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ORIGINAL PAPER

A Gaussian model approach to determine the commencement, termination and length of the major growing season over the dry zone of Sri Lanka

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Abstract
The commencement, termination and length of the major (*Maha*) growing season over the dry zone of Sri Lanka were determined using daily rainfall records from 1981 to 2019 of five meteorological stations (Anuradhapura, Polonnaruwa, Hambantota, Puttalam and Batticaloa). Cumulative percentages of daily rainfall were plotted against the time and maximum positive and maximum negative curvatures were derived as the commencement and termination dates of the season. A Gaussian model was fitted on the cumulative distribution curve in order to remove limitations in deriving maximum positive and maximum negative curvatures. The difference between commencement and termination dates was taken as the length of the growing season. Results disclosed that there is a considerable inter-annual variation of commencement and termination dates and the length of the *Maha* season. Mean commencement and termination dates fall in the standard week 44.04 ± 2.61 (end of October) and 5.10 ± 4.20 (1st week of February). The average seasonal length is 13.7 ± 4.24 weeks. The terminating date acts as the key determinant of the seasonal length. Any significant ($p > 0.05$) trend could not be observed for commencement, termination and length of the season for the analyzed period in any of the locations. It can be concluded that cumulative distribution of rainy days can be successfully used to determine commencement and termination dates of the *Maha* season over the dry zone of Sri Lanka where a single peak rainy period is characteristic. However, the method needs modifications, when it applies in the wet zone of the country where bimodal rainfall pattern is prominent.

Keywords Commencement · Termination · Gaussian model · Sri Lanka · *Maha* season

1 Introduction

Sri Lanka is located between 5°55' and 9°55' N, and between 79°41' and 81°53' E in the Indian Ocean and occupying a landmass of 65,610 km^2. The central part of the country consists of highlands rising up to more than 2500 m, called Central Highlands and most of the other parts are relatively flat with scattered rocks. As a tropical country, Sri Lanka is exposed to tropical monsoon systems and their associated winds, which are named as southwest monsoon (SWM) and northeast monsoon (NEM). These two monsoons predominantly govern the rainfall climate of the country, accordingly, two principle monsoon seasons (SWM: from May to September and NEM: from December to February) and two inter-monsoon rainfall seasons (first inter-monsoon; FIM: from March to April and second inter-monsoon; SIM: from October to December) can be recognized (Thambyahpillay 1954; Domroes 1974; Suppiah 1996). Owing to calm atmospheric conditions, dominant rainfall is the convectional type during the inter-monsoon seasons; however, a considerable amount of rainfall is also blessed from the tropical depressions originating in the Bay of Bengal, especially during SIM. Seasonality of monsoon rainfall and topographical diversity creates highly variable rainfall patterns over the island, both spatially and temporally. According to the annual average rainfall amount, three major climatic zones can be described as wet zone (annual rainfall is higher than 2500 mm), Intermediate zone (1750–2500 mm) and dry

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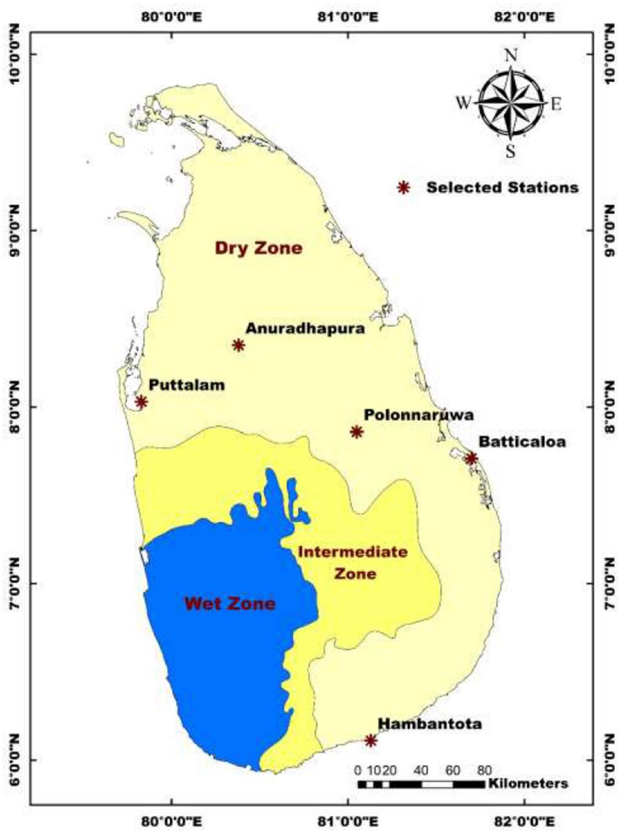

Fig 1 The geographical distribution of selected locations: Anuradhapura, Polonnaruwa, Hambantota, Puttalam and Batticaloa. The dry zone, intermediate zone and wet zones are also marked

zone (rainfall is less than 1750 mm) (Fig. 1). The southwest part of Sri Lanka is comprised of wet zone which is directly exposed to SWM rainfalls and FIM also brings substantial rainfall. The rest of the parts of the island are comprised of the Dry Zone. The dry zone is mainly blessed by NEM and FIM rainfalls where SWM produces less rainfall. The difference of elevation is the main source of temperature variation at different places, whereas regional geographical features are also modifying the temperature climate. In lowland areas, the annual mean temperature of Sri Lanka varies between 26 and 28 °C while it is between 14 and 16 °C in the Central Highlands (Basnayake 2007).

