Rainfall Variability in Ratnapura District: A Comparative Study of the Two 30-year Standard Periods of 1961-1990 and 1991-2020

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Abstract

Ratnapura district in Sri Lanka could be identified as an area that is constantly affected by the adverse effects of rainfall variability; hence it is important to study the temporal patterns and distribution of rainfall variability in the area during the recent past decades. Therefore, this research aims to compare the annual and seasonal rainfall variability of the Ratnapura district based on the standard 30-year periods of 1961-1990 and 1991-2020. Fundamental statistical methods of coefficient of variation, Precipitation Concentration Index, and Standardised Precipitation Index were used to analyse the data. The study revealed that temporal patterns of rainfall variability in the district showed almost similar situations for both the 30-year periods. Temporal distribution of annual and seasonal rainfall variability also showed almost similar situations for both periods and was remarkable with uniform and moderate concentrations of rainfall variability. Relatively the highest variability of rainfall could be detected during the Northeast monsoon season. Although no differences in occurring extreme wet conditions between the two 30-year periods, it is clear that drier conditions of rainfall have decreased in the second 30-year period. The study also confirmed that no prolonged wet and dry conditions were reported in the Ratnapura district during the considered two 30-year periods.

Keywords: Climate, Extreme Events, Rainfall Variability, Ratnapura District, Seasonal Rainfall

INTRODUCTION

Ratnapura district can be identified as an area that is constantly subjected to extreme rainfall conditions. Rainfall-induced natural disasters, especially floods and landslides are common in the district (Edirisooriya et al., 2018). The economy of the district is mainly based on agriculture. Therefore, it is important to identify the temporal pattern and distribution of the rainfall variability in the Ratnapura district.

As a country located in the tropical region, Sri Lanka can be called a country that receives rainfall that can be expected throughout the year and the main weather element is the rainfall. The most important factor in Sri Lanka's rainfall is the seasonal pattern and it varies temporally and spatially. Four rainfall seasons prevail on the island, namely the First Inter-monsoon season (FIMS) from March to April, the Southwest-monsoon season (SWMS) from May to September, the Second Inter-monsoon season (SIMS) from October to November, and the Northeast-monsoon season (NEMS) from December to February (Ranasinghe, 2004). Thus, various weather and climate factors have influenced the formation of a seasonal rainfall pattern in the country: the location of the Inter Tropical Convergence Zone (ITCZ), the location within the equatorial trough, the maritime influence as an island, and the topography of the country i.e. the central highlands (Ranasinghe, 2004).

Due to the seasonal variability of rainfall as mentioned above, rainfall has become a factor that directly affects the lives of the local people. The local people had to face the most remarkable variations or extreme conditions in the rainfall, especially during certain seasons (Ranasinghe, 2018). Extreme excesses of rainfall lead to flooding and extreme deficits of rainfall lead to water scarcity or drought (IPCC, 2007). Considering the rainfall data from many meteorological stations in Sri Lanka, it appears that extreme conditions show an increasing trend in recent decades (Navaratne et al., 2019).

Ratnapura district can be named as an area that is constantly subjected to extreme conditions of rainfall. According to many literature investigations (Edirisooriya et al., 2018; Navaratne et al., 2019; Ranasinghe 2018), it has been confirmed that the Ratnapura district is highly vulnerable to climate change. Examples of positive extreme rainfall conditions affecting the Ratnapura district are 347.2 millimetres (mm) of rainfall on May 17 2003 and 186.1 mm of rainfall on July 18, 2008 (Navaratne et al., 2019). Due to

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these extreme conditions, the people of Ratnapura district have to face various natural disasters (Edirisooriya et al., 2018). This means that the floods and landslides caused by high-intensity rainfall within a short period of time have become common natural disasters that could be identified in the area. Limited number of research on rainfall variability in the Ratnapura district could be found and Ranasinghe (2004), and Nawagamuwa et al., (2014) had used the rainfall data from 1951- 2000 and 2000-2010 respectively. Another two studies (Ranasinghe, 2018; Navarathna et al., 2019) focused on the periods of 1951-2010 and 1976- 2017 respectively. Therefore, it is clear that there is lack of research on rainfall variability in the Ratnapura district to identify the most recent variability and changes of the rainfall factor. With this background, the research focused on the temporal patterns and distribution of the rainfall variability in the district considering the standard 30-year climate normals of 1961-1990 and 1991-2020 which are suggested by the World Meteorological Organization (National Centers for Environmental Information, n.d.). The main aim of this study was to analyse the temporal nature of rainfall variability in the Ratnapura district comparing the new standard thirty-year period (1991-2020) with the previous standard thirty-year period (1961-1990). The study focused on the following objectives:

1. To analyse the temporal patterns of annual and seasonal rainfall variability
2. To analyse the temporal distribution of annual and seasonal rainfall variability
3. To analyse the extreme conditions of annual and seasonal rainfall.

LITERATURE REVIEW

The amount of rainfall, which is an important feature of the climate of a region, and its continuous variation over a period of time or across a region is called rainfall variability in meteorology and climatology (IPCC, 2007). Accordingly, rainfall variability can be identified on a daily, monthly, seasonal, and annual basis. This study focuses on seasonal and annual rainfall variability in the Ratnapura district.

Global precipitation Variabilities

Average precipitation is subject to increase over most regions of the world, especially in the cold season, due to an intensified hydrological cycle. It is also projected that rising temperatures could lead to changes in the intensity of global average precipitation (Meehl, 2007). According to Alexander et al. (2006), precipitation changes showed a widespread and significant increase. However, the changes are much less spatially coherent when compared with temperature changes. Precipitation indices calculated based on a sample consisting of over 70% of the global land area showed a tendency toward wetter conditions throughout the 21st century.

According to the IPCC's 4th assessment report (2007) changes in precipitation lead to changes in runoff and water availability. The process of runoff is projected with high confidence to increase by 10% to 40% by mid 21st century (IPCC, 2007). At higher latitudes and in some wet tropical areas, including highly populated areas in East, South, and South-East Asia, changes in precipitation patterns will have adverse impacts on multiple sectors, for example agriculture, water supply, energy production, and health. Regionally, large increases in irrigation water demand resulting from changes in precipitation patterns are also projected. The negative impacts of climate change directly affect freshwater systems, which is a major environmental issue in the 21st century (IPCC, 2007). There is a general expectation that precipitation variability will increase at daily, monthly and inter-annual timescales (Meehl, 2007). Due to climatic changes, the spatial and temporal patterns of precipitation are also subject to variation. Moreover, Sun and Farquhar (2012) stated that the largest changes in precipitation variances were generally found in regions having the largest aerosol emissions and scientists have speculated that aerosol loading has played a key role in changing the variability of precipitation.

