Analysis of rainfall distribution and variation during the Southwest monsoon in the wet zone of Sri Lanka

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Analyzing the Rainfall variation and distribution in Sri Lanka (1981-2010) using drought indices

Can identify monsoon seasonal rainfall trends

Very supportive in agricultural planning, adapting to climate change and better risk management

Highlights

- Mid country was the most affected area during the Southwest monsoon in Sri Lanka.
- Monsoon is highly activated in the middle of the season (June and July).
- Nearly 50% of the years were deficit years according to RAI and SPI classification.
- 2000 - 2008 was identified as a continuously dry period.
- Three rain gauge stations in hill country showed linear decreasing rainfall trends.

RESEARCH ARTICLE

Analysis of rainfall distribution and variation during the Southwest monsoon in the wet zone of Sri Lanka

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Abstract: The monsoon rainfall variation and distribution have an impact on economical, ecological and sociological aspects of Sri Lanka. Therefore, this research aimed to study the spatial-temporal variation and distribution of the Southwest monsoon rainfall during the period of 1981-2010. Daily rainfall data were collected from 13 rain gauge stations which are located in Southwest part (wet zone) of Sri Lanka. Monsoon rainfall distribution was analyzed by comparing monthly average rainfall and rainy days. The monsoon rainfall variability was analyzed using drought indices: Rainfall Anomaly Index (RAI) and Standardized Precipitation Index (SPI). Trend analysis was carried out on both indices considering the Mann-Kendall test and Sen's slope estimator. Monthly average rainfall highlighted that the mid country experienced the highest amount of rainfall during the season and maximum number of rainy days occurred in the middle of the season. Analysis based on drought indices revealed that 14 years were dry. Both indices agreed on significant linear decreasing trends in rainfall at three rain gauge stations. Population growth, global warming, deforestation, etc., may be the reasons for these decreasing trends. These results create the need to discuss the economical, ecological and social impact of the rainfall which leads to better planning and rationalization.

Keywords: Trend analysis; Mann-Kendall test; Sen's slope estimator; Southwest monsoon; RAI; SPI.

INTRODUCTION

Precipitation is a main component in the hydrologic cycle. Sub-seasonal or seasonal variability of rainfall in areal and temporal scale is becoming a huge problem and many countries consider it as a consequence of climate change. Rainfall is the key climate driver which mainly affects the island of Sri Lanka. The monsoon rainfall variations influence cultivation, economy of the country, existence of its people, etc. Increased variability and trends in the seasonal characteristics of rainfall in an environment can be seriously affected to the country in many ways. Many research studies have been done related to the rainfall of Sri Lanka for various purposes such as agrarian, risk management, etc. (Suppiah and Yoshino, 1984a, b; Yoshino and Suppiah, 1984; Ranatunge *et al.*, 2003; Zubair and Chester, 2006; Karunathilaka *et al.*, 2017; Nisansala *et al.*, 2020). Researchers have found that in Sri Lanka,

variability of all seasonal rainfall has increased but annual rainfall remains closer to the average (Punyawardene, 2002). Therefore, studies on the seasonal rainfall variation and its distribution will enhance the forecasting ability. However, a limited number of research studies have been conducted related to seasonal rainfall variation in Sri Lanka. Investigations of the seasonal rainfall distribution considering agro climate zones and analyzing seasonal rainfall variation considering trend analysis will be useful in many socio-economic aspects. Agricultural land use in Sri Lanka roughly shows a division of the island into two major areas, according to the climatic division: wet zone and dry zone. They are also referred to agro climate zones. Moreover, considering the geographic features, wet zone can be divided into three parts: Low Country, Mid Country and Up Country (Domroes, 1979).

Though the trend analysis on rainfall in Sri Lanka has been conducted, drought indices have not been considered in trend analysis. Drought indices simplify a large data set on water supply indicators (rainfall, snowpack, stream flow, etc.) into an understandable big picture. A drought index value is usually a single number and more useful for decision making (Hayes *et al.*, 2007). There are several drought indices that measure anomalous behavior of a historical series of precipitation data set. Standardized Precipitation Index (SPI) and Rainfall Anomaly Index (RAI) are two widely used drought indices. There are several ways to perform trend analysis on precipitation. Non-parametric methods such as Mann-Kendall test (MK test) and Sen's slope estimator are more realistic to use in real world problems than the parametric methods because they do not require the data set to follow any specific distribution. Since drought indices simplify information about complex data sets and non-parametric tests are more reliable in real world situations, results gained from these will be more advantageous than results gained from a raw data set together with parametric trend analysis. The main seasonal monsoon which considered in this research study was the Southwest monsoon. A very few research studies have been done related to the Southwest monsoon (Domroes and Ranatunge, 1993; Ranatunge *et al.*, 2003; Premathilake and Gunatilaka, 2013). Research studies

