International Journal of Scientific Research and Engineering Development-– Volume 6 Issue 3, May-June 2023

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RESEARCH ARTICLE OPEN ACCESS

Study on Drought Events in the Dry Zone of Sri Lanka and the Relationship between Meteorological Factors

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Abstract:

Drought is one of the most hazardous meteorological disasters in Sri Lanka. The dry zone of Sri Lanka has been selected as the study area and the period was 1983 to 2020. SPI was chosen as the drought index because SPI is simple, powerful, and can estimate both short-term and long-term drought effects. SPI calculated for 12-month, 6-month, and 1-month timescales and identified an extreme drought that occurred in the 1995 to 1997 period. Although SPI indicated that Yala season has a higher frequency of occurrence of drought than Maha season and more of the dry zone suffers from droughts in Yala season. But overall severity of SPI < -1 has shown that drought severity in the Maha season is higher than Yala season, severities were about -1.66 and -1.4 respectively.

Variation of drought with influencing meteorological factors has shown that increases in precipitation and RH were reducing the frequency of the occurrence of drought while increases in temperature and wind speed induced the frequency of occurrence of drought. Pearson's correlation coefficient indicated that RH was highly correlated with precipitation and temperature, positively and negatively. Although SPI was highly correlated with RH and temperature, positively and negatively respectively.

Keywords **—SPI, Drought, Meteorological variables, Correlation coefficient, Dry zone of Sri Lanka.**

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I. INTRODUCTION

Studies on the impact of Meteorological disasters have become an often concern in recent years all over the world [1], [2]. The primary induced factor of these meteorological disasters is global climate change [3]–[5]. Many published work shows evidence of recent climate changes [6]–[8]. Drought could be named one of the most hazardous meteorological disasters when compared with other meteorological disasters. Drought [9] can be defined as an extended dry period, shortage of water, or many more dry conditions than normal for a considered period [10]. Agriculture [11], [12], ecosystems, soil water content, livestock, and economy [13] can adversely be affected by the phenomena. When a drought may last for a few months or elongated for years respectively.

Although, drought is a worldwide disaster because droughts occur in almost all regions of the world. Recent publications in several regions of the world are reflecting the damage a drought can commence [14]–[17]. Drought directly relates to the wetness of governed region [12], it can be identified by studying the precipitation patterns. Otherwise, drought relates to other meteorological variables [18], [19] such as temperature, wind speed, and vapor amount considering the region. According to the publications, the frequency and the occurrence of droughts have increased in recent years [14], [15].

According to the publications, drought is the most affected meteorological disaster for crop production in Sri Lanka [9], [21]. Recorded data for extreme drought events that occurred in 1908, 1911, and 1938 have shown that almost all the districts in Sri Lanka were affected [20]. There are plenty of publications that are mainly focused on the spatial and temporal distribution of drought [21], [22]. Although carrying out studies on a regional level might be very reasonable because droughts show highly diverse characteristics in different places [23]–[25]. Recent publications have shown there is a lack of studies on drought considering a specific region. Based on that the dry zone of Sri Lanka has been chosen as the study area of this study. Although the dry zone of Sri Lanka is the center of agriculture and paddy cultivation in Sri Lanka [26], [27] and it is widely spread over the region. On the other hand, the dry zone indicates the lowest annual precipitation and relatively higher temperature when compared to the wet and intermediate zones [28], [29]. Because of that reason, the dry zone might be more prone to drought. Therefore it is obvious to study the variation of drought events in the dry zone of Sri Lanka, drought characteristics, and the relationship with meteorological factors, other than the only study on the spatial and temporal variations of drought.

II. STUDY AREA, DATA, AND METHODOLOGY

A. *Study Area*

Sri Lanka is an island located in the Southwest of the Bay of Bengal and to the South of the Indian Subcontinent. According to the Department of Senses and Statistics of Sri Lanka, the area extent of the island is about 65,610km^2 with a population of about 21.8 million [1]. According to the location of Sri Lanka, the average temperature varies from 16 ℃ to 34 ℃ [2].Rainfall can be seen as the precipitation type in Sri Lanka and seasonal monsoon is the primary source of the rainfall. The annual rainfall of Sri Lanka varies largely from less than 1000mm to more than 4500mm [3]. Based on annual precipitation land area of Sri Lanka can be divided into three regions, they are wet zone, intermediate zone, and dry zone [4]. The dry zone of Sri Lanka is from the northern parts of the island to the southern regions along the eastern portion of Sri Lanka. The dry zone has the lowest annual precipitation less than about 1800mm. But when comparing the land extent among these regions, the dry zone belongs to the largest portion of the

