The Behavior of Daily Rainfall Extremes in the Context of Climate Change

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Abstract:

The devastating floods from extreme rainfall in Sri Lanka during January – February 2011, caused billions of rupees in damages which included a major loss in the rice crop. Nearly a million people were rendered homeless and 62 lives were lost. Furthermore, during the last one hundred years, Sri Lanka has experienced severe floods at various times due to extreme rainfall. Given this scenario and the ever growing concerns of climate change, the objective of this paper is to investigate whether a trend exists in extreme rainfall, so that extreme events can be identified and the likely consequences reduced. Accordingly, annual maximum daily rainfall series at six meteorological stations were analyzed using over 100 years of data. Three statistical tests, Spearman's Rho, Mann – Kendall and Linear Regression which cover both parametric and non-parametric approaches have been used to identify trends. These tests indicate the absence of a significant trend at all stations. However, if very recent data (2006-2010) for Colombo are included in the analysis interestingly a significant increasing trend is shown. Such features in the trend of rainfall extremes will have implications in hydrologic design and dam safety studies. The research findings suggest that the risk of disasters associated with severe floods is very likely to increase and deserves close monitoring. A better understanding of trends in extreme rainfall, will help mitigate the impact flood disasters, enabling society to achieve greater economic prosperity and forge towards sustainable development.
Keywords: Trends, Rainfall Extremes, Sustainability, Floods, Randomness

Introduction

Global warming and its likely impacts on water resource systems have been a much debated topic (Klemes, 1998; Shiklomanov, 1999). Detecting changes in climatic extremes is gaining increasing importance due to the threat posed by global warming. Thus, much attention has been paid to the study of extreme rainfalls. Extreme rainfalls can be defined as the least likely events in a statistical sense where the values are far away from the mean. Global warming is the name given to the possible climatic effect of an increasing concentration of "green house" gases, primarily carbon dioxide (CO_2), methane and nitrous oxide (Arnell, 1996). A change in green house gas concentration can result in a change in rainfall which affects catchment ecosystems. Changes in rainfall can be observed in various ways such as change in amount, intensity, duration and timing during the year.

According to the Intergovernmental Panel on Climate Change (IPCC) (2001), extreme rainfall can increase irrespective of an increase or decrease in mean total rainfall.

Furthermore, weather hazards, which can be deadly and destructive, are occurring with increase in frequency throughout the world. The recent floods during 2010 – 2011 in Colombo and Batticloa caused enormous damage to infrastructure and crops, with serious economic consequences. To mitigate such flood disasters, a better understanding of long term rainfall patterns is necessary.

The main objective of this paper is to identify whether a trend exists in the annual maximum daily rainfall series in Sri Lanka.

Literature Review

Detection of a gradual trend in annual maximum rainfall series is vital in the evaluation of extreme events. A linear trend has a constant rate of change and it has been widely used to approximate the magnitude of trends in time series analysis (Chatfield, 2000).

Most studies done on trend analysis in Sri Lanka are limited to monthly and annual rainfall series. Jayawardene *et. al.*(2005) has carried out tests on trend for monthly rainfall considering 15 meteorological stations. The results revealed that there is an increasing long-term trend at Colombo. A statistically significant increasing trend in seasonal (south-west monsoon) rainfall was observed at Colombo, Puttalam and Hambantota by Malmgren *et. al.* (2003). Madduma Bandara (2004) showed that there is a significant decreasing trend in annual rainfall at Nuwara Eliya and Watawala while negative trends of annual rainfall have been detected in the Kalu Ganga basin (Ampitiyawatta and Guo, 2009).

Study Area

Six meteorological stations were analyzed using continuous rainfall records of data (Table 1).

Table 1 – Summary of selected meteorological stations

No.	Station	Total length (years)	Continuous record		Max. daily Rainfall (mm)	Date
			Length (years)	Period		
1	Anuradhapura	107	55	1951-2005	219.7	25.12.1957
2	Batticaloa	135	135	1871-2005	330.7	05.12.1967
3	Colombo	105	105	1901-2005	493.7	04.06.1992
4	Galle	91	75	1931-2005	282.6	11.05.1992
5	Hambantota	101	55	1951-2005	296.9	06.05.1975
6	Puttalam	111	111	1895-2005	275.7	22.04.1984

Methodology

Three statistical tests, Spearman's Rho (SR), Mann – Kendall (MK) and Linear Regression (LR) which cover both parametric and non-parametric approaches have been used to identify trend.