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have not been reported related to the rainfall variation and distribution in the Southwest monsoon in Sri Lanka. Therefore, the objectives of this study were to examine the Southwest monsoon rainfall distribution, especially in agro climate zones, analyze the Southwest monsoon rainfall trends using drought indices (RAI and SPI) and identify the significant trends using MK test along with Sen's slope estimator.

MATERIALS AND METHODS

Daily rainfall data were acquired from 13 rain gauge stations from the Department of Meteorology, Sri Lanka. The daily precipitation data for the Southwest monsoon season (May-September) for the period 1981-2010 at stations located in Ambewela, Colombo, Galle, Hatton, Katugastota, Katunayaka, Maliboda, Maskeliya, Nuwara Eliya, Pasyala, Ratnapura, Watawala, and Weweltalawa were utilized.

Monthly average rainfall and monthly average number of rainy days for each station were obtained from the daily rainfall data series, with the purpose of understanding the rainfall distribution within and between the stations along with the time. The yearly rainfall analysis was carried out using RAI and SPI, to investigate the Southwest monsoon rainfall variation throughout the years.

The RAI was established by Van Rooy (1965). The RAI process assigns magnitudes to positive and negative precipitation anomalies incorporated with a ranking procedure. The RAI values for each station were calculated as follows:

$$RAI = 3 \left(\frac{N - \bar{N}}{\bar{M} - \bar{N}} \right), \text{ for a positive anomaly} \quad (1)$$

$$RAI = -3 \left(\frac{N - \bar{N}}{\bar{X} - \bar{N}} \right), \text{ for a negative anomaly} \quad (2)$$

where N is the Southwest monsoon rainfall at a particular rain gauge station in a particular year, $\bar{N}$ is the long period average Southwest monsoon rainfall at a rain gauge station, $\bar{M}$ is the average of ten highest Southwest monsoon rainfalls of the series, $\bar{X}$ is the average of ten lowest Southwest monsoon rainfalls of the series (Costa *et al.*, 2017). Classification of RAI intensity is shown in the Table 1 (Van Rooy, 1965).

Table 1: Classification of RAI intensity.

RAI value	Classification
≥ 3.00	Extremely Wet
2 to 2.99	Very Wet
1 to 1.99	Moderately Wet
0.50 to 0.99	Slightly Wet
-0.49 to 0.49	Near Normal
-0.99 to -0.5	Slightly Dry
-1.99 to -1	Moderately Dry
-2.99 to -2	Very Dry
≤ -3.00	Extremely Dry

RAI values which are above zero (positive RAI values) indicate wet (excess) periods and RAI values which are below zero (negative RAI values) indicate dry (deficit) periods.

The SPI concept was developed by McKee *et al.* (1993). This was designed to evaluate precipitation deficits on multiple time scale. In the calculation procedure, first, data set is fitted to the Gamma function which is then transformed into a normal distribution with a mean zero and standard deviation of unity (Hayes *et al.*, 2007). Classification of SPI intensity is shown in the Table 2 (McKee *et al.*, 1993).

Table 2: Classification of SPI intensity.

SPI value	Classification
≥ 2.00	Extremely Wet
1.5 to 1.99	Severely Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
≤ -2.00	Extremely Dry

SPI values which are above zero (positive SPI values) indicate wet (excess) periods and SPI values which are below zero (negative SPI values) indicate dry (deficit) periods.

In the MK test, the null hypothesis, H_0 is that the observations are randomly distributed (no trend). The alternative hypothesis, H_1 is that data follow an increasing or decreasing monotonic trend. The MK test statistic (S) is calculated as in Mishra and Gupta (2015) by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \quad (3)$$

where x_j and x_k are the data values at time j and k , ($j < k$), respectively. n is the length of the data set and $\text{sign}(\cdot)$ is the sign function which is computed as follows:

$$\text{sign}(\cdot) = \begin{cases} +1 & \text{if } \text{sign}(x_j - x_k) > 0 \\ 0 & \text{if } \text{sign}(x_j - x_k) = 0 \\ -1 & \text{if } \text{sign}(x_j - x_k) < 0. \end{cases} \quad (4)$$

For $n > 10$, S can be approximated by a standard normal random variable Z which is calculated as

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0, \end{cases} \quad (5)$$

where $\text{Var}(S)$ denotes the variance of S . A positive (negative) value of Z indicates an increasing (decreasing)

trend. If data have a significant trend, assuming that it is a linear trend, magnitude of the slope can be estimated using Sen's slope estimator which is developed by Sen (1968). The linear slope can be calculated as in Mishra and Gupta (2015) by

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, 2, 3, \dots, n, \quad (6)$$

where x_j and x_k are the data values at time j and k , ($j < k$), respectively and n is the length of the data set.