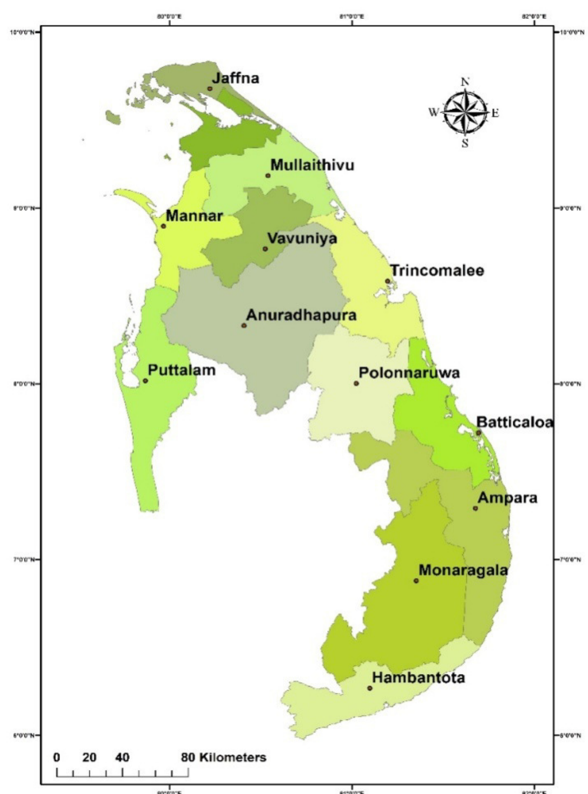

Fig. 1 Study area, the dry zone of Sri Lanka

country. There are two main cropping seasons in the dry zone of Sri Lanka [5] based on rainfall. They are the “Maha” season and the “Yala” season. Maha season usually starts at the end of September and ends at the end of March of the following year. Yala season is from April to September.

B. Data

Daily data of precipitation, mean temperature, wind speed, and relative humidity for 12 administrative districts of the dry zone of Sri Lanka were used in this study. Considering the period is from 1983 to 2020. Each data set is starting on January 1st of 1983 and ends on December 31st, 2020. Data were downloaded from the data access of, https://power.larc.nasa.gov/. This ARD (Analysis Ready Data) is a model developed using remotely sensed data and long-term climate data. Although the data provider is certifying that the data is accurate enough and reliable.

TABLE I
Administrative districts selected for the study

Data Points				
Admin. District	Main City	Longitude (◦)	Latitude (◦)	Elevation (m)
Ampara	Ampara	81.67	7.29	40
Anuradhapura	Anuradhapura	80.40	8.33	81
Batticaloa	Batticaloa	81.69	7.72	9
Hambantota	Hambantota	81.08	6.29	10
Jaffna	Jaffna	80.19	9.70	8
Mannar	Mannar	80.00	8.92	8
Monaragala	Monaragala	81.31	6.79	151
Mullaithivu	Mullaithivu	80.53	9.18	53
Polonnaruwa	Polonnaruwa	81.01	7.99	51
Puttalam	Puttalam	79.84	8.05	16
Trincomalee	Trincomalee	81.21	8.58	8
Vavuniya	Vavuniya	80.50	8.77	91

C. Methodology

1) Calculation of drought

SPI is a powerful and simple tool, but its specialty is that SPI only needs monthly precipitation data to calculate drought events [6]. SPI is developed by a group of American scientists. The SPI is simple to calculate, it is flexible. Also, SPI calculates droughts in multiple time scales, showing both short and long-term drought characteristics and effects. It is called a drought event when the SPI value is continuously less than -1. The drought event is ending when the negative SPI becomes positive again. Duration of drought is defined from the first month in which SPI is less than -1 and until the month that the SPI value becomes positive again. To identify the severity of the drought event, a range of values is introduced. Table 2 is showing different drought severity levels. According to the objectives of the study, SPI was calculated in 3-time scales. They are monthly, 6 monthly, and annual time scales. SPI can be calculated using the gamma probability density function and gamma cumulative distribution functions [7]. In this study, we used a library called CDT (Climate Data Tools) in the R Studio 4.2 software package.

TABLE II
Administrative districts selected for the study

SPI	
Value	Category
"2.0 +"	extremely wet
"1.5" to "1.99"	very wet
"1.0" to "1.49"	moderately wet
"0.99" to "-0.99"	mild drought
"-1.0" to "-1.49"	moderately dry
"-1.5" to "-1.99"	severely dry
"-2" and less	extremely dry

2) Calculation of the relationship between meteorological factors and drought events

The correlation coefficient is calculated to establish the relationship between meteorological factors and drought events. The correlation coefficient is a measurement resulting in how strong the relationship between considering variables is. Pearson's correlation coefficient [8] is used in the study. The result of Pearson's correlation coefficient lies between -1 to 1. A positive correlation can be identified, if the correlation between the 2 variables are increasing and decreasing together. The negative relationship can be identified by opposite variation between 2 variables. The correlation between meteorological factors and drought events is calculated in IBM SPSS Statistics 21 software package. Although Pearson's correlation coefficient (r_{xy})can be calculated by using the following equation,