Rainfall variability in the South Asian region

As indicated by the IPCC's 5th assessment report (2014), the South Asian region as a whole has large climate variability, making climate change harder to identify and showing that the low understanding of how the climate change is influenced by human activity. Despite this, climate anomalies and changes in extreme events and El- Niño frequency have been observed throughout the region with intense rains and floods, droughts, and cyclones reported. Associated with climate change, the spatial and temporal distribution of rainfall is also predicted to have a major impact on the water and agricultural sectors in the South Asian region (IPCC, 2014). It has been identified that the availability and quality of fresh water in the region will be a major environmental issue of the 21st century (IPCC, 2007). NASA has predicted an increase of 5% in rainfall over the tropical oceans while slightly declining in the land regions (Hansen, 2013).

Rainfall and its Variability in Sri Lanka

Rainfall in Sri Lanka has multiple origins. The majority of the annual rainfall comes from monsoon rains, with significant rainfall from convection and cyclones (Ranasinghe, 2004). Average annual rainfall varies from less than 900 mm in the drier areas (Southeast and Northwest) to over 5000 mm in the wetter areas (Western and Southwestern slopes of the Central Highlands) (Department of Meteorology Sri Lanka, 2016). The rainfall affecting Sri Lanka within 12 months can be identified as four seasons, namely the First Inter-monsoon season (FIMS) (March and April), the Southwest-monsoon season (SWMS) (May to September), the Second Inter-monsoon season (SIMS) (October and November) and the Northeast-monsoon season (NEMS) (December to February) (Domros, 1978).

During the FIMS the weather characteristic of the island is light variable wind conditions as well as afternoon and evening thunderstorms. During this period, 700 mm of rainfall is received in some places on the Southwestern slopes (Kaaragala - 771 mm) and 250 mm of rainfall is received in the Southwestern part of the hills. Rainfall varies from 100 mm to 250 mm over most parts of the island except for the notable difference in Jaffna Peninsula (Jaffna - 78 mm, Elephant Pass - 85 mm) (Department of Meteorology Sri Lanka, 2016).

The prevailing winds during the SWMS wash away the heat that prevailed during the FIMS period. Southwest monsoon is expected during both day and night and possibly intermittent rains mainly over the southwestern part of the island. The rainfall during this time varies between 100-3000 mm. The central highlands of the Western Ranges receive the highest rainfall (Ginigathena - 3267 mm, Watawala - 3252 mm, Nortonbridge - 3121 mm). From these central highlands to the higher highlands, the rainfall falls rapidly and in Nuwara Eliya, it falls to 853 mm. This variation is slower towards the southwest coast and the southwest coast receives 100-1600 mm of rain during this five month period. The lowest value is reported from the northern and southeastern regions (Department of Meteorology Sri Lanka, 2016).

Afternoon or evening thunderstorms are the characteristic weather feature of the SIMS. Unlike during the FIMS, depressions and storms in the Bay of Bengal are common during the SIMS. Under those conditions, the entire island faces strong winds and widespread rains in some cases with floods and landslides. The whole of Sri Lanka will get a more balanced distribution of rainfall in this rainy season. Accordingly, the entire island receives an excess of 400 mm of rainfall during this period and the Southwest slopes receive high rainfall in the range of 750-1200 mm (Yatianthota Vewelthalawa Estate - 1219 mm) (Department of Meteorology Sri Lanka, 2016).

During the NEMS, the dry winter wind blowing from India will establish a relatively cool but dry weather condition in most parts of the island, creating pleasant and healthy weather conditions around except for a few very cold mornings. Cloudless skies and bright sunny days will make for pleasant cool nights. During this period, the highest rainfall was recorded from Trincomalee and Batticaloa districts (average rainfall of 1250 mm), and the lowest rainfall was recorded from the west coast area around Puttalam (Chilaw - 177 mm) (Department of Meteorology Sri Lanka, 2016).

Much research was conducted on the rainfall variability in Sri Lanka. Similarities, as well as dissimilarities, are seen in the conclusions given by those researchers. There are several scientific studies on the subject of mean annual rainfall (MAR) in Sri Lanka. Domrös (1996), and Domrös and Schaefer (2000) have indicated that the country's average annual rainfall was estimated at 2005 mm during the 30-year standard period from 1931-1960, declining to 1861 mm from 1961-1990. Comparing the same two 30-year standard periods (1931-1960 and 1961-1990), Chandrapala (1996) found that the mean annual rainfall in Sri Lanka had decreased by 7% (144 mm) during the second 30-year period when compared to the first 30-year period.

In contradiction, a time series analysis based on the wet zone identified that positive trends are more apparent over the period from 1971-2000. However, none of these are significant (Ranasinghe, 2004). Jayatillake et al. (2005) have revealed that during the 20th century, downward or upward trends of mean annual rainfall in Sri Lanka were statistically not significant. According to Jayewardene et al. (2005), no coherent increase or decrease in trends was observed in the wet and dry zones of Sri Lanka during the 20th century.

Several studies have examined changes in the seasonal rainfall pattern in Sri Lanka. According to Suppiah (1997), rainfall anomalies are greater during the SWM and SIM seasons when compared with other two seasons. A study has shown that intra-seasonal variability is a significant aspect of rainfall climatology in Sri Lanka (Malmgren et al., 2003). Herath and Ratnayake (2004) concluded that among the four rainy seasons, the highest variability is during the FIM season. Some rainfall studies have shown that during the FIM and NEM seasons, the rainfall amounts have reduced and therefore had increased in variability (Basnayake et al., 2004; Chandrapala, 1996; Jayatillake et al., 2005). Imbulana et al. (2006) reported that a reduction of rainfall was noticeable during the SIM and NEM seasons. Furthermore, a significant decline in rainfall was identified on the western slopes of the Central Highlands due to the reduction of SWM rains (Domrös & Schaefer, 2000; Jayewardene et al., 2005; Madduma Bandara & Wickramagamage, 2004).

Similarly, a reduction in rainfall during the SWM season was confined to the higher elevation areas while enhanced rainfall is pronounced in the lowlands of the Southwest sector of the country. During the NEM season, none of the stations follow significant increasing or decreasing trends (Malmgren et al., 2003). Furthermore, a study showed that rainfall amounts and the number of rainy days have reduced in the up-country region of Sri Lanka, which could adversely affect the drainage system of the country (Herath & Ratnayake, 2004). Punyawardena (2008) stated that the variability of seasonal rainfall in Sri Lanka has made the prediction of rainfall difficult.

The seasonal rainfall variability identification based on the coefficient of variation, Fernando and Chandrapala (1996) found that variability has risen during the FIM, SIM and NEM seasons, from 1961 to 1990, compared with the period from 1931-1960. Contradictorily, Premalal (2009) showed that the coefficient of variation in seasonal rainfall during the NEMS and SIMS is higher from 1931 to 1960 when compared with the period from 1961-1990, while the SWMS has remained static with no significant changes.