RESULTS AND DISCUSSION

Comparison of monthly average rainfall for rain gauge stations and wet zone divisions are shown in Figure 1 (a) and (b).

Analysis of monthly average rainfall for the considered consecutive 30 years revealed that Maliboda and Watawala, which are located in the hill country experienced the highest amount of rainfall during the Southwest monsoon compared to the other rain gauge stations considered in this research study (Figure 1a). In the wet zone, the highest amount of rainfall occurred at locations which are in mid country than at the locations of low country and up country (Figure 1b). This can be due to the variations in geographic features such as orographic effect, wind barriers, etc. in each part of the wet zone.

The monthly average number of rainy days resulted at 13 rain gauge stations are shown in Figure 2.

In the comparison of average number of rainy days, Figure 2 shows that there were a smaller number of rainy days during the arrival (May) and departure (August and September) of the monsoon while the highest number of rainy days occurred in the middle of the monsoon (June and July). Monsoon circulations in the atmosphere over Indian sub-continent region gradually establish during the months of June and July in which Sri Lanka experiences strong Southwest wind flow over the country bringing more moist air from South Indian Ocean and the Arabian Sea. As a result of that, South Western part of the country receives more rainfalls than the other parts due to the orographic characters in the area during these months.

Occurrence of wet (excess) years and dry (deficit) years during 1981 - 2010 are shown in the following Figure 3 (a) and (b). RAI values were calculated using equations (1) and (2).

Analysis of Southwest monsoon rainfall variation based on RAI and SPI revealed that in the years of 1982, 1985, 1988, 1989, 1992, 1993, 1995, 1998, and 2010, majority of the stations had positive RAI and SPI values (wet/excess years) while in the years of 1983, 1986, 1987, 1990, 1991, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, and 2008, majority of the stations had negative

Figure 1: Monthly average rainfall for (a) 13 rain gauge stations (b) low, mid, and up country for 13 rain gauge stations during 1981 - 2010.

Figure 2: Monthly average rainy days for 13 rain gauge stations during 1981 - 2010.

Figure 3: Values obtained for (a) RAI and (b) SPI for 13 rain gauge stations during 1981 - 2010.

RAI and SPI values (dry/deficit years) (Figure 3). Results revealed that many years in the most recent decade (2001, 2002, 2003, 2004, 2005, 2006, 2007, and 2008) were dry. According to the World Meteorology Organization (WMO), they also have recorded 2001 - 2010 as the warmest decade ever (WMO, 2014). In the past recent decade, only one year (2010) was a wet/excess year. Disaster Management

Center, Sri Lanka, also stated that heavy monsoon rainfall caused floods in some areas in 2010.

Results obtained from the trend analysis using equations (3) to (6), for the two drought indices are shown in Table 3 and observed decreasing trends are shown in Figure 4.

Figure 4: RAI and SPI trend plots for (a) Ambewela (b) Katugastota (c) Nuwara Eliya (d) Hatton rain gauge stations during the period of 1981 - 2010.

Trend analysis on both RAI and SPI resulted that, most of the rain gauge stations (10 stations) showed decreasing rainfall trends (negative Z values) while only 3 stations (Galle, Maliboda, and Pasyala) showed slightly increasing rainfall trends (positive Z values) in the Southwest monsoon with respect to normalized MK statistic (Z). However, trend analysis on RAI revealed that only 4 rain gauge stations: Ambewela, Hatton, Katugastota, and Nuwara Eliya, showed statistically significant decreasing linear trend in the Southwest monsoon during the considered 30 years while all the other 9 rain gauge

stations showed no trend. However, trend analysis based on SPI revealed that only 3 rain gauge stations: Ambewela, Katugastota, and Nuwara Eliya, showed statistically significant decreasing linear trend during the Southwest monsoon during the period 1981 - 2010 (Table 3). Both drought indices, RAI and SPI agreed on significant decreasing rainfall trends in Ambewela, Nuwara Eliya, and Katugastota in the Southwest monsoon season (Figure 4). Two rain gauge stations out of those three (Ambewela and Nuwara Eliya) are located in up country while Katugastota is located in mid country, *i.e.*, all those three rain gauge stations are located in the hill country.

