Trends in the temperature and rainfall extremes during recent past in Gujarat

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ABSTRACT

In the present study, an attempt has been made to analyze the temperature and rainfall extremes observed in Gujarat during the recent past. Observed daily data of maximum and minimum temperature and rainfall for 32 geographically well distributed locations in Gujarat for the available time series during year 1958 to 2011 has been used to calculate various extreme climate indices and their trends. Results revealed signature of warming in Gujarat as indicated by statewide uniform increase in numbers of warm nights (TR25), decrease in cold days (FD10), decrease in frequency cool nights (TN10p), increase in minimum of minimum temperature (TNn) and increase in frequency of warm nights (TN90p). The results also indicated an increase in total amount of precipitation (PRCPTOT) and extremely wet days (R99p) over more numbers of stations of the state. However, most temperature and rainfall extremes showed mixed over the state.

Keywords: Extremes, climate indices, temperature, rainfall, trend, percentile

In the context of global warming, the study of extreme weather events has become important due to its impact on socio-economic activities (Karl and Easterling, 1999). Much work has been devoted to the study of extreme weather events over India. De *et al. (*2005) reviewed various extreme weather events over India in the past 100 years and discussed their causes and socio-economic impacts. Revadekar *et al.* (2012) studied temperature extremes over India. They noted a widespread warming over Indian region through both frequency and intensity indices of temperature extremes. Rupa Kumar *et al.* (1992) examined the trends in the total precipitation during 1871-1984 and found increasing trends in the precipitation amounts all along the west coast of India and northwest India. Joshi *et al.* (2006) examined the trends in extreme rainfall indices for the period of year 1901 to 2000 over India. Their study showed that there were significant positive trends for most of the extreme rainfall indices over the west coast and northwestern parts of Indian peninsula. However, very little work has been done on the climate extremes at regional level especially for Gujarat state. Ray *et al.* (2009) studied climate variability and extreme weather events like cold wave and heat wave conditions and heavy rainfall events in Gujarat and they recorded a significant steady increase in these events. In the present study an attempt has been made to analyze the observed trend in the temperature and rainfall extremes in Gujarat over past few decades.

MATERIALS AND METHODS

Observed daily data of maximum temperature, minimum temperature and rainfall of 32 geographically well-distributed locations in Gujarat for the available time series during 1958 to 2011 has been used to calculate various extreme climate indices. The locations of these stations (Fig. 1) along with the period for which the time series at various stations were used given in Table 1.

Assessment of the data quality is pre-requisite for calculating extreme indices. The RClimDex, a program script written in R language developed at the Meteorological Service of Canada was used for data quality assessment (Zhang and Yang, 2004). All the outliers and suspected values of maximum and minimum temperature were discarded. The indices and their trends were worked out using RClimDex. The indices that have been calculated are listed in Table 2. Station records with more than 25% of the data either missing or recording zero for any particular index was considered invalid. The significance of each trend was examined at 95% confidence level.

