



Research Article

Characterisation of dry spells for agricultural applications in Malawi



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Abstract

Dry spells are one of the climate change hazards that continue to exert pressure on the agriculture sector, hence affecting food security. Understanding dry spell characteristics of an area helps in coming up with interventions and adaptive measures among other advantages. This study aimed at understanding characteristics of dry spells for Malawi by using climate hazards group infrared precipitation with stations precipitation data from 1981 to 2019. The study focused on the spatial distribution, maximum number of dry days, trend of maximum dry days and time of occurrence of dry spells. Data was analysed using Mann–Kendal trend analysis in R software. The results indicate a high number of occurrences of dry spells in the southern region than the other two regions of Malawi. In addition, the southern region experienced the highest maximum number of dry days. However, there is an upward trend for maximum days of dry spells in central region than all other regions. Local scale topographic influences on dry spell occurrence were also apparent. The study further established that the number of dry spell occurrence in the rainfall season starts to increase towards end of March. In this regard, although rainfall season in the study area is considered to be from November to April, the study recommends that growing season should be considered to be November to March so that crops are not affected by end of season dry spells which are common. Farmers should ensure that they plant crops that will mature with this growing period.

Article highlights

- Analysis of dry spells over Malawi from 1981 to 2019 using CHIRPS identified areas prone to dry spells.
- There is an increase in trend of dry spells in centre with high number of occurrence in the south and that the spatial distribution and trends are influenced by topography, rainfall onset and cessation.
- Characteristics of dry spells informs optimal crop growing periods.

Keywords CHIRPS · Dry spell · Dry spell length · Return period · Spatial distribution · Malawi

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1 Introduction

Impacts of natural hazards, some of which are a result of climate change, are a global challenge. Such hazards include droughts and dry spells, which have various impacts on agricultural production, affecting the people's socioeconomic livelihoods including agriculture [1]. A dry spell can be defined as a sequence of dry days including days with less than a threshold value of rainfall [2]. In Africa, 90% of the food production is from rain-fed agriculture, and the occurrence of dry spells during the growing season leads to low yields and a high risk of crop failure [3], consequently leading to food insecurity. With few resources to adapt to climate change hazards such as dry spells, developing countries in Africa such as Malawi are left vulnerable [4]. The effects of dry spells in agriculture are more pronounced especially in countries that rely on rain fed agriculture like Malawi. The studies on dry spell characteristics are motivated by the underlying problem that dry spells are considered to be the origin of poor crop production, assuming other environmental factors constant [5]. Among other factors, the frequency and length of dry spells has a huge impact on the success and failure in crop production during rainy seasons. Malvern et al. [5] further states that understanding characteristics such as dry spell distribution within a rainy season enhances benefits in rain fed agricultural regions. Knowledge of the dry spell characteristics can be useful for deciding a particular crop or variety, supplementary irrigation water demand and drought interpretation [2, 6]. In irrigation the information on dry spells can also help in irrigation schemes to plan for supplementary irrigation during a rainy season as well as predicting irrigation demand. Due to variability in rainfall patterns, the dry period in 1 year is not necessarily the same as drying in another year, hence the knowledge of behaviour of these patterns has become increasingly important to understand [7].

Many studies have therefore been undertaken to study both the spatial and temporal variations of dry spells to understand their characteristics as well as impacts of dry spells on agricultural productions. In their study, [8] examined long-term spatial and temporal patterns of dry spells in Calabria region of southern Italy between 1916 and 2006. The study established that there were negative trends at annual scales while positive trends were established for the winter period. In addition [9] analysed trends in dry spell frequencies such as frequency of dry spell (FDS), total dry spell (TDS), maximum dry spell (MxDS) and mean dry spell (MDS) in the Sudano-Sahelian region of Nigeria from 1981 to 2018. The study found that a positive gradient for some