Spearman's Rho Test

Spearman's Rho Test (Siegel, 1956; Dahmen & Hall, 1989) is a rank based, distribution free test for a correlation between time and the data series. In addition, it has nearly uniform power to detect for linear and non-linear trends. Spearman's rank correlation coefficient, R_{sp} is defined as;

$$R_{sp} = 1 - \frac{6\sum_{i=1}^{n} D_i^2}{n(n^2-1)} \quad (1)$$

where, n – total number of data

$D_i = Kx_i - Ky_i$

Kx_i – the rank of the variable, x, which is the chronological order number of the observations

y – ranked rainfall series (in increasing order of magnitude)

Ky_i – the rank of the variable y in the original series

If there are ties, K should be taken as the average rank.

$$\text{Test statistic, } t_t = R_{sp}\left(\frac{n-2}{1-R_{sp}^2}\right)^{1/2} \quad (2)$$

where, t_t has student's t-distribution with degrees of freedom; df = n-2

Null hypothesis, H_0: no trend

Alternate hypothesis, H_1: there is a trend

At 5 per-cent level of significance, the time series has no trend if;

$t\{df, 2.5\%\} < t_t < t\{df, 97.5\%\}$

Mann – Kendall test

Mann – Kendall test (Rakhecha & Singh, 2009) is another rank-based test, which is similar to Spearman's rho but using a different measure of correlation which has no parametric analogue (Kundzewicz & Robson, 2004). The Mann – Kendall test statistic, S is given as

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn(X_j - X_i) \quad (3)$$

The application of trend test is done to a time series X_i that is ranked from i = 1, 2, ...n-1, and X_j which is ranked from j = i+1, ...n. Each data point X_i is taken as a reference point which is compared with the rest of the data points X_j so that,

$$Sgn\left(X_j - X_i\right) = \begin{Bmatrix} +1, > \left(X_j - X_i\right) \\ 0, = \left(X_j - X_i\right) \\ -1, < \left(X_j - X_i\right) \end{Bmatrix} \quad (4)$$

The test statistic Z_c is computed as

$$Z_c = \begin{Bmatrix} \frac{S-1}{\sqrt{Var\,(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}}, S < 0 \end{Bmatrix} \quad (5)$$

Z_c follows a standard normal distribution. A positive (negative) value of Z signifies an upward (downward) trend. A significance level, α is also utilized for testing either an upward or downward trend. If Z_c appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered as significant.

Linear Regression

Linear Regression (Haan, 1977; Hirsch, et. al., 1982) is one of the most common tests for trend and in its basic form assumes that data are normally distributed. This is based on the assumption of a linear relationship between two variables and the test statistic is the regression gradient. The general expression of the linear regression model is,

$$y_i = \beta_0 + \beta_1 x_i + \epsilon_i \qquad i = 1, 2, ...n$$

where, y_i – i^{th} observation of the dependent variable (rainfall)

x_i- i^{th} observation of the explanatory variable (time)

β_0 – intercept

β_1 – slope

ϵ_i – random erroe or residual for the i^{th}observation

n – sample size

Parameters of the regression model, β_0 and β_1 can be estimated by using the formulae summarized in Hirsch et. al. (1982).

$$\text{Test statistic, } t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \qquad 6)$$