RESULTS AND DISCUSSION

The extreme climate indices (trends) discussed for the stations. Inferences were drawn for the state considering the overall pattern of trend over regions. Statistical significance was considered for each index. Though, inferences were not strictly based on test of significance as many indices values
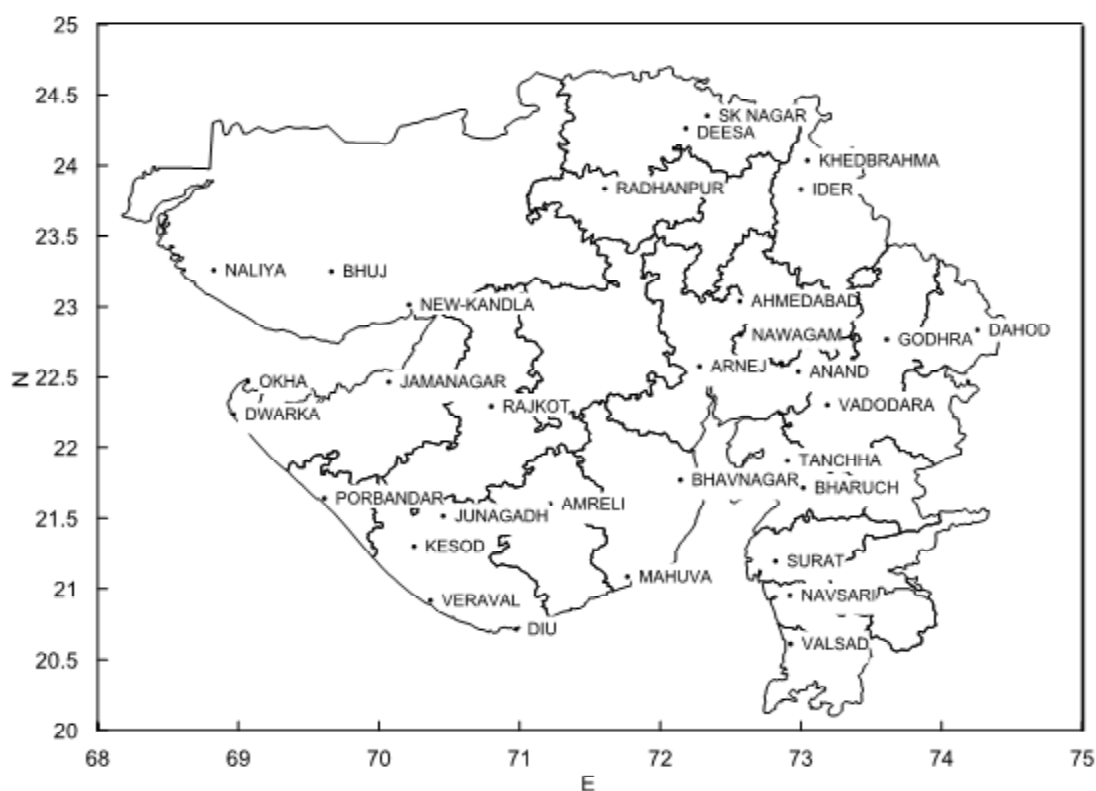
Fig.1: Location of meteorological stations

Table 1: Stations selected for study

Station Name	Start year	End year	Station Name	Start year	End year
Ahmedabad	1969	2006	Khedbrahma	1992	2009
Amreli	1973	2006	Mahuva	1987	2011
Anand	1958	2011	Naliya	1969	2006
Arnej	1989	2011	Navsari	1980	2011
Bharuch	1990	2011	Nawagam	1978	2011
Bhavnagar	1969	2006	New Kandla	1969	2006
Bhuj	1969	2006	Okha	1969	2006
Dahod	1969	2003	Porbandar	1969	2006
Deesa	1969	2006	Radhanpur	1992	2011
Diu	1969	2001	Rajkot	1969	2006
Dwarka	1969	2006	S K Nagar	1981	2011
Godhra	1989	2011	Surat	1969	2006
Idar	1969	2006	Tanchha	1994	2011
Jamnagar	1992	2011	Valsad	1974	2006
Junagadh	1987	2008	Vadodara	1969	2006
Kesod	1969	2006	Veraval	1969	2005

Table 2: Extreme climate indices used in the study

Index	Index name	Definition	Unit
SU35	Hot days	Annual count when Tmax (daily maximum) >35ºC	Days
SU40	Very Hot days	Annual count when Tmax (daily maximum) >40ºC	Days
TR25	Hot nights	Annual count when Tmin (daily minimum) >25ºC	Days
FD10	Cold days	Annual count when Tmin (daily minimum) <10ºC	Days
TXx	Maximum of Maximum temperature	Monthly maximum value of daily maximum temperature	°C
TXn	Minimum of Maximum temperature	Monthly minimum value of daily maximum temperature	°C
TNx	Maximum of Minimum temperature	Monthly maximum value of daily minimum temperature	°C
TNn	Minimum of Minimum temperature	Monthly minimum value of daily minimum temperature	°C
TX90p	Warm Days	Percentage of days when Tmax >90th percentile	Days
TX10p	Cool days	Percentage of days when Tmax <10th percentile	Days
TN90p	Warm nights	Percentage of days when Tmin >90th percentile	Days
TN10p	Cool nights	Percentage of days when Tmin <10th percentile	Days
DTR	Diurnal Temperature Range	Monthly mean difference between Tmax and Tmin	°C
RX1day	Maximum 1 day rainfall amount	Monthly maximum 1 day rainfall	mm
R100	Number of very heavy rainfall days	Annual count of days when Rainfall>=100mm	Days
R99p	Extremely wet days	Annual total Rainfall when Rainfall>99th percentile	mm
PRCPTOT	Annual total rainy days	Annual total Rainfall in wet days (Rainfall>=2.5mm)	mm

were not significant because of limited length of weather parameters time series or broken time series with few missing values for many stations. The values of the all climatic extreme indices are given in the Table 3 and discussed accordingly. The indices showing almost uniform trend pattern for the state and concluding, are also presented with spatial distribution by mapping (Fig. 2).