dry spell indices in some regions. However there was a decline in TDS, MxDS, and MDS from May to October, which has a strong potential for improving agricultural productivity. Achite et al. [10] analysed dry and wet spells in the Wadi Cheliff Basin of Algeria. Applying the Theil–Sen and Mann–Kendall test on the Standardized Precipitation Index (SPI) during the period 1970 to 2018, the study found contrasting positive (increasing) and negative (decreasing) trends in the southern and northern parts of the basin, respectively. To improve adaptation to dry spell in agriculture, in the Wei River Basin of China, [11] applied a regional frequency analysis using L-moments to analyze the annual maximum dry spell length (AMDSL) between 1960 and 2014. The study found that regions in the west east of the basin had a higher dry risk as compared to those in the west. Further, most of the dry events had a close association with the occurrence of El Nino and Southern Oscillation. To understand the occurrences of mid-summer dry spells, Mengistu et al. [12] investigated spatial–temporal trends of the magnitude, length and time of occurrence of dry spells in the major maize growing areas of the summer rainfall region of South Africa. In the study, no notable trends in the dry spell frequency were found, and a general west to east decline in the dry spells was observed. Thoithi et al. [13] assessed dry spells (defined pentads having < 5 mm) over southern Africa were assessed high resolution (0.05°) using Climate Hazards group Infrared Precipitation with Stations (CHIRPS) datasets during the period between 1981/82 and 2018/19 for October–November (ON), December–February (DJF) and March–April (MA). The study used climatology, intensity–frequency and trend analysis and found a close influence of topography, with highland areas having lower frequency of dry spells.

Malawi has been experiencing dry spells which have a great impact on agricultural production [14]. One major dry spell event was reported by the Ministry of Agriculture that occurred during the 2015–2016 growing season and affected crops in many districts. However, not many studies have looked at characteristics of dry spells in Malawi, according to the literature. Such few studies include that of among others [15] who used rainfall data from 10 stations from 1961 to 2012 to investigate the occurrence of dry spells within the rainy season. The study found an increasing trend for 7 and 10 days length dry spell. The study further established that Malawi dry spells vary both in space and time making the vulnerability even more severe. The high spatial variability and decreasing trend of rainfall contributes to occurrence of extreme weather events such as dry spells and droughts in Malawi. A study by [16] investigated the spatio-temporal patterns of droughts in Lake Chilwa Basin. The study analysed the stationarity

difference in rainfall between 1973 to 1995 and 1996 to 2018 and climatological trends using Mann–Whitney and Mann–Kendall tests, respectively. Overall, a decreasing trend was observed for rainfall, although not statistically significant to be the only cause of droughts that lead to drying of Lake Chilwa. For effective and efficient implementation of disaster risk management activities [17] mapped and produced a hazard and vulnerability atlas to various extreme weather events for Malawi. In vulnerability mapping the study looked at vulnerability of population to drought, temperature, forest fire and floods among other events. However, dry spells were not mapped despite their significance. Overall, the study did not focus on various characteristics of the dry spells. Therefore, this study aimed at understanding characteristics of dry spells across Malawi. This was achieved by: (i) examining spatial distributions; (ii) analysing maximum spatial–temporal trends; (iii) assessing their time of occurrence.

