Spatial Patterns and Temporal Trends of Rainfall Seasonality in Sri Lanka

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ABSTRACT

Understanding and knowledge of rainfall variability is necessitated for agricultural planning, flood mitigation activities, and water resources planning and management. Like other rainfall characteristics seasonality of rainfall is also spatio-temporally specific which has not been evaluated to Sri Lanka. In this study, seasonality in rainfall over Sri Lanka was analyzed using the seasonality index (SI) proposed by Walsh and Lawler. Rainfall data at 39 raingauge stations for the period 1988-2017 were collected to obtain the annual monthly rainfall cycles. The SI, a measure of annual rainfall distribution, was used to identify different rainfall regimes. Southwest and central highlands covering the stations Baddegama, Pelawatte, Kudawa, Deniyaya, Mawarella, Mapalana and Beausejour (lower) were identified as "equable with a definite wetter season". Skirting to the definite wetter season was the "rather seasonal with a short drier season" regime surrounding the Colombo, Ratmalana, Nuwara Eliya, and Bandarawela. The region centered on Mannar received the most rain in three months or less. Markedly seasonal with a long drier season is in the eastern extending from Pottuvil to Trincomalee and in the northern part of the country above Puttalam and Maha Illuppallama except the surrounding of Mannar. Intermediate region to SI classes "rather seasonal with a short drier season" and "markedly seasonal with a long drier season" was designated as "seasonal". However, the seasonal rainfall contribution, i.e., in NEM (Dec.-Feb.), IM1 (March-April), SWM (May-Sep.), and IM2 (Oct.-Nov.), and the annual monthly rainfall profiles confirmed the presence of sub-regimes within the identified rainfall regimes. Non-parametric Mann-Kendall test and Sen's slope were applied to identify the temporal changes in SI. Approximately, half of the country showed strong trends in the SI. Sixty one percent of the area including the northern part of the country surrounding Jaffna and the definite wetter region in the southern corresponds to the decreasing trend in seasonality.

KEYWORDS: *Intra-annual variation, rainfall regimes, rainfall variability, seasonality index, Sri Lanka, trend analysis.*

1 INTRODUCTION

Rainfall is the major component of the hydrological cycle. Many activities including agricultural, domestic, industrial, and hydropower generation rely on rainfall. Its variation depends on the topographical and geographical characteristics and is characterized by the seasonal distribution, intensity, duration, frequency, precipitation extremes, annual total rainfall, etc.

There have been many attempts to analyze the rainfall variability around the world. Among those attempts, empirical orthogonal function analysis (Sun, et al., 2012; Lyons, 1982), harmonic analysis (Horn & Bryson, 1960) and index-based methods (Walsh & Lawler, 1981; Oliver, 1980) are the most widely applied methods in the literature. Each of these methods has its own specific basis to identify the variations in rainfall. Out of these methods, index-based methods provide a value to identify and compare the characteristic features. An index is easier to interpret and enables better communication

ISSN 2961-5011 | https://doi.org/10.54389/QRSP2741

with the relevant sectors. There are many different indices such as climate change indices (Deniz, et al., 2011), Environmental indices (Dobbie & Dail, 2014), Water quality indices (Abbasi & Abbasi, 2012; Wickramagamage, 2010). Precipitation indices include Seasonality Index (SI) (Walsh & Lawler, 1981), Precipitation Concentration Index (PCI) (Oliver, 1980), Standard Precipitation Index (SPI) (WMO, 2012), and Gini index (GI) (Monjo & Martin-Vide, 2016), to name a few, developed for specific purposes. Both the SI and the PCI can be used to identify the rainfall regimes based on the intra-annual variations in rainfall considering the monthly rainfall distribution. The SI is more specific and has wider range providing a descriptive output on the intra-annual rainfall variation. It has been applied to countries such as Africa (Dunning, et al., 2016), India (Rai & Dimri, 2019) and China (Zeng, et al., 2003).

Sri Lanka has been generalized into three climate zones: wet zone, dry zone, and intermediate zone (Meteorology Department, 2021).This climate zone classification is based on the average annual rainfall distribution in Sri Lanka. The intra-annual variation of rainfall is not interpreted through this approach. There is not much research work to identify the variations of intra-annual rainfall seasonality in Sri Lanka. Further, many studies have been carried out to identify the trends in rainfall data, however those are limited to the trends in annual total rainfall, seasonal rainfall, rainfall extremes, monthly rainfall (Alahacoon & Edirisinghe, 2021; Naveendrakumar et al., 2018; Karunathilaka et al., 2017; Jayawardene et al., 2005;). This research study aims to apply the SI to identify the rainfall regimes with intra-annual rainfall variations in Sri Lanka and to evaluate its temporal changes.