A few researchers have pointed out that in Sri Lanka the number of consecutive wet days has decreased, while the number of consecutive dry days has increased (Herath & Ratnayake, 2004; Premalal, 2009). It has also been shown that the intensity of daily rainfall and the average rainfall per spell in Sri Lanka's rainfall have also increased (Herath & Ratnayake, 2004). When compared to global and South Asian trends of extreme rainfall events, the intensity and frequency of extreme events of rainfall in Sri Lanka have also increased in recent decades (Imbulana et al., 2006).

The increased occurrence of extreme rainfall events due to climate change, droughts and floods have become a common feature of the climate of Sri Lanka during recent decades (Sirinanda, 1983; Panabokke & Punyawardane, 2010). Therefore, crop losses due to decreased soil moisture and excess water, both in terms of quality and quantity are inevitable. In recent years, rainfall variability accompanied by climate extremes has become a norm (Panabokke & Punyawardane, 2010). The increase in positive rainfall anomalies is likely to cause severe damage to existing irrigation infrastructure, thus limiting irrigated water availability for crop production (Punyawardane, 2012). It is further suggested that the indirect effects of increased rainfall intensity are of special significance in terms of land degradation, which has a significant bearing on crop production in Sri Lanka (Punyawardane, 2012).

When focusing on the rainfall studies conducted in the Ratnapura district, Nawagamuwa et al. (2014) found that there is a positive trend in annual rainfall where rainfall in the wettest month (October) increased by 2.1 mm per year, but rainfall in the driest month (January) decreased by 9.3 mm per year. Nawaratne et al. (2019) have identified a slight increase in the number of rainy days in the district. According to Kaleel (2018), it has been identified that the rainfall during the SWMS showed relatively decreasing trends in Embilipitiya, Balangoda, Lellopitiya rain gauge stations and a relatively increasing trend in the Ratnapura rain gauge station.

The research gap that could be identified from the research discussed above is that more attention has been paid to the analysis of the trend of rainfall, and in much research, rainfall data has been used only up to 2010 for the analysis where, only one researcher (Nawaratne et al., 2019) used rainfall data up to 2017. However, not much attention has been given to the seasonal rainfall which is important when considering the rainfall in Sri Lanka. Furthermore, some researchers have taken into account only the SWMS and their attention has been focused only on the trend analysis of the rainfall. With this background, this research focused on analysing the rainfall variability concerning the four rainy seasons in the Ratnapura district as a comparison study between the two 30-year standard periods: 1961-1990 and 1991-2020.

MATERIAL AND METHODS

The Ratnapura district is located between 6.2354^0-6.9306^0 North latitude and between 80.1772^0 - 80.9546^0 East longitude. It has an area of 3275.4 km^2. Some areas of the district are less than 50 m above sea level and the central area of the district is about 400 m above sea level. The western border is about 700 m, the southwestern border is about 1300 m and the northern area is about 2500 m high. According to the location in the wet zone of Sri Lanka, the district experiences a considerable amount of rainfall from all four rainy seasons and the SWMS is the predominant season. When considering the spatial distribution of rainfall, the area bordering the Central Highlands receives an annual rainfall of more than 4000 mm, and in contrast, the driest areas of the district such as Ambilipitiya receive less than 1300 mm of annual rainfall. The district faces the threat of floods due to the heavy rains brought by the SWMS (from May to September). In the dry areas of the district, for example Embilipitiya and Kalthota receive more rainfall during the SIMS and the NEMS that prevail from November to February. There are considerable spatial variations in terms of air temperature in the district, around the Samanala range it is recorded as low as 12^0 C, and in the dry areas, it is about 32^0 C (Survey Department of Sri Lanka, 2017).

This study is based on secondary data sources. Monthly rainfall data of the Ratnapura district for the period 1961-2020 was obtained from the Department of Meteorology, Sri Lanka. Then the whole period of data was divided into climate normal i.e. standard 30-year periods: 1961-2020 (the first 30-year period) and 1991-2020 (the second 30-year period). To identify decadal scale rainfall variability, the considered whole period was divided into six decades (1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010, and 2011-2020).

All the analyses were done according to the annual and seasonal basis of rainfall. In that manner, the collected monthly rainfall data were then segregated into seasonal values according to the four rainy seasons in Sri Lanka, which is shown as follows:

Month	Season
March and April	First Inter-monsoon (FIMS)
From May to September	Southwest-monsoon (SWMS)
October and November	Second Inter-monsoon (SIMS)
From December to February	Northeast-monsoon (NEMS)

Both annual and seasonal rainfall variabilities were analysed by using fundamental statistical methods of Coefficient of Variation (CV), Precipitation Concentration Index (PCI), and the Standardised Precipitation Index (SPI).

CV refers to a statistical measure of the distribution of data points in a data series around the mean. Among many statistical tests available to detect the variability of rainfall, the CV is considered to be a more robust approach. Generally low rainfall amounts are coincided with higher CV values and vice versa (an inverse relationship). However, in some cases though the rainfall amounts are higher, CV values are also higher due to greater variability of rainfall brought by the irregularities of rainfall or in other words marked fluctuations (Gregory, 1964). The coefficient of variation is computed using the following formula:

$$\text{Coefficient of Variation} = \frac{\sigma}{\bar{x}}$$

- σ = Standard Deviation
- $\bar{x}$ = Mean

The PCI introduced by Oliver (1980) has been used to identify the seasonal pattern of precipitation. According to Oliver (1980), the PCI is a powerful indicator for temporal precipitation distribution and is also very useful for the assessment of seasonal precipitation changes. Below is the equation used to calculate it.

$$PCI_{annual} = \frac{\sum P^2}{(\sum P)^2} \times 100$$

- PCI_{annual} = $Annual\ Precipitation\ Concentration\ Index$
- $\sum P^2$ = Sum of the squares of monthly rainfall in a year
- $(\sum P)^2$ = Square of rainfall in a year

While constructing the seasonal PCI, the index should be prepared considering the number of months in a rainy season. Table 1 shows how the seasonal PCI is calculated according to the number of months in a season.