Sri Lanka, being predominantly an agricultural country, the seasonality of rainfall is very much important to the success of agriculture. Timely commencement and subsequent seasonal characteristics such as the amount of seasonal rainfall, the termination of the rainy season and the length of the growing season are key determinants of the type of crop and varieties, the extent of cultivation, the success of each growing stage and finally the yield. Annual variability of rainfall makes it critical, also difficult, in the planning of planting dates under rainfed agriculture (Hussein 1987; Kinsey et al. 1998; Raes et al. 2009; Sonnadara and Jayewardene 2015). Late commencement and early termination of seasonal rainfalls cause to shorten growing seasons and significantly reduce the crop yields. The occurrence of dry spells, when the crops are at their vegetative or reproductive stages, cause to aggravate the yield reduction. Further, marked variability of seasonal rainfall also contributes negatively to the availability of drinking water for livestock and wildlife, natural vegetation, the health of the community, etc. (Ampitiyawatta and Wijeratne 2015). Since the economy of the country is highly dependent on agriculture, early knowledge on seasonal variations of the rainfall climate, such as commencement, termination and length of the rainy season as well as dry and wet spells, is vital to boost agricultural productivity.

The agricultural potential of the dry zone of the country is conspicuous which occupies 60% of the total land with flat and fertile soils; however, seasonal variation of monsoon rainfalls, high evaporation and lack of rainfall restrain gaining the maximum yield (Punyawardena and Kulasiri 1996). Due to seasonal variations of monsoon rainfalls, two distinct growing seasons could be observed as major and minor throughout the dry zone of the country. The major (*Maha*) growing season is from September to March and the minor (*Yala*) is from April to August (Jayawardene et al. 2005). The northeast monsoon is prevailing during the *Maha* season, bringing a major portion of the annual rainfall of the dry zone which is adequate only for the *Maha* season rainfed cultivation (Jayawardene et al. 2005). The fluctuations of commencement and termination dates cause the seasonal length to shorten which further hinders the growing activities. Hence, the actual commencement, termination and the length of the growing season are important to obtain satisfactory results under rainfed agriculture.

In the past, several methods have been used to detect the commencement, termination and length of the growing seasons of monsoon rainfalls in tropical and subtropical climates (Ilesanmi 1972a, b; Benoit 1977; Stern et al. 1981; Olaniran 1983; Holland 1986; Adejuwon et al. 1990; Omotosho 1990, 2002; Sivakumar 1990; Tadross et al. 2005; Adejuwon and Odekunle 2006; Marteau et al. 2011; Guenang and Mkankam Kamga 2012; Sonnadara and Jayewardene 2015). All of these methods have been classified into five main categories by Odekunle (2006). Accordingly, the cumulative mean rainfall model was one of the most widely used methods for determining the starting and ending days of a rainy season (Odekunle 2006). Sivakumar (1990) has found a strong relationship between the onset date and the length of the growing season in the southern Sahelian and Sudanian climatic zones of West Africa. Stewart (1988) has analyzed rainfall records of 18 countries in North America, Middle East, Africa and Asia and found a strong correlation between the date of onset and duration of the growing season. Based on the percentage cumulative mean rainfall model, Odekunle (2006) has studied on the commencement (onset) and termination (retreat) dates of the rainy season in Nigeria by using both the number of rainy days and the amount of daily rainfall and has concluded that both rainy days and rainfall amount are equally effective in the determination of the mean rainfall commencement and termination dates. However, Odekunle (2006) further stated that more realistic commencement and termination dates for individual years could be generated efficiently by using the number of rainy days. Recently a number of authors (Laux et al. 2008; Hachigonta et al. 2008; Ramesh Kumar et al. 2009; Mupangwa et al. 2011; Guenang and Mkankam Kamga 2012; Vellinga et al. 2013) have been successfully identified the commencement, termination and duration of the rainy/growing season by adopting various methods classified by Odekunle (2006).

Though many agronomic experiments have been conducted for the advancement of agriculture in the dry zone, less attention was paid to the detection of climatic potential in the entire region. Punyawardena (2002) has studied the time of onset, withdrawal and the duration of the season in the north-central dry zone and Sonnadara (2015) has studied the same for the northeastern dry zone. However, no detailed study could be found to cover the entire dry zone region. Therefore, the objective of the present study is to determine the commencement, termination and length of the major growing season (*Maha*) over the dry zone of Sri Lanka by Gaussian model approach using 39 years (1981–2019) of daily rainfall data of 5 meteorological stations. It is also expected to examine inter-annual variations of the above criteria and to find whether there is any trend of commencement and termination dates.

2 Data and methodology

2.1 Data

Manually observed daily rainfall data from 1981 to 2019 (39 years) of five meteorological stations (Anuradhapura, Polonnaruwa, Hambantota, Puttalam and Batticaloa) which cover the whole dry zone were collected from the Department of Meteorology, Sri Lanka. The quality and homogeneity of all data series have been checked by the Department of Meteorology. Selected five stations are well distributed over the dry zone and two locations (Anuradhapura and Polonnaruwa) are located mid of the country (Fig. 1) which are in major agricultural regions. Both station sites are directly affected from the northeast monsoon. Hambantota and Puttalam are located southeast and northwest coastal belts, respectively. Due to the specific geographical location and geomorphological features of those regions, both stations are not directly exposed to northeast monsoon as well as southwest monsoon rainfalls. Therefore, the annual average rainfall of those stations is comparatively less than other regions of the dry zone so that long dry spells could be observed. However, agricultural importance is conspicuous. In 2019/2020, these two districts alone contributed 8.7% of the total extent of paddy cultivation in the country (Central Bank of Sri Lanka 2020). Batticaloa is located toward to eastern coastal belt and is exposed directly to the northeast monsoon. Since northeast monsoon is the dominant rainfall season for the dry zone, *Maha* is the major growing season throughout the entire dry zone. Table 1 shows locations, mean annual rainfall and estimated percentages of missing data of these stations. There were no missing data for Anuradhapura and Polonnaruwa stations for the study period. Missing data of other stations were replaced by the long-term mean daily rainfall values which were estimated for a particular day of the year. Fig. 1 shows the geographical locations of these stations and respective areas of the wet and dry zone of the country. The monthly rainfall distribution of 5 locations is shown in Supplementary Fig. S1.