Trends in temperature extreme indices

The warm extreme index of SU35 in general showed increasing trend for more numbers of stations in Gujarat and many of those including Mahuva, Valsad and Idar were significant. The trends in the index of SU40 were mix and very few stations showed significant trend. Only Porbandar had significant rising trend while SK Nagar showed significant declining trend. The index of number of hot nights (TR25) also showed increasing trend at most of the stations (Fig. 2a). The stations of Jamnagar, Arnej, Idar, Surat and Veraval had comparatively high rising trend which were statistically significant. While very few stations showed a declining trend. Diu and Mahuva among them revealed significantly decreasing trends.

A decreasing trend for the frequency of cold days (FD10) was observed at most of the stations during the investigation period (Fig. 2b) and trends were significant at many of these stations. Only five other stations revealed

increasing trends among which only Diu shows significant increasing trend.

The index of monthly maximum value of daily maximum temperature (TXx) indicated positive and negative mix trend values over the state. Among all stations Dwarka and Valsad showed rising while Anand showed significant decrease in trend value. The event of minimum of maximum temperature (TXn) also showed mixed trend values for stations of Gujarat. However, the increasing trends were significant only at Anand and some coastal stations (New kandla, Porbandar, Veraval, Diu and Mahuva). Only Radhanpur shows significantly decreasing trend.

The event of monthly maximum of minimum temperature (TNx) had mix trend values. The extreme index of minimum of minimum temperature (TNn) showed rising trend in most parts of Gujarat except some stations (Fig. 2c). Many of them showed significantly rising trends, thereby indicating a decrease in the night temperature in the state over past few decades. Only Diu revealed significantly decreasing trend.

The percentile based indices were worked out for those stations satisfying the criteria with no more than 25% of data recording zero for the index. The event of warm days (TX90p) showed mixed trend for the state. However, only Porbandar had positive significant trend. Events of cool