Rainfall Season	Equation for seasonal PCI
First Inter-monsoon	$PCI_{seasonal} = \frac{\sum P^2}{(\sum P)^2} \times (2 \div 12 \times 100)$
Southwest-monsoon	$PCI_{seasonal} = \frac{\sum P^2}{(\sum P)^2} \times (5 \div 12 \times 100)$
Second Inter-monsoon	$PCI_{seasonal} = \frac{\sum P^2}{(\sum P)^2} \times (2 \div 12 \times 100)$
Northeast-monsoon	$PCI_{seasonal} = \frac{\sum P^2}{(\sum P)^2} \times (3 \div 12 \times 100)$

Table 1: Seasonal Precipitation Concentration Index

Source: Oliver (1980)

In 1993, McKee, Doesken and Kleist, a group of American scientists, used the SPI to identify the intensity of rainfall. It has been endorsed by the World Meteorological Organisation in 2012 as a suitable indicator for identifying rainfall intensity. The equation used to calculate SPI values is given below. In this study, SPI values have been calculated on a twelve-month and monthly time scale to identify the extreme cases of annual and seasonal rainfall in Sri Lanka.

$$SPI = \frac{Ri - Rm}{SD}$$

- Ri = Rainfall amount of year i
- Rm = Long term mean of rainfall
- SD = Standard Deviation of rainfall

Source: World Meteorological Organisation, 2012

RESULTS AND DISCUSSION

Temporal Pattern of Rainfall Variability

The coefficient of variation was used to identify the temporal patterns of annual rainfall variability.

Temporal Patterns of Annual Rainfall Variability: Figure 1 shows the calculated coefficient of variation values of annual rainfall for the two 30-year periods; 1961-1990 (first 30-year period) and 1991-2020 (second 30-year period). Accordingly, it is seen that the annual rainfall variability is less in the area and almost similar values are seen in both periods, and there is a very slight decrease (1.2%) in the second 30-year period compared to the first 30-year period. This finding is comparable with the other researchers' (Ranasinghe, 2004; Ranasinghe, 2018) conclusion of no significant variability in annual rainfall in Sri Lanka.

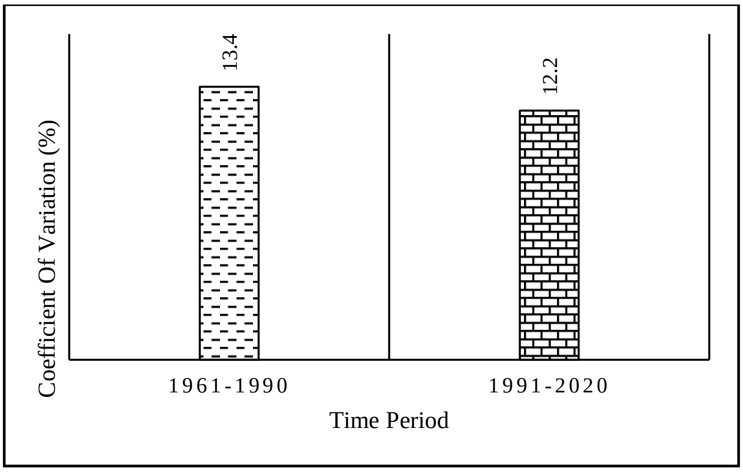

Figure 1: Coefficient of Variation of Annual Rainfall in Two 30-year Periods

Source: Prepared by the Authors based on the Rainfall Data of the Department of Meteorology, Sri Lanka

Figure 2 represents the decadal-wise coefficient of variation in annual rainfall and all the values show low rainfall variability. When comparing the decades, rainfall variability appears relatively high during the decade of 1981-1990. A similar conclusion of the study area was also made by Ranasinghe (2018) and confirmed that a severe El- Nino event in 1983 and 1984 was responsible for such variability. Another remarkable feature that could be recognized in the study area is that the variability is relatively high in the recent decade i.e. 2011-2020.

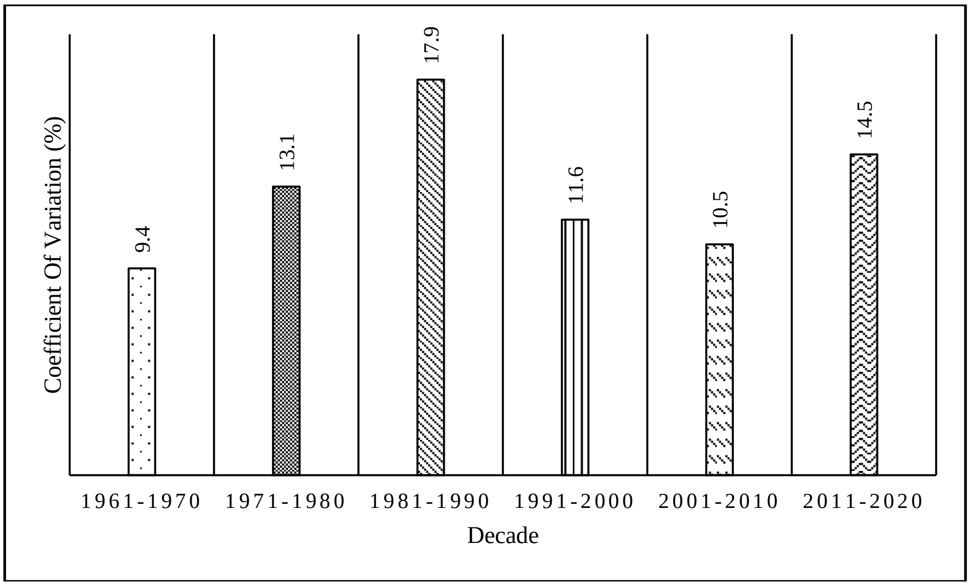

Figure 2: Decadal-wise Coefficient of Variation in Annual Rainfall

Source: Prepared by the Authors based on the Rainfall Data of the Department of Meteorology, Sri Lanka.

Temporal Patterns of Seasonal Rainfall Variability: Figure 3 represents the calculated coefficient of variation values in seasonal rainfall in the Ratnapura District for the two 30-year periods: 1961-1990 and 1991-2020. According to the figure, all four rainfall seasons showed relatively higher variability in the second 30-year period. However, except during the NEMS which showed an increase of variability by about 8.6% in the second 30-year period, the other three rainfall seasons appeared with very slight increases, as 3.1% in the FIMS, 0.9% in the SWMS, and 1% in the SIMS