Table 3: Trend analysis on RAI and SPI for 13 rain gauge stations over the period 1981 - 2010 using MK test and Sen's slope estimator.

Rain Gauge Station	Normalized MK Statistic (Z)		Sen's Slope		p-value		Trend (at 95% significant level)	
	RAI	SPI	RAI	SPI	RAI	SPI	RAI	SPI
Ambewela	-2.587	-2.231	-0.1678	-0.0476	0.0097	0.0257	DT	DT
Colombo	-1.035	-0.928	-0.0652	-0.0216	0.3008	0.3535	NT	NT
Galle	0.357	0.642	0.0114	0.0147	0.7212	0.5207	NT	NT
Hatton	-2.248	-1.820	-0.1394	-0.0312	0.0246	0.0688	DT	NT
Katugastota	-2.391	-2.641	-0.1544	-0.0448	0.0168	0.0083	DT	DT
Katunayaka	-1.427	-1.713	-0.0957	-0.0366	0.1535	0.0868	NT	NT
Maliboda	1.160	0.660	0.0813	0.0220	0.2461	0.5091	NT	NT
Maskeliya	-2.964	-1.750	-0.2212	-0.0406	0.0835	0.0802	NT	NT
Nu. Eliya	-2.105	-2.105	-0.1311	-0.0485	0.0353	0.0353	DT	DT
Pasyala	0.642	0.535	0.0256	0.0120	0.5207	0.5925	NT	NT
Ratnapura	-0.678	-0.714	-0.0351	-0.0143	0.4978	0.4754	NT	NT
Watawala	-1.304	-1.518	-0.0960	-0.0349	0.1922	0.1291	NT	NT
Weweltalawa	-0.161	-0.767	-0.0115	-0.0173	0.8724	0.4429	NT	NT

These decreasing trends in rainfall may cause reduction in soil moisture and then the ground water levels which mainly affect the agriculture sector. Population growth, global warming, deforestation, etc. might be the reasons for these decreasing trends of rainfall in the hill country. Based on the above results it is important to discuss economic, social and ecological impact of rainfall. If these decreasing trends continue in the hill country, then it could influence the sustainability of surface water resources and ground water recharge (Green Timothy *et al.*, 2011). In addition, this could affect to hydroelectricity production then the hydropower economics in which Sri Lanka has invested a significant capital (Khaniya *et al.*, 2020). Reduction in rainfall in hill country is leading to low yields and drop in productivity in tea plantations. It was also revealed that there was statistically significant reduction in annual rainfall in the hill country for the period 1869 - 2006 and it has been suggested the need for better planning and rationalization (De Silva and Sonnadara, 2009).

CONCLUSION

Monthly average rainfall comparison revealed that, mid country is the most affected area in the wet zone during the Southwest monsoon in Sri Lanka. According to the comparison of monthly average number of rainy days, in the middle of the season (June and July) monsoon is highly active than the arrival (May) and the departure (August and September) of the monsoon. Though the study was considered the South Western part of Sri Lanka (wet zone) during the Southwest monsoon, almost 50% of the years (14 years) were observed as dry/deficit years during the period of 30 years. 2000-2008 was a continuously dry period. Even though all the considered rain gauge stations are located in the wet zone, almost 75% of the rain gauge stations (10 rain gauge stations) experienced decreasing

rainfall trends in Southwest monsoon, but not all of them were significant at 95% level of significance. Moreover, rain gauge stations which showed significant linear decreasing rainfall trends during the Southwest monsoon are located in the hill country. If these decreasing trends continue in the hill country, it may cause negative impacts on agriculture, transportation, tourism, etc. and ultimately affect the whole economy of the country and livelihood of the people. Therefore, results gained from this research study can be supportive to local decision makers in order to make decisions and manage risks by monitoring floods and droughts.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

- Costa, J.A. and Rodrigues, G.P. (2017). Space-time distribution of rainfall anomaly index (RAI) for the Salgado Basin, Ceará State-Brazil. *Ciência e Natura* **39**(3): 627 - 634.
- De Silva, G.J. and Sonnadara, D.U.J. (2009). Climate change in the hill country of Sri Lanka. *Proceedings of the Technical Sessions, Institute of Physics, Sri Lanka*, **25**: 7 - 12.