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where,
x, y - Sample variables
$\bar{x}, \bar{y}$- Mean of x and y
Mean can be calculated by,

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

III. RESULTS AND DISCUSSION

A) Drought Events over The Dry Zone of Sri Lanka

SPI was calculated for three timescales, 1 month, 6 months, and 12 months using monthly precipitation values of the twelve administrative districts in the dry zone. A 12-month timescale of SPI was used to derive drought events in the agricultural year starting in October and ending in September of the following year. SPI for a 6months timescale was the representation of two cropping seasons of Sri Lanka. March and September were selected to represent SPI values for the Mahaseason between October and March of the following year and the Yala season from April to September. A 1month timescale was used to reveal SPI in April and October because these 2 months are initiating Yala and Maha cropping seasons respectively.

The spatial distribution of annual SPI for the dry zone of Sri Lanka varied from -0.007 to 0.0021. Both the highest and the lowest values were indicating near-normal or mild drought conditions over the dry zone of Sri Lanka. According to Fig 2Puttalam district indicated the highest occurrence of drought relative to other districts. Although Vavuniya district was the lowest. Districts like Hambantota, Ampara, Trincomalee, Batticaloa, Mullaithivu, and Mannar showed relatively better conditions. Overall most districts of the dry zone were less affected by the drought.

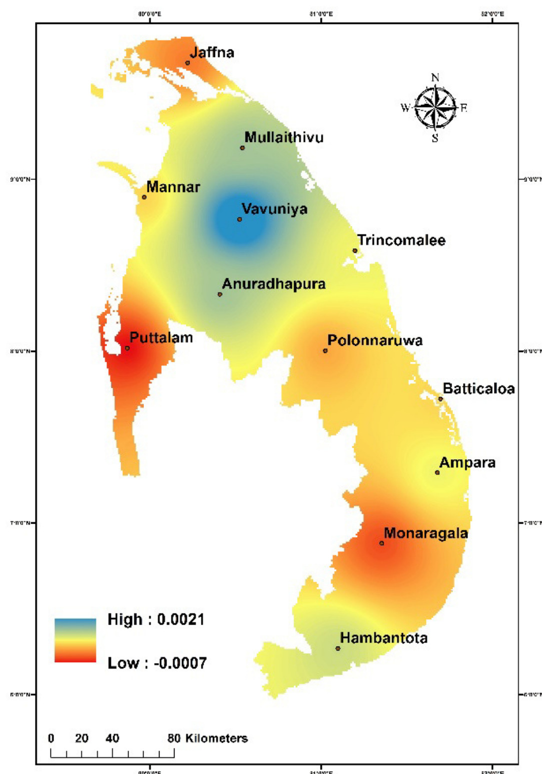

Fig. 2 Spatial distribution of annual SPI for the dry zone of Sri Lanka

Fig 3 shows that the dry zone of Sri Lanka has shown a decreasing trend for the occurrence of drought events. There were much significant drought events that occurred in the years of 1995, 1996, and 1997. According to the figure, 1996 was the highest drought event, SPI-12 was less than -2.6 and can be categorized under extreme drought according to the severity categorizing a range of SPI-12 in Table 2.2. 1995 and 1997 were severe drought years with severity less than -1.7 and -1.8 respectively. Although after 2005 the occurrence of drought is getting less. There was no considerable drought event after 2005. But the occurrence of drought events might differ in different time scales.

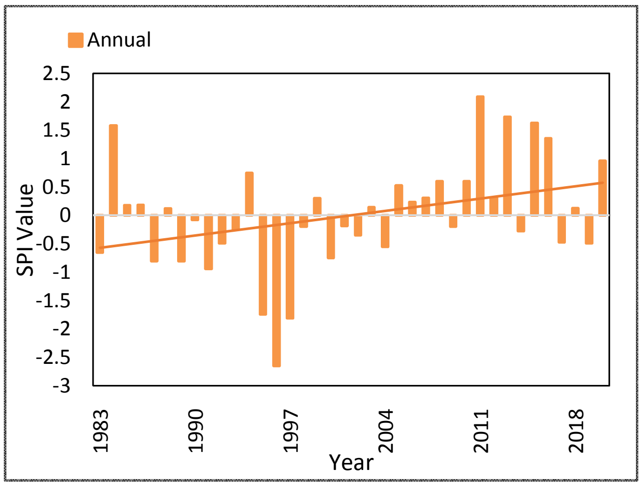

Fig. 3 Temporal variation of SPI-12 in the dry zone of Sri lanka

In SPI-6 the spatial distribution of drought for the Maha and Yala seasons was carried out separately. The results of SPI-6 were similar to annual SPI but much more informative. The spatial distribution of drought in cropping seasons was shown in Fig 4 and Fig 5 respectively. In the Maha cropping season, the Ampara district was highly affected by drought. Although Puttalam, Batticaloa, and Monaragala were also highly vulnerable to drought when compared with other districts. According to the figure districts like Mullaithivu and Vavuniya were much more stable and less prone to drought. SPI-6 distribution in Maha ranged from -0.0078 to 0.0028.