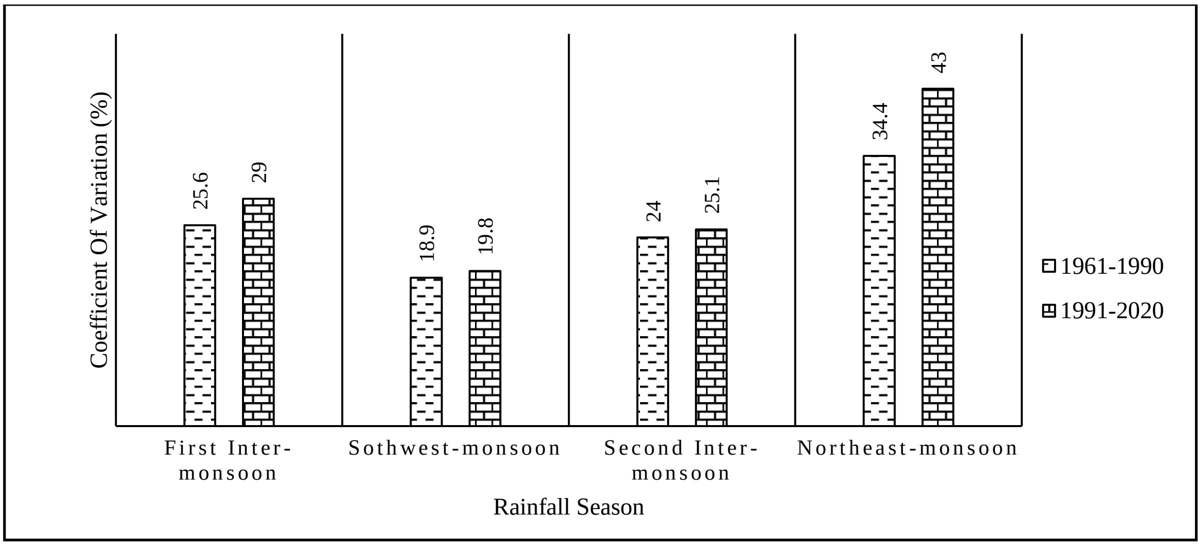

Figure 3: Coefficient of Variations in Seasonal Rainfall for the Two 30-year Periods

Source: Prepared by the Authors based on the Rainfall Data of the Department of Meteorology, Sri Lanka.

Figure 4 represents the decadal-wise coefficient of variation values of the seasonal rainfall Accordingly, the FIMS, SWMS, and SIMS showed their highest variability in the decades of 1981-1990 and 2011-2020. According to Ranasinghe (2018), both FIMS and SWMS in Sri Lanka were negatively correlated with the 1983 to 1984 El-Nino event, therefore higher rainfall variability in the decade of 1981-1990 was a remarkable feature in many districts of the country. Additionally, another significant feature identified in terms of the three seasons was that the recent decade i.e. 2011-2020 is shown remarkably higher values compared to the previous decade i.e. 2001-2010, especially in the FIMS and SIMS. It is noticeable that the rainfall variability of the NEMS is relatively higher than the other seasons however, the temporal pattern is different from the other seasons and the highest value is seen in the decade of 1991-2000, afterwards a gradual decrease in rainfall variability could be seen.

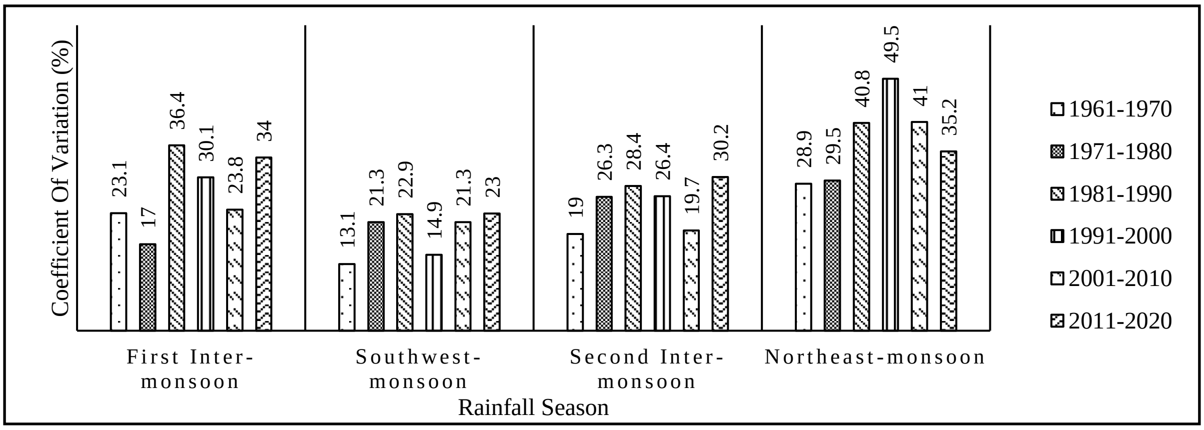

Figure 4: Decade-wise coefficient of variation of seasonal rainfall

Source: Prepared by the Authors based on the Rainfall Data of the Department of Meteorology, Sri Lanka.

Temporal Distribution of Rainfall Variability

Numerical values of the Precipitation Concentration Index were used to characterise the temporal distribution of rainfall variability in Rathnapura District and Table 2 shows the form of rainfall variability that is classified according to the PCI values suggested by Oliver (1980).

PCI value	Form of rainfall variability
PCI ≤ 10	Uniform rainfall variability
11 ≤ PCI ≤ 15	Moderate rainfall variability
16 ≤ PCI ≤ 20	Irregular rainfall variability
PCI ≥ 20	Strongly irregular rainfall variability

Table 2: Classification of PCI

Source: Oliver, J.E. (1980)

Temporal distribution of Annual Rainfall Variability: The temporal pattern of annual rainfall variability in the two standard 30-year periods is shown in Figures 5 (i) and 5 (ii) for the periods 1961-1990 (first) and 1991-2020 (second), respectively. The maximum value of PCI in the first 30-year period can be identified as 14 in 2016. According to **Figure 5**, both periods represented uniform and moderate concentrations of rainfall variability. Moderate concentration of rainfall variability could be identified in 66.7% of the years in the first period, while the remaining years (33.3% of the years) were in the uniform category. An almost similar pattern could be seen in the second 30-year period too, denoted by 63.3% and 36.7% of the years with moderate and uniform concentrations of rainfall variabilities respectively. Thus, it appears that there is no clear difference in the annual rainfall variability between the two periods. Therefore, it is important to pay attention to the temporal distribution of seasonal rainfall variability

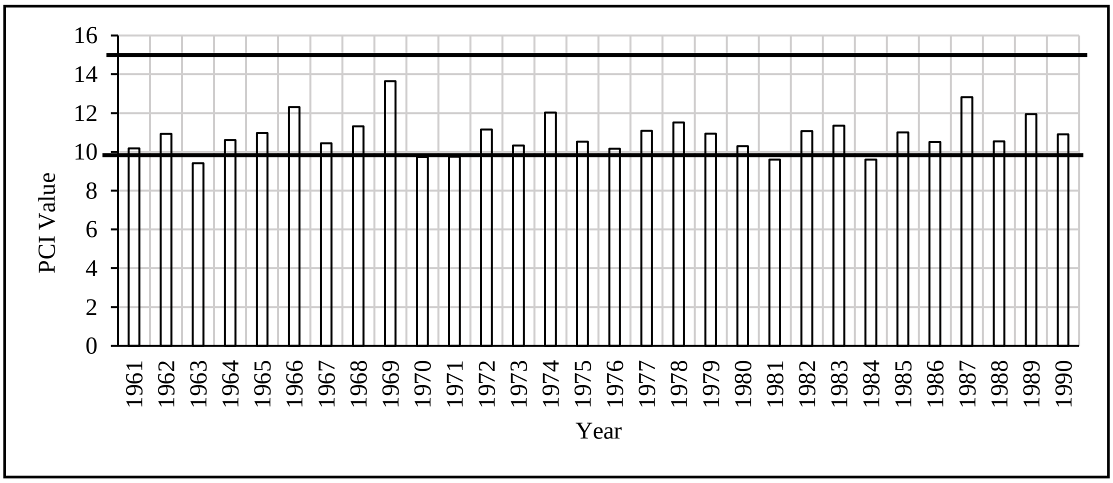

Figure 5(i): PCI Values of annual rainfall for the period 1961-1990

Source: Prepared by the Authors based on the Rainfall Data of the Department of Meteorology, Sri Lanka.