2.2 Methodology

This study used cumulative distributions of rainy days to detect the commencement and termination of northeast monsoons (*Maha* rainfalls). As shown by Odekunle (2006), both rainy days and rainfall amounts could be used to generate cumulative distributions. However, the use of the count of rainy days is more efficient than the rainfall amount for individual years since rainfall amounts produce unrealistic dates of onset and retreat for isolated rainfalls, which is also more common in the dry zone of Sri Lanka.

Initially, a rainy day was defined by considering a threshold value of minimum rainfall. The least available rainfall measurement was 0.1 mm; however, this amount of rainfall could evaporate easily under the dry zone conditions (Sonnadara and Jayewardene 2015). Hence, a higher threshold value of 0.85 mm/day has been used by Wimalasiri et al. (2017) to define a rainy day relevant to the dry zone of Sri Lanka. Therefore, 0.85 mm/day was used as the threshold value in this study also, where lower is a dry day and higher is a wet day.

The rainy season, corresponding to the northeast monsoon (*Maha* season), falls between 2 years, which spans from October to January. Hence, the calendar was shifted by 6 months, July 1st as the starting day of the hydrological year, to capture the season in the middle of a 365-day year. This enables easy detection of the commencement and the termination of the rainy season. After the initial preparation of the data set, the number of rainy days for 5-day intervals was calculated and followed by the computation of the cumulative percentages for those for the same time intervals. Thereafter, the statistical fluctuation was reduced by applying a five-point moving average filter on cumulative percentages. Then, daily intervals were generated using a cubic spline interpolation followed by a ten-point moving average window for further reduction of fluctuations. Since the analysis is dealing with a data set of natural phenomena, the current study proposes fitting a Gaussian Model to generalize rainfall events and detect the commencement and termination dates of the rainy season, as a novel step. The commencement and termination dates of the *Maha* season were calculated using the fitted Gaussian model on ten-point moving average window as follows,

$$Y' = a \times e^{-\left(\frac{x-b}{c}\right)^2}$$

where Y' = ten-point moving average data, x = day of the year and *a, b, c* are constants.

Gaussian model fitness was done using MATLAB, 2017 statistical software and *a*, *b* and *c* constants were calculated for 39 years separately. Figure 2 shows the fitted Gaussian model for the Anuradhapura station using the average values for the 1981 to 2019 period. The day of the year which corresponds to the maximum of the first derivative gives the commencement whereas the minimum of the first derivative gives the termination of the rainy season (Fig. 3). The period between commencement and termination days was considered as the length of the growing season. After estimating commencement and termination dates for 39 years separately, mean commencement, termination and the mean length of the season were computed. Further, probability of occurrence in commencement and termination of Maha season in a specific week was calculated in a particular year. Trends of the commencement, termination and length of the season were calculated using Mann–Kendall nonparametric trend analysis.

Table 1 Locations, mean annual rainfall and percentages of missing data of selected stations

Station	Latitude (N°)	Longitude (E°)	Mean annual rainfall (mm)	Missing data (%)
Anuradhapura	8.35	80.38	1674	0.00
Polonnaruwa	7.86	81.05	1584	0.00
Hambantota	6.11	81.13	1021	3.15
Puttalam	8.03	79.83	1191	0.40
Batticaloa	7.71	81.69	1736	0.85

3 Results and discussion

3.1 Commencement and termination of *Maha* season

Table 2 shows mean dates of commencement, termination and length of the *Maha* season together with the number of rainy days, amount of rainfall and percentage of rainfall during the *Maha* season for analyzed 39 years for the selected locations. Accordingly, Anuradhapura and Polonnaruwa have similar commencement and termination dates for *Maha* season. The estimated average commencement dates for both locations occur around the last week in October (October 29), while termination dates fall around the end of the first week in February (February 8). *Maha* rainfall season for Hambantota and Puttalam regions commence 1 week earlier than previous (approximately October 23), while the termination is nearly 1 month earlier (approximately January 11). Hence, the length of the season (about 80 days) is shortened by 1 month. The average length of the *Maha* season for Anuradhapura and Polonnaruwa regions expands up to 100 days. In compassion to Anuradhapura and Polonnaruwa, the commencement of *Maha* season for Batticaloa region is delayed about 1 week (November 5), while termination happens similarly. The length of the season (93 days) is shortened by 10 days. When considering the estimated commencement and termination dates of *Maha* season for five locations, Anuradhapura, Polonnaruwa and Batticaloa locations show similar results, while Hambantota and Puttalam behave similarly. This is expected because Anuradhapura, Polonnaruwa and Batticaloa stations are located in the North Central and Eastern provinces of the country so that directly expose to the northeast monsoon. It is evident that the rainfall contribution from the northeast monsoon is about 60% (Table 2) for these three locations. Due to the marginal position of Hambantota and Puttalam areas, the contribution from northeast monsoon is lower than at the other three stations (about 40% of total rainfall), hence both locations have the shortest seasonal length and minimum rainy days during the *Maha* season. Anuradhapura has the highest number of rainy days during the *Maha* season, nearly 50% of days of *Maha* season receives rainfalls. Though the seasonal length of Batticaloa is shorter by 10 days, this location also has nearly 50% wet days.