2 METHODOLOGY

2.1 Study Area and Data

Sri Lanka is an island in the South Asia located between latitudes 5°-10° N and longitudes 79°-82° E. It has a tropical climate due to the moderating effect of the ocean winds. The mean annual rainfall of the country varies from less than 900 mm in southeastern and northwestern to more than 5000 mm in the western slope of the central highlands (Meteorology Department, 2021). Sri Lanka experiences four climatic seasons: SWM-SouthWest Monsoon (May to September), NEM-NorthEast Monsoon (December to February), IM1-first Inter-Monsoon (March to April), and IM2-second Inter-Monsoon (October to November) (Meteorology Department, 2021).

In this study, monthly rainfall data at 39 stations located over the country, representing the climate zones, were obtained from the Department of Meteorology, Sri Lanka (Figure 1). The most recent 10 years' period 2008 to 2017 was considered in analyzing the SI variability in Sri Lanka, while data from 1988-2017 was utilized for trend analysis in SI in some locations depending on the availability of data.

2.2 Seasonality Index

The SI was applied for the monthly rainfall data of the selected stations. It was developed by Walsh and Lawler in 1981. It measures the degree of seasonal variation in monthly rainfall. The intra-annual variation of the rainfall can be clarified clearly by considering the monthly rainfall distribution. This index method can also be used to demarcate the boundaries of the rainfall regimes (Walsh & Lawler, 1981). The SI is defined as;

$$SI = \frac{1}{\overline{R}_{annual}} \sum_{n=1}^{n=12} |\, \overline{R}_m - \overline{R}_{annual}/12| \quad (1)$$

Where $\overline{R}_m$ is the mean monthly rainfall and $\overline{R}_{annual}$ is the mean annual rainfall.

This index varies from 0 to 1.83. The value 0 indicates equal rainfall in all months while a value of 1.83 refers to all rainfall in one month. Table 1 shows the classification of SI classes (Walsh & Lawler, 1981).

The SI calculated using mean monthly rainfall data is referred to as $\overline{SI}$ and the averaged SI value calculated for individual years is denoted as $\overline{SI_i}$.

