TRENDS IN DAILY CLIMATIC EXTREMES OF TEMPERATURE AND PRECIPITATION IN NEPAL

SARAJU K. BAIDYA[1], MADAN L. SHRESTHA[2] and MUHAMMAD MUNIR SHEIKH[3]
[1] *Department of Hydrology and Meteorology, Kathmandu, NEPAL*
[2] *Nepal Academy of Science and Technology, Kathmandu, NEPAL*
[3] *Global Change Impact Studies Centre, Islamabad, PAKISTAN*

ABSTRACT

The daily temperature data for 36 years from 1971 to 2006 and the precipitation data for 46 years from 1961-2006 of Nepal were analyzed. The network of stations was so chosen that it encompasses all the climatic zones of the country as far as possible. Trends in precipitation and temperature extremes have been investigated using the precipitation and temperature indices of climate extremes for this study using specially designed software, RClimDex.

General increasing trend has been observed in the temperature extremes. Most of the temperature extreme indices show a consistent different pattern in the mountainous and the terai belt. The trend is of relatively higher magnitude in mountainous region. Such pattern may be associated with the occurrence of prolonged fog in the terai region. Days and nights both are becoming warmer and cool days and cool nights are becoming less frequent. The precipitation extremes show increasing trend in total and heavy precipitation events at most of the stations. However, the systematic difference is not observed in extreme precipitation trend between hills and low land southern plains of terai. The evidence suggests complex processes in precipitation extremes, but at the same time there is indication that more weather related extreme events like floods, landslides can be expected in future.

KEY WORDS**:** Temperature indices, precipitations indices, trends, RClimDex, Nepal

1. INTRODUCTION

Extreme events like floods and droughts are the result of extreme meteorological and hydrological conditions. Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) presented the recent understandings and findings on observed climate change, climate processes and attribution, changes in extreme weather events and on many other topics. This report clearly states that the frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increase of atmospheric water vapour. Widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost days have become less frequent, while hot days, hot nights, and heat waves have become more frequent. Such assessment in a country like Nepal becomes more challenging both physically as well as scientifically.

[1] Corresponding Author (Email: sarju@dhm.gov.np)

Nepal lying in the southern flank of the Himalayas is affected profoundly by the monsoonal circulation of South Asia. Though small in size, it has a complex and fragile topography with altitude ranging from almost sea level in the south to the highest place on the earth (Mount Everest) in the north just within a span of about 200 km. This large north-south variation of topography gives rise to different climatic regions. These hills/mountains and the Himalayas are very sensitive to climate change and variability.

Very little studies have been made in this field in Nepal. Global temperature rise is an important subject as it affects various sectors like agriculture, water resource management, tourism and many others. In this context, there are differences of increase in temperature depending on the ground surface, topography and locations. Hingane et al. (1985) made a detail study of the historical time series of temperature data of India and found that there is a definite warming trend in mean annual all India temperature with an increase of 0.4°C during the past century. The trend analysis of maximum temperature in Nepal carried out by Shrestha et al. (1999) found that the average annual warming between 1971 and 1994 was 0.06°C/year. The warming in the maximum temperature is found to be more pronounced in the high altitude regions.

For decades, global climate change studies using observational temperature and precipitation data have focused only on changes in mean values. However, only few studies (Alexander et al, 2005; Frich et al, 2002; Klein Tank A.M.G. and G.P. Können, 2003; Manton et al., 2001) have been done in climatic extremes. Changes in frequency and intensity of extreme climate events would have immediate and intense impacts on all sectors of the nature and the society.

The understanding of the characteristics in the extreme temperature and precipitation fields is necessary to look at their variability and trend. With this in view, the extreme climatic events have been examined both in spatial as well in the temporal basis.

2. DATA AND METHODOLOGY

The Commission for Climatology (CCl) / World Climate Research Programme (WCRP) of World Meteorological Organization, project on Climate Variability and Predictability (CLIVAR) and Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) jointly recommended 27 climate change indices primarily focusing on extremes for climate change monitoring and detection studies. Out of these, 16 indices are temperature related and 11 are precipitation related (Table 1). These indices are derived from daily temperature and precipitation data.

Table 1: List of ETCCDMI core Climate Indices

ID	Indicator name	Definitions	UNITS
FD0	Frost days	Annual count when TN(daily minimum)<0ºC	Days
SU25	Summer days	Annual count when TX(daily maximum)>25ºC	Days
ID0	Ice days	Annual count when TX(daily maximum)<0ºC	Days
TR20	Tropical nights	Annual count when TN(daily minimum)>20ºC	Days
GSL	Growing season Length	Annual (1st Jan to 31st Dec in NH, 1st July to 30th June in SH) count between first span of at least 6 days with TG>5ºC and first span after July 1 (January 1 in SH) of 6 days with TG<5ºC	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	ºC
TNx	Max Tmin	Monthly maximum value of daily minimum temp	ºC
TXn	Min Tmax	Monthly minimum value of daily maximum temp	ºC

TNn	Min Tmin	Monthly minimum value of daily minimum temp	ºC
TN10p	Cool nights	Percentage of days when TN<10th percentile	Days
TX10p	Cool days	Percentage of days when TX<10th percentile	Days
TN90p	Warm nights	Percentage of days when TN>90th percentile	Days
TX90p	Warm days	Percentage of days when TX>90th percentile	Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX>90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN<10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	Mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	Mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year	Mm/day
R10	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
Rnn	Number of days above nn mm	Annual count of days when PRCP>=nn mm, nn is user defined threshold	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
R95p	Very wet days	Annual total PRCP when RR>95^{th} percentile	Mm
R99p	Extremely wet days	Annual total PRCP when RR>99^{th} percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

For this study, daily temperature and precipitation data have been used to compute these climate change indices using specially designed software, RClimDex. RClimDex (1.0) is designed to provide a user friendly interface to compute indices of climate extremes. It computes all 27 core indices (Table 1) recommended by the ETCCDMI as well as some other temperature and precipitation indices with user defined thresholds. R is a free and yet very robust and powerful software for statistical analysis and graphics. It runs under both Windows and Unix environments. It also includes a data quality control procedure before computing the indices.