But when considering the Yala season in Fig 5 most districts were affected by the drought, Puttalam, Hambantota, Monaragala, Ampara, Batticaloa, Polonnaruwa, and Anuradhapura. Among them, Batticaloa was highly affected. SPI-6 for the Yala season varied from -0.043 to 0.0005. By comparison of 2 cropping seasons, it was evident that the Yala season was more highly affected by drought than the Maha season.

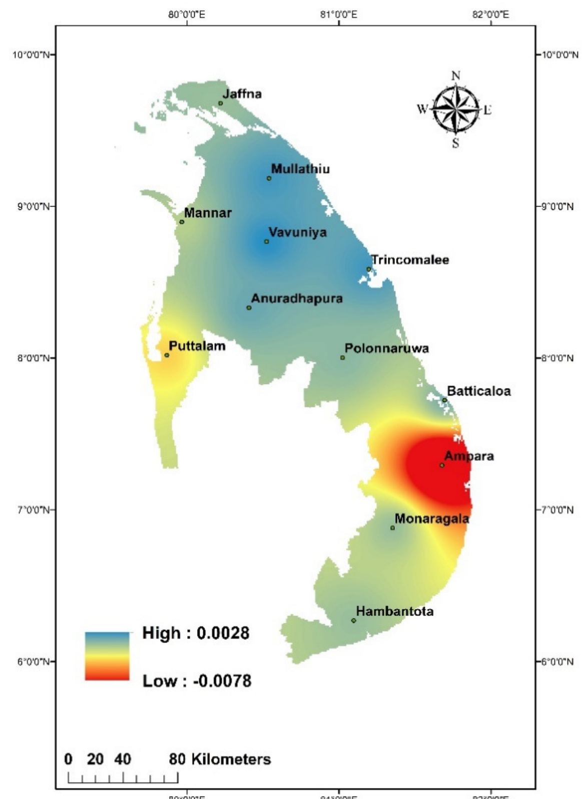

Fig. 4 Spatial distribution of SPI-6 in the Maha season

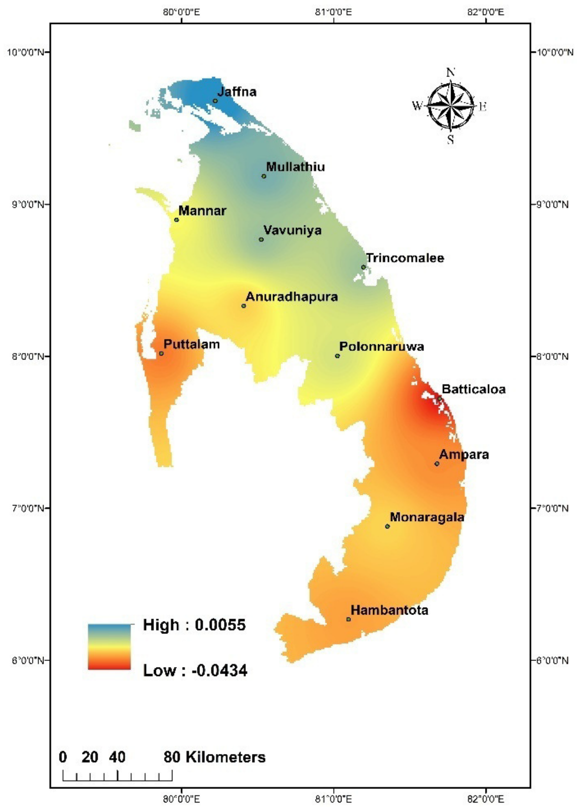

Fig. 5 Spatial distribution of SPI-6 in the Yala season

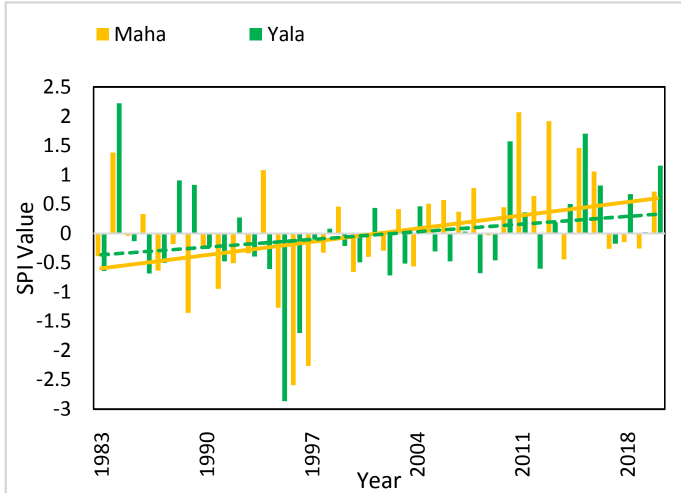

Fig. 6Temporal variation of SPI-6 in Maha andYala seasons

According to the time series in Fig 6, both seasons showed a decreasing trend of drought because SPI-6 tends to be more positive values from 1983 to 2020. Similar to the annual time series, there was a significant drought from 1995 to 1997. The Yala season of 1995 showed the lowest SPI about -2.9. That can be categorized as an extreme drought event. According to the figure, this drought event was initiated in 1994 with a value of about -0.6. This drought was elongated until 1998. Although the 1996 and 1997 Maha seasons with values about -2.6 and -2.3 respectively are extreme drought events.