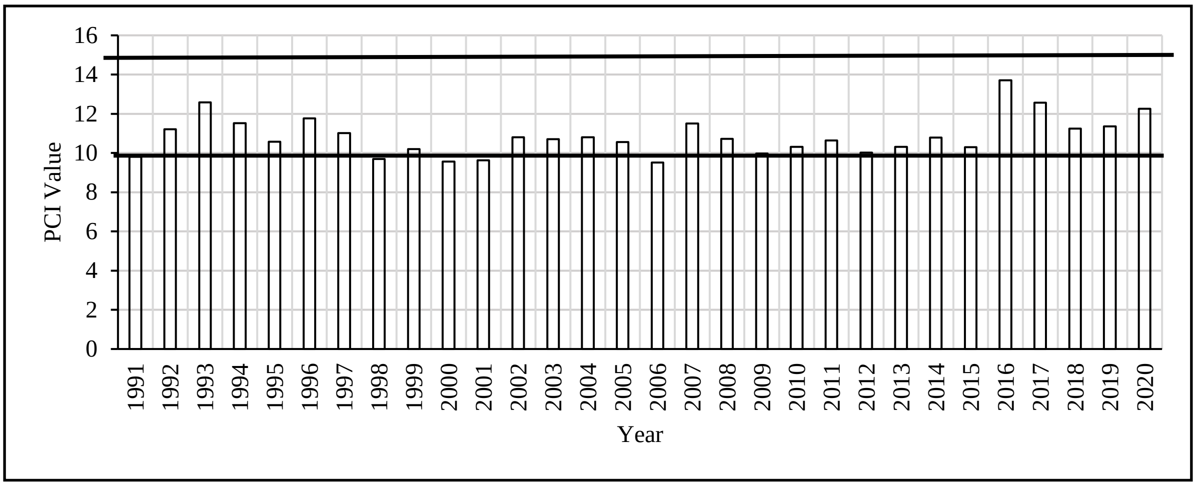

Figure 5(ii): PCI Values of annual rainfall for the period 1991-2020

Source: Prepared by the Authors based on the Rainfall Data of the Department of Meteorology, Sri Lanka.

Temporal distribution of Seasonal Rainfall Variability: The temporal distribution of rainfall variability in the FIMS is shown in Figure 6 for the two standard 30-year periods. In the first 30-year period, the maximum value of PCI can be identified as 12 in 1974, and in the second period as 13 in 1992. According to the Figure **6**, both periods are denoted by only uniform and moderate concentrations of rainfall and the uniform concentration of rainfall is the noteworthy feature. However, compared to the first 30-year period which is represented by 96.7% of the years with uniform concentration slightly decreased in the second 30-year period which is represented by 86.7% of the years.

Figure 6 shows the PCI values in the SWMS for two standard 30-year periods. In the first 30-year period, the maximum value of PCI could be identified as 13 in 1969. While in the second 30-year period, it is about 15 in 2016. During the SWMS also only uniform and moderate concentrations of rainfall variations appeared in both periods. However, the percentages of numerical values are rather different in the two periods: the first 30-year period comprised 56.7% of the years with a uniform concentration of rainfall variability and the remaining (43.3% of the years) showed moderate concentrations. In the second 30-year period, 83.3% of the years were identified as having a uniform concentration of rainfall variability. Accordingly, it appears that the temporal distribution of rainfall in the SWMS has become more uniform in the second 30-year period compared to the first 30-year period.

The temporal distribution of the seasonal rainfall in the Rathnapura District during the SIMS is shown in Figure 6 for the standard 30-year periods. In the first period, the maximum value of PCI was 13 and was represented in 1974. While in the second period, the maximum value of PCI is 10, and could be seen in 2004, 2007, and 2014. A noteworthy feature observed in the SIMS is that both periods are highly accompanied by a uniform concentration of rainfall, 98% of the years and 100% years in the first and second 30-year periods respectively. Thus, it is seen that the two months (October and November) of the SIMS have received approximately equal rainfall in all the years except in 1974 during the period under consideration.

The temporal pattern of rainfall variability of the NEMS for the two standard 30-year periods is shown in Figure 6. In the first period, the maximum value of PCI was 17 in 1981/82, showing irregular rainfall distribution due to the high rainfall (534.8 mm) in December 1981 and the relatively low rainfall in January and February 1982. In the second period, the maximum value of PCI was 14 in 2012/13 and 2016/17. Except for these two features, uniform and moderate concentrations of rainfall were the common features in the two periods. About 63.3% of the years were found with a uniform concentration of rainfall in the first 30-year period, while it was about 56.7% in the second 30-year period.

Moderate rainfall variability can be detected in 33.3% of the years in the first period and uniform variability can be detected in 63.3% of the years. In the second period, 43.3% of the years have moderate rainfall variability and 56.7% have uniform rainfall variability. Accordingly, it appears that the mean form of rainfall variability in the NEMS has slightly increased during the second period as compared to the first period.

Identification of the Intensity of Rainfall

The intensity of rainfall was analysed using the Standardised Precipitation Index (SPI) and Table 3 shows the intensity of rainfall is classified according to SPI values suggested by the World Meteorological Organization (2012).