Table 3. Climatic indices trend values for stations of Gujarat

Station	SU35	SU40	TR25	FD10	TXx	TXn	TNx	TNn	Tx10p	Tx90p	TN10p	TN90p	DTR	RX1day	R100mm	R99p	PRCPTOT
Ahmedabad	-0.130	-0.166	**1.150**	-0.073	-0.005	0.017	0.023	-0.016	0.042	-0.015	-0.195	0.204	-0.018	0.873	-0.001	1.968	1.634
Bhavnagar	0.072	-0.119	0.607	**-0.396**	0.009	0.002	0.018	**0.102**	-0.050	0.058	**-0.433**	**0.220**	**-0.026**	-0.238	-0.016	-1.865	1.514
Bhuj	-0.259	-0.313	0.359	**-0.961**	-0.019	-0.011	0.017	**0.112**	0.057	0.002	**-0.287**	**0.506**	**-0.051**	0.788	0.021	0.531	1.561
Dahod	0.620	0.166	0.091	0.134	0.033	0.009	-0.058	0.020	-	-	-	-	0.017	-1.864	-0.013	-3.385	-15.4
Deesa	0.312	-0.150	-0.878	0.068	-0.003	0.022	-0.027	-0.024	-0.151	0.099	**0.607**	-0.078	**0.036**	0.454	0.011	-1.226	2.052
DIU	0.154	-0.005	**-4.347**	**0.816**	-0.006	**0.071**	**-0.117**	**-0.248**	-	-	-	-	**0.261**	-1.023	-0.011	-2.519	-3.315
Dwarka	**0.164**	0.000	**0.617**	0.000	**0.038**	0.041	**0.011**	0.019	-	-	-	-	0.000	0.154	0.000	0.308	1.128
Idar	**1.005**	0.431	**1.305**	-0.023	0.039	0.034	0.004	0.044	-	-	-	-	0.011	-1.037	-0.018	**-3.257**	-3.943
Kesod	0.279	-0.040	**0.546**	**-0.260**	-0.004	-0.002	0.008	0.021	-0.049	-0.013	**-0.274**	0.193	-0.015	0.775	-0.004	-0.675	0.884
Vadodara	0.633	0.036	**0.875**	**-0.337**	0.000	0.039	0.009	**0.068**	-0.143	0.185	**-0.497**	0.187	-0.012	**1.908**	**0.056**	3.859	8.263
Naliya	**0.781**	0.109	**0.738**	**-0.723**	0.054	0.012	**0.023**	0.058	-	-	-	-	-0.002	0.838	-0.010	1.036	-1.041
NewKandla	**0.766**	0.047	**0.811**	-0.025	0.028	**0.064**	**0.016**	0.036	-	-	-	-	0.006	0.296	-0.005	-1.232	-0.323
Okha	0.026	0.000	0.760	0.000	-0.006	0.028	0.014	-0.011	-	-	-	-	**0.026**	-0.341	0.000	0.010	2.466
Porbandar	**0.796**	**0.103**	0.021	-0.044	0.043	**0.051**	-0.001	0.011	**-0.375**	**0.473**	-0.105	0.204	**0.021**	-1.791	-0.005	-2.565	-2.269
Rajkot	0.394	0.309	**0.930**	**-0.374**	0.029	0.029	**0.041**	**0.071**	-	-	-	-	**-0.019**	-2.075	0.002	-2.675	-0.473
Surat	**-0.689**	-0.043	**1.261**	-0.037	-0.016	-0.019	0.014	0.013	**0.148**	-0.226	0.069	**0.499**	**-0.028**	0.485	0.016	1.102	4.521
Valsad	**1.982**	0.122	0.464	-0.069	**0.093**	0.076	0.009	0.059	-	-	-	-	**0.050**	**6.052**	0.051	**18.667**	18.579
Veraval	0.228	0.036	**1.254**	**-0.104**	0.024	**0.034**	0.017	**0.085**	-	-	-	-	-0.020	-0.235	-0.009	1.011	1.147
Amreli	1.202	0.889	0.184	-0.373	-0.006	0.018	-0.035	0.068	**-0.328**	0.086	-0.279	0.001	0.002	3.186	0.045	7.121	22.221
Anand	**0.534**	-0.200	**0.596**	**-0.185**	**-0.028**	**0.042**	**-0.020**	0.046	**-0.300**	-0.127	**-0.338**	0.099	-0.001	0.494	-0.009	0.991	0.671
Amej	-0.287	0.129	**2.008**	**-0.579**	0.003	0.051	0.028	**0.166**	-0.048	-0.166	**-0.395**	**0.420**	**-0.062**	3.866	0.036	**7.458**	**19.482**
Godhra	-0.123	-0.211	0.991	-0.110	-0.082	-0.257	0.002	-0.019	-	-	-	-	-0.024	**-5.908**	-0.054	**-11.247**	-4.365
Jamnagar	-1.284	-0.100	**2.876**	**-1.047**	-0.042	-0.090	0.044	0.018	-	-	-	-	**-0.176**	1.549	-0.002	-0.917	12.200
Khedbrahma	-1.391	-0.430	0.639	-0.430	0.015	-0.575	0.131	-0.084	-	-	-	-	-	-1.380	-0.034	1.000	-10472
Mahuva	**2.973**	0.005	**-5.675**	0.025	-0.066	**0.130**	**-0.227**	-0.014	-	-	-	-	**0.166**	0.423	0.029	3.970	-0.463
Navsari	-0.576	-0.014	**1.811**	**-0.315**	-0.011	0.033	0.022	**0.096**	-	-	-	-	**-0.071**	-0.921	-0.011	-6.241	3.161
Nawagam	1.067	0.426	0.741	-0.260	0.009	0.034	-0.054	0.056	-	-	-	-	0.028	1.911	0.031	1.503	18.293
Radhanpur	-7.648	-2.835	-3.815	-0.818	-0.365	**-0.997**	-0.026	0.128	-	-	-	-	**-0.580**	2.990	0.071	5.012	22.388
SKNagar	-1.210	**-0.884**	-0.615	0.285	-0.316	-0.233	-0.022	0.072	-	-	-	-	0.024	-0.834	-0.002	-3.218	3.562
Junagadh	-0.044	-0.388	0.437	**-1.018**	-0.048	-0.114	-0.043	**0.133**	-	-	-	-	**-0.070**	3.177	0.075	12.210	17.379
Tancha	-2.005	0.153	1.458	-0.661	-0.604	-0.742	-0.005	0.123	-	-	-	-	0.016	0.115	0.012	3.009	2.945
Bharuch	0.666	-0.144	0.686	-0.147	-0.042	-0.144	**-0.047**	0.126	-	-	-	-	-0.032	-1.710	-0.018	-4.371	-0.059