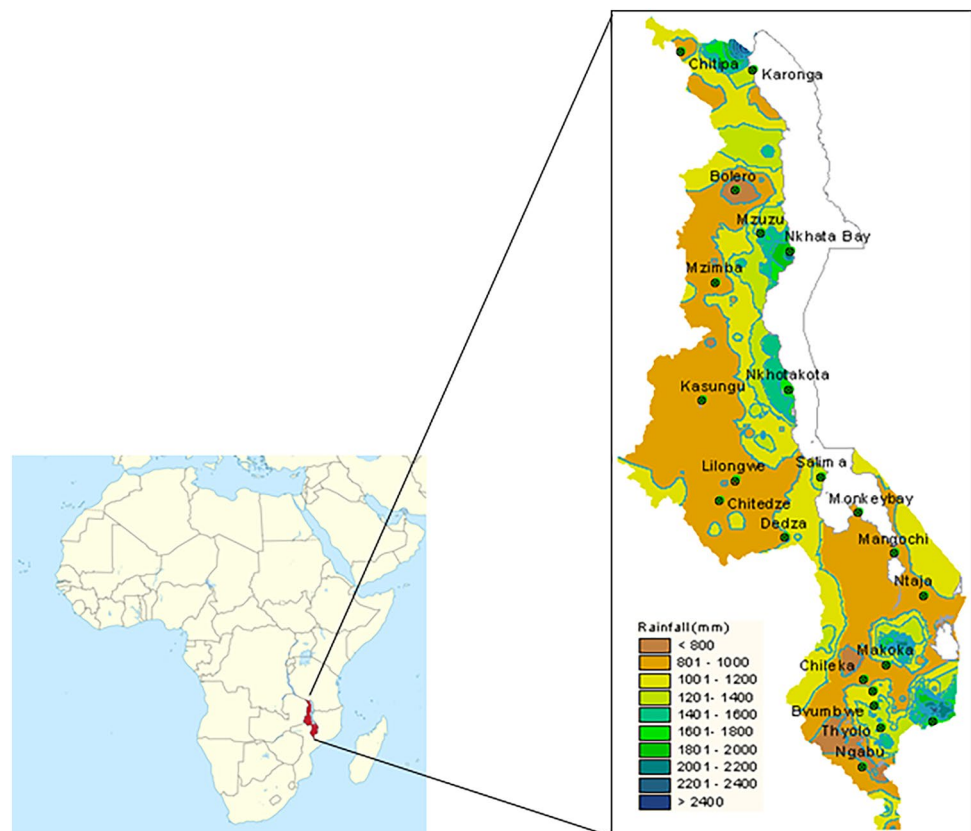
2 Data and methods

2.1 Study area

Malawi is a land locked country in the southeastern region of Africa. It lies between latitudes 9° and 18°S,

and longitudes 32° and 36°E and a territorial area of 118,484 km², of which 20% is covered by water bodies. Malawi is characterized by a tropical wet and dry climate (Savanna), with a distinct rainy season between November and April and a dry season between May and October. The climate is dependent on the migration of the Inter-Tropical Convergence Zone (ITCZ), the sub-tropical high-pressure belt in the south, and the topography [18]. Mean annual rainfall in Malawi varies between 800 mm in low lying areas to over 1600 mm in the highlands [19]. Spatial precipitation trends shows high rainfall in the northern Malawi and some parts of southern Malawi, with the central and lower Shire regions exposed to less rainfall as in Fig. 1 from the DCCMS|Climate Services (metmalawi.gov.mw). Malawi experiences mean annual minimum and maximum temperatures of 12–32 °C [20], the highest temperatures occur at the end of October or early November. The Shire Valley recorded the highest temperatures while the lowest are recorded over the high altitude areas particularly the Viphya and Nyika plateau, Dedza and Mulanje mountains and other high-altitude areas. According to the World Bank group report [21], the Malawi economy is mainly dominated by the agricultural sector, it accounts for almost 30 percent of GDP, around three-quarters of total exports and 64 percent of the labour force. Additionally, the study established that 80 percent of households

Fig. 1 Map of Malawi showing spatial distribution of mean rainfall (mm)



depend on agriculture sector for at least some of their income. The World Bank report further states that of the total land available about 5,738,000 ha representing 61% of the land area are suitable for agriculture.

2.2 Data

In this study, Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) precipitation data for 38 year-period from 1981 to 2019 was used. This is a satellite-based precipitation data set. Ideally, these studies need data from gauge-based observation stations. However, rainfall data from station observations up to the most recent period are inadequate over many parts of the world, including Malawi. This is mainly due to sparse rainfall data collection points or limited reporting of gauge observations [22]. Remote sensing data is prone to modifiable areal unit problem (MAUP) and modifiable temporal unit problem (MTUP) [23] and CHIRPS data is no exception. The sparse gauge point-based rainfall data is aggregated into spatial partitions leading to MTUP. Similarly, the daily rainfall data can be aggregated into weekly, monthly, or yearly, creating some statistical bias and errors [24]. In the study, no further aggregation of CHIRPS data was done, daily precipitation data was used which is similar to temporal resolution of the rain gauge data hence minimal temporal aggregation.

The CHIRPS precipitation data is available on daily temporal resolution and 0.05° (5 km) spatial resolution, serving as a good dataset for spatial characterization of dry spells. Additionally [25] carried out a comparative analysis of three satellite precipitation products including Tropical Rainfall Measuring Mission (TRMM-3B43V7), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR), and Climate Hazards Group InfraRed Precipitation with Station (CHIRPS V2) with ground-measured. From the study, CHIRPS data showed the closest agreement with the IMD precipitation and was relatively better in capturing the drought characteristics. Further [26] evaluated 20 precipitation products for Ethiopia, and of the 20 precipitation data products, the study found that CHIRPS is a relatively better precipitation data product in capturing drought development, followed by FLDAS and GPCC. Validation of the CHIRPS data by [22] indicated that CHIRPS satellite data performs better and has low bias than other satellite-based data in eastern Africa. Funk et al. [27] examined a correlation between rain gauge data and other precipitation estimates and it was established that CHIRPS had good correlation of $R > 0.75$. Additionally, it was established that compared to other satellite data, CHIRPS exhibited a low bias. This is supported by a study that was done for Malawi by [28] on CHIRPS gridded dataset for validity

against gauge measurements. The study established that CHIRPS correlation with gauge data was high and therefore argued that the data set is reliable for application in the absence of gauge data. CHIRPS has also a better spatial resolution of 5 km compared to TRMM which has a low spatial resolution of 25 km [29]. Hence the dataset was preferred than other satellite products in this study. The CHIRPS precipitation data was downloaded from the University of California, Santa Barbara (USA) website on daily temporal scale.

