for stations under study has been compared with long period average (1961-1990) and shown in Table 2. Annual mean max temperature has decreased in Ambala (-0.5 °C) and increased in Hissar (+0.1 °C), and Chandigarh (+0.1 °C) in Haryana from normal value. Mean minimum temperatures decreased in Ambala (-0.3 °C) Increased in Hissar (+0.04 °C), Chandigarh (+0.09 °C) from climatological value. In Punjab mixed trends have been seen. In Punjab mean maximum temperature have decreased in Ludhiana (-1.1 °C) Amritsar (-0.4 °C), Patiala (-0.6 °C) compared to long period average.

2.1. Stations under study has been subjected to linear trend analysis and shown in Table 3. Analysis shows that temperatures annual maximum, minimum is increasing in Punjab and Haryana as shown in Table 3 . Amritsar (+0.09 °C/year) Ludhiana (+0.02 °C/year), Patiala(+0.01 °C/year) in Punjab. Ambala (+0.02 °C/ year), in Haryana showing significant increasing trends in maximum temperatures whereas no significant increasing trends have been observed in remaining stations of Met. sub-division Haryana. An annual mean minimum temperature is increasing in almost all stations in both the sub-divisions except for Ambala in Haryana wherein no trend have been observed. Stations having significant trends in annual mean minimum temperatures are Hissar (+0.06 °C/year), Chandīgarh (+0.03 °C/year) in Haryana and Patiala (+0.04 °C/year), Ludhiana (+0.01 °C/year) in Punjab. Annual mean temperatures is also increasing almost in all stations in both sub-divisions. Stations with significant trends are Amritsar (+0.01 °C/year), Patiala (+0.03 °C/year), in Punjab and Hissar (+0.02 °C/year), Ambala (+0.01 °C/year), Chandigarh (+0.01 °C/year) in Haryana.

2.2. All stations are showing decreasing trends in DTR except for Ambala in Haryana which is showing increasing trends. Significant decreasing trends in DTR is primarily due to significant increase in minimum temperature in all the stations in Punjab and Haryana and increase in DTR is primarily due to increase in Mean maximum temperatures among other factors. Stations having significant decreasing trends in DTR are Hissar (-0.08 °C/year) Chandigarh (-0.03 °C/year) in Haryana and Amritsar (-0.2 °C/year), Patiala (-0.02 °C/year in Punjab. Ambala (+0.03 °C/year) shows increasing trends in Haryana whereas no trends have been observed in Ludhiana Punjab.

2.3. Season wise analysis of temperatures (max/min) shows that maximum temperatures is decreasing in Hissar, Chandigarh in Haryana and increasing in Patiala, Ludhiana in Punjab in winter season (Jan - Feb). Stations having significant trends are Patiala (+0.04 °C/year), Amritsar (-0.02 °C/year), Ludhiana (+0.01 °C/year) in Punjab, Chandigarh (-0.03 °C/year) and Hissar (-0.02 °C/year) in Haryana. Minimum temperatures in winter showing increasing trends in Hissar (+0.05 °C/year), Haryana whereas no trends have been observed for remaining stations in both these states. In pre monsoon season (Mar-May) both maximum and minimum temperatures shows significant increasing trends in all stations with maximum temperatures in the range (+0.04 to 0.08 °C/ year) and minimum temperatures in the range (+0.1 to 0.05 °C/year). Stations having significant trends in maximum temperatures are Ambala, Hissar, Amritsar, Ludhiana ranging (+0.07 °C/year), Patiala (+0.08 °C/ year), Chandigarh (+0.04 °C/year). Stations having significant trends in minimum temperatures are Chandigarh (+0.05 °C/year), Ambala (+0.03 °C/year), Hissar (+0.01 °C/ year) in Haryana Ludhiana (+0.02 °C/ year), Patiala (+0.02 °C/year), Amritsar (+0.02 °C/year) in Punjab. In monsoon season decreasing trends in maximum temperature in the range (-0.01 to -0.03 °C/year) and increasing trends in minimum temperatures in the range (+0.01 to +0.02) have been observed in all