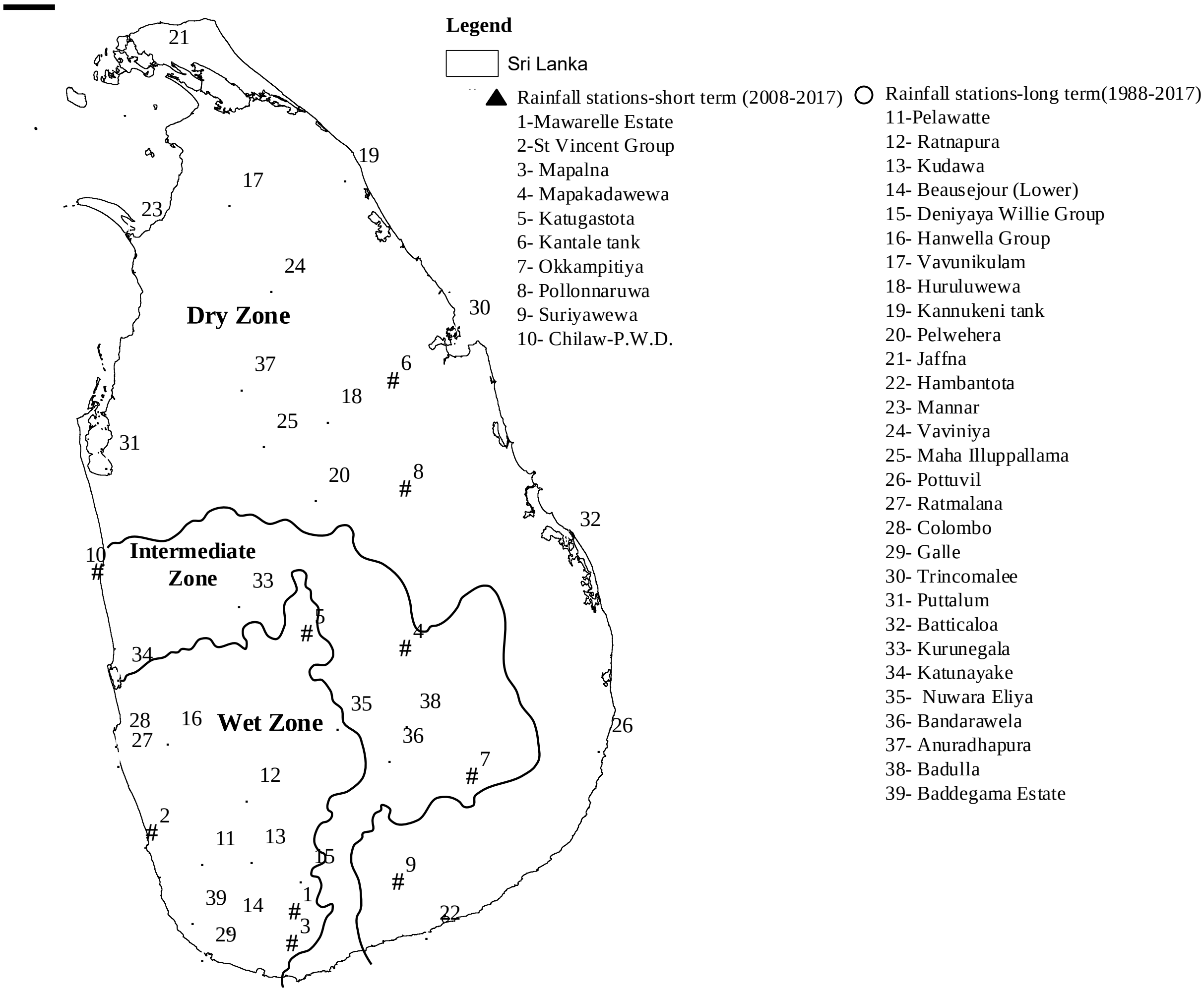

Figure 1. Location of the raingauge stations

Table 1. Seasonality index classes (Walsh & Lawler, 1981)

Rainfall regime	SI class limits
Very equable	≤0.19
Equable but with a definite wetter season	0.20-0.39
Rather seasonal with a short drier season	0.40-0.59
Seasonal	0.60-0.79
Markedly seasonal with a long drier season	0.80-0.99
Most rain in 3 months or less	1.00-1.19
Extreme, almost all rain in 1-2 months	≥1.20

2.3 Trend Analysis

Trend analysis is used to identify the significant changes in the temporal patterns in the $\overline{SI}_i$. This research study applied widely accepted non-parametric Mann Kendall test and Sen's slope estimator in identifying the trends in SI.

Static S is obtained from the Eq.(2).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(SI_j - SI_k) \quad (2)$$

Where $sgn(SI_j - SI_k) = \begin{cases} +1, if\ (SI_j - SI_k) > 0 \\ 0, if\ (SI_j - SI_k) = 0 \\ -1, if\ (SI_j - SI_k) < 0 \end{cases}$, n is the number of years, SI_k and SI_j are from $k = 1,2,..,n-1$ and $j = k+1, ..., n$.

The test statistic Z is given by

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{var(S)}}, if\ S < 0 \end{cases} \quad (3)$$

Where $var(S) = \frac{n(n-1)(2n+5)}{18}$

Positive values of Z indicate an increasing trend, and vice versa. In this study, 0.05 confidence level was used and the categories of trends are as in Table 2.

Table 2: Significance of the rainfall trends and the range of Z statistics

Categories	Scales
Very weak	0.1
Weak	0.1-0.19
Moderate	0.19-0.29
Strong	Above 0.29

The magnitude of the trend in SI was evaluated using the Sen's slope estimator(β).

$$\beta = median\left(\frac{SI_j - SI_i}{j - i}\right)$$

$\beta > 0$ indicates upward trend and vice versa.

3 RESULTS AND DISCUSSION

3.1 Seasonality Index Variation

Mean±std of the ratio $\frac{\bar{SI}}{\bar{SI}_i}$ was 0.90±0.21 indicating that no much degree of variation in the occurrence of the rainfall peaks and the troughs through time. The $\bar{SI}_i$ obtained for the selected stations for the period of 10 years were interpolated using the Inverse Distance Weighting (IDW) method. Figure 2 presents the SI map for Sri Lanka.

The obtained $\bar{SI}_i$ values vary from 0.26 in Pelawatte, close to the central highland to 1.04 in Mannar, in the southwest of the country. Mainly, four classes of rainfall regimes were present in the country based on the SI: Equable but with a definite wetter season, Seasonal, Rather seasonal with a short drier season, and markedly seasonal with a long drier season.