A minimum threshold for dry spell was considered to be 1 mm. This means that a day with rainfall amount less than 1 mm was considered to be a no rainfall day, which is consistent with studies by [9] [9, 28, 29]. The 1 mm of rainfall threshold translates to 1 L of water per m^2 and is therefore sufficient to wet the surface layer of the soil. Further, according to Department of Climate Change and Meteorological Services of Malawi (DCCMS-www.metmalawi.gov.mw), a rainy day for weather purposes is considered to be a day with minimum rainfall of 0.3 mm. On the other hand, the DCCMS considers a day with a rainfall above 1 mm as a rainy day specifically for agriculture sector, hence a minimum of 1 mm rainfall was adopted in the study. Additionally, [11] highlights that a minimum of 1 mm can also be considered, since this amount of rainfall is mostly directly evaporated. In this study, the dry spells were calculated for the rain season only to minimize the effect of dry days within the dry season, since Malawi has a tropical savanna seasonal climate. In this study, the rainy season was considered to be from November to April, for instance November 1990 to April 1991 was one rainy season.

2.3 Methods

2.3.1 Spatial distribution of dry spell

The spatial distribution and number of dry spells were calculated for each pixel size of 5 km. The dry spells were calculated for four thresholds of 7, 10, 15 and 20 consecutive days without rainfall. These thresholds were considered following [5], who found that dry spell lengths of 7 days can cause plant stress to shallow rooted crops, 10 days to medium rooted crops, 15 days to deep rooted crops and 20 days almost all crop root categories. In deriving the number of occurrence for dry spells from 1981 to 2019, the study applied the formula by [32] as follows: if a dry spell of i consecutive days occurs in a month j and year k , then the number of occurrences of the spell during a month and year within a pixel can be expressed as:

$$F_{ijk} = \sum_{i=1}^m F_{ijk} \quad (1)$$

Where i is consecutive number days with rainfall less than 1.0 mm in a month (j) and year (k), with (m) the total number of years. In the study i was replaced with 7, 10, 15 and 20 and m was 38 since data was considered from 1981 to 2019. The total number of dry spells for each threshold were then displayed on a map within a pixel. All the computations were done using R software and maps were generated using Arc Map.

2.3.2 Maximum dry spell length and trend

The maximum number of dry days was the longest number of consecutive days an area had rainfall equal to or less than 1 mm. To identify the spatial location of the maximum dry spell length, the longest number of days a pixel had no rainfall from 1981 to 2019 was considered.

The trend for maximum days of dry spells for each pixel were analysed using Mann–Kendall (MK) non-parametric test. The MK method was recommended for analysis of trends in hydro meteorological variable by the World Meteorological Organisation [33]. Among its strengths are its robustness in identifying trends in non-normally distributed time series data like the rainfall data and its insensitivity to outliers [34]. For a part x_k is the time interval (1 year in this case), the MK statistic (S) is given as [35]:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \tag{2}$$

$$\text{Sign}(x_j - x_k) = 1 \text{ if } x_j - x_k > 0$$

where: $= 0 \text{ if } x_j - x_k = 0$

$$= -1 \text{ if } x_j - x_k < 0$$

The statistic was calculated for each pixel and plotted on a map. From the equation, a very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend and a zero indicates no trend.

2.3.3 Return period of dry spells

The return period of a dry spell of a specified magnitude is also one of the important dry spell characteristics, since it helps in understanding the vulnerability of the area to such a dry spell. The calculation of return period was adopted from [36] and was calculated as follows:

$$T_r = \frac{1}{\beta\{1 - F(x_r)\}} \tag{3}$$

Where β is the average number of observations per unit time, expressed here in years and x_r is the corresponding dry spell length. In the study 7, 10, 15 and 20 days dry spell length were used.