- Disaster Management Centre, Ministry of Disaster Management, Sri Lanka. (2010). Available from: http://www.dmc.gov.lk/index_english.html [Accessed: 15th March, 2020]
- Domroes, M. (1979). Monsoon and land use in Sri Lanka. *Geo Journal* **3**(2): 179 - 192.
- Domroes, M. and Ranatunge, E. (1993). Analysis of inter-station daily rainfall correlation during the southwest monsoon in the wet zone of Sri Lanka. *Geografiska Annaler: Series A Physical Geography* **75**(3): 137 - 148. DOI: <https://doi.org/10.1080/04353676.1993.11880391>.
- Green, T.R., Taniguchi, M., Kooi, H., Gurdak, J.J., Allen, D.M., Hiscock, K.M., Treidel, H. and Aureli, A. (2011). Beneath the surface of global change: impacts of climate change on groundwater. *Journal of Hydrology* **405**(3-4): 532-560. DOI: <https://doi.org/10.1016/j.jhydrol.2011.05.002>.
- Hayes, M.J., Alvord, C. and Lowrey, J. (2007). Drought indices. *Intermountain West Climate Summary* **3**(6): 2 - 6.
- Karunathilaka, K.L.A.A., Dabare, H.K.V. and Nandalal, K.D.W. (2017). Changes in rainfall in Sri Lanka during 1966–2015. *Engineer: Journal of the Institution of Engineers, Sri Lanka* **50**(2): 39-48.
- Khaniya, B., Priyantha, H.G., Baduge, N., Azamathulla, H.M. and Rathnayake, U. (2020). Impact of climate variability on hydropower generation: a case study from Sri Lanka. *ISH Journal of Hydraulic Engineering* **26**(3): 301 - 309.
- McKee, T.B., Doesken, N.J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. *Proceedings of the 8th Conference on Applied Climatology*, **17**(22): 179 - 183.
- Mishra, N. and Gupta, S. (2015). Precipitation trend analysis by MK test in Garhwal Region Districts of Uttarakhand (1901-2010). *Journal of Space Science and Technology* **4**(3): 25 - 35.
- Nisansala, W.D.S., Abeysingha, N.S., Islam, A. and Bandara, A.M.K.R. (2020). Recent rainfall trend over Sri Lanka (1987–2017). *International Journal of Climatology* **40**(7): 3417 - 3435. DOI: <https://doi.org/10.1002/joc.6405>.
- Premathilake, R. and Gunatilaka, A. (2013). Chronological framework of Asian Southwest monsoon events and variations over the past 24,000 years in Sri Lanka and regional correlations. *Journal of the National Science Foundation of Sri Lanka* **41**(3): 219-228.
- Punyawardana, B.V.R. (2002). Climate change: Challenges and opportunities in Sri Lanka. Natural Resource Management Centre, Sri Lanka.
- Ranatunge, E., Malmgren, B.A., Hayashi, Y., Mikami, T., Morishima, W., Yokozawa, M. and Nishimori, M. (2003). Changes in the Southwest monsoon mean daily rainfall intensity in Sri Lanka: relationship to the El Niño–Southern Oscillation. *Palaeogeography, Palaeoclimatology, Palaeoecology* **197**(1-2): 1-14. DOI: [https://doi.org/10.1016/S0031-0182\(03\)00383-3](https://doi.org/10.1016/S0031-0182(03)00383-3).
- Suppiah, R. and Yoshino, M.M. (1984a). Rainfall variations of Sri Lanka Part 1: Spatial and temporal patterns. *Archives for Meteorology, Geophysics, and Bioclimatology, Series B* **34**(4): 329 - 340.
- Suppiah, R. and Yoshino, M.M. (1984b). Rainfall variations of Sri Lanka, Part 2: regional gluctuations. *Archives for Meteorology, Geophysics, and Bioclimatology, Series B* **35**(1-2): 81 - 92.
- Van Rooy, M.P. (1965). A rainfall anomaly index independent of time and space, *Notos* **14**: 43 - 48.
- Yoshino, M.M. and Suppiah, R. (1984). Rainfall and paddy production in Sri Lanka. *Journal of Agricultural Meteorology* **40**(1): 9 - 20.
- Zubair, L. and Ropelewski, C.F. (2006). The strengthening relationship between ENSO and northeast monsoon rainfall over Sri Lanka and southern India. *Journal of Climate* **19**(8): 1567-1575. DOI: <https://doi.org/10.1175/JCLI3670.1>.