For the study of climate change long period of data are required to gain more confidence on the results. In Nepal the Hydrological and Meteorological services started in a systematic manner only from 1966. The temperature data for 36 years was considered from 1971 to 2006 and in case of the precipitation, 46 years of data from 1961-2006 was used. The network of stations was chosen so that it encompasses all the climatic zones of the country as far as possible. Due to the complex topography of the country and the limited number of stations available, it was not possible to satisfy this condition, however attention has been given so as to have a much spatial coverage as possible. There are eight stations considered in this study to look at the trend pattern in temperature. Out of these, four stations Lumle, Kathmandu, Okhaldhunga and Ilam Tea Estate lie in the hilly region with altitude more than 1300 m, whereas other four stations namely, Chisapani Karnali, Bhairahawa airport, Simara airport and Biratnagar airport lie in the southern low lying Terai belt with altitude less than 300 m. Similarly, 26 stations were used for precipitation study. The network of temperature stations is shown in Figure 1 and the precipitation network is depicted in Figure 2. The details of the stations used for the computation of the temperature and precipitation indices are presented in Table 2 and 3 respectively.

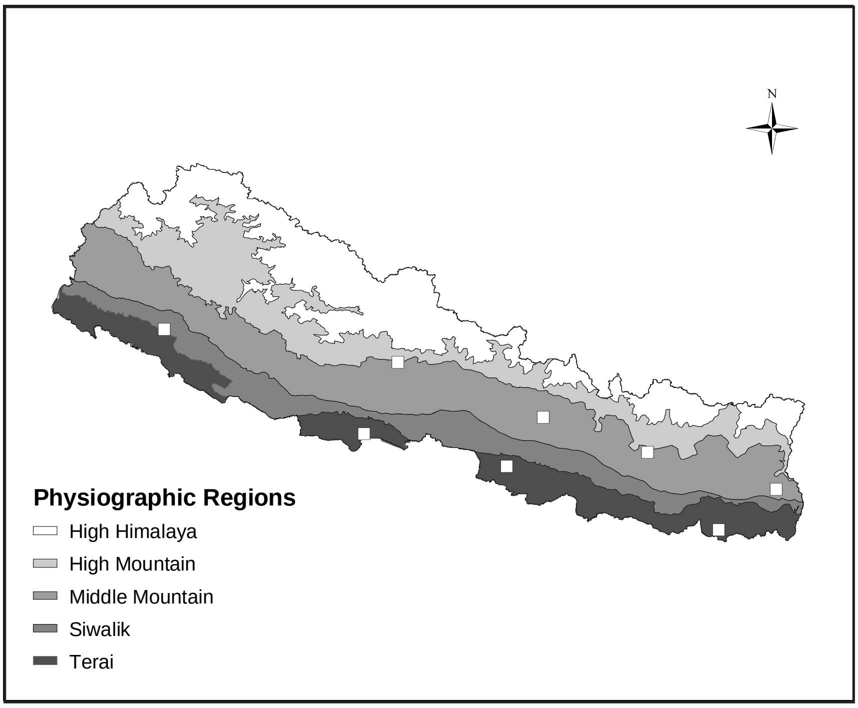


Figure 1: Network of temperature stations.

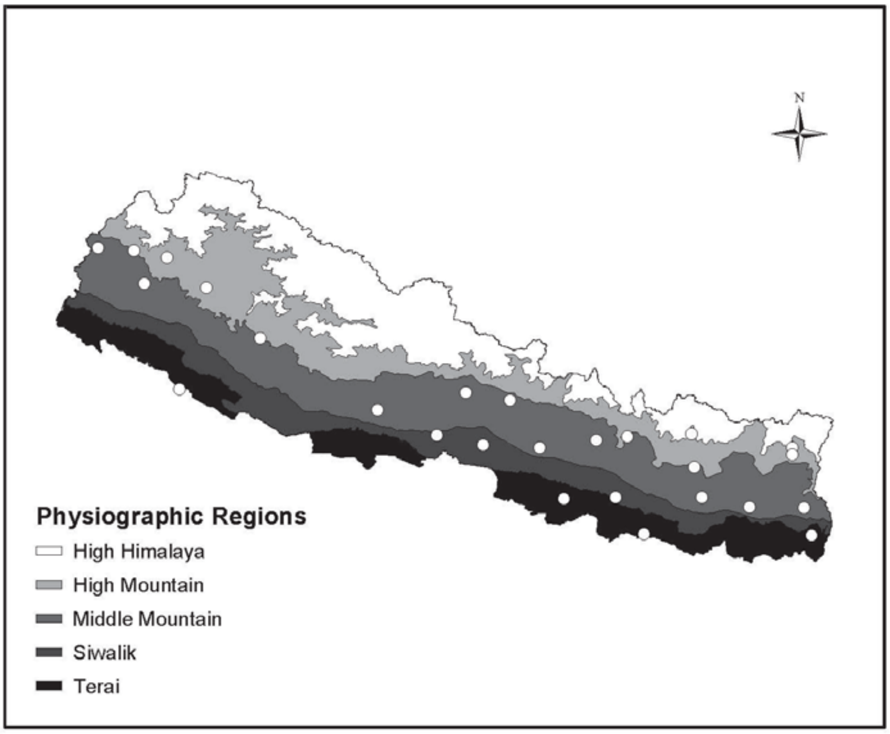


Figure 2: Network of rainfall stations.

Table 2: Details of the stations (8) considered for the temperature indices.

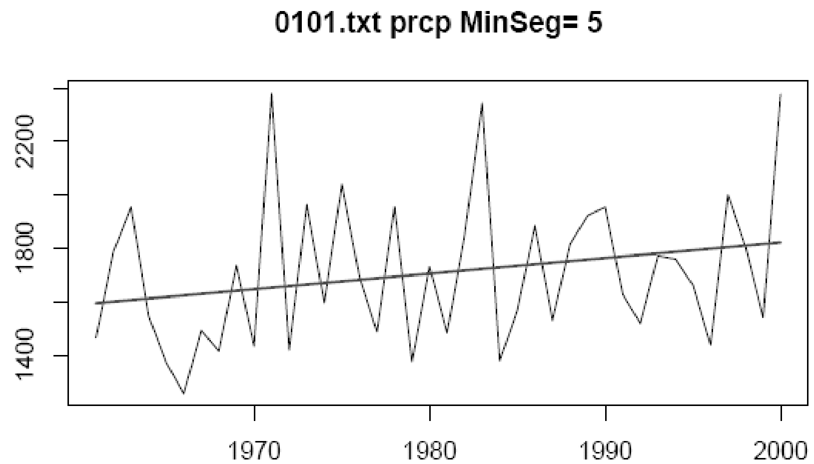
Index No.	Station Name	Longitude (°E)	Latitude (°N)	Altitude (m)
0405	Chisapani (Karnali)	81.27	28.65	225
0705	Bhairahawa Airport	83.43	27.52	109
0814	Lumle	83.80	28.30	1740
0909	Simara Airport	84.98	27.17	130
1030	Kathmandu Airport	85.37	27.70	1337
1206	Okhaldhunga	86.50	27.32	1720
1319	Biratnagar Airport	87.27	26.48	72
1407	Ilam Tea Estate	87.90	26.92	1300