In earlier studies, Punyawardena (2002) has identified the commencement (onset) and withdrawal dates of *Maha* season for Maha-Illuppallama location which is very close to the Anuradhapura by using simulated weekly rainfall data for 1000 years. The method adopted to define the commencement and termination dates was based on a threshold value of 30 mm rainfall per week in three consecutive weeks after a previously defined week (standard week). 35th and

50th standard weeks were considered as previously defined weeks for commencement and termination, respectively. Accordingly, the first occurrence of this criterion with equal or higher than 30 mm rainfall was considered as the commencement of the season and the first occurrence of a long dry spell with less than 30 mm rainfall was considered as the termination of the rainy season. The resulted commencement was the 42nd standard week which is mid-October and the 4th and 5th standard weeks were termination which is extending up to late January. In the present study, estimated commencement and termination weeks for Anuradhapura were 44th and 7th weeks, respectively (Table 3) which are 2 weeks later than the previous results by Punyawardena (2002). The slight difference in the results of the previous study may be due to the type of data used (simulated weekly data) where the present study used observed daily data. However, the length of the season found in both studies are exactly the same which is 14 weeks. Sonnadara (2015) has done another study using 40 years (from 1961 to 2000) observed daily rainfall data for identifying commencement,

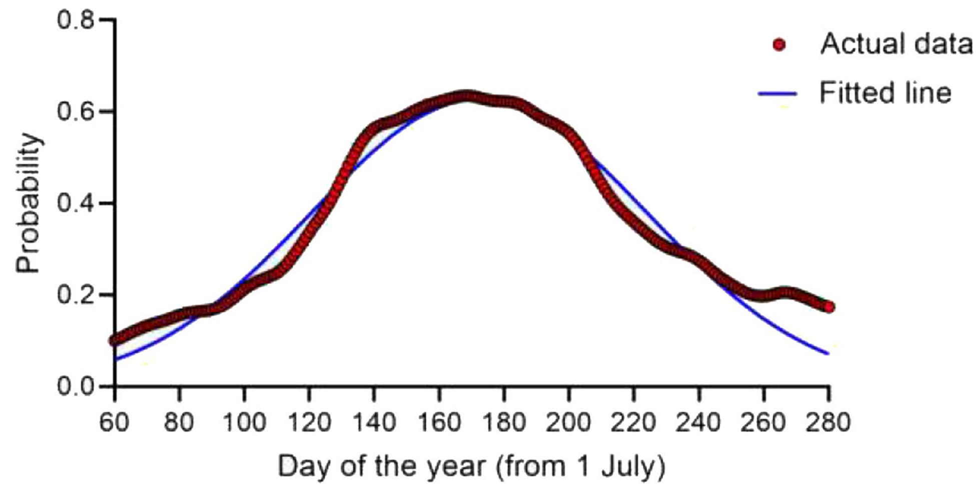

Fig 2 Fitted Gaussian model for the Anuradhapura station from 1981 to 2019 **a** = 0.6275, **b** = 172.3, **c** = 72.92 (coefficients with 95% confidence bounds), goodness of fit: SSE = 0.2274. R^2 = 0.9629, RMSE = 0.03389

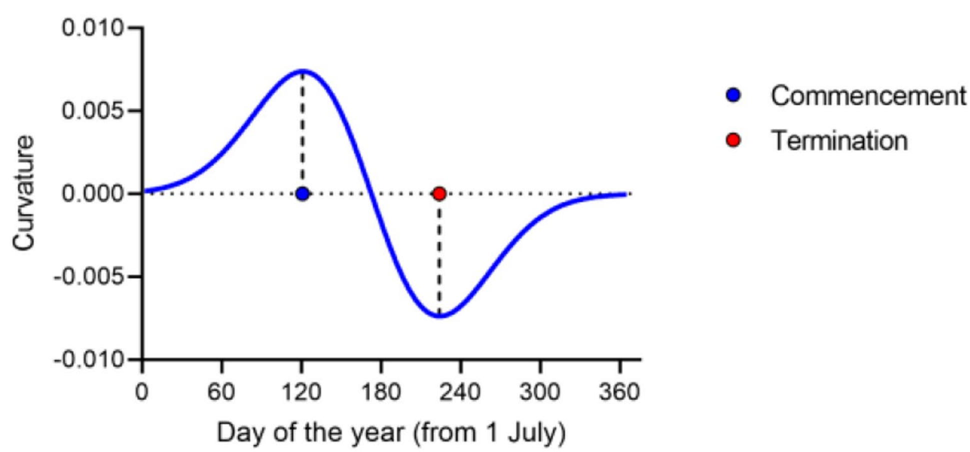

Fig. 3 Maximum and minimum first derivatives of the fitted Gaussian model (commencement and termination)

Table 2 Dates of mean commencement and termination, length, number of rainy days, amount of rain and percentage of rain of *Maha* season

Station	Date of commencement (DOY)*	Date of termination	Length in days	No. of Rainy Days	Rainfall (mm)	% of Rain
Anuradhapura	29-Oct (302)	8-Feb (39)	102	47	1069	60.7
Polonnaruwa	29-Oct (302)	9-Feb (40)	103	39	1031	59.5
Hambantota	24-Oct (297)	12-Jan (12)	80	28	438	40.4
Puttalam	22-Oct (295)	10-Jan (10)	80	34	526	42.3
Batticaloa	4-Nov (308)	5-Feb (36)	93	43	1142	59.1

* Date of the year

termination and length of the growing season in the north-eastern coastal region of Sri Lanka. Maximum positive and maximum negative curvature of the cumulative distribution function of rainy days were identified as commencement and termination days. The findings of Sonnadara (2015) are not tally with both the present study and Punyawardena (2002). The commencement date of the rainy season obtained by Sonnadara (2015) was approximately 26 September (38th week) which was 1 month earlier than the present study while the termination date (approximately 5th January) was also earlier than nearly 1 month. Sonnadara (2015) has used a combination of data of all available years for deriving commencement and termination dates while the present study analyzed individual years and finally computes the average dates. In this paper, Gaussian model approach is used to derive the maximum positive (commencement) and maximum negative (termination) roots of the curve. The approach was used by scientists (Wang et al. 2015; Watanabe et al. 2020) to minimize the noise of data sets, especially in the rainfall data which are highly variable with the time, while providing the best fit curve for a given data set. Hence, the proposed Gaussian model approach is a more statistically acceptable method to derive near realistic roots for a data set of natural phenomenon. However, the length of the season seems to be similar in all three analyses.