TABLE 2

Annual mean maximum/minimum mean temperature and season wise temperature

Element	Period	Haryana			Punjab		
		Ambala	Hissar	Chandigarh	Amritsar	Patiala	Ludhiana
Max. temp (°C)	1961-1990	30.7	32.5	30.4	30.7	30.5	30.9
	1980-2010	30.2	32.6	30.5	30.3	29.9	29.8
Min. tem (°C)	1961-1990	17.5	17.8	16.5	15.7	17.3	17.3
	1980-2010	17.2	18.2	17.4	15.2	17.3	17.1
Mean temp (°C)	1961-1990	24.1	25.2	23.4	23.2	23.9	24.1
	1980-2010	23.7	25.4	24.8	22.8	23.6	23.5
			Winter season (Jan – Feb)				
Max. temp (°C)	1961-1990	21.5	22.5	20.0	21.0	21.0	22.5
	1980-2010	20.7	22.8	21.5	20.2	20.9	19.7
Min. temp (°C)	1961-1990	8.0	7.5	7.6	4.5	7.5	7.0
	1980-2010	7.8	7.7	8.3	5.0	7.6	7.3
			Pre-monsoon season (Mar – May)				
Max. temp (°C)	1961-1990	34.0	36.0	34.0	33.0	33.7	33.7
	1980-2010	33.7	36.3	33.8	33.2	33.7	33.3
Min. temp (°C)	1961-1990	18.3	19.0	18.0	16.3	18.3	18.0
	1980-2010	18.9	19.9	18.9	17.0	18.4	17.7
			Monsoon season (Jun – Sep)				
Max. temp (°C)	1961-1990	35.0	37.3	34.7	36.3	35.0	35.7
	1980-2010	34.8	37.5	34.6	35.6	34.6	34.8
Min. temp (°C)	1961-1990	25.0	26.3	23.5	24.7	25.3	25.5
	1980-2010	24.7	26.5	24.8	24.2	25.5	25.7
			Post-monsoon season (Oct – Dec)				
Max. temp. (°C)	1951-2000	27.7	29.3	27.6	27.3	27.7	27.3
	1980-2010	26.9	29.0	27.4	26.9	26.7	26.2
Min temp (°C)	1951-2000	13.0	12.3	12.3	10.3	12.0	12.7
	1980-2010	11.9	13.5	12.2	9.3	12.0	11.8

stations except for Ambala which is showing decreasing trend. Stations having significant trends in maximum and minimum temperatures are Hissar (-0.01 °C), Chandigarh (-0.03 °C) Amritsar (-0.03 °C), Ludhiana (-0.02 °C in maximum temperatures and Ambala (-0.04 °C), Hissar (+0.02 °C) Chandigarh (+0.01°C) and Ludhiana (+0.02 °C) in minimum temperatures.

In post monsoon season increasing trends in maximum temperatures in the range (+0.3 to 0.4 °C/years) has been observed in Punjab whereas mixed trends has been observed in Haryana. Minimum temperature shows increasing trends ranging (+0.02 to + 0.07 °C /years) of stations in Haryana whereas mixed trends have been observed in Punjab. Stations having significant trends in maximum temperatures are Ludhiana (+0.02 °C), Patiala (+0.04 °C), in Punjab Hissar (-0.02 °C), Ambala (+0.02 °C) in Haryana. Stations having significant trends in minimum temperatures are Hissar (+0.07 °C), Chandigarh (+0.02 °C) in Haryana and Amritsar (+0.02 °C), Ludhiana (-0.01 °C) in Punjab.

