OCCURRENCE OF EXTREME CLIMATIC EVENTS IN SRI LANKA

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ABSTRACT

Being an island with a tropical monsoonal climate, Sri Lanka exemplifies a variety of climatic conditions along with some extreme climatic events mainly attributing to vagaries of the rainfall and temperature regimes at irregular intervals in different localities of the island. These include droughts, heavy rainfall events with floods, high and low temperatures, lightning, tornado type winds and very occasional cyclonic storms. As long series of quantified data on some of the climatic extreme events such as tornado type winds, lightning etc. are meager, this study attempts only to ascertain any possible trends in direct measurements related to rainfall and temperature regime of some selected locations in Sri Lanka. It has used 11 indices of extreme climatic events related to rainfall and temperature as defined by the World Meteorological Organization (WMO). Daily rainfall and temperature data from 1960-2007 from 14 meteorological stations scattered throughout the island was analyzed using RClimDex software developed by the Climate Research Branch, Meteorological Service of Canada. Trend analysis of temperature reveals that both daytime maximum and nighttime minimum temperature are significantly increasing at a rate of 0.01 to 0.03 °C per year with few exceptions. Results have also clearly shown that both numbers of days with Cold Daytimes and Cold Nighttimes are significantly decreasing in most places of the country. Meanwhile, a significantly increasing trend has also been observed with number of days with Warm Daytimes and Warm Nighttimes. All these clearly signal a warming trend of the temperature regime in Sri Lanka. Nevertheless, six indices used for identification of trends in extreme rainfall events did not show any significant trend in almost all locations studied.

INTRODUCTION

Global climate has been changing mainly due to rapid increase of emission of greenhouse gases through the anthropogenic activities. Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) has documented that the global temperature had increased by about 0.74°C during the period 1905 – 2006, with a warming over the past 50 years nearly being 2 times higher compared with the past 100 years (Alley *et al.*, 2007). There is also evidence that the 11-year period from 1995 to 2006 was the warmest on record (Alley *et al.*, 2007). This was accompanied by regional level warming patterns.

Trend analysis of temperature in Sri Lanka reveals that both daytime maximum and nighttime minimum temperature are significantly increasing at a rate of 0.01 to 0.03 °C per year with a few exceptions. In addition, number of days with higher temperature values has also been reported during recent years. Compared to the global trend of increasing temperature (0.74°C), the increasing trend in Sri Lanka is very significant. Increasing trend of temperature as well as extreme temperatures has resulted many negative sectoral impacts such as agriculture, health, water etc.

The increasing trend of global temperature in some of the regions in the world has produced a greater rate of increased frequency and/or intensity in the occurrence of extreme temperatures (Easterling *et al.*, 2000). This has been further validated by Meehl *et al.*, (2000), who found a greater possibility in the occurrence of extreme heat stress related events in a warmer climate. Exposure to extreme heat can overwhelm a person's ability to thermo-regulate, resulting in physiologic heat stress, which sometimes leads to death (Luber *et al.,* 2006). Studies of heat waves and mortality in the United States demonstrate that days with increased temperature or periods of extended high temperatures have increased heat-related mortality (Chestnut *et al.,* 1998), cardiovascular-cause mortality (Curriero *et al.,* 2002; Medina-Ramon *et al.,* 2006; Semenza*et al.,* 1996), respiratory mortality (Mastrangelo *et al.,* 2007), heart attacks (Braga *et al.,* 2002), and all-cause mortality (Curriero *et al.,* 2002).

Being a tropical island with uniformly high temperature regime, most of the cultivated crops in Sri Lanka operate at near maximum of the optimum temperature range of respective crops. Thus, crop injuries due to extreme temperatures are inevitable in Sri Lankan agriculture due to changing climate. This is of particular importance for the country's major staple food, rice. It is well established that high temperature injuries in rice are inevitable if the plant is exposed to an ambient temperature that exceeds 35° C just for 60-90 minutes at the anthesis stage (flowering). Even though, it was used to be a rare event to experience such an environmental temperature regime in major rice growing regions of the country, recent agro-meteorological observations have confirmed that frequency of such temperature events has increased significantly in both Dry and Intermediate zones, especially during dry (*Yala*) seasons resulting high rate of un-filled grains due to increased spikelet sterility. High temperature regime will also increase the evapotranspiration losses leading to frequent soil moisture stress conditions in upland crops.