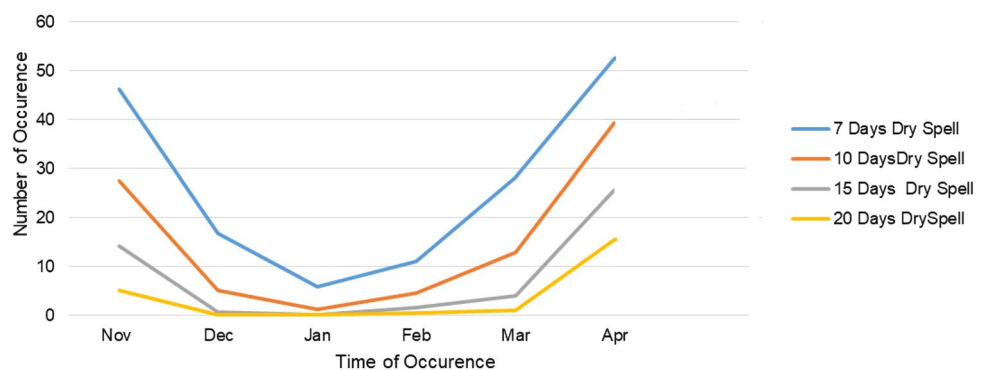
3 Results and discussions

3.1 Time of occurrence of dry spell

The time of the year or growing season when the dry spells occur is also an important characteristic of the dry spell. Understanding the time when dry spells are most frequent within the growing seasons helps to plan when interventions would be mostly required in relation to crop production. The timing of breaks in rainfall (dry spells) relative to the cropping calendar rather than total seasonal rainfall is fundamental to crop viability [37].

Figure 2 shows the time of occurrence of dry spell within the rainy/growing season. For all the dry spell length, the number of occurrences start to drop in December and start to increase towards the end March. The lowest number of dry spells coincides with the peak of rainy period which is between December and April. It can be observed that after February, the number of dry spells starts to get higher for 7 days dry spell. In addition, the results show a relatively significant increase of the 10, 15 and 20 days dry spells days after March. The increase

Fig. 2 Plots showing time of occurrence of dry spell



in number of 7 days dry spell after March cannot have a huge impact on the maize growth. This is because in March, the crop is normally fully grown and the roots are deep. Thus, the 7 dry spell, the lowest of all thresholds analyzed, may not have much impact on the crops.

The increase in number of dry spells in April is mostly related to the early rainfall cessations, which agrees with [36, 37], among others. It can also be observed that there are high occurrences of dry spells in November and after April which are attributed to changes in rainfall pattern. These occurrences are within normal cropping season for Malawi and affects the growing season, type of crops grown and planting time [40]. Therefore, the early occurrence of these dry spells within the growing season reduces the period in which crops can be grown. In a similar study on growing season rainfall and scenarios of future change in southeast Africa by [41] an early cessation was observed which places added strain on farmers who are faced with a shorter season of less consistent rain. This means that despite the rainfall period being November to April, the actual crop growing period should be considered to be November to March. Hence from the results, the optimal crop growing period would be December to early March, where there is a smaller number of occurrence for dry spell. This is to ensure that farmers' crops are not affected by the dry spells. Since the early season dry spells may affect the germination rate of maize, late season dry spells affect grain filling, a critical growth stage when maize needs enough water [41]. Thus, the use of drought tolerant crops with early maturity becomes essential. With these early maturing crops, farmers can escape the effects of late-season moisture stress [42] which can be from late-season dry spells.

Although the early and late season dry spells are apparent, any occurrence of dry spells in agriculture is critical as it affects plant growth. The results show fewer occurrence of dry spells within the high rainfall periods of December, January and February. These times are critical since it is the grain filling period for most crops. Not only does the dry spells affect actual yield, but it also creates a bias in crop yield estimate, which is one of the important processes in agricultural production [43]. Despite inter seasonal dry spells affecting grain filling, the subsequent rainfall may improve leafage in plants. This creates some biasness when using remote sensing techniques in yield estimation since the interaction of sensors with crop canopy forms the basis for yield estimation and quantification of other crop biophysical parameters like leaf area index (LAI) and above-ground biomass [43]. Hence understanding time of occurrence of these dry spells becomes important input in yield estimation.