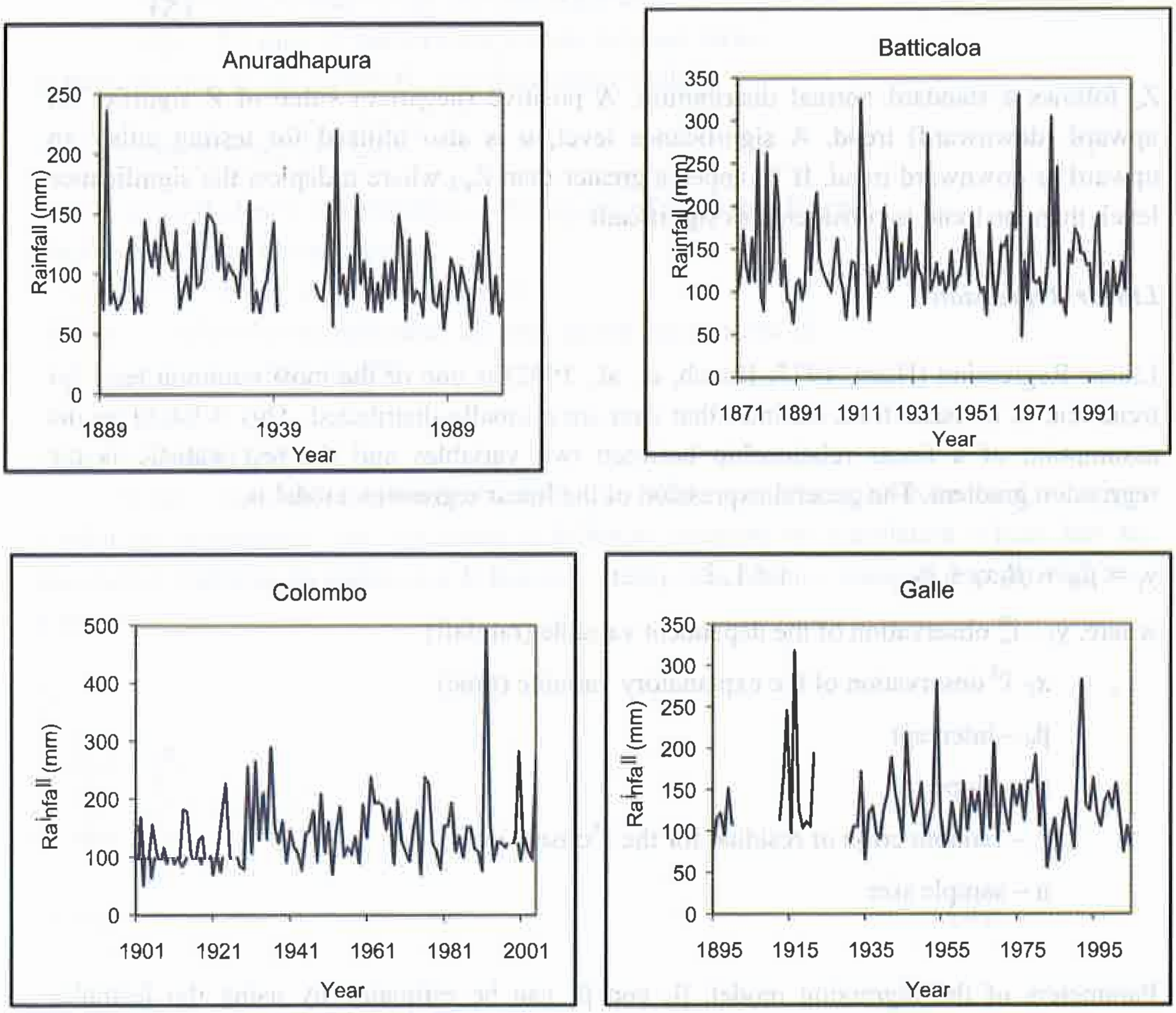
where, r is the correlation coefficient

If $|t| > t_{crit}$, the series of data is considered as having a trend.

where, tcrit is the point on the student's t distribution with n-2 degrees of freedom that has a probability of exceedance of $\alpha/2$.

Results and Discussion

Figure 1 shows annual maximum daily rainfall series for selected stations. Trends of increasing rainfalls, although not statistically significant, are apparent in Colombo and Puttalam. However, a decreasing trend was observed at Anuradhapura.