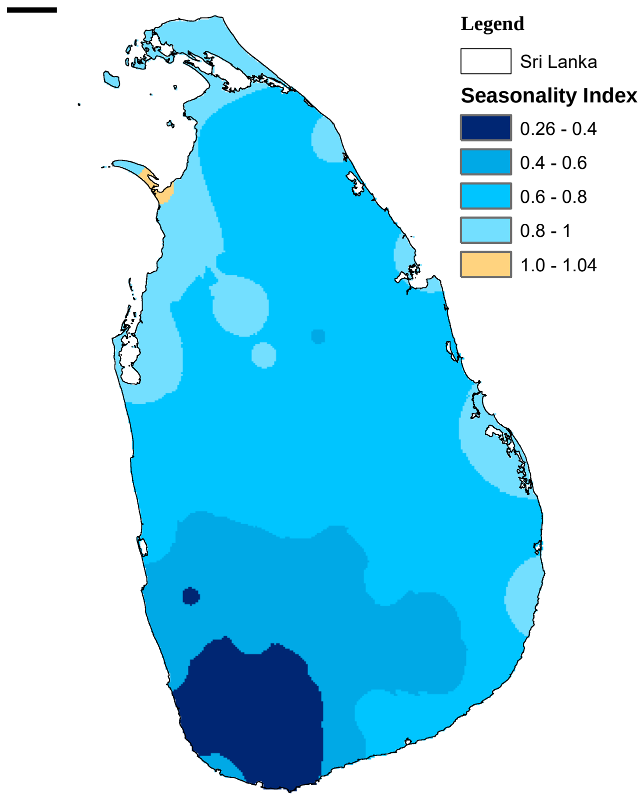

Figure 2. Seasonality index map of Sri Lanka

Southwestern region showed the lowest variation in monthly rainfall from the mean monthly rainfall providing the SI from 0.2 to 0.4 marking a definite wetter season. All stations shared a similar profile in monthly rainfall distribution receiving the lowest rainfall in the NEM. Stations closer to central highlands get quite high rainfall and decreases towards the stations in the lowland. Northwest to southeast coastal region extending from Puttalum to Pottuvil region shows markedly seasonal characteristics with a long drier season. Monthly rainfall profiles show disparity in shape due to the fall of rain in different seasons. Trincomalee, Pottuvil, and Batticaloa stations in the eastern part of the country receive substantial rainfall in the NEM and IM1, and experience dry season from March to September. Compared to eastern coast stations, Northern stations, i.e, Kannukeni tank, Jaffna, and Mannar receive rain only at the start of the NEM extending the dry season further. On the other hand, nearby stations Puttalum, Anuradhapura, and Maha Illupallama located in between northeast and west get rain mainly in the IM2, IM1, and at the start of the NEM. Skirting to the coastal belt rainfall regime extending up and around to the west and southeast is the region exhibiting seasonal characteristics. This ‘seasonal’ rainfall regime shows significant dissimilarities in the monthly rainfall profile. For example, rainfall stations, Chilaw, Suriyawewa, and Hambantota receives the lowest rainfall with mean monthly rainfall less than 100 mm. IM1, IM2, and NEM bring high rainfall to the stations just above the central highlands whereas northern stations, Vavunikulam, Vavuniya get comparatively less rain in IM1 and SWM. Mapakadawewa, Pollonnaruwa, and Kantale stations have similar profiles as eastern coast stations. Intermediate rainfall regime lies between the ‘seasonal’ and ‘markedly seasonal with a long drier season’ regimes with a shorter drier season. However, Okkampitiya, Huruluwewa, and Nuwara Eliya stations monthly rainfall profiles mismatched with that of other stations.

3.2 Trend Analysis

Z statistic varies from 1.96 to -1.88. Figure 3 shows Z statistic variation over the country and Figure 4 presents the change in SI per year. Out of the total area, 55%, 16%, 13%, and 16% of the area display strong, moderate, weak, and very weak trends in SI, respectively. Further, 35% of the area shows strong decreasing trend in SI while 20% of the area corresponds to the strong increasing trend. Mainly, southern and northern parts of the country show strong decreasing trend in the seasonality. Northeastern and southwestern areas exhibit strong increasing trend in seasonality.