SPI- 6 for seasonal scale visualized many more intense values than in annual SPI. The SPI-1 is calculated for the first month of each cropping season. Because the wetness in the first month is very important for crop growth and development. April and October were chosen as the initiating months of the Yala and Maha seasons respectively. SPI-1 for October in Fig 7 showed that districts like Anuradhapura, Vavuniya, and Polonnaruwa were highly affected by drought, but the SPI-1 for April in Fig 8 has shown that high drought occurrence has moved to southeastern and southern parts of the dry zone like Ampara, Monaragala, and Hambantota.

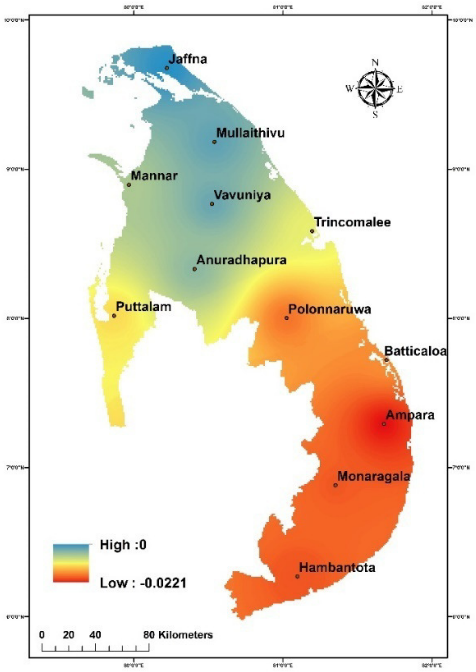

Fig. 7 Spatial distribution of SPI-1 in October

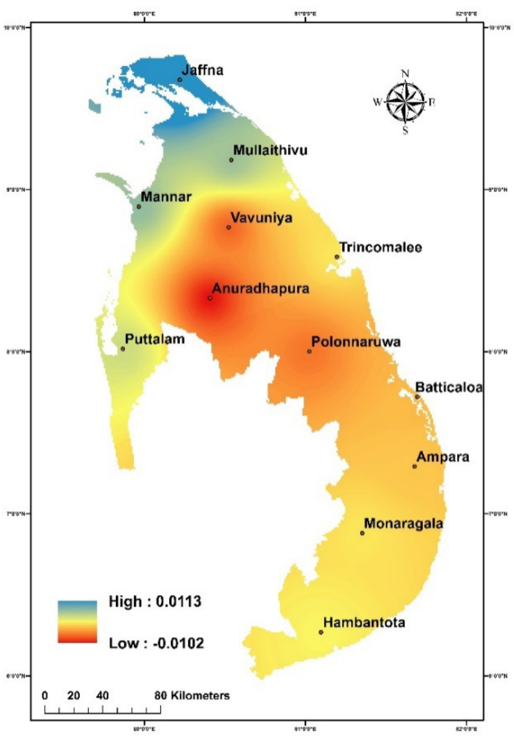

Fig. 8 Spatial distribution of SPI-1 in April

According to Fig 9, the time series of SPI-1 for April and October has shown much more intense values than in both annual and seasonal. 1983, 1988, 1995, 1996, 1998, and 2020 showed moderate and severe drought values for October, and in 1983, 1990, 1995, 1996, 1998, and 2017 were correspond to April. But both time trends owned decreasing trends for the occurrence of drought events.