Temperature changes are more obvious and it depends on the rediative force to some extent, but the change of precipitation is not only depending on the radiative force, which alter the heating capacity of the atmosphere. The amount of precipitation depends on the moisture holding capacity of the atmosphere, but atmospheric circulation play an vital role for changing the amount of precipitation. *ElNino* Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) and Indian Ocean Dipole (IOD) are some of the phenomena which change the general atmospheric circulation. Therefore, extreme rainfall events are linked with those aforesaid phenomena. The IPCC AR4 stated that the increases of temperature lead to increases in the moisture-holding capacity of the atmosphere at the rate of about 7% per 1 Celsius degree. Together these effects alter the hydrological cycle, especially characteristics of precipitation (amount, frequency, intensity, duration, type) and extremes (Trenberth *et al.,* 2003). IPCC also stated that, in weather systems, convergence of increased water vapor leads to more intense precipitation, but reductions in duration and/or frequency, given that total amounts do not change considerably.

Analysis of rainfall in Sri Lanka also revealed that there is no significant trend over the time, but short term duration of heavy or extreme rainfall events have observed during the recent past leading to flash floods in low-lying areas. Moreover, occurrence of landslides has also increased during recent times in the central highlands. Frequent, short term and intense drought periods have also become a common feature in most parts of the country with significant damage to annual crop and plantation agriculture. Hence, this paper has attempted to examine the trend of occurrence of extreme climatic events in Sri Lanka using 11 indices of extreme climatic events with rainfall and temperature as defined by the WMO.

METHODOLOGY

Daily rainfall and temperature data for the period 1961-2007 were used for the analysis, to find Climate Extreme Indices (CEI). RClimdex software was used for the analysis which was developed jointly by the WMO CCl/CLIVAR Expert Team (ET) on Climate Change Detection and monitoring. Indices have defined 27 core climate indices mainly focusing on extreme climatic events that on freely available softwares., RClimDex developed by Environment Canada(http://cccma.seos.uvic.ca/ETCCDMI/. RClimDex) uses the free "R" statistical package. Out of 27 core climate indices, 11 indices shown below were used in the analysis to study the trends of extreme climatic events in Sri Lanka, *viz.* no. of warm nights, no. of warm days, no. of cold nights, no. of cold days, warm spell duration indices, annual trend of rainfall, consecutive dry days, consecutive wet days, one day heavy rainfall, five day heavy rainfall and simple daily Intensive Index.

Out of 11 indices, the first 5 indices are related to maximum and minimum temperatures, while the others are related to rainfall. Outliers of daily temperature and rainfall were identified using the RClimdex software and corrected using original data available in the Meteorology Department. Number of cold days and cold nights are defined as number of days reported below 10th percentiles for the day maximum and night minimum, respectively. Number of warm days and warm nights are defined as the days reported above 90th percentiles for the daytime maximum and nighttime minimum, respectively. The other index related to extreme temperature event is Warm Spell Duration Indices (WSDI). The WSDI also based on above the 90th percentile of daytime maximum temperature, however, in this context it should continue at least 6 consecutive days having above 90th percentile temperatures.

RESULTS AND DISCUSSION

Trend of cold days and warm days

Trends shown in the Table 1 (a) and (b) reveals that there is a significant increasing and decreasing trends except a few instances in the number of warm days and in the number of cold days.

Figs. 1 (a) and (b) show the spatial distribution of these trends. It reveals that decreasing number of cold days in South-East, Northern, Eastern, North-Eastern and South-Western part of the island while increasing number of warm days in Southern, South-Eastern and South-Western part of Sri Lanka.

Table 1. Trend of number of cold days (a) and warm days (b) during 1961-2007

(a)

Station	Trend	p-Value
Anuradhapura	-0.233	0.000
Badulla	-0.218	0.000
Batticaloa	-0.249	0.000
Colombo	-0.194	0.000
Galle	-0.235	0.000
Hambantota	-0.255	0.000
Katugastota	-0.097	0.044
Katunayaka	-0.234	0.000
Kurunegala	-0.157	0.004
Maha-Illuppallama	-0.099	0.027
Mannar	-0.208	0.004
Nuwara Eliya	-0.069	0.144
Ratmalana	-0.239	0.000
Ratnapura	0.045	0.317

(b)