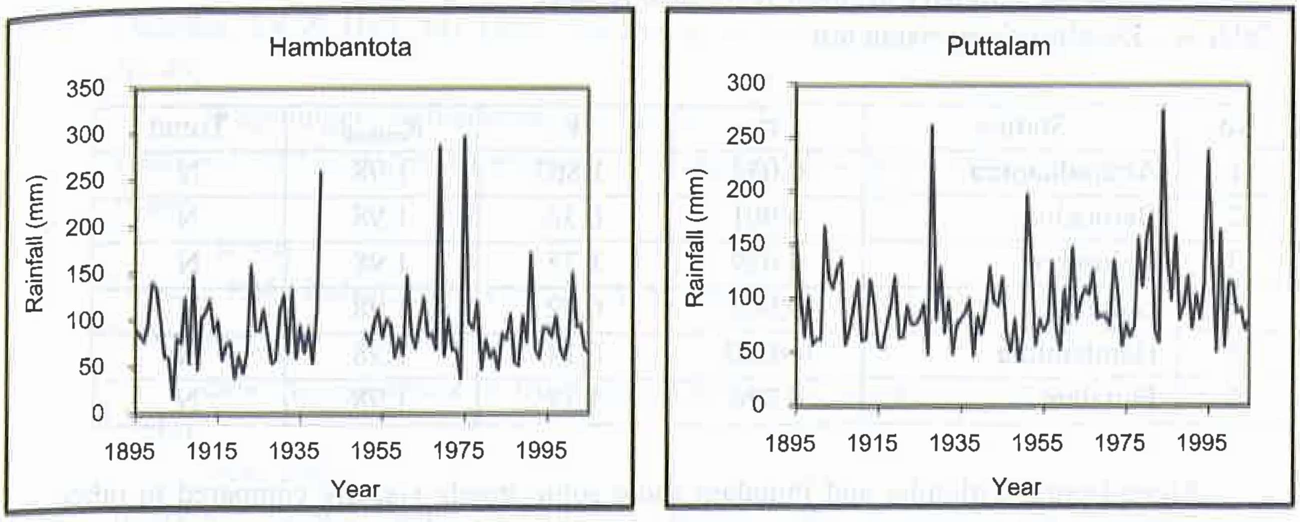


Figure 1 – Annual maximum daily rainfall series at selected meteorological stations

Table 2 shows the summary of Spearman's Rho correlation test for the time series of selected meteorological stations.

Table 2 – Results of Spearman's Rho correlation test

No.	Station	R_{sp}	t_t	$t_{2.5}$	$t_{97.5}$	Trend
1	Anuradhapura	-0.166	-1.722	-1.98	1.98	NS
2	Batticaloa	-0.018	-0.208	-1.97	1.97	NS
3	Colombo	0.151	1.56	-1.98	1.98	NS
4	Galle	0.017	0.163	-1.98	1.98	NS
5	Hambantota	-0.038	-0.377	-1.98	1.98	NS
6	Puttalam	0.157	1.66	-1.98	1.98	NS

Results of Mann – Kendall (MK) trend analysis are shown in Table 3 .

Table 3 – Results of MK test

No .	Station	Z_c	$\lvert Z_{\alpha/2}\rvert$	Trend
1	Anuradhapura	-0.57	1.98	NS
2	Batticaloa	-0.22	1.98	NS
3	Colombo	1.53	1.98	NS
4	Galle	0.36	1.98	NS
5	Hambantota	-0.87	1.98	NS
6	Puttalam	1.72	1.98	NS

Table 4 shows the summary of linear regression results.

Table 4 – Results of regression test

No.	Station	r^2	t	$\lvert t_{critical} \rvert$	Trend
1	Anuradhapura	0.032	-1.863	1.98	N
2	Batticaloa	0.001	0.36	1.98	N
3	Colombo	0.029	1.75	1.98	N
4	Galle	0.002	0.42	1.98	N
5	Hambantota	0.0002	0.14	1.98	N
6	Puttalam	0.026	1.17	1.98	N

Anuradapura, Colombo and Puttalam show some trends visually compared to other stations (Figure 1). Anuradapura shows a downward trend while the other two indicate upward trends. However, from the results shown in Table 2 and 3, these trends are not significant at the 95% confidence level.

The results of linear regression also indicate that Colombo and Puttalam show an increasing trend but not significant at 95% confidence level. Similarly, a decreasing trend in rainfall can be seen at Anuradhapura but it is not significant.

In summary, all results indicate an increasing trend of annual maximum daily rainfall at Colombo and Puttalam and a decreasing trend at Anuradhapura. However, none of the results at any of the stations are significant at the 95% confidence level. Interestingly, if very recent data of Colombo (2006 – 2010) are included in the analysis, all three tests will show an increasing trend which is significant at the 95% confidence level.

Conclusion

The study has analyzed the annual maximum daily rainfall series to detect trends at six meteorological stations. Statistically significant trends were not detected at any of the stations if data until 2005 are considered. However, Colombo shows a significant increasing trend if data from 2006 to 2010 are considered. It is recommended that this analysis be extended to cover other principal stations in Sri Lanka, including the most recent data. The impact of climate change on extreme rainfalls could be different across the country.

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