Table 3: Details of the stations (26) considered for the precipitation indices

Index No.	Station Name	Longitude (°E)	Latitude (°N)	Altitude (m)
101	Kakerpakha	80.50	29.65	842
201	Pipalkot	80.87	29.62	1456
202	Chainpur (West)	81.22	29.55	1304
203	Silgadhi Doti	80.98	29.27	1360
309	Bijayapur	81.63	29.23	1814
404	Jajarkot	82.20	28.70	1231
408	Gulariya	81.35	28.17	215
701	Ridi bazar	83.43	27.95	442
704	Beluwa	84.05	27.68	150
807	Kunchha	84.35	28.13	855
903	Jhawani	84.53	27.58	270
904	Chisapani Gadhi	85.13	27.55	1706
912	Ramoli Bairiya	85.38	27.02	152
1002	Arughat Bazar	84.82	28.05	518
1023	Dolalghat	85.72	27.63	710
1102	Charikot	86.05	27.67	1940
1110	Tulsi	85.92	27.03	457
1202	Chaurikhark	86.72	27.70	2619
1204	Aiselukhark	86.75	27.35	2143
1211	Khotang bazar	86.83	27.03	1295
1216	Siraha	86.22	26.65	102
1308	Mulghat	87.33	26.93	365
1403	Lungthung	87.78	27.55	1780
1404	Taplethok	87.78	27.48	1383
1407	Ilam Tea Estate	87.90	26.92	1300
1409	Anarmani Birta	87.98	26.63	122

3. QUALITY CONTROL AND HOMOGENEITY TEST

The main part of this study is to ensure the quality of the data. The data have been checked for outliers, errors and the sudden jump in the series. The software RClimDex has the procedure to identify those aspects. The errors were manually checked and edited on a case by case basis going through the original data as far as possible. Erroneous outliers and artificial step changes could be caused by changes in station location, observing procedures and practice, instrumentation changes etc. [*Aguilar et al.*, 2003]. However, there is not always a consistent approach to deal with data inhomogeneity [*Peterson et al.*, 1998]. RHtest is the software used for identifying the inhomogeneity in the data. For example, homogeneity testing for a station with index number 0101 (Figure 3) shows no sudden jumps in the data series and is considered to be the good one. In the other sample case, the station 0205 (Figure 4) exhibit differently. There is a sudden jump and the F-test shows that the jumps are significant and looking at the stations data more carefully these types of data were rejected. Such tests are applied to all the station data considered in this study.



No significant break point found.

Figure 3: Test for precipitation data at station 0101 (Kakerpakha)

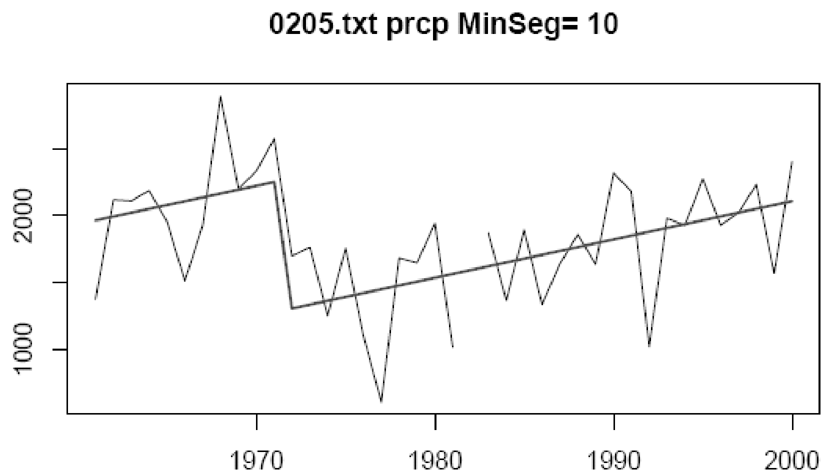


Figure 4: Test for precipitation data at station 0205 (Katai)

Year	F–stat	P–value	Fm90	Fm95	Fm99	Stepsize	Segment
1971	20.54	0	9.25	11.22	16.17-970.73		1961-2000

4. RESULTS AND DISCUSSIONS

The daily data of temperature and precipitation are analysed and using RClimDex software. The various indices in temperature and precipitation as described above are computed with the help of this software and scrutinized in detail to understand the underlying characteristics in the extreme climatic events.

4.1 TEMPERATURE INDICES

The trend of temperature indices are presented in Table 4. The table shows that there is decrease in the annual occurrence of cool nights (TN10p) and increase in warm nights (TN90p) (Fig. 5). Similar features are also observed in the trend of the maximum temperature extremes ie. warm days are increasing and cool days are decreasing. As depicted in Table 4, the trend in maximum temperature are slightly mixed. Few stations exhibit changes in extremes corresponding to decreases in temperature. However, majority of the stations show warming in the maximum temperature.

Table 4: Trend of the temperature indices (per year)

Index No	Altitude (m)	SU25	TXx	TXn	TNx	TNn	TX10p	TX90p	TN10p	TN90p	WSDI	CSDI	DTR
0405	225	0.083	-0.055	-0.076	0.007	0.052	0.056	-0.397	-0.464	0.226	-0.603	-0.749	-0.057
0705	109	0.418	0.018	-0.151	-0.004	0.037	-0.026	0.299	-0.230	0.166	0.399	-0.203	-0.013
0814	1740	0.592	0.025	0.083	0.013	0.021	-0.290	0.652	-0.127	0.121	1.624	0.129	0.043
909	130	0.439	-0.018	-0.162	-0.011	0.002	0.073	0.121	-0.116	0.163	0.161	-0.004	-0.018
1030	1337	1.916	0.071	0.031	0.008	0.031	-0.391	0.899	-0.301	0.263	1.173	-0.091	0.048
1206	1720	3.152	0.093	0.057	0.021	0.025	-0.338	1.131	-0.334	0.199	1.753	-0.375	0.069
1319	72	0.647	0.003	-0.088	0.004	0.013	-0.095	0.369	-0.231	0.220	0.433	-0.048	-0.006
1407	1300	2.587	0.009	0.065	0.029	0.037	-0.276	0.644	-0.092	0.165	0.926	-0.141	0.042
Average		1.035	0.020	-0.044	0.005	0.026	-0.144	0.439	-0.258	0.194	0.706	-0.192	0.009
# of stations with Positive trend		7	5	3	5	7	2	6	0	7	6	1	3
# of stations with Negative Trend		0	2	4	2	0	5	1	7	0	1	6	4