Station	Trend	p-Value
Anuradhapura	0.395	0.000
Badulla	0.933	0.000
Batticaloa	0.548	0.00
Colombo	0.260	0.002
Galle	0.702	0.000
Hambantota	0.547	0.000
Katugastota	0.256	0.002
Katunayaka	0.031	0.681
Kurunegala	0.168	0.08
Maha-Illuppallama	0.025	0.774
Mannar	0.336	0.027
Nuwara Eliya	-0.164	0.016
Ratmalana	0.884	0.000
Ratnapura	-0.067	0.354

Trend of cold nights and warm nights

Trends of cold nights and warm nights are shown in the Table 2 (a) and (b), respectively. There is a statistically significant trend in both parameters except in few instances. Cold nights are significantly decreasing while the opposite is true for warm nights. Figs. 2(a) and (b) show the spatial distribution of trends of cold nights and warm nights. It reveals that decreasing number of cold days in South-Western and North Central regions of the island while increasing number of warm days in South-Western, North-Western and Northern part of Sri Lanka.

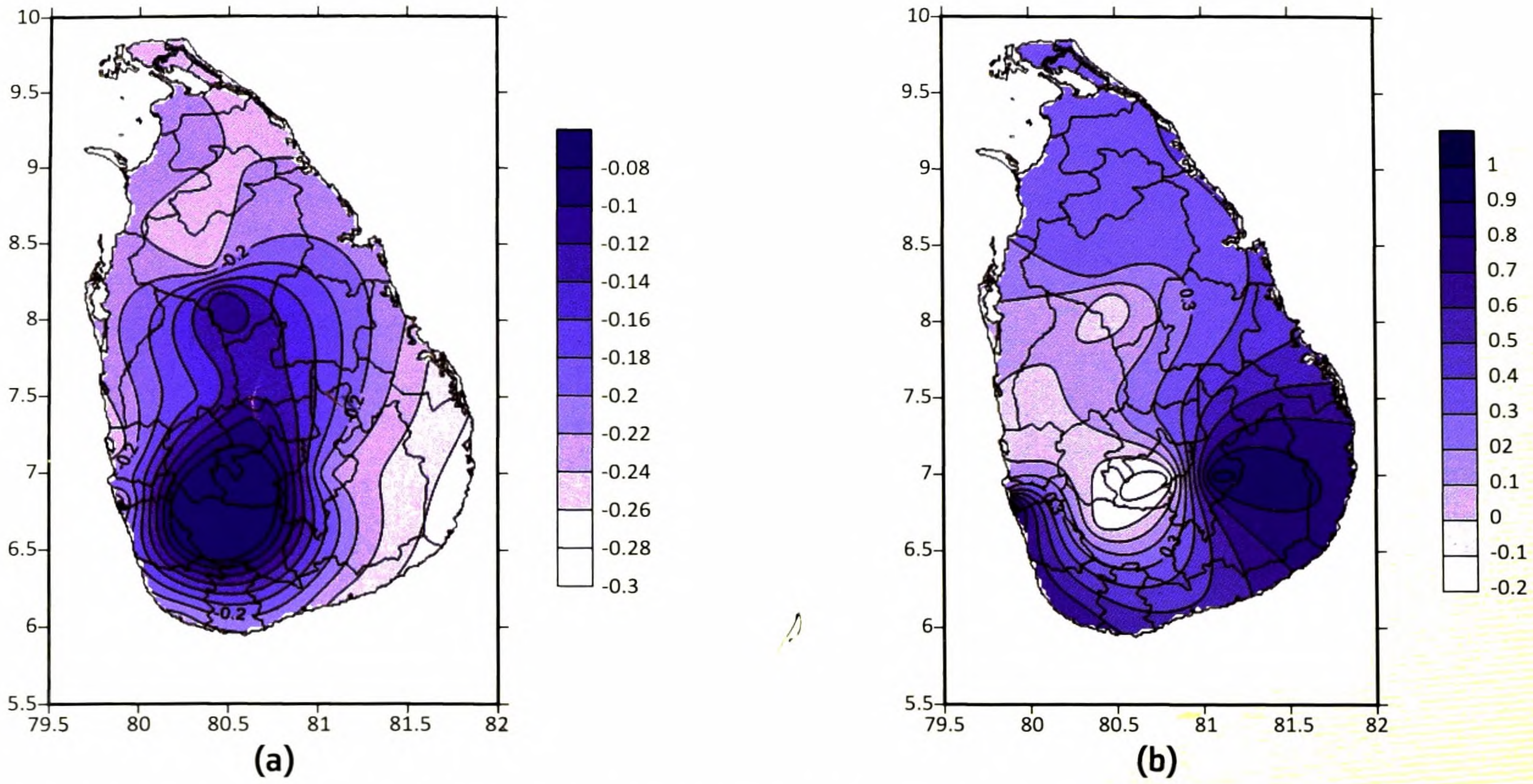


Fig. 1. Spatial distribution of trends in (a) number of Cold Days (b) number of Warm days during 1961 - 2007