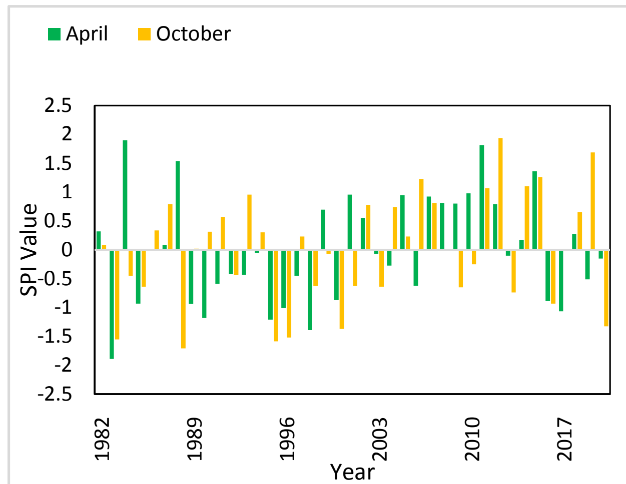

Fig. 9Temporal variation of SPI-1 in April andOctober

B) The Severity of the Drought in Maha and Yala Cropping Seasons

Fig 10 represents the percentage of the area of the dry zone affected by droughts in the study period, SPI less than -1 is considered. According to the figure, 1984, 85, 88, 90, 92, 94, 98, 2000 to 01, 2003 to 07, 2010 to 2011, 2014 to 16, and after 2017 recorded no considerable drought events in both cropping seasons. Although there was a considerable extreme drought event has occurred from 1995 to 1997. In this period Maha season for three consecutive years was affected and the whole area of the dry zone was affected in these consecutive seasons.

Although for the Yala season, the whole area is affected in 1995 and more than 90% in 1996. Even though, no considerable droughts have occurred in the Maha season after 1997 drought events in the Yala season have occurred throughout from 1983 to 2020. The figure is representing the occurrence of drought events in the Yala season is higher than in the Maha season.

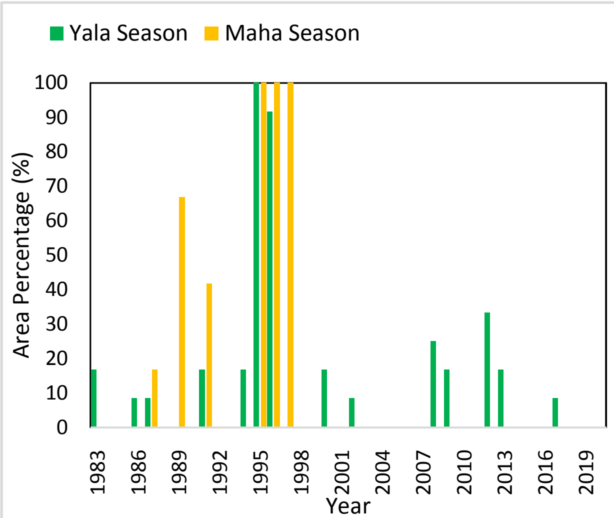

Fig. 10Drought occurrence in Maha and Yala seasons as an area percentage

But when considering the overall severity of droughts that have occurred in both cropping seasons in the dry zone, the figure shows Maha season showed higher severity than the Yala season about -1.7 and -1.4 respectively. So there might be a high severity of droughts occurring in the Maha season.

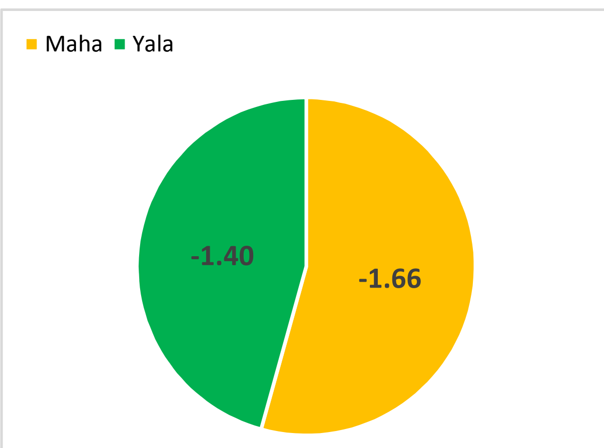

Fig. 11Severity of drought occurred in the Maha and Yala seasons

C) Variation of Drought with Influencing Meteorological Factors

Fig 12.a represents the time series between drought and precipitation. In 1984, 2011, 2013, 2015, and 2016 SPI showed much wetter values more than +1. Although annual precipitation of these years is also higher above 1750 mm, even though in years like 1995, 96 precipitation was very low below 450 mm, the severity of drought in those years is very high. Also, some years like 1994, 2004, 2009, 2016, and 2019 showed unusual behavior. In 1994 and 2016 annual rainfall is relatively low about 970 mm, but SPI was positive. Increasing the value of SPI from 1991 might be the reason for that unusual observation. Although in 2004 annual precipitation is relatively high about 1430 mm but the SPI value was negative. The reason for these opposite observations might be the slope of SPI and the amount of rainfall in the previous year.

Not like the annual precipitation, the mean temperature showed a proportional relationship with the occurrence of drought. According to Fig 12.b temperature tends to increase the occurrence of droughts is also increasing and when the temperature was relatively low, wet conditions tend to occur which can be seen in the drought event in 1995 to 97 and low mean temperature years like 1984, 2011, 13, etc. respectively. Although abnormal observation can be seen in 2016. The temperature was relatively high about 27.7℃ this year but, SPI calculated this year as a wet year. But when comparing with 2016, the year 2015 has shown a relatively less temperature of about 27.1℃.