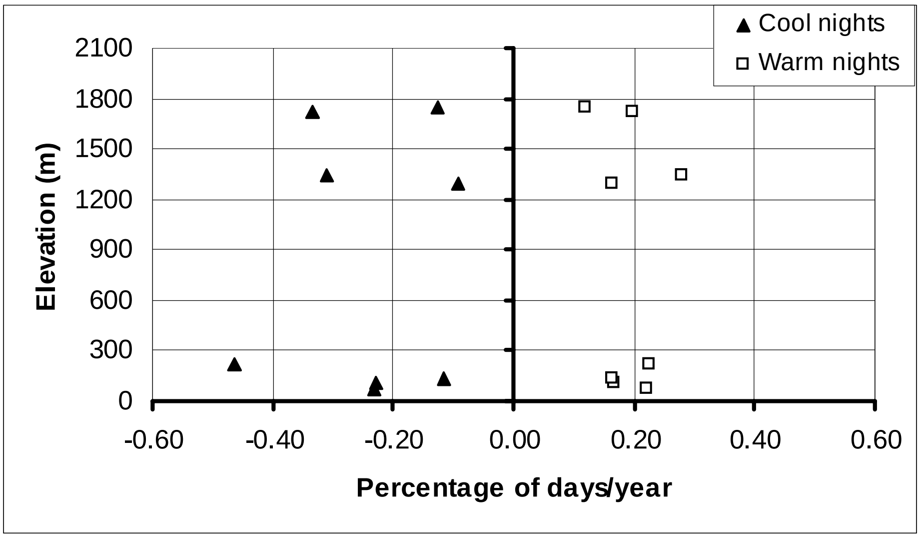


Figure 5: Trend in cool and warm nights with elevation

It is interesting to note here that the decreasing trend of cool days and increasing trend of warm days are very clearly seen at higher elevations (Fig.6). Globally the annual number of warm nights (cold nights) increased (decreased) by about 25 (20) days since 1951 (Alexander et al., 2005). Trends in maximum temperature extremes showed similar patterns of change, although of smaller magnitude. For Nepal, the annual number of cool days and cool nights have decreased by about 5 and 9 days respectively since 1971 till 2006. However, the warm days during the same period have increased by about 16 days and warm nights have increased by only about 7 days.

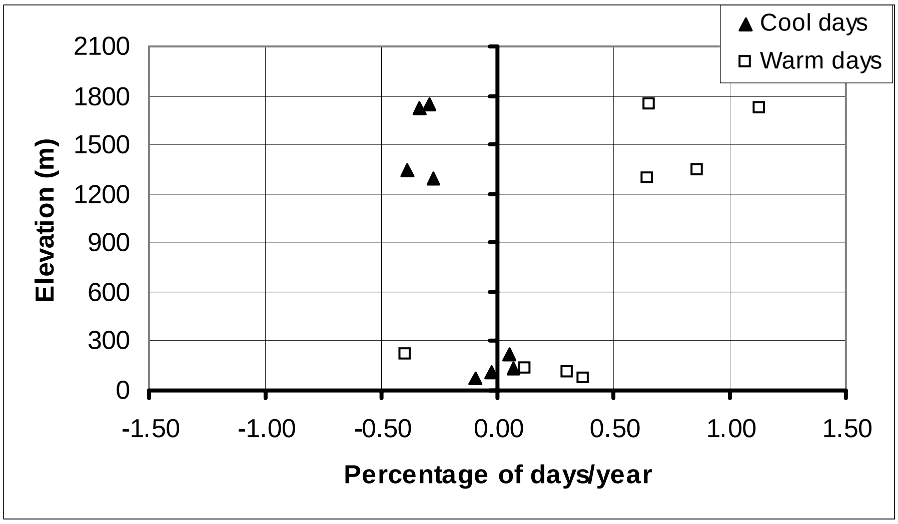


Figure 6: Trend in cool and warm days with elevation.

The absolute temperature indices also exhibit a similar pattern. Figure 7 presents the pattern of the trend of the monthly maximum value of daily maximum temperature (TXx) and daily minimum temperature (TNx) with respect to elevation where all stations show positive trends at stations at higher elevations whereas at lower elevations it is not clearly visible. All the stations showed increasing trend in the minimum value of minimum temperature (TNn) while the trend of minimum value of daily maximum temperature (TXn) is observed to be increasing at four stations and decreasing at other four. It is to be noted that the stations with decreasing trend in TXn all lie in the Terai region (Figure 8). It is very likely that such negative trend is due to the fog episode that appears in the winter season during the past one decade or so in the southern plains of the country (Manandhar, 2006) as part of the Indo-Gangetic plain phenomenon which reduce the maximum temperature significantly. In the recent decade such fog episodes are more frequent lasting for more than a week and sometimes even for a month.

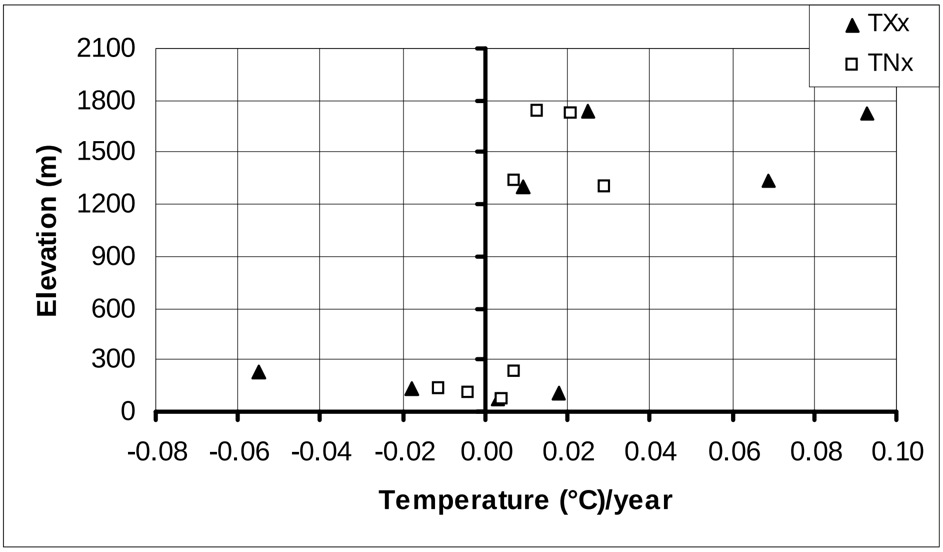


Figure 7: Trend in TXx and TNx with elevation.