Bold trend values are significant at 95% of level
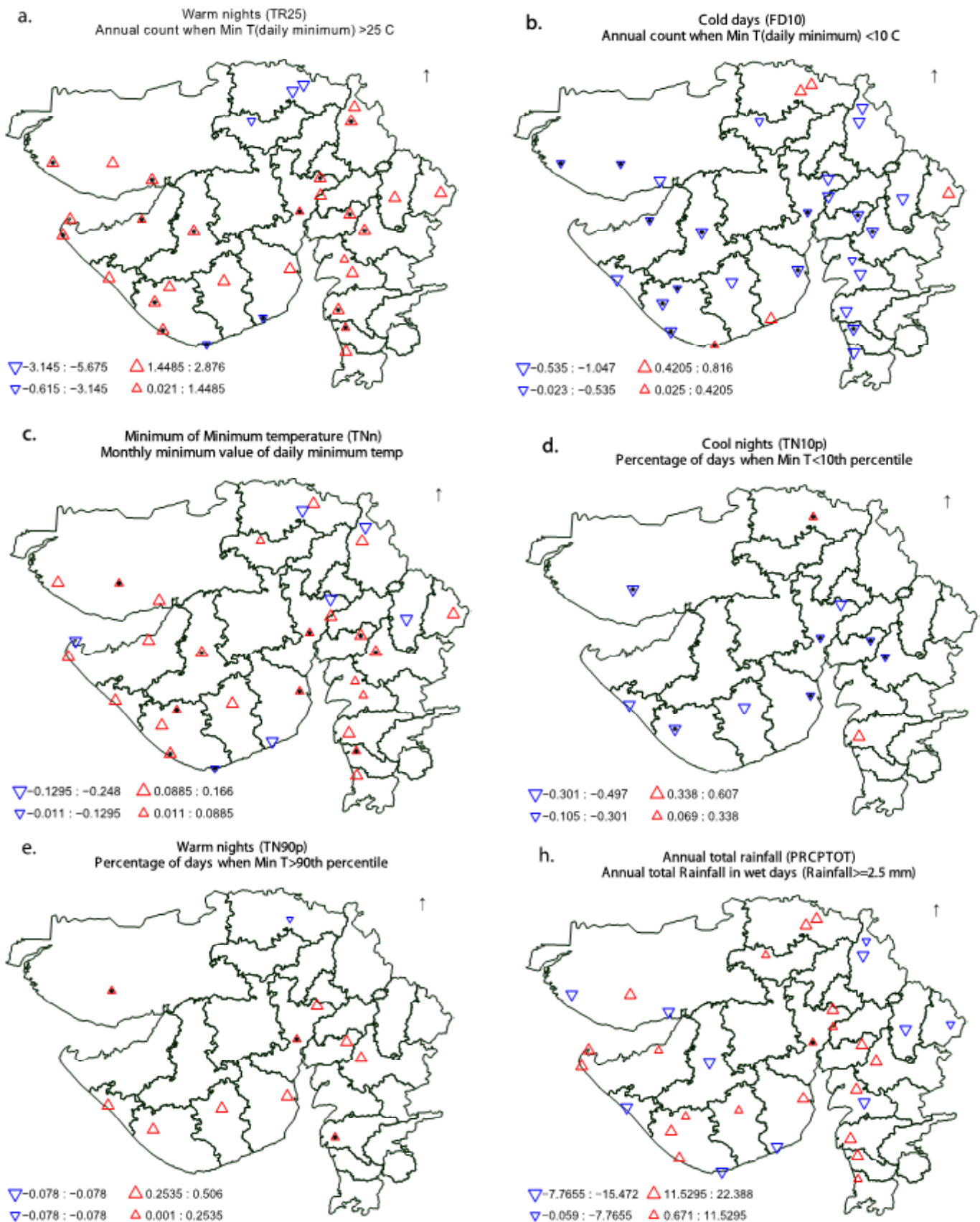
Fig. 2 (a-h) : Spatial mapping of climatic extreme indices (trends) over Gujarat. [Triangle indicates positive trend/index value, Inverted triangle indicates negative trend/index value, Asterisk (*) in marker indicates statistically significant value at 0.05 level.]