Table 3 shows the mean and standard deviation of commencement, termination and length of the *Maha* season for five locations (in a weekly basis). Accordingly, the commencement and termination week and length of the *Maha* season of Anuradhapura and Polonnaruwa regions are the same. This is in broad agreement with the geographical location of both stations as discussed earlier. It can be expected northeast monsoon rainfalls for these two locations from 44th standard week and it may continue up to next year 7th week. Extended seasonal length up to 4 months (15 weeks) is a favorable factor for the main agricultural crop of the country which is paddy. Results of Batticaloa are also on par with the Anuradhapura and Polonnaruwa results. One week later commencement and 1 week early termination cause to shorten the seasonal length to 13 weeks. This scenario may beneficial in selecting crop varieties, especially rice, for the *Maha* agricultural season. Hambantota and Puttalam have earlier commencement (43rd week) and earlier termination (next year 3rd week) in comparison with the other locations and the length of the season is also the shortest (11 weeks). Short seasonal length, lowest rainfall and least number of rainy days can be recognized as major limitations for the agriculture of these two regions.

Overall, the average commencement of *Maha* season for the dry zone falls in the standard week 44.04 ± 2.61 and terminates in the standard week 5.10 ± 4.20. The length of the *Maha* season, which is the main crop growing season of the dry zone is 13.7 ± 4.24 weeks. The observed deviations (outliers) of commencement and termination dates from the average (average ± 2SD) for the entire analysis period are 5.12% and 3.59%, respectively, being the accuracy of the method adopted to derive commencement and termination dates are about 95%. Large deviations such as false commencement and termination may be attributed due to sudden weather changes of those particular years.

Tables 4 and 5 show the probability of a week being the commencement and termination, respectively. Results of the probability analysis for the commencement week are slightly different from the average commencement week for the analysis period. The highest probability of occurrence of the commencement of Anuradhapura, Polonnaruwa and Batticaloa locations falls in the 46th week. However, the cumulative probability of 44th, 45th and 46th weeks accounts over 60% for these three locations, making a higher chance to occur the commencement of *Maha* season toward to end of October to the first couple of weeks in November. Since the study period is limited only to 39 years, results are not normally distributing and some unrealistic figures are appearing. Therefore, a long period should be considered in probability analysis. In Hambantota, the commencement of *Maha* season falls into 42nd to 43rd weeks being a probability of 35% whereas in Puttalam having a chance of 59% for commencement in 43rd and 44th weeks. It is obvious that the commencement of *Maha* season for the entire dry zone is not unique and it is slightly varying location-wise.

In contrast to probability values of commencement dates, results for termination dates are more similar to the period average. The termination of the *Maha* season in Anuradhapura and Polonnaruwa occurs during 7th and 8th standard

Table 3 Mean and standard deviation of the commencement, termination and length of the *Maha* season (in a weekly basis)

Station	Commencement		Termination		Length	
	Week	Standard deviation	Week	Standard deviation	Week	Standard deviation
Anuradhapura	44	2.67	7	3.60	15	4.10
Polonnaruwa	44	2.82	7	4.34	15	5.45
Hambantota	43	3.02	3	3.60	11	4.41
Puttalam	43	1.75	3	4.14	11	3.37
Batticaloa	45	2.27	6	3.25	13	3.93

weeks having probabilities of 23% and 20%, respectively. There is about 69% probability to occur termination in Batticaloa during the 5th to 7th weeks. It is likely to occur termination in Hambantota and Puttalam in the 3rd week or before having the chance of about 67%.

3.2 Inter-annual variation of commencement and termination dates and length of the *Maha* season

Figure 4(a)–(e) shows the variation of commencement and termination dates from 1981 to 2019 for the analyzed five stations. Accordingly, high inter-annual variation can be seen in the commencement and termination dates of all analyzed locations. The variation of commencement of the *Maha* season in Anuradhapura and Polonnaruwa is very similar where the standard deviations (SD) are 18.6 and 19.3 days, respectively. It is further confirmed by the coefficient of variance (CV) which are 15.4% and 15.9% for Anuradhapura and Polonnaruwa locations, respectively. Though Batticaloa is also showing a similar variation pattern, the resulted variation is less than in previous locations (SD = 14.9 days and CV = 11.7%). A conspicuous commencement time cannot be seen from the results of Hambantota where the inter-annual variation is very high with the standard deviation of 20.5 days (CV = 17.6%). However, Puttalam shows a clear commencement time (around 22nd October) with a minimum standard deviation of 12 days (CV = 10.5%), though all the seasonal characteristics (commencement, termination, length, rainfall and number of rainy days) are resembled to Hambantota, as discussed earlier. In comparison with the commencement dates, termination dates of the *Maha* season of all locations are highly variable, being the key determinant of the seasonal length. The standard deviation of termination dates varies between 22 and 29 days where Puttalam has the lowest SD and the CV of 14.3%. Therefore, commencement, termination and the length of the *Maha* season in Puttalam are more stable compared to other localities.