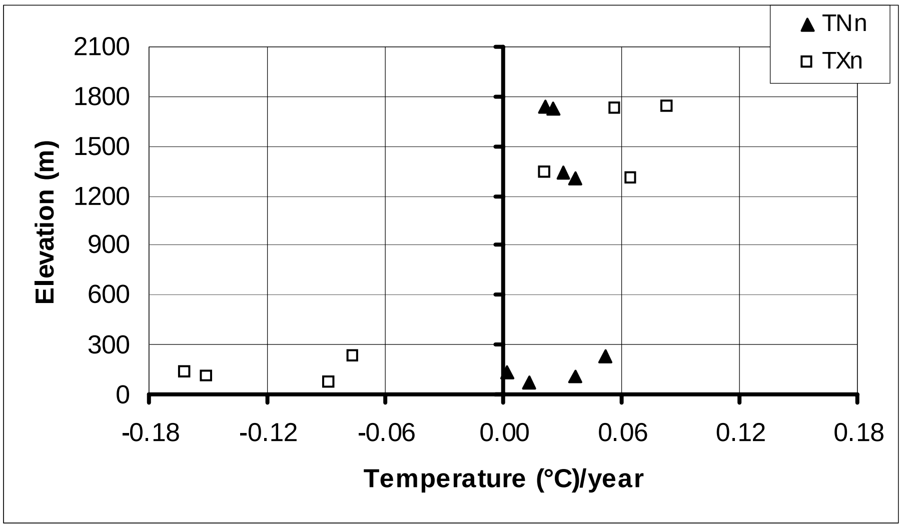


Figure 8: Trend in TNn and TXn with elevation.

The annual count of days with at least 6 consecutive days when maximum temperature is greater than the 95th percentile is termed as warm spell duration indicator (WSDI). At most of the stations WSDI show an increasing trend (Figure 9) except at Chisapani (Karnali) in the Terai region. Among this general increasing trend, the stations in hills show more prominence than that in the Terai area. Similarly, most of the stations indicate negative trend of the annual occurrence of cold spell (CSDI) except at Lumle station (Figure 9). The trend in warm spell is found to be greater in magnitude. Summer days defined as the annual count of number of day with daily maximum temperature greater than 25°C (SU25) show significant increase at all the stations (Figure 10). Here also the trend of SU25 is more prominent at stations over higher elevation than over low lands. Diurnal temperature range (DTR) has been observed to be both decreasing as well as increasing (Figure 11). However, it is interesting to note that DTR is decreasing in the southern plains while the increasing trend has been observed over hilly region. The decrease in diurnal temperature in the Terai plains is consistent with the decreasing trend in the minimum value of daily maximum temperature.

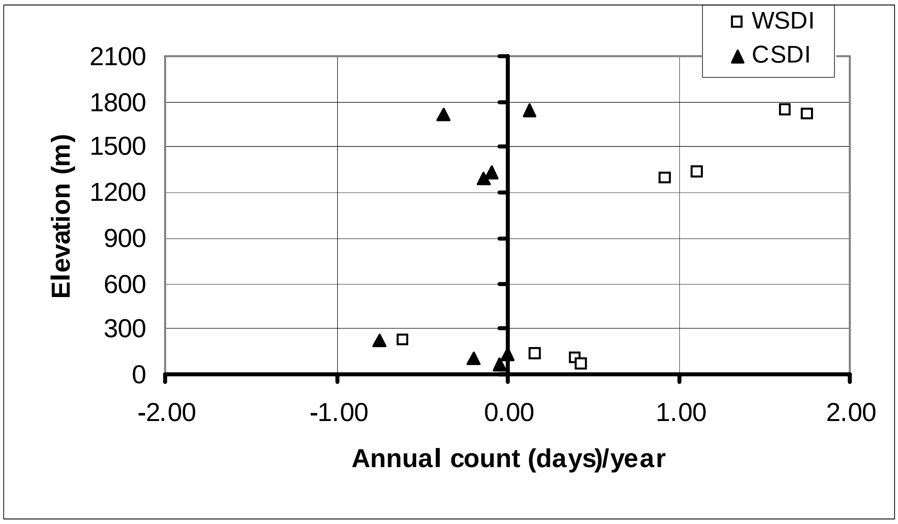


Figure 9: Trend in WSDI and CSDI with elevation

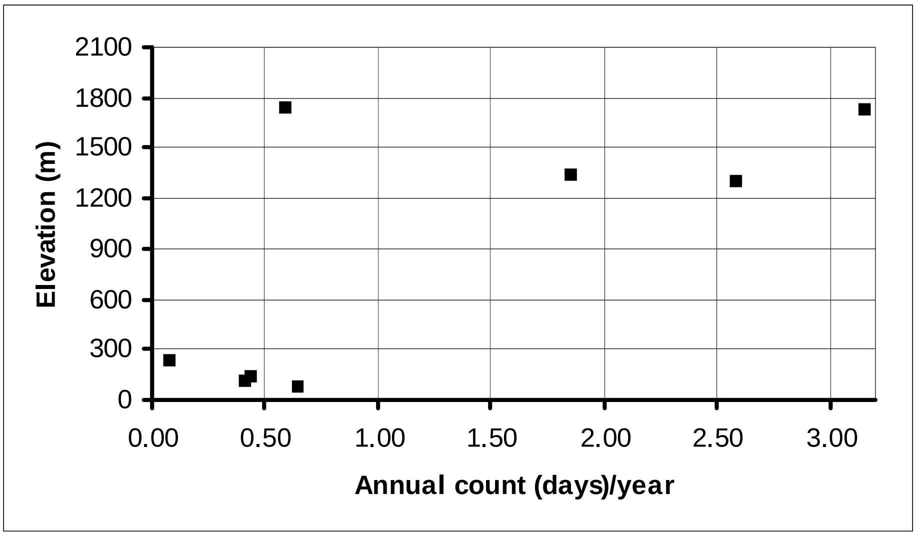


Figure 10 : Trend in summer days (SU25) with elevation.