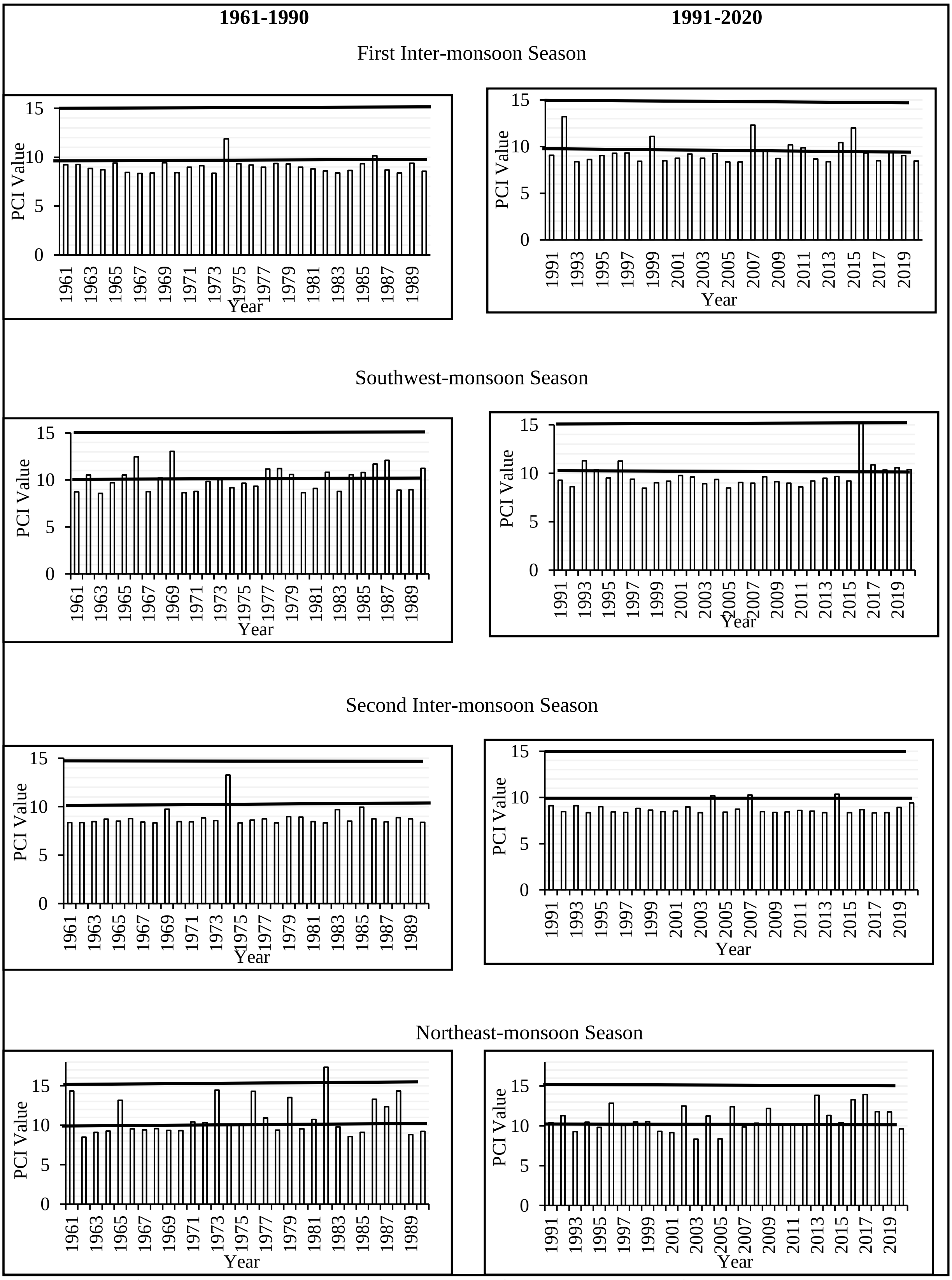

Figure 6: Seasonal Precipitation Concentration Index, comparison between 30-year periods

Rainfall Intensity	SPI Value
Extremely Wet	2.0+
Very Wet	1.5 to 1.99
Moderately Wet	1.0 to 1.49
Near Normal	(-0.99) to 0.99
Moderately Dry	(-1.0 to -1.49)
Severely Dry	(-1.5 to -1.99)
Extremely Dry	(-2.0+)

Table 3: Classifying SPI Values

Source: World Meteorological Organization (2012)

Annual Rainfall Intensity: The Standardised Precipitation Index (SPI) was used to calculate the amount of wet and dry years in the Ratnapura district for the considered two 30-year periods on an annual and monthly basis. Annual SPI values for the 30-year periods 1961-1990 (first) and 1991-2020 (second) are shown in Figures 7(i) and 7(ii) respectively. Years with SPI values exceeding the black colour horizontal lines in the Figure **7** denoted as the years with rainfall irregularity.

According to Figures 7(i) and 7(ii), the years 1982 and 2014 could be observed as extreme wet years, and 1973, 1983, and 2016 as severely dry years. Notably, extreme dry years cannot be identified here. And another peculiarity is that the cases of 'SPI< (-0.99)' which are close to each other cannot be identified in the period 1991-2020. This means that although dry conditions exist, they were not continuous. Also, the years with wet 'SPI>0.99' can be identified only in 1998 and 1999. A very wet period and a moderately wet period are to be seen in 1998 and 1999 respectively.

Table 4 shows the percentages of each category of SPI values represented by the two 30-year periods. As seen in Table 4, the intensity of rainfall is slightly different between the two 30-year periods. As in Table 4, dry conditions decreased in the second period, however, moderate wet have increased. A remarkable feature is in the two periods where a similar percentage of extremely wet conditions was represented by both periods.