Figure 5(a)–(e) shows the variation of the length of *Maha* rainy season of five studied locations for the period from 1981 to 2019. Results show that inter-annual variation of the length of *Maha* season of five locations is highly variable. The standard deviation (SD) and the coefficient of variance (CV) of the seasonal length vary from 26 to 38 days and from 27 to 39%, respectively. Although the mean length of the *Maha* season of Anuradhapura and Polonnaruwa (102 days) are similar, there is a higher variability of the inter-annual seasonal length in Polonnaruwa having a 36.7% coefficient of variance while the CV of Anuradhapura is 27.9%. This scenario is further verified by the standard

Table 4 Probability of a week being the commencement of *Maha* season

	Probability of commencement				
Commencement Week number	Anuradhapura	Polonnaruwa	Hambantota	Puttalam	Batticaloa
40 or before	0.051	0.061	0.088	0.054	0.059
41	0.103	0.030	0.088	0.108	0.029
42	0.128	0.061	0.176	0.108	0.059
43	0.000	0.091	0.176	0.216	0.088
44	0.179	0.030	0.088	0.378	0.029
45	0.154	0.242	0.118	0.081	0.235
46	0.205	0.333	0.147	0.081	0.324
47 or after	0.179	0.152	0.118	0.000	0.176

Table 5 Probability of a week being the termination of *Maha* season

	Probability of termination				
Termination Week number (Next year)	Anuradhapura	Polonnaruwa	Hambantota	Puttalam	Batticaloa
3 or before	0.128	0.205	0.677	0.694	0.241
4	0.179	0.128	0.097	0.111	0.069
5	0.077	0.103	0.032	0.028	0.207
6	0.077	0.077	0.065	0.083	0.241
7	0.205	0.103	0.097	0.028	0.241
8	0.026	0.103	0.000	0.000	0.000
9	0.103	0.026	0.032	0.000	0.000
10 or after	0.205	0.256	0.000	0.056	0.000

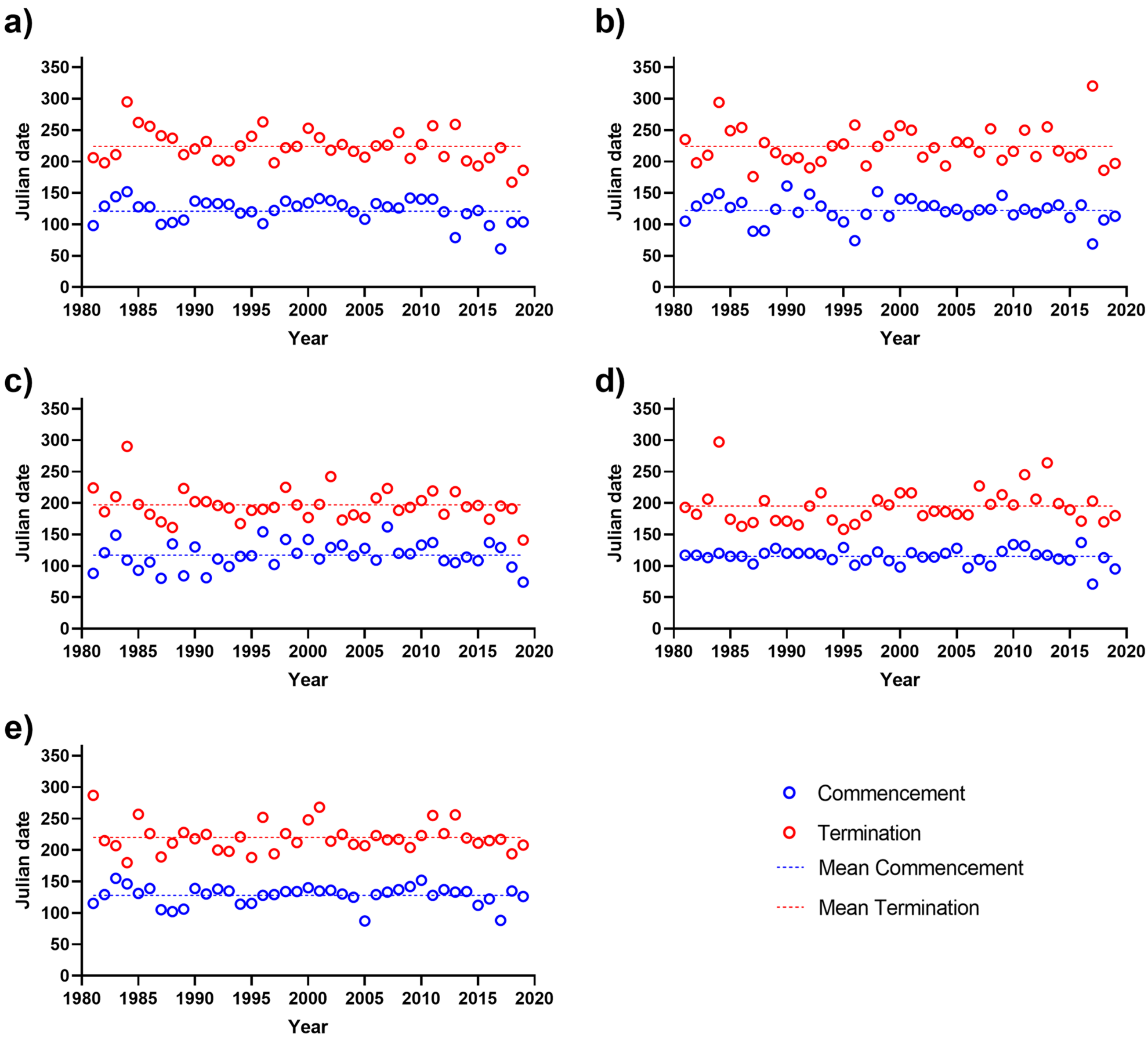

Fig. 4 The variation of commencement and termination dates of (**a**) Anuradhapura, (**b**) Polonnaruwa, (**c**) Hambantota, (**d**) Puttalam and (**e**) Batticaloa during 1981-2019 period. The mean values of the commencement and termination dates were marked in dashed lines