RH has shown similar variations to annual precipitation. When the RH is higher, the occurrence of drought is decreasing much positive SPI values are observed, and when the RH is relatively lower SPI tends to have negative values according to Fig 12.c. In 1984, 2008, 2010, 11, 13, and 2015 showed relatively higher RH with much wetter conditions, also 1983, 1995 to 97, and 2000 were observed less RH year. In those years drought events have occurred. Although wind speed showed similar variation like mean temperature. Although the variation of mean wind speed is also limited in a low variation like 3.5 m/s to 4.5 m/s. Fig 12.d represents that wind speed is increasing much drier conditions are prone. But wind speed is much slower, and SPI tends to wetter values. However, this variation was not clear as SPI with mean temperature. But 1984, 2010, 11, and 2015 showed positive SPI values with relatively slow wind speeds. Even though from 1995 to 97 much severe negative SPI was observed with higher wind speeds.

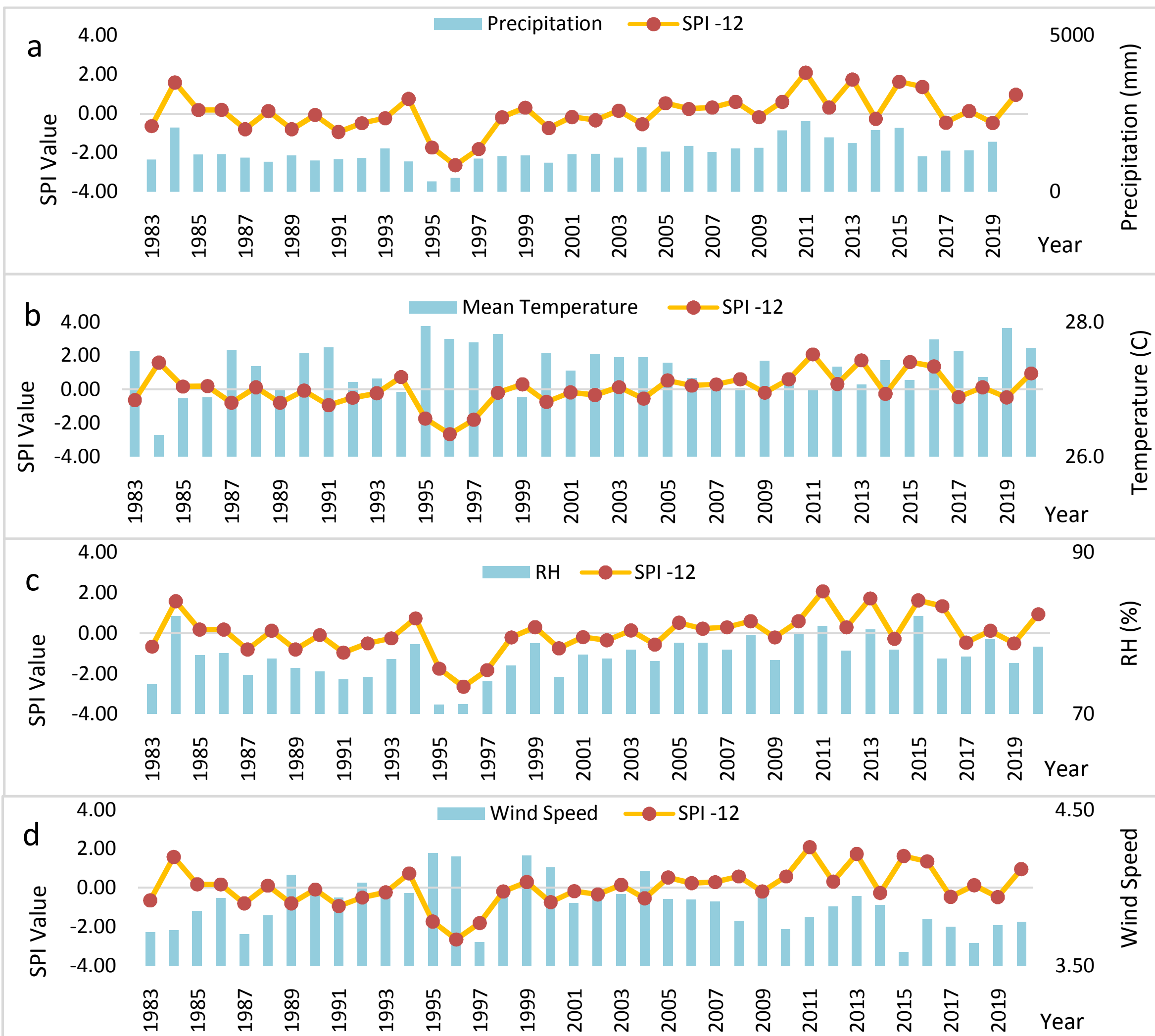

Fig. 12Relationship between drought events and drought influencing meteorological factors, (a) Rainfall (Precipitation), (b) Mean Temperature, (c) Relative Humidity, (d) Mean wind speed.Severity of drought occurred in the Maha and Yala seasons