3.2 Spatial distribution of dry spells over Malawi

The number of times a dry spell of a particular length occurs is one of the most important characteristics of dry spells. The number of occurrences of dry spell relates to the amount of exposure for an area to dry spell. Figure 3 shows total number of occurrences per threshold across Malawi from 1981 to 2019 per pixel, which has 5 km spatial resolution. Each pixel shows the total number of times each threshold occurred from 1981 to 2019. To highlight the spatial variability colour bands for all the thresholds are the same for visualization, however the number of occurrence is not the same for each threshold as it can be observed from the legend.

From Fig. 3, the shortest dry spell lengths of 7 days are the most frequent in the study area, whereas the longer dry spell lengths have fewer number of dry spells occurrences. In addition, the 7 days dry spell length has a minimum of 143 and maximum of 333 number of occurrences. On the other hand, the 20 days threshold has a minimum of 16 and a maximum of 75 occurrences. Furthermore, the overall trend shows high number of occurrence of dry spells in the southern part of Malawi than the other two regions. It can also be noted that incidences of dry spells in northern region are lower than the southern region for all dry spell lengths. This indicates a sizeable difference in the incidence of dry spell between these areas. Whilst the northern region has more low number of occurrence of dry spells for all the thresholds, other low dry spell occurrence are observed across Malawi, in high plateau areas of Thyolo, Zomba and Mulanje. This could be largely attributed to higher levels of precipitation (greater than 1000 mm per year) in these high elevation areas, in contrast to the lower precipitation (less than 800 mm) in the Shire River Valley area, where dry spell occurrence is high. This is related to the orography which influences the climatic characteristics of rainfall amount and its distribution. Similarly, studies in eastern Africa by [22] attributed the complex orography as contributing to very diverse climates that span eight different climate zones ranging from warm deserts to humid highland climate. This is also consistent with the rainfall pattern (Fig. 1) for Malawi since in low lying regions there is high occurrence of dry spells due to low rainfall.

3.3 Number of occurrence

Figure 4 is a box and whisker plot of total number of dry spell occurrence for 7, 10, 15 and 20 days thresholds from 1981 to 2019. From the box plots, it can be observed that there is a variation in the number of occurrence for all the four thresholds as they are all not falling in the same number of days. The mean for 7-day dry spell is the highest