deviations which are 28.6 and 37.6 of Anuradhapura and Polonnaruwa, respectively. As discussed earlier, Puttalam has the least seasonal length variation (SD = 23.3 and CV = 27.8%) while Hambantota has the highest (SD = 30.6 and CV = 38.6%). All studied locations are highly important for agriculture, especially for paddy cultivation (Central Bank of Sri Lanka 2020). The seasonal changes such as late commencement, early termination and shorten the growing season are highly influencing crop failures and yield reduction. Therefore, these regional results are interesting in planning agricultural activities in advance for minimizing crop failures.

Generally, farmers use the short-term (month or week) weather forecasts in agricultural decisions making at their level. Therefore, the relationship between the commencement and the length of the season was evaluated using week, instead of the days. A strong negative correlation ($p < 0.0001$) was observed between the commencement week and the length of the season (in weeks) (Fig. 6). The following equation shows the general relationship between commencement and the length of the season for the locations studied.

$$LS = 47.09 - 0.7725 \times OS$$

where LS is the growing seasonal length (in weeks) and OS is the commencement week of the season. According to Fig. 6, a shorter length of the season can be expected with the delayed commencement of the season and vice versa. This finding agrees with the previous studies conducted by Sonnadara (2015) and Punyawardena, 2002) on which who obtained a similar relationship for dry zone Sri Lanka.

3.3 Trend of commencement and termination dates

According to the nonparametric Mann–Kendall trend analysis, commencement, termination and length of the season did not show a significant ($p > 0.05$) trend during the 1981–2019 period in any of the locations studied. The trend (Kendal's tau) of commencement, termination and length of the season is shown in Table 6. Nisansala et al. (2020), who analyzed rainfall trends in Sri Lanka during 1987–2017, found that generally, there was no significant trend in rainfall amount in dry zone Sri Lanka. Further, authors reported that rainfall amount in Anuradhapura, Batticaloa, Hambantota and Puttalam did not show a significant ($p > 0.05$) trend during northeast monsoon, which was covered in this study. In parallel to the rainfall amounts, the commencement, termination and length of the season did not show a clear trend.

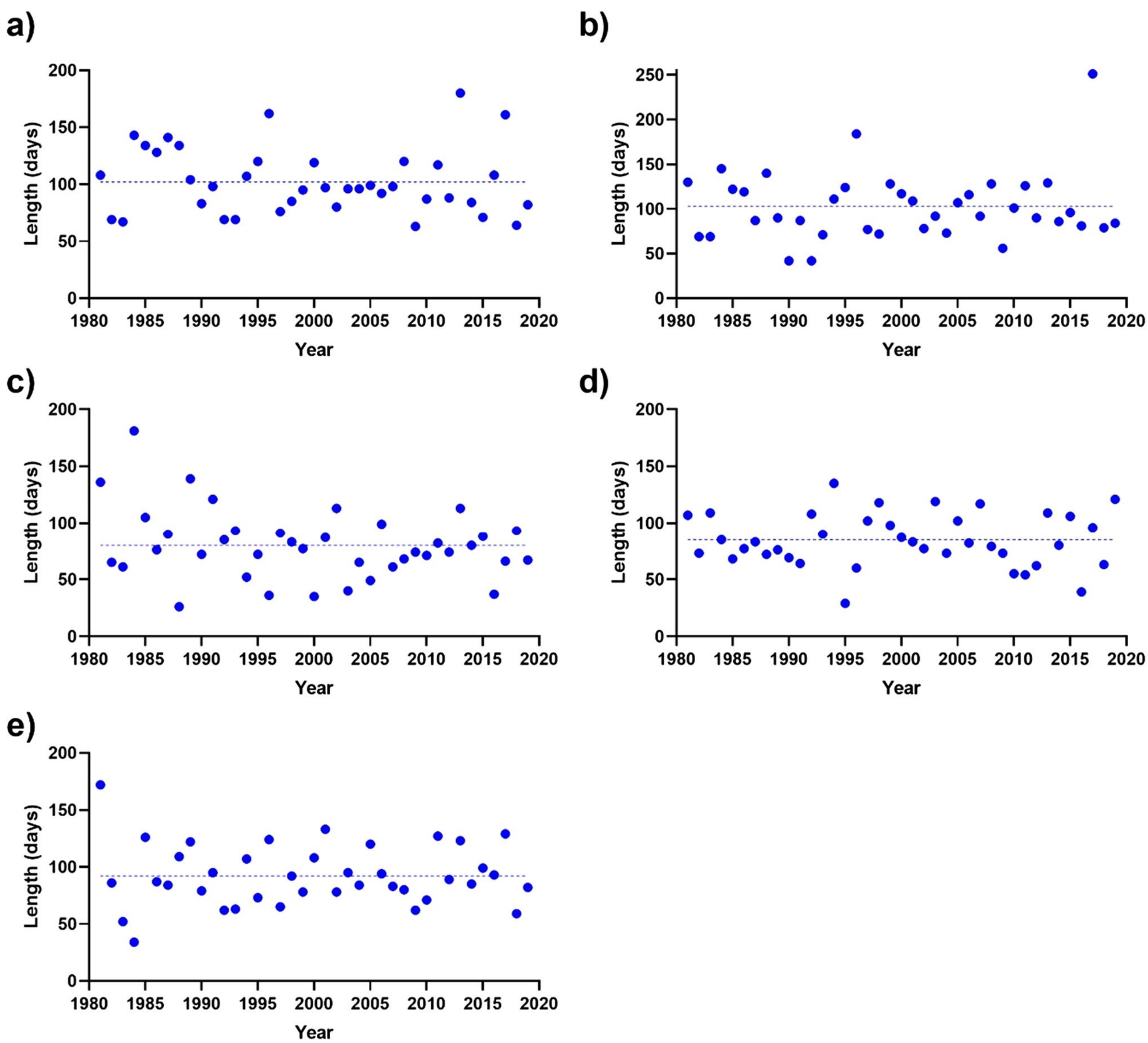

Fig. 5 The variation of the length of the rainy season of (**a**) Anuradhapura, (**b**) Polonnaruwa, (**c**) Hambantota, (**d**) Puttalam and (**e**) Batticaloa during 1981-2019 period