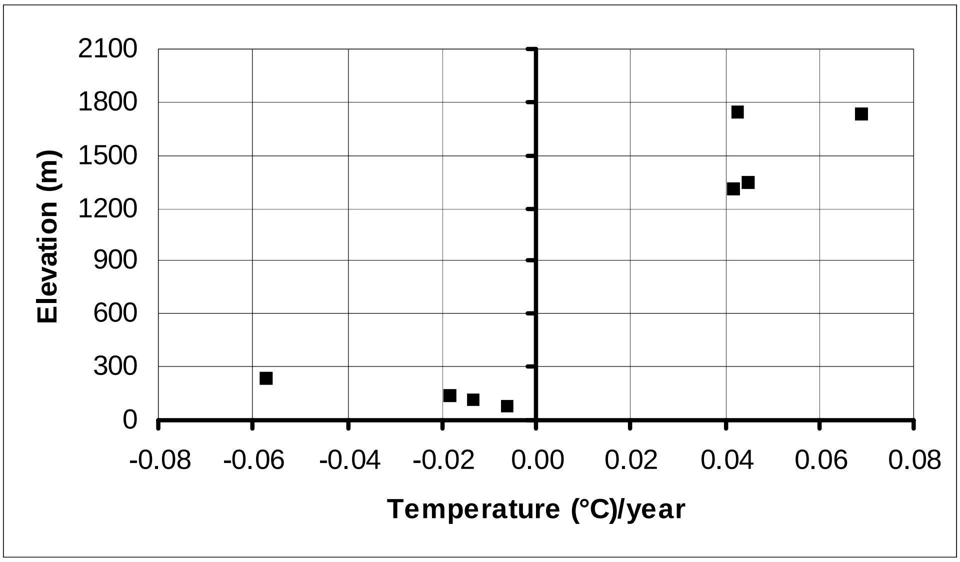


Figure 11 : Trend in Diurnal Temperature Range (DTR) with elevation.

4.2 PRECIPITATION INDICES

As in the case of temperature it is equally important to look at the precipitation characteristics. Number of heavy precipitation days (R10, R20, R50) show an increasing trend at majority of the stations (Table 5). 73% of the stations exhibited increase in the annual count of days when precipitation is greater or equal to 50 mm. In comparison to R10 and R20, R50 shows more stations having increasing trend signifying the occurrence of precipitation extreme events. Alexander et al. (2005) also found that averaged across the globe, more extreme precipitation events have been increasing.

Table 5: Trend of the precipitation indices (per year)

Index No.	Station Name	Elevation	RX1	RX5	R10	R20	R50	CDD	CWD	R95p	R99p	PRCPTOT
101	Kakerpakha	842	0.08	-0.66	0.00	-0.05	-0.02	-0.25	0.04	0.10	-0.47	2.48
201	Piplakot	1456	-0.69	-0.44	-0.22	0.17	0.03	-0.20	0.03	1.99	0.37	1.96
202	Chanipur (West)	1304	0.19	-0.21	0.02	0.02	0.06	-0.15	0.07	3.53	1.18	2.18
203	Sligadhi Doti	1360	-0.39	-0.37	0.15	0.11	0.01	-0.10	0.07	-0.20	-2.09	3.58
309	Bijayapur	1814	-0.58	-0.01	0.15	0.24	-0.04	2.19	-0.04	-1.08	-0.96	0.46
404	Jajarkot	1231	0.79	1.79	0.13	-0.04	-0.01	0.45	-0.01	3.92	1.35	6.02
408	Gulariya	215	1.16	1.52	0.19	0.08	0.01	0.18	0.04	0.01	0.96	4.21
701	Ridibazar	442	-0.54	0.40	-0.10	-0.01	0.05	0.08	0.01	0.18	-2.29	-1.17
704	Beluwa	150	0.06	-0.04	-0.02	0.04	0.05	-0.13	-0.10	1.46	-0.15	5.11
807	Kunchha	855	0.06	-0.13	0.00	0.05	0.09	0.09	-0.04	4.78	1.85	7.47
903	Jhawani	270	1.10	1.51	0.04	0.03	0.06	-0.23	-0.17	7.09	4.20	8.12
904	Chaisapani Gadhi	1706	0.68	-0.27	-0.12	-0.02	0.01	-0.09	-0.31	1.28	0.77	-1.91
912	Ramoli Bairiya	152	-0.11	1.99	0.07	0.06	0.04	0.28	-0.03	1.88	1.66	1.91
1002	Arughat Bazar	518	-1.39	-1.64	0.06	-0.09	-0.06	-0.09	0.01	-7.60	-7.95	-3.91
1023	Dolalghat	710	0.44	0.57	-0.28	-0.04	0.03	-0.96	0.06	3.58	0.07	1.48
1102	Charikot	1940	0.15	0.37	-0.09	-0.06	-0.01	0.10	-0.27	-0.78	-0.11	-2.76
1110	Tulsi	457	0.38	1.87	0.10	0.04	0.03	0.09	-0.08	0.25	0.33	3.56
1202	Chaurikhark	2619	-0.42	-0.45	-0.02	0.08	0.00	-0.03	0.47	0.26	-1.02	0.76
1204	Aiselukhark	2143	0.08	-0.17	0.17	-0.29	-0.15	-0.74	0.57	-3.85	0.87	-3.64
1211	Khotang bazar	1295	0.22	0.21	0.26	0.04	0.00	0.06	-0.04	-0.22	0.55	2.10
1216	Siraha	102	1.16	1.28	0.09	0.07	0.03	-0.03	0.06	3.06	2.41	5.13
1308	Mulghat	365	0.82	1.17	-0.04	-0.07	0.00	0.07	0.06	1.96	3.14	1.35
1403	Lungthung	1780	-0.64	-1.02	0.10	0.10	-0.10	-0.01	0.44	-3.19	-6.94	1.29
1404	Taplethok	1383	-0.48	-0.44	0.10	0.10	0.03	1.01	-0.33	2.55	-0.65	1.19
1407	Ilam Tea Estate	1300	0.12	0.20	0.03	0.13	0.02	0.00	-0.03	2.29	-0.09	4.97
1409	Anarmani Birta	122	0.08	0.89	0.09	-0.04	0.05	-0.82	0.09	1.94	-1.81	6.81
Average			0.09	0.30	0.03	0.02	0.01	0.03	0.02	0.97	-0.19	2.26
% of stations with Positive trend			65	50	62	62	73	42	54	73	54	81
% of stations with Negative trend			35	50	35	38	27	54	46	27	46	19

Trend analysis of the monthly maximum 1-day precipitation (RX1) showed that 65% of stations exhibited increasing trend, whereas the rest of the stations showed decreasing trend. In the trend analysis of precipitation index the annual precipitation in wet days (PRCPTOT) showed that 81% of stations indicated increasing trend and rest of the stations showed decreasing trend. Annual total precipitation when it is greater than 95th percentile are termed as very wet days and represented as R95p. 73% of the stations showed increase in the very wet days The other precipitation indices, indicate less spatial coherence. Other indices like monthly maximum consecutive 5 day precipitation (RX5), Consecutive dry days (CDD), Consecutive wet days (CWD), Extremely wet days (R99p) do not show significant pattern in trends.

5. CONCLUSION

This study has attempted to investigate the trend pattern in temperature as well as in precipitation associated with the extreme events. General warming trend has been observed in the temperature extremes. Even though number of temperature stations analysed are not many, the results show a significant trend consistent with the global trend. Most of the extreme indices show a consistent different pattern in mountainous and southern plains. SU25 shows positive trend but stations in mountainous range show relatively higher magnitude in trend. Similar pattern can also be seen in TXx, TNx, TX90p, WSDI and DTR. In case of daily minimum value of maximum temperature (TXn) and the daily temperature range (DTR) show a typical pattern with increasing trend in mountainous region and decreasing trend in terai region. Such pattern may be associated with the occurrence of prolonged fog in the terai region. Monthly minimum value of daily minimum temperature trend (TNn) is found to be increasing for all the stations, but the pattern difference in mountains and terai is not as distinct as in SU25. In the trend of cool days (TX10p), all the stations in mountainous belt show significantly negative trend indicating that decreasing trend in the cool days. All the stations show the decreasing trend in cold nights (TN10p) and increasing trend in the warm nights (TN90p).

The trend analysis of the extreme temperature indices indicates a systematic difference in the mountainous and terai region. Since the numbers of stations considered are less, care should be taken in giving more emphasis to the magnitude of the trend. Therefore, it is necessary to conduct further research considering more stations so as to give the good spatial resolution.

The precipitation extremes show increasing trend in total and heavy precipitation events at most of the stations. In view of the extreme events, the results are significant in the sense that there is strong evidence that it is likely to have more intense precipitation in future. For very wet days (R95p) and very heavy precipitation days (R50), most of the stations below 1500 m show increasing trend while decreasing trend is observed above 1500 m (Figures 12-13).

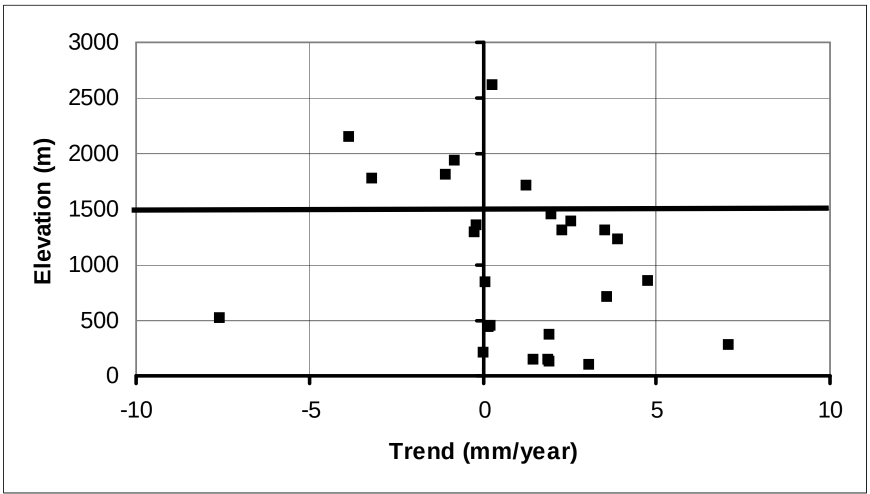


Figure 12: Trend in R95p with elevation.

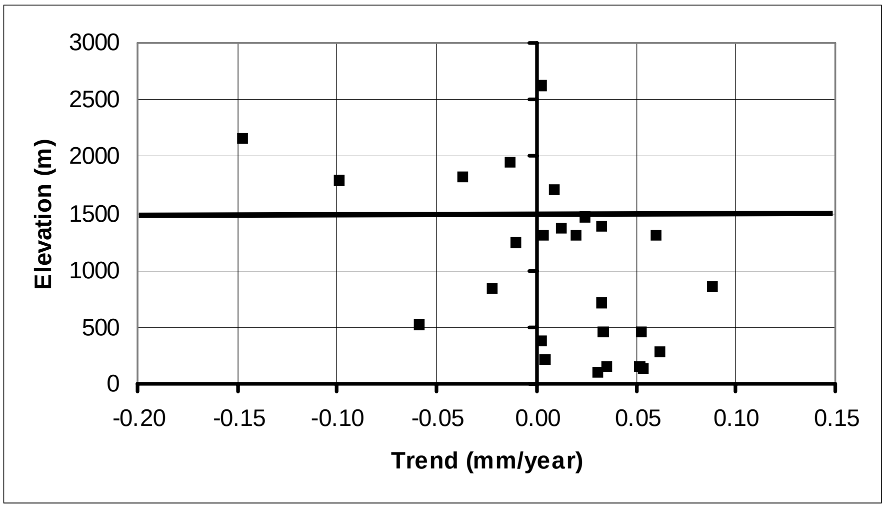


Figure 13: Trend in R50 with elevation.

In case of the total annual precipitation (PRCPTOT) as depicted in Fig.14, it has been observed that most of the stations below 1500 m show increasing trend whereas above that level the trends are not clearly defined. However, the systematic difference as in the case of temperature between hills and low lands is not observed in extreme precipitation trend between hills and low lands. The evidence suggests complex processes in precipitation extremes but at the same time there is indication that more weather related disasters, for example, floods and landslides can be expected in future. With this study, it has been realized that more rigorous analysis using the additional rainfall and temperature stations are needed to accurately assess the changes in temperature and precipitation extremes.

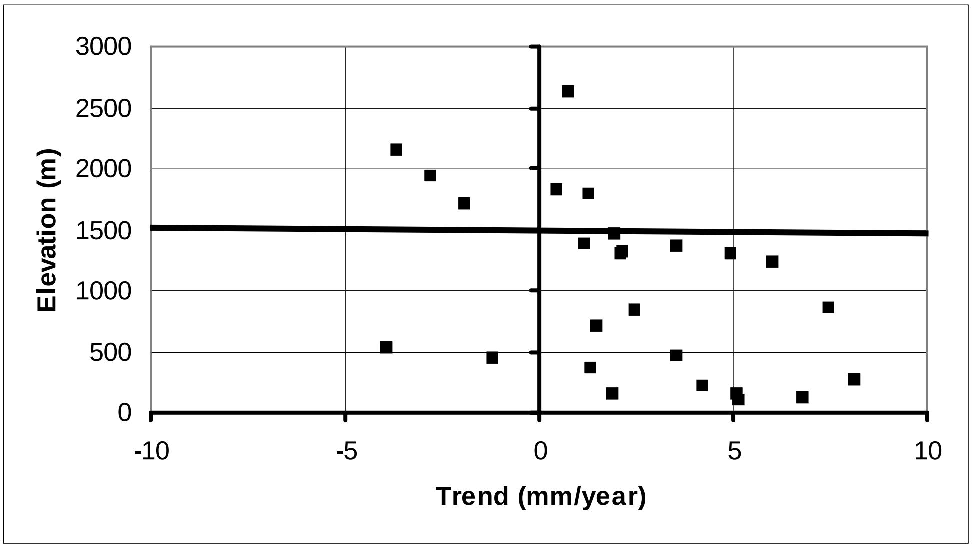


Figure 14: Trend in PRCPTOT with elevation.

This study on extreme events will help the policy makers to look seriously towards the role of this warming and its consequences in water resources sector in turn having a direct impact in agriculture and other water related activities. The Himalayas known as the abode of the substantial reserve of fresh water in the form of the snow and glaciers will have to be also considered seriously in the light of climate change and its manifestation in extreme events.

ACKNOWLEDGEMENTS

This study is the result of the Asia Pacific Network for Global Change (APN) regional project APN2005-10-NSY-Sheikh on "Development and Application of Climate Extreme Indices and Indicators for Monitoring Trends in Climate Extremes and Their Socio-Economic Impacts in South Asian Countries". The authors would like to show their appreciation to the APN for its support to carry out this research.

REFERENCES

Aguilar, E., I. Auer, M. Brunet, T.C. Peterson, and J. Wieringa (2003), Guidelines on Climate Metadata and Homogenization, WCDMP-No. 53, WMO-TD No. 1186, 55 pp., World Meteorological Organization, Geneva.

Alexander L. V., X. Zhang, T. C. Peterson, J. Caesar, B. Gleason, A.M.G Klein Tank, M. Haylock, D. Collins, B. Trewin, F. Rahimzadeh, A.

Tagipour, K. Rupa Kumar, J. Revadekar, G. Griffiths, L. Vincent, D. B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci, J. L. Vazquez-Aguirre (2005), Global observed changes in daily climate extremes of temperature and precipitation, British Crown Copyright (Pages 13 of 65)

Frich, P., L.V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A.M.G. Klein Tank, and T. Peterson (2002), Observed coherent changes in climatic extremes during the second half of the twentieth century, *Clim. Res.*, *19*, 193-212.

Hingane, L.S., K. Rupa Kumar and Bh. V. Ramana Murthy (1985), Long-term trends of surface air temperature in India, Journal of Climatology, Vol. 5, 521-528.

IPCC Fourth Assessment Report (2007), Climate Change 2007: The Physical Science Basis

Klein Tank A.M.G., and G.P. Können (2003), Trends indices of daily temperature and precipitation extremes in Europe, 1946-99, *J. Climate*, *16*, 3665-3680.

Klein Tank A.M.G., T.C. Peterson , D.A. Quadir , S. Dorji , Z. Xukai , T. Hongyu ,K. Santhosh , U.R. Joshi, , A.K. Jaswal , R.K. Kolli , A. Sikder , N.R. Deshpande ,J. Revadekar , K. Yeleuova , S. Vandasheva , M. Faleyeva , P. Gomboluudev ,K.P. Budhathoki, A. Hussain, M. Afzaal, L. Chandrapala, H. Anvar, D. Amanmurad, V.S. Asanova, P.D. Jones, M.G. New, and T. Spektorman, (2005), Changes in daily temperature and precipitation extremes in Central and South Asia, *J. Geophys. Res*.

Manandhar, K. B. (2006), The fog episode in southern terai plains of Nepal: some observations and concepts, *Journal of Hydrology and Meteorology*, volume 3, Number 1

Manton, M.J., P.M. Della-Marta, M.R. Haylock, K.J. Hennessy, N. Nicholls, L.E. Chambers, D.A. Collins, G. Daw, A. Finet, D. Gunawan, K. Inape, H. Isobe, T.S. Kestin, P. Lefale, C.H. Leyu, T. Lwin, L. Maitrepierre, N. Ouprasitwong, C.M. Page, J. Pahalad, N. Plummer, M.J. Salinger, R. Suppiah, V.L. Tran, B.Trewin, I. Tibig, and D., Yee (2001), Trends in extreme daily rainfall and temperature in southeast Asia and the South Pacific: 1916-1998, *Int. J. of Climatol*, *21*, 269-284.

Peterson, T. C., D. R. Easterling, T. R. Karl, P. Ya. Groisman, N. Nicholls, N. Plummer, S. Torok, I. Auer, R. Boehm, D. Gullett, L. Vincent, R. Heino, H. Tuomenvirta, O. Mestre, T. Szentimre, J. Salinger, E. Førland, I. Hanssen- Bauer, H. Alexandersson, P. Jones, and D. Parker (1998), Homogeneity of in situ atmospheric climate data: A review, *Int. J. Climatol.*, *18*, 1493-1517.

Shrestha, A.B., Wake, C.P., Mayewski, P.A., and Dibb, J.E. (1999). Maximum temperature trends in the Himalaya and its vicinity. An analysis based on temperature records from Nepal for the period 1971-94. *Journal of Climate* 12, pp 2775-2787.