days (TX10p) showed negative trend at more numbers of the stations and some of them reaved significant trend. While the station records at Bhuj, Surat and Ahmedabad indicated increasing trend with the trend at Surat station being significant. The trend for events of warm nights (TN90p) also increased all over Gujarat (Fig.2e) with significant trends at Bhuj, Bhavnagar, Surat and Arnej stations. Only the trend at Deesa station in North Gujarat showed a non-significant decrease. Thus, the frequency of warm nights in a year was increasing in most part of the state. The trend in the event of cool nights (TN10p) indicated a decrease all over Gujarat except at Deesa (Fig. 2d). The positive trends at Bhuj, Bhavnagar, Arnej, Anand, Kesod and Vadodara stations were found significant. The observed declining trends for this event were consistent with the observed rising trend in the event of warm nights. However, the rising trend for this event only at Deesa station in North Gujarat was noted to be significant.

The index of diurnal temperature range showed mixed pattern in the trend (Fig. 2f). Though, more numbers of stations revealed significantly decreasing trends. The value of the trends, either positive or negative, at most of the stations is very small that indicates that there is no much change in the DTR during past few decades. Only Deesa in north Gujarat and coastal stations (Dwarka, Porbandar, Diu, Mahuva and Valsad) showed significant increasing trend in diurnal temperature pattern.

Trend in extreme rainfall events

The index of maximum one day rainfall amount (RX1day), Monthly maximum consecutive 5-day rainfall (RX5day) and Number of very heavy rainfall days (R100) revealed mixed trend values and most of them were non-significant.

Annual total rainfall (PRCPTOT) also revealed positive and negative trend values (Fig.2h). However, more numbers of stations had positive trend values including only a single station (Arnej) having statistically significant trend. It indicates, rainfall quantum has increased over more stations of Gujarat during last few decades. Meanwhile, extremely wet days (R99p) also had similar pattern and indicating irregular distribution of rainfall (Fig.2g).

As the rainfall being stochastic parameter having high variability all rainfall event indices (trends) at most stations were found non-significant.

CONCLUSION

The study revealed mixed pattern for most temperature and rainfall extreme indices over the Gujarat. However, increase in numbers of warm nights (TR25), decrease in cold days (FD10), increase in minimum of minimum temperature (TNn), decrease in frequency cool nights (TN10p) and increase in frequency of warm nights (TN90p) revealed statewide uniform pattern, indicating signature of warming in Gujarat. These warming trend in indices based on minimum temperature reveals trend of less cooling during night period. Rainfall indices also showed no uniformity for any negative or positive trends over Gujarat. Total annual rainfall (PRCPTOT) and extremely wet days (R99p) were found to increase at more numbers of stations. As the rainfall is the parameter having very high variability, very few stations showed statistically significant trends. Thus, still there is ambiguity in the rainfall pattern for Gujarat state.

REFERENCES

De , U.S., Dube R.K. and Prakasa Rao, G.S.(2005). Extreme Weather Events over India in the last 100 years, *J. Ind. Geophys. Union*, 9, (3):173-187.

Joshi, U. R. and Rajeevan, M.(2006). Trends in Precipitation Extremes over India, National Climate Centre Research Report No: 3.

Karl, T.R. and Easterling, D.R.(1999). Climate extremes: selected review and future research directions. *Climatic Change* 42:309–325.

Ray, K., Manorama Mohanty and J. R. Chincholikar, 2009. Climate variability over Gujarat, India, ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture.

Revadekar J.V., Kothawale D.R., Patwardhan S.K., Pant G.B., Rupa Kumar K., 2012. About the observed and future changes in temperature extremes over India, *Natural Hazards*, 60:1133–-1155, DOI: 10.1007/s11069-011-9895.

Rupa Kumar, K., Pant, G.B., Parthasarathy, B., Sontakke, N.A.(1992). Spatial and subseasonal patterns of the long term trends of Indian summer monsoon rainfall, *International J. Climatol.* 12:257–268.

Zhang, X. and Yang, F.(2004). RClimDex user manual, Climate Research Branch, Environmental Canada, Ontario, Canada.