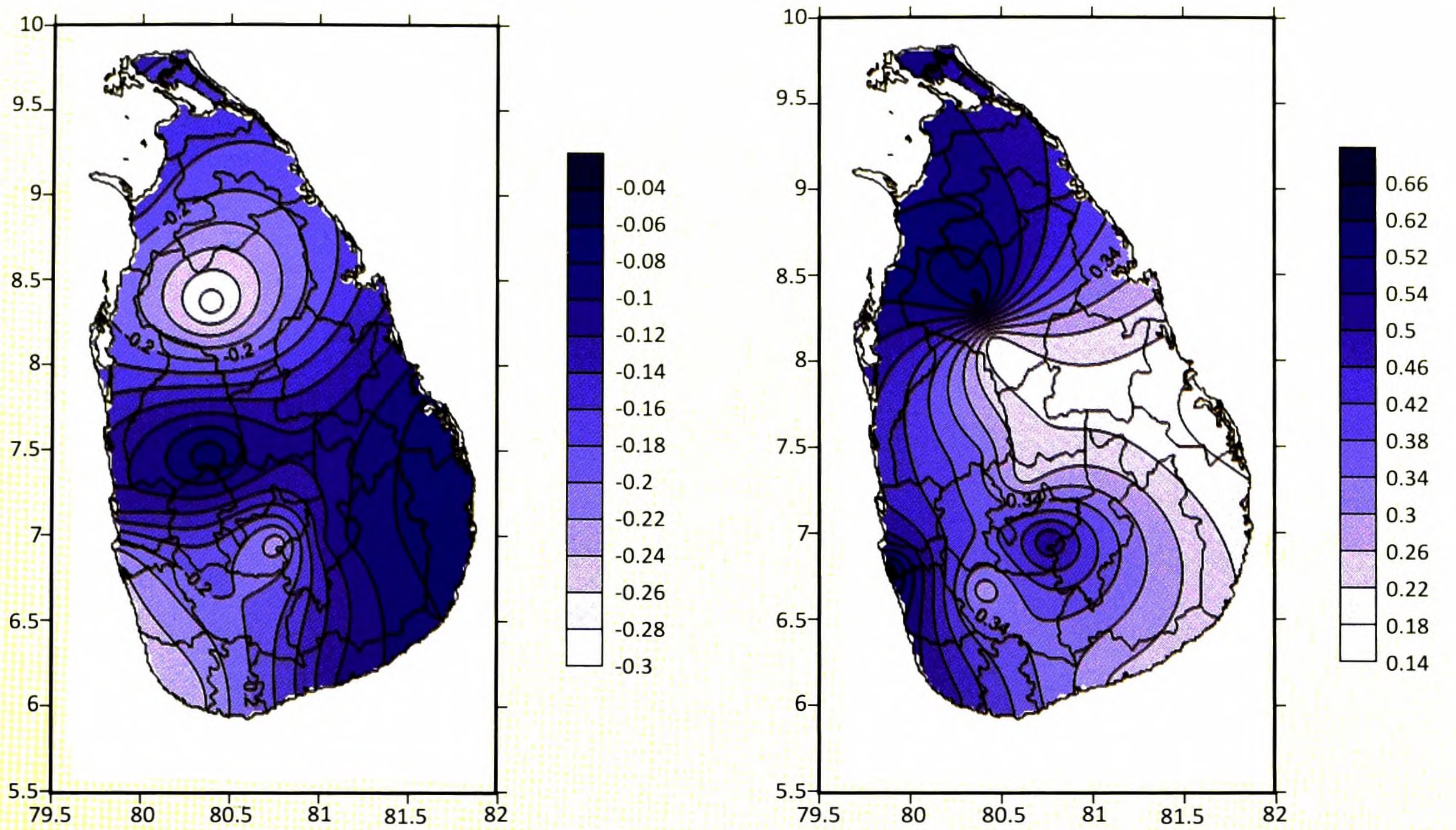
Table 2. Trend of number of cold nights (a) and warm nights (b) during 1961-2007