D) Relationship of Drought with Influencing Meteorological Factors

Variations in Fig 12 only return the pattern of the relationship, but not the value. Therefore, it was important to calculate how strong the relationship is. The correlation coefficient can be used to calculate the correlation of variables that are dependent on each other. For the study, Pearson's correlation is used to calculate the correlation coefficient between drought events and influencing meteorological factors.

According to the values of Table 3.2, annual precipitation and RH have the strongest positive relationship correlation coefficient is about 0.8 between meteorological variables while mean temperature and RH have the strongest negative relationship correlation coefficient was about -0.7. Therefore, temperature and precipitation could be the highest contribution to the moisture in the dry zone of Sri Lanka. When considering SPI-12, mean temperature and RH have the highest contribution. The strongest positive relationship of SPI was with RH, with a correlation coefficient was about 0.9 and the strongest negative was with mean temperature with a correlation coefficient was about -0.6. When considering the dry zone of Sri Lanka in the period of the study, RH has the strongest negative influence on the occurrence of drought while mean temperature has the strongest positive influence. Although mean wind speed and precipitation have a positive and negative relationship for the occurrence of drought.

TABLE III
Pearson's correlation coefficient between SPI and meteorological variables

Pearson's Correlation		SPI	Mean Temp. (℃)	Annual Rainfall (mm)	RH (%)	Wind Speed (m/s)
SPI	Correlation	1	-0.57	0.70	0.89	-0.39
	Sig.		0.00	0.00	0.00	0.02
Mean Temp. (℃)	Correlation	-0.57	1	-0.45	-0.69	0.09
	Sig.	0.00		0.00	0.00	0.58
Annual Rainfall (mm)	Correlation	0.70	-0.45	1	0.80	-0.52
	Sig.	0.00	0.00		0.00	0.00
RH (%)	Correlation	0.89	-0.69	0.80	1	-0.43
	Sig.	0.00	0.00	0.00		0.01
Wind Speed (m/s)	Correlation	-0.39	0.09	-0.52	-0.43	1
	Sig.	0.02	0.58	0.00	0.01	

IV. CONCLUSIONS

The current study is focused on the drought events that occurred in the dry zone of Sri Lanka. The study period was from 1983 to 2020. The primary objective of this study was to identify the relationship of drought with above mentioned influencing meteorological factors. According to the spatial distribution of drought on an annual scale considered from October to September western and southeastern parts of the zone have a relatively higher occurrence of drought, but the distribution has changed SPI-6 from October to March for the Maha season and April to September for the Yala season. The highest occurrence of drought is shown in the eastern part of the study area in the Maha season, but in the Yala season occurrence of drought has expanded dominating western, eastern, and southern parts of the dry zone.

So when compared with the Maha season, drought can be more frequent in the Yala season over a huge area. SPI-1 was used to identify the occurrence of drought in each initiating month of cropping seasons. In the Maha season north-central part has shown the highest occurrence of drier conditions, but in Yala southern and eastern parts have shown this higher occurrence. Similar to SPI-6, the Yala season has a higher vulnerability to drought than the Maha season in SPI-1. Time series of SPI in all timescales have shown a significant extreme drought event from 1995 to 97. When considering SPI-6 and SPI-1, the Yala season has the highest occurrence of drought events. But the average severity of drought in the dry zone is higher in the Maha season and it is about -1.66.

Variation of drought with influencing meteorological factors has shown that precipitation and RH were inversely proportional to the occurrence of drought while temperature and wind speed was proportional to the occurrence of drought in the study period. Although there were some years with low precipitation, the corresponding SPI was negative, similar observations occurred in temperature and SPI variation curve too. The reason for this was the value of precipitation and mean temperature in the previous year and the slope of SPI. According to the correlation coefficient, among meteorological factors, rainfall was the strongest positive correlation, and mean temperature was the strongest negative correlation to RH. When considering the correlation coefficient between SPI and meteorological factors, RH has shown the strongest positive relationship while the mean temperature was the strongest negative relationship to SPI values. Because of that, it is clear to conclude that When the RH is higher, the frequency of the occurrence of drought is decreasing while, when the higher the mean temperature is, the occurrence of drought is increasing in the dry zone of Sri Lanka.

This study recommends further investigations into district-level drought distribution in the dry zone and how environmental and human-induced factors might influence the occurrence of drought events. Although the information in this study may be helpful for, parties responsible for natural disaster policy-making for early warning and mitigation.

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