3. Annual rainfall shows significant decreasing trends range (-1.4 to -6.2 mm/year) in both the states.

TABLE 3

Increasing (+) / decreasing (-) trends of annual means of maximum temperature (max), minimum temperature (min), mean temperature (mean) / diurnal temperature rang (DTR) & rainfall. Data period 1980-2010 N.T. - No trend values significant at 95% level of significant are shown in bold trend values per year

Station	Annual temperature (°C)				Max/Min (°C) Season wise				Rainfall season wise					Rainy days
	Max	Min	Mean	DTR	Jan-Feb	Mar-May	Jun-Sep	Oct-Dec	Annual	Winter	Summer	Monsoon	Post monsoon	
Ambala	0.02	N. T.	+0.01	+0.03	N. T./ N. T.	+0.07/+0.03	N.T./-0.04	+0.02/N.T.	-0.83	-0.8	+0.17	+5.4	-0.8	-0.26
Hissar	N. T.	0.06	+0.02	-0.08	0.02/+0.05	+0.07/+0.1	-0.01/+0.02	-0.02/+0.07	-3.05	+0.4	-0.2	1.5	-4.9	N.T.
Amritsar	0.09	0.01	+0.01	-0.2	-0.02/ N.T.	+0.07/+0.02	-0.03//N.T.	N.T./+0.02	-6.2	-0.2	-3.1	-2.0	-1.1	-0.2
Patiala	0.01	0.04	+0.03	-0.02	+0.04/-0.01	+0.08/+0.02	N.T./N.T.	+0.04/N.T.	-1.4	+0.2	-4.4	-0.01	-1.05	+0.02
Ludhiana	0.02	0.01	N. T.	N. T.	+0.01/N. T.	+0.07/+0.02	-0.02/+0.02	+0.03/-0.01	-4.5	+0.6	-2.7	+1.05	-1.2	-0.07
Chandigarh	N .T.	0.03	-0.03	-0.03	-0.03/ N.T.	+0.04/+0.05	-0.03/+0.01	N.T./+0.02	+1.7	-0.2	-2.1	+6.1	-4.9	N.T.

Stations having significant trends are Ambala (-0.83 mm/year), Hissar (-3.05 mm/year), Chandigarh (+1.7 mm/year) in Haryana and Amritsar (-6.2 mm), Patiala (-1.4 mm), Ludhiana (-4.5 mm) in Punjab. Seasonal rainfall analysis indicates that rainfall is decreasing during post monsoon (Oct-Dec) range (-1.0 to -4.5 mm/year), Summer (Mar-May) range (-2.0 to -4.4 mm/year) in both the state as shown in Table 3.

In monsoon season (June-September) rainfall is increasing in Haryana (+1.0 to +6.0 mm/year) and decreasing in Punjab (-0.01 to -2.0 mm/year). In winter season mixed trends have been observed in all the stations under study. Annual rainy days also showing mixed trends in both the states. Stations having significant trends of annual rainy days are Amritsar (-0.2 mm), Patiala (+0.02 mm), Ludhiana (-0.07 mm) in Punjab and Ambala (-0.26 mm), in Haryana. Annual rainfall shows deceasing trends in both the states and is in consistent with work reported by Bhutiyani *et al*. (2007) on decrease in precipitation over north western Himalayan region. Increase in temperatures may be attributed to many causes, like, industrialization, land used pattern, high input agricultural practices, urbanization etc.