(a)

Station	Trend	p-Value
Anuradhapura	-0.295	0.000
Badulla	-0.108	0.004
Batticaloa	-0.062	0.253
Colombo	-0.226	0.000
Galle	-0.261	0.001
Hambantota	-0.112	0.008
Katugastota	-0.12	0.003
Katunayaka	-0.128	0.000
Kurunegala	-0.061	0.466
Maha-Illuppallama	-0.224	0.000
Mannar	-0.159	0.001
Nuwara Eliya	-0.236	0.000
Ratmalana	-0.242	0.000
Ratnapura	-0.196	0.001

(b)

Station	Trend	p-Value
Anuradhapura	0.630	0.000
Badulla	0.368	0.000
Batticaloa	0.150	0.032
Colombo	0.538	0.000
Galle	0.481	0.000
Hambantota	0.247	0.003
Katugastota	0.236	0.001
Katunayaka	0.459	0.000
Kurunegala	0.354	0.001
Maha-Illuppallama	0.187	0.009
Mannar	0.523	0.000
Nuwara Eliya	0.507	0.000
Ratmalana	0.655	0.000
Ratnapura	0.270	0.001



(a) (b)

Fig.2. Spatial distribution of trends in number of cold nights (a) and warm nights (b) during 1961-2007

Trend of Warm Spell Duration Index (WSDI)

The other indicator used in the study was to examine the warming trend using Warm Spell Duration Index (WSDI). The WSDI is defined as annual count of days with at least 6 consecutive days when the daily maximum temperature exceeds the 90th percentile in the calendar 5-day window for the base period 1961-1990. Accordingly, RClimDex was used to analyze the data and the trends and the map of trends are shown in Table 3 and Fig. 3, respectively. It also indicates that a warming trend in the island, especially in South-Western, South-Eastern Eastern and Northern area.

Table 3. Trends in warm spell duration indices (WSDI) during 1961-2007

Station	Trend	p-Value
Anuradhapura	0.729	0.001
Badulla	1.718	0
Batticaloa	1.142	0
Colombo	0.32	0.018
Galle	1.037	0.001
Hambantota	0.733	0
Katugastota	0.408	0.031
Katunayaka	-0.043	0.606
Kurunegala	0.326	0.043
Maha-Illuppallama	0.127	0.372
Mannar	0.764	0.102
Nuwara Eliya	0.059	0.421
Ratmalana	1.145	0.003
Ratnapura	0.044	0.726