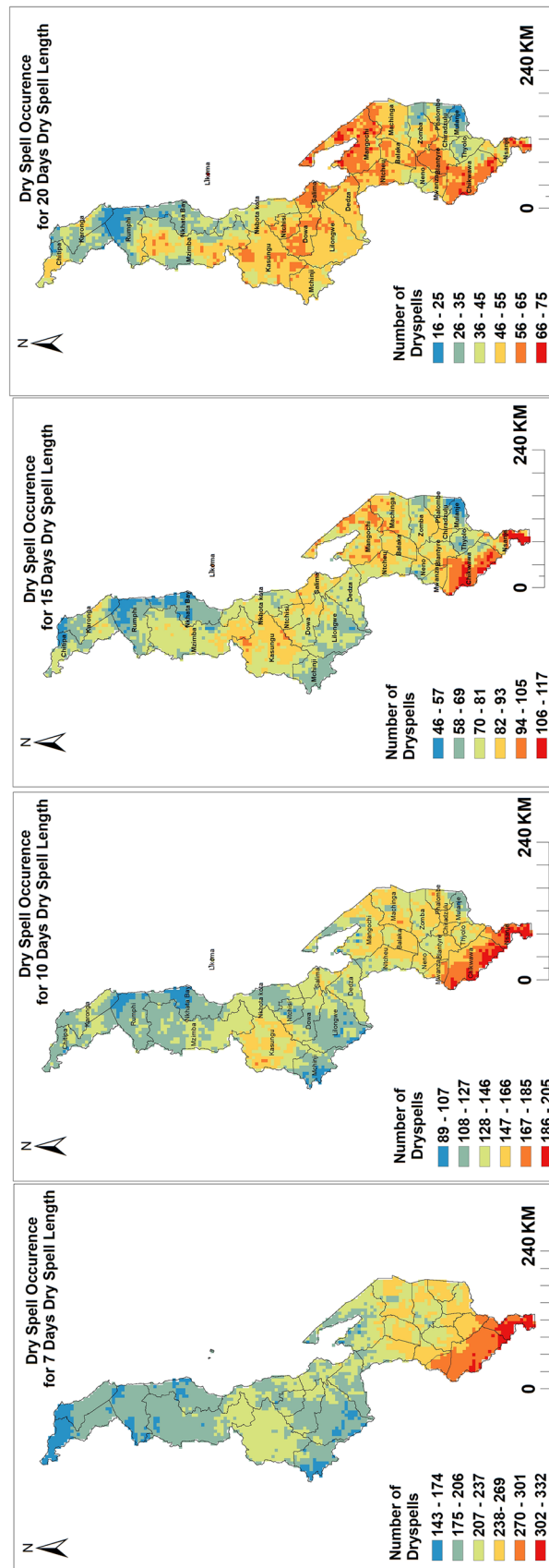


Fig. 3 Number of dry spell occurrence for 7, 10, 15 and 20 days length from 1981 to 2019

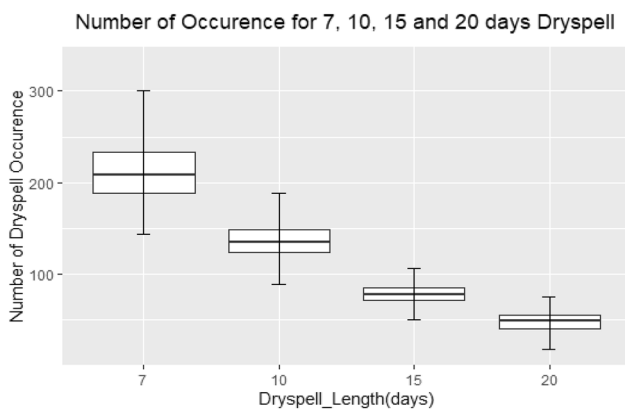


Fig. 4 Box plots for total number of Occurrence for 7, 10, 15 and 20 days thresholds

among all the threshold and dominates the study area and the 20 days dry spell is the lowest indicating low number of occurrence of dry spell. This shows the high number of occurrence for 7 day dry spell than other threshold and low number of occurrence for 20 days dry spell length. Furthermore, from the whiskers it can be seen that 20 days length dry spell extends only to about 75 number of occurrence which is way less than that of 7, 10 and 15. By having less number of occurrence this indicates that the 20 days occur way less than the 7 days. The boxplot statistics are consistent with the results of spatial distribution map in Fig. 3, which had 7 days as highest in terms of number of occurrence of dry spell.