4 Conclusions

The commencement, termination and length of the major (*Maha*) growing season of the dry zone of Sri Lanka were examined based on the number of rainy days from 1981 to 2019 from five weather stations: Anuradhapura, Polonnaruwa, Hambantota, Puttalam and Batticaloa. As a novel step, this study proposes to fit a Gaussian model on the cumulative distribution curve of rainy days to remove limitations in finding maximum positive and maximum negative curvatures as commencement and termination dates. The method works well when a single rainy season is available with one peak.

Results revealed that the mean commencement of the main (*Maha*) growing season of the dry zone of Sri Lanka occurs during the 44th standard week which towards to end of October and the mean termination of the season occurs on the 5th standard week (1st week of February). The average length of the growing season is about 14 weeks for the entire dry zone whereas it is shorter by nearly 1 month in Hambantota and Puttalam areas. Except for Hambantota and Puttalam areas, the locations which are not directly exposed to the northeast monsoon, most of the other regions of the dry zone receive more than 1000 mm rainfall during the *Maha* growing season which is about 60% of the annual rainfall. Approximately 38 days of the *Maha* season are rainy days for the entire dry zone which positively affects rainfed agriculture in the zone.

There is a high inter-annual variation of commencement and termination dates throughout the dry zone. In contrast with the commencement dates, termination dates are highly variable, being the key determinant of the length of the season. However, the Puttalam area which is covering the northwestern parts of the country has more stable commencement and termination dates for the *Maha* season. The inter-annual variation of the seasonal length is also fluctuating dramatically corresponding to the location, creating a major limitation for the agricultural activities of the zone. No significant ($p > 0.05$) trend was found for commencement, termination and length of the season in the regions during the study period.

In certain years, unexpected heavy rainfalls occur at the end of the season due to a combination of northeast monsoon and tropical depressions which create difficulties in identifying a clear peak of the season. That was affected to the model fitness process and deriving perfect commencement and termination dates for the season so that further modifications are required to smooth the process. Further, the method could be tested in the wet zone of the country where bimodal rainfall pattern is prominent with suitable modifications. Based on the findings of this study, it can be concluded that the agricultural activities of the major (Maha) growing season of the dry zone should commence from the end of October and need to be completed toward the early February of the next year. It is recommended to cultivate three and half months of long-duration crop varieties (paddy) during the Maha season.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00704-022-03964-2.

Table 6 Trend (Kendal's tau) of commencement and termination dates and length of the season during the 1981–2019 period

Location	Commencement	Termination	Length
Anuradhapura	-0.146	-0.190	-0.115
Polonnaruwa	-0.131	-0.023	-0.001
Hambantota	0.073	-0.099	-0.112
Puttalam	-0.082	0.143	0.175
Batticaloa	-0.035	-0.012	0.023

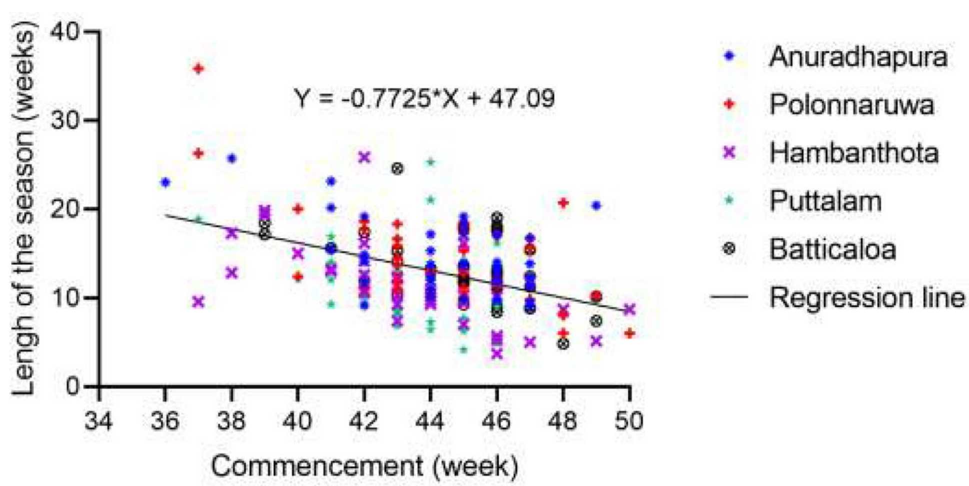

Fig. 6 The relationship between commencement week and the length of the season

Author's contribution This study was planned and designed by A.D. Ampitiyawatta and Eranga M. Wiamasiri. Calculations and data analysis were done by A.D. Ampitiyawatta, E.P.R.H.H.W. Nilmalgoda and Eranga M. Wiamasiri. Manuscript drafting was done by all three authors and was reviewed and modified by A.D. Ampitiyawatta.

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Declarations

Ethics approval Not applicable.

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Conflict of interest The authors declare no conflict of interest.

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