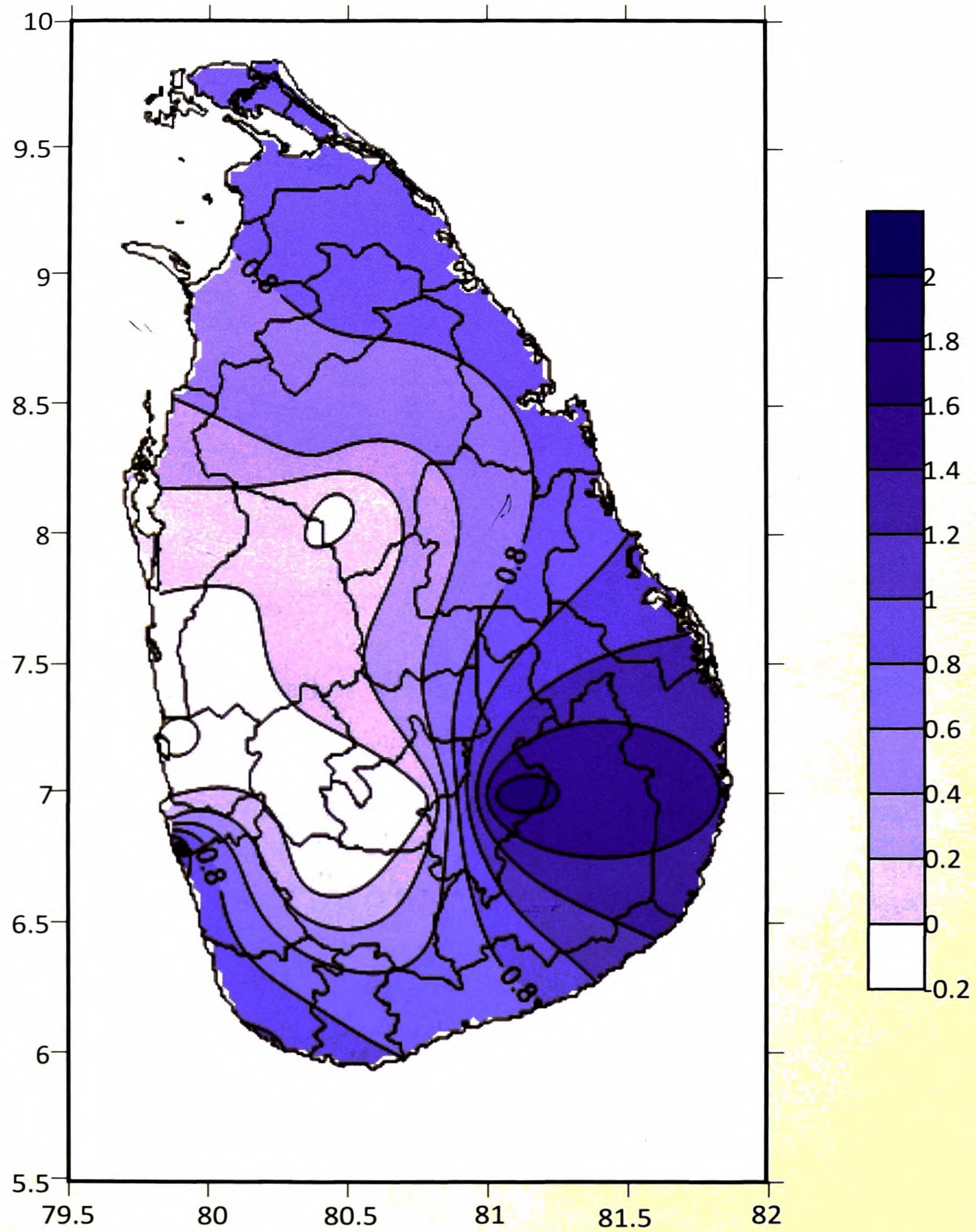


Fig. 3. Spatial distribution of the trends of warm spell duration indices during 1961-2007

Trend of annual rainfall

Table 4 shows the linear trends of annual total rainfall of different rainfall stations in Sri Lanka. It indicates an apparent decreasing trend which is not significant except in two locations, namely, Colombo and Katunayaka. One logical reason for this trend could be attributed to the failure of southwest monsoon rains during recent years. However, it cannot be generalized as other stations located within the effective area of southwest monsoon have not performed in similar manner.

Table 4. Trend of annual total precipitation

Station	Trend	p-Value
Anuradhapura	-3.976	0.142
Badulla	-2.739	0.395
Batticaloa	-2.603	0.661
Colombo	-10.67	0.028
Galle	-8.605	0.054
Hambantota	-3.379	0.216
Katugastota	-3.213	0.242
Katunayaka	-11.54	0.021
Kurunegala	-7.099	0.081
Maha-Illuppallama	-1.868	0.569
Mannar	0.052	0.985
Nuwara Eliya	-2.31	0.521
Ratmalana	-5.454	0.228
Ratnapura	-0.411	0.934

Indices used in identification of extreme rainfall events

Threshold value to designate a Wet day was taken as 1 mm per day for the analysis in order to derive extreme rainfall events. Accordingly, consecutive dry days and consecutive wet days are defined as follows;

Consecutive Dry Days (CDD)

Highest number of consecutive days in a year with the daily rainfall less than 1mm

Consecutive Wet Days (CWD)

Highest number of consecutive days in a year with the daily rainfall greater than 1mm

Number of consecutive dry days (CDD) and consecutive wet days (CWD)

Table 5 and 6 show the trends in CDD and CWD, respectively. Even though they are not significant statistically, the trends of CDD and CWD are positive and negative, respectively. It indicates an apparent increase long dry spells leading to frequent drought conditions.