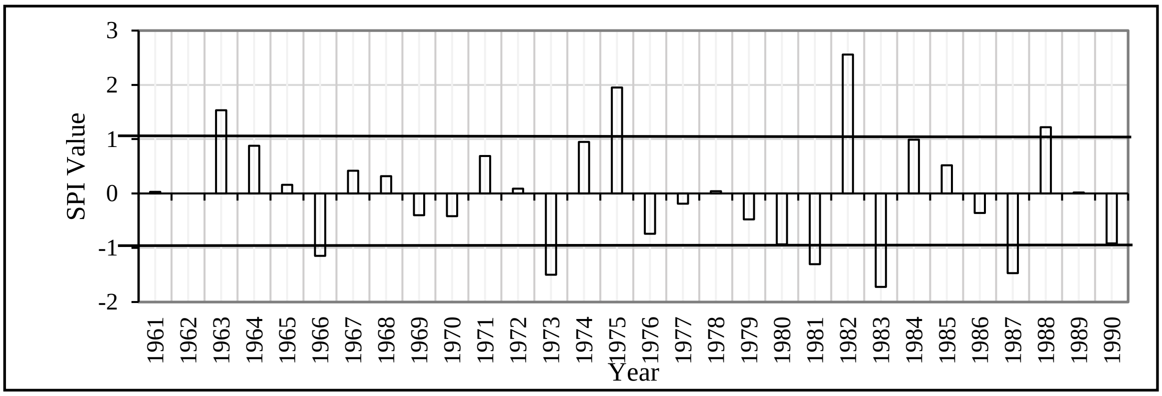

Figure 7(i): SPI values of annual rainfall for the period 1961-1990

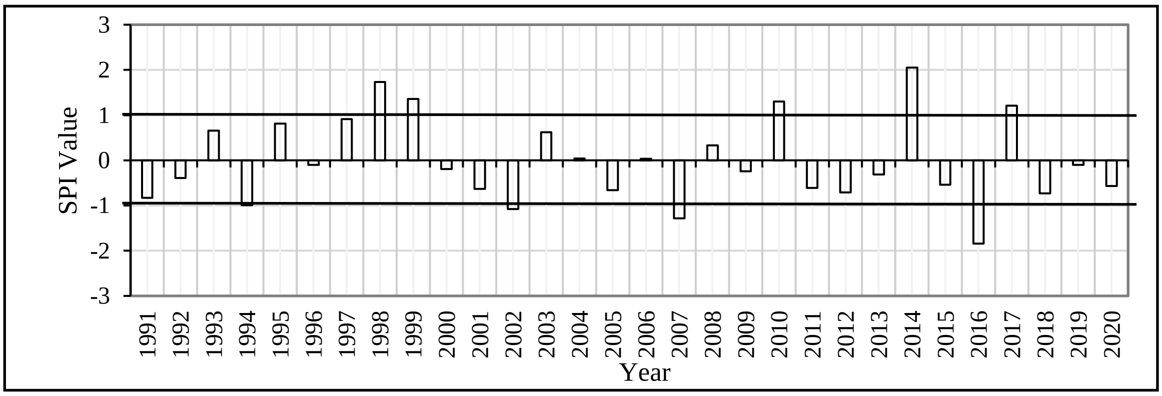

Figure 7(ii): SPI values of annual rainfall for the period 1991-2020

Rainfall Intensity	Time Period	
	1961-1990 years (%)	1991-2020 years (%)
Near Normal	70	73.4
Moderately Dry	10	6.7
Severely Dry	6.7	3.3
Moderately Wet	3.3	10
Very Wet	6.7	3.3
Extremely Wet	3.3	3.3

Table 4: Rainfall intensity in 30-year periods

Intensity of Seasonal Rainfall: Cases of 'SPI>1' were identified as wet conditions and cases of 'SPI<(-1)' were identified as dry conditions. Table 5 shows the percentages of each category of SPI values represented by the decades within the considered whole period of 1961-2020 for the four rainy seasons.

Decade	First Inter-monsoon		Southwest-monsoon		Second Inter-monsoon		Northeast-monsoon	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
1961-1970	10	10	18	14	10	5	10	3.3
1971-1980	10	10	14	14	20	15	10	10
1981-1990	15	20	20	16	20	25	26.7	16.7
1991-2000	5	15	18	10	20	20	20	16.7
2001-2010	25	10	8	10	25	10	13.3	10
2011-2020	20	30	16	18	15	20	13.3	23.3

Table 5: Seasonally abnormal rainfall conditions (%)

According to Table 5, no uniform pattern of wet and dry conditions of rainfall could be discerned. Therefore, the years with the maximum percentage of wet or dry conditions are discussed according to the rainfall seasons. According to that, the wet rainfall conditions of the SWMS and NEMS could be observed in the decade of 1981-1990. For the FIMS and SIMS, the wet conditions of rainfall were maximum in the decade of 2001-2010. In terms of dry conditions of rainfall, the FIMS, SWMS, and NEMS appeared with a similar feature, which could be identified in the decade of 2011-2020. While an opposite feature is seen in the SIMS marked with the decade of 1981-1990, this could be linked with the idea of enhanced rainfall in the SIMS during the El-nino years as revealed by Punyawardena and Cherry (1999), and Ranasinghe (2018).

More adverse effects are caused by extreme rainfall conditions: hence, Table 6 shows the extreme events identified according to the SPI calculation.

Rainfall Season	Extreme Status	Year	Month	Rainfall (mm)
First Inter Monsoon	Wet	1984	March	356.7
		1999	April	708.6
		2008	April	650.8
		2011	April	731.7
	Dry	1992	March	44.8
Southwest Monsoon	Wet	1964	July	641.2
		1966	September	759.3
		1968	June	843
		1969	May	984.1
		1974	July	617
		1974	September	726.9
		1982	June	892.5
		1985	June	746.2
		1987	August	660.4
		1989	July	610.9
		2014	August	618.6
		2017	May	983.6
		2019	August	642.1
	Dry	1987	July	18.8
2nd Inter Monsoon	Wet	1975	November	668.5
		1982	November	638.8
		1993	October	795
		2014	October	813
	Dry	1974	November	65.5
		1983	October	146
		2016	October	156.2
Northeast Monsoon	Wet	1982	December	534.8
		1984	January	274.7
		1984	February	407.1
		1998	December	461.8
		2000	February	513.7
		2001	January	359.4
		2010	December	469.7
		2014	January	293.4
		2014	December	444

Table 6: Extreme rainfall incidents identified according to SPI

Considering a month with marginally dry rainfall in the Ratnapura district, even if there is a shortage of water in that month, the effect caused by it is minimal. However, the impact of excess water caused by even one month of extreme moisture rainfall is relatively high. During such months, landslides are reported in the high-altitudinal zones and flood disasters in the lower altitudinal zones of the study area.

CONCLUSION

In terms of temporal patterns of annual rainfall variability, both 30-year periods showed less values and almost similar values in the Ratnapura district. The FIMS, SWMS and SIMS represented relatively less seasonal rainfall variabilities than the NEMS. It could be confirmed that the rainfall variability has increased in the NEMS in the Ratnapura district. Further, the decade of 2011-2020 could be identified as the decade that showed the highest variability in the SWMS as well as the SIMS.

Regarding the temporal distribution of annual rainfall variability, uniform and moderate concentration of rainfall are more visible. A similar situation has been identified for both monsoon and inter-monsoon seasons and an irregular distribution of rainfall has been identified only in the year 1981/82 during the NEMS. Accordingly, it can be concluded that there were uniform or moderate concentrations of rainfall variabilities in the Ratnapura district within the period 1961-2020.

According to the Standard Precipitation Index, 1982 and 2014 were identified as extremely wet years, and 1973, 1983, and 2016 were observed as severely dry years. It has been confirmed that there were no extremely dry years and there are no continuous wet or dry periods in the study area for the considered period of data. Although no differences in extreme wet conditions could be detected between the two 30-year periods. While the dry conditions decreased in the second 30-year period. Wet rainfall conditions were identified as maximum during the SWMS and the NEMS in the decade of 1981-1990 and during the First and Second Inter-monsoons, in the decade of 2001-2010. Furthermore, maximum dry rainfall conditions were observed in the FIMS, SWMS, and NEMS in the decade of 2011-2020.

Therefore, the study concludes that the comparison between the two 30-year standard periods showed almost similar temporal patterns and distribution of annual and seasonal rainfall and no prolonged wet and dry conditions in the Ratnapura district for the considered periods. However, further analysing rainfall data in the district will be helpful to identify the trends of rainfall and reliability of rainfall during the recent 30-year standard period that is vital for water resource management, agricultural planning, and natural hazard management in the area. The new knowledge derived from this study is that the findings of the recent 30-year climate normal i.e. 1991-2020 could be used as the base line for future predictions of rainfall variability and changes in the Ratnapura district.

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