4. Above analysis indicates that temperatures is increasing in all the stations under study. Increase in maximum temperatures is more in Punjab than Haryana. These rising trends is also consistent with increase of temperature globally (IPCC fourth report) and also consistent with trends in Northwestern Himalaya as reported by Bhutiyani *et al.* (2007). Seasonal analysis of temperature (maximum and minimum) of stations under study indicates that pre-monsoon season is more warmer than other seasons which is consistent with national temperature scenario. Diurnal range of temperatures is decreasing in all stations except for Ambala in Haryana. DTR is difference between daily maximum and minimum temperatures and change in DTR is possibly caused due to cloud cover, urban heat, land use, change water vapour, local effect such as urban growth, irrigation, desertification etc. Decrease of DTR is mainly due to daily minimum temperature increasing at a faster rate or decreasing at a slower rate than the daily maximum, resulting in a decrease in the DTR. Increase in DTR is due to increase in daily mean maximum temperatures. Decreases in DTR were first identified in the United States, where large-area trends show that maximum temperatures have remained constant or have increased only slightly, whereas minimum temperatures have increased at a faster rate. A study by Braganza *et al*., 2004, attributes reduction in DTR to global warming. [http://www.met.sjsu.edu/~wittaya/journals/diurnalTempRange.pdf)]. Aerosols have a large influence on DTR. A study [Makowski *et al*., 2008, "Diurnal temperature range over Europe between 1950 and 2005", (http://www.atmos-chem-phys.org/8/6483/2008/acp-8-6483-2008.html)]: Aerosols have a large influence on DTR "It has been widely accepted that diurnal temperature range (DTR) decreased on a global scale during the second half of the twentieth century.

Annual rainfall is decreasing in all stations under study except for Chandigarh wherein it is increasing which may be due to its topographical features and also due to influence of west to eastwards moving systems across Himalayas due to its location. Seasonal rainfall for the period under study indicates that rainfall is significantly decreasing in post-monsoon season (October-December) of stations under study for both the states. Rainfall in summer season is also decreasing except for Ambala in Haryana wherein it is increasing. Rainfall during monsoon and winter season is showing mixed trends as shown in Table 3.

5. Finding of this study give broader pictures of warming (increasing temperatures) and decrease in annual, post monsoon season in stations selected for study. This work may not be exhaustive and need further investigation with more data base and locations. Following conclusion can be drawn out of this study.

(*i*) Annual temperature, *i.e.,* maximum, minimum and mean are increasing in Punjab and Haryana for stations under study. Trends analysis shows that annual temperature, *i.e.,* mean maximum, minimum and mean temperatures show increasing trends in Punjab ranging (+0.01 to +0.02 °C/year) for maximum, (+0.01 to +0.04 °C/year) for minimum and (+0.01 to +0.02 °C/year) for mean temperature. Diurnal range of temperature shows decreasing trends except for Ludhiana in Punjab and Ambala in Haryana.

(*ii*) Seasonal analysis indicates that in winter season (January - February) maximum temperatures is decreasing (-0.02 to -0.04 °C/year) in both the states. Minimum temperature is decreasing in Punjab (-0.01 to -0.02 °C/year) and increasing in Haryana (+0.01 to +0.04 °C/year).

In pre-monsoon season both mean maximum and minimum temperatures show increasing trends ranging (+0.07 to 0.08 °C/ year) for maximum and (+0.02 to 0.05 °C/year) for minimum for both Met. sub-divisions. In monsoon season decreasing trends in maximum temperature ranging (-0.01 to -0.03 °C/year) and increasing trends in minimum temperatures (+0.01 to +0.02 °C/year) has been observed in Haryana except Ambala. In Punjab maximum temperature is decreasing (-0.01 to -0.02 °C/year) and minimum temperature is increasing (+0.01 to +0.02 °C/year). In post-monsoon season maximum temperatures is increasing (+0.03 to 0.04 °C/year) in Punjab whereas mixed trends have been observed in Haryana. Minimum temperature is increasing (+0.01 to 0.07 °C/years) in Punjab and Haryana.

(*iii*) Annual rainfall shows significant decreasing trends in Punjab and Haryana during the period under study. Decreasing trends have also observed in summer and post-monsoon seasons in all stations. Monsoon rainfall shows decreasing trends in Punjab while increasing trends in Haryana. Mixed trends have been observed in winter season.

Annual rainy day shows decreasing trends in all the stations in Punjab. In Haryana also trends in rainy days is decreasing but not significant.

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