Table 5. Trends in consecutive dry days

Station	Trend	p-Value
Anuradhapura	0.508	0.015
Badulla	0.05	0.673
Batticaloa	-0.044	0.835
Colombo	0.205	0.225
Galle	0.18	0.108
Hambantota	0.282	0.138
Katugastota	0.049	0.726
Katunayaka	0.136	0.58
Kurunegala	0.027	0.88
Maha-Illuppallama	0.406	0.026
Mannar	-0.015	0.969
Nuwara Eliya	0.075	0.645
Ratmalana	0.111	0.368
Ratnapura	-0.016	0.853

Table 6. Trends in consecutive wet days

Station	Trend	p-Value
Anuradhapura	-0.011	0.776
Badulla	0.019	0.659
Batticaloa	-0.005	0.906
Colombo	-0.059	0.127
Galle	-0.007	0.853
Hambantota	-0.043	0.032
Katugastota	-0.010	0.737
Katunayaka	-0.098	0.002
Kurunegala	0.019	0.578
Maha-Illuppallama	-0.059	0.192
Mannar	-0.004	0.926
Nuwara Eliya	-0.023	0.611
Ratmalana	-0.006	0.836
Ratnapura	-0.143	0.037

One day heavy rainfall

The highest reported rainfall in a year is considered for the analysis and the results are shown in Table 7. Many stations show a negative trend while a few stations depict a positive trend; however these trends are not statistically significant. It suggests that there is no indication of either increasing or decreasing trend of heavy rainfall events in Sri Lanka. A similar trend on positive extreme anomalies of rainfall has been reported by Punyawardena and Premalal (2013) in a study carried out for the central highlands of Sri Lanka.

Table 7. Trend of one day heavy rainfall

Station	Trend	p-Value
Anuradhapura	-0.316	0.260
Badulla	0.278	0.420
Batticaloa	-1.072	0.091
Colombo	-0.210	0.791
Galle	-0.296	0.516
Hambantota	-0.606	0.292
Katugastota	-0.072	0.856
Katunayaka	0.017	0.976
Kurunegala	-0.030	0.944
Maha-Illuppallama	-0.097	0.854
Mannar	-0.204	0.741
Nuwara Eliya	0.007	0.989
Ratmalana	-0.171	0.772
Ratnapura	0.622	0.428

Five day heavy rainfall

The highest cumulative rainfall in a five day period of a year is considered for the analysis and, the results are shown in the Table 8. Many stations show a negative trend while a few stations reveal a positive trend. However, none of these trends are statistically significant. It suggests again that there is no indication of increasing or decreasing trend of heavy rainfall events in Sri Lanka contrary to common belief.

Simple daily intensity index (SDII)

Annual total rainfall divided by the number of Wet days (Wet day $\geqslant$ 1.0 mm) was considered as the Simple Daily Intensity Index Analysis shows that there is a mixture of non significant positive and negative trends.

Table 8. Trend of five day heavy rainfall

Station	Trend	p-Value
Anuradhapura	-0.303	0.496
Badulla	0.068	0.942
Batticaloa	-1.817	0.049
Colombo	-1.325	0.170
Galle	-1.141	0.210
Hambantota	-0.848	0.328
Katugastota	-0.245	0.628
Katunayaka	-0.985	0.336
Kurunegala	0.108	0.851
Maha-Illuppallama	-0.375	0.621
Mannar	-0.198	0.816
Nuwara Eliya	-0.566	0.489
Ratmalana	-0.738	0.415
Ratnapura	-0.293	0.779

Table 9. Trend of simple daily intensity index (SDII)

Station	Trend	p-Value
Anuradhapura	0.033	0.110
Badulla	0.013	0.443
Batticaloa	0.042	0.308
Colombo	-0.006	0.798
Galle	-0.008	0.722
Hambantota	0.033	0.148
Katugastota	0.012	0.447
Katunayaka	-0.021	0.390
Kurunegala	0.013	0.628
Maha-Illuppallama	0.032	0.240
Mannar	0.021	0.531
Nuwara Eliya	-0.011	0.520
Ratmalana	0.007	0.737
Ratnapura	0.030	0.134

CONCLUSIONS

All these analysis on rainfall reveals that contrary to common belief, there are no significant trends in extreme positive rainfall anomalies of Sri Lanka under a changing and variable climate. It could be probably attributed to the fact that the current degree of global warming may not have been strong enough to make such a change in the rainfall regime of the country though it has resulted in variability of seasonal and annual rainfall along with a significant warming trend.

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