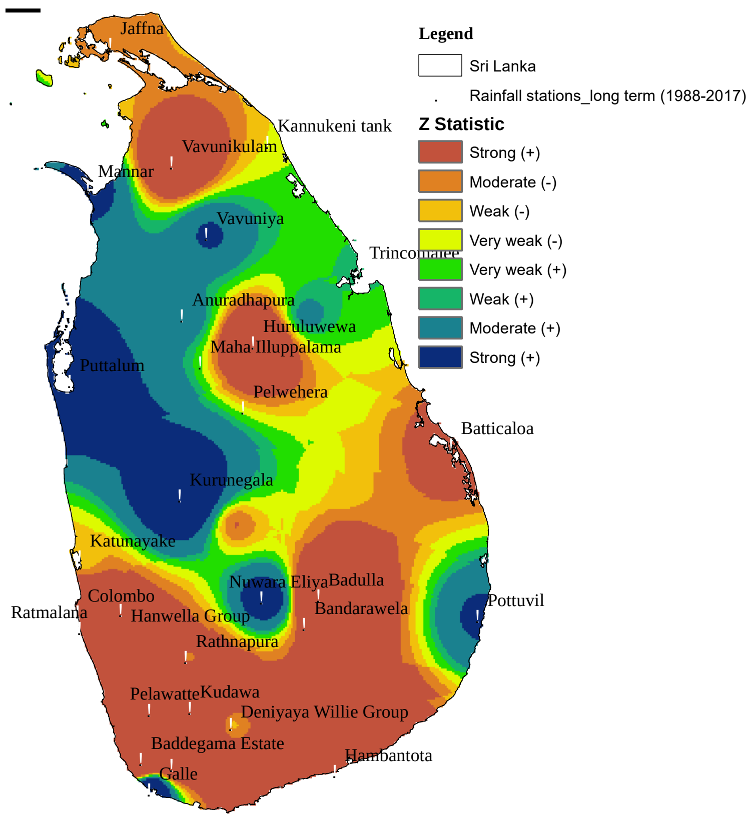

Figure 3. Z statistic variation over Sri Lanka

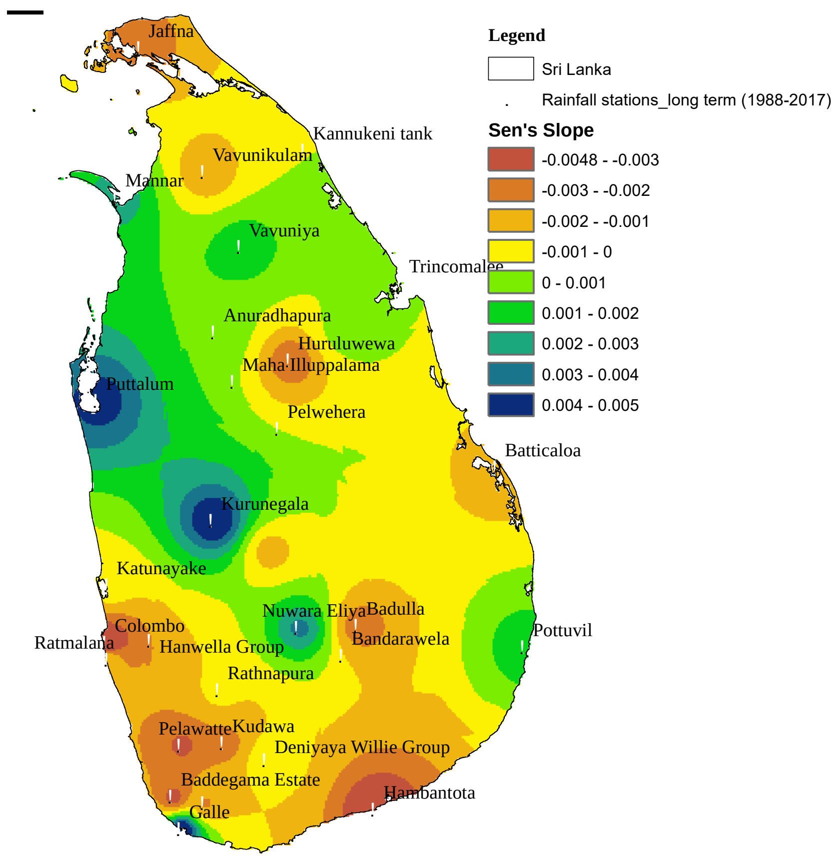

Figure 4. Sen's Slope variation over Sri Lanka

4 CONLUSIONS

This study evaluates the seasonality index variation over Sri Lanka and its temporal trends for the period 1988-2017. Analysis of results showed the presence of four regimes: Equable but with a definite wetter season, Seasonal, Rather seasonal with a short drier season, and markedly seasonal with a long drier season. The SI is a measure of degree of variability of monthly rainfall distribution and not an indicator for intra-seasonal variation in rainfall pattern. Therefore, attempts should be made to revise the index to include the intra-seasonal variation leading to homogeneous rainfall regimes. Trend analysis results indicated that the 55% of the area has undergone a significant change in the SI over the 30-year period from 1988 to 2017. Rainfall regimes with a definite wetter season and short drier season and the northern part of the country showed a strong decreasing trend while long drier season areas, Mannar, Potuvil and Puttalum exhibited strong increasing trends in the seasonality. The findings of this research will provide possible avenues for introducing management and adaptation procedures.

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