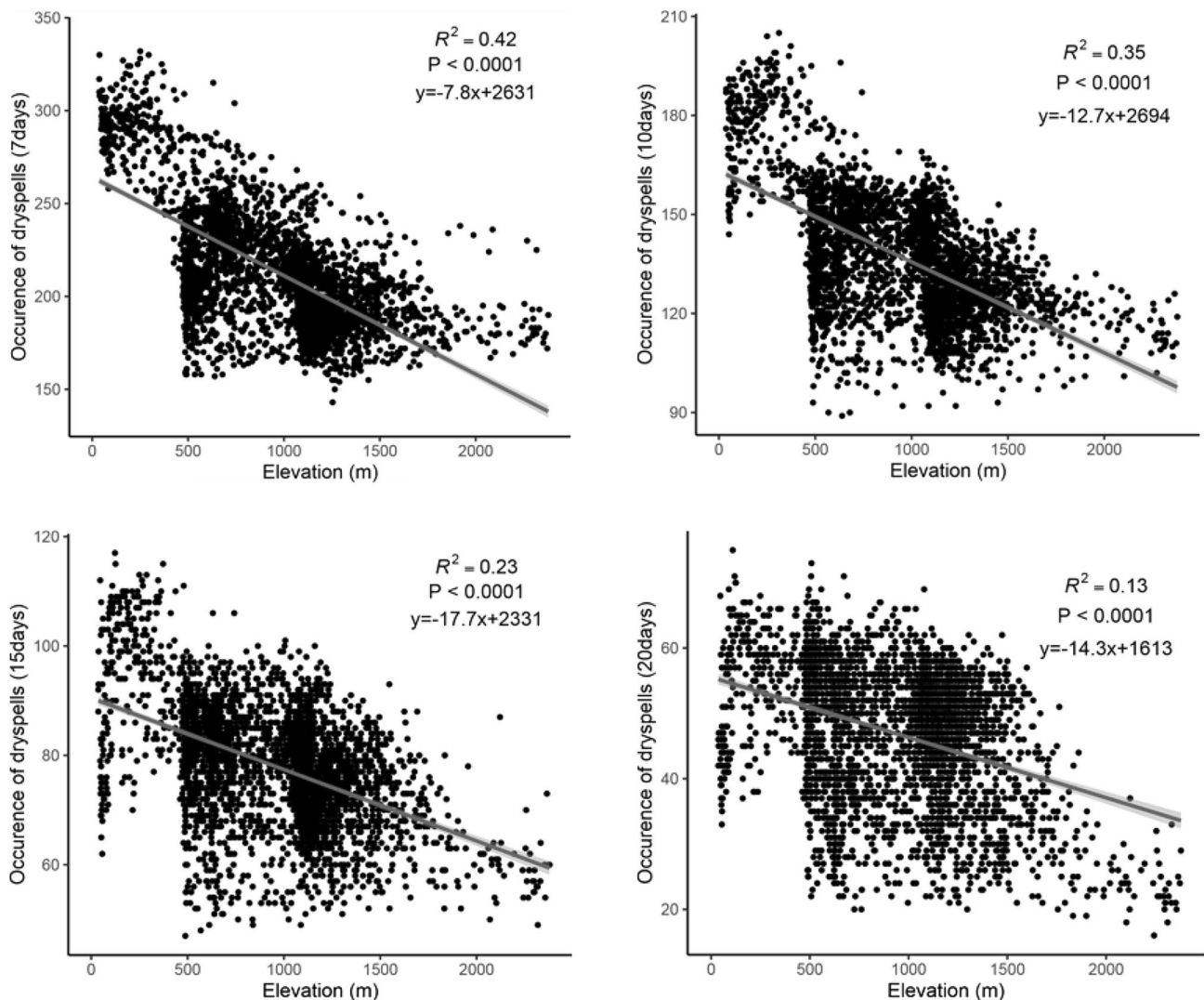


Fig. 5 Correlation plots for elevation and number of occurrence of dry spells for 7, 10, 15 and 20 days dry spell length

3.4 Spatial correlation for elevation and dry spells

Further analysis on the elevation and number of occurrence for the area was done. The number of occurrence of dry spells for each threshold was plotted against elevation as in Fig. 5. For all the thresholds the trend line is negative with best fit line equations of $y = -7.8x + 263$, $y = -12.7x + 2694$, $y = -17.7x + 233$ and $y = -14.3x + 1613$ for 7, 10, 15 and 20 days dry spell length respectively, which indicates a negative correlation for all the thresholds. The number of occurrences of dry spells is decreasing as the elevation is increasing. The high elevation highly contributes to the area receiving high rainfall. This is also consistent with the rainfall pattern of Malawi since it's also influenced by topography and this is in agreement with [19]. Similar study by [44] suggests that local factors like topography have a dominant role in the spatial distribution and nature of the rainfall pattern in Malawi hence contributing to fewer number of dry spells in high elevation area and a greater number of dry spells in lower elevation places. Similarly in Italy [8] evaluated the yearly average and the maximum length of the dry spells for south Italy and dry spells longer than 14 days were observed for the entire region. However, the mountainous areas, specifically the higher summits of the Sila Plateau and of the Pollino Massif, with high elevation presented lower values of less than eight days. A similar observation was made by [45] where it was established that the mountainous and forested areas found at the middle and northeastern part of Pra River catchment of Ghana had fewer events of dry spells which was possibly due to topographic influence which enhances rainfall. Similarly for Malawi a correlation between elevation and dry spells was observed, this is mainly due to elevation of an area having an influence on rainfall distribution.

In agriculture, the less dry spells and high rainfall can have an influence on the type of crops grown in these areas, some of which are high rainfall amount types of crops. For instance, from the results Chitipa and Mulanje districts shows less number of occurrence of dry spells of which coffee and tea are common type of crops grown in these districts. Overall, the P values of 0.0001 are consistent for all the threshold agreeing that there is a negative relation between occurrence of dry spell and elevation. However, this relationship is not strong especially for the 15 and 20 days dry spells length which have R^2 values of 0.23 and 0.13 respectively. This can be attributed to fewer occurrence of these dry spells in the study area and these occurrences are even rare in high elevation areas.

3.5 Spatial distribution for maximum dry spells

One of critical factors determining crop failure is the maximum dry spell duration that can be expected during a growing season. This relates to the total number of days an area experienced no rains and relates the amount of time crops are exposed to dry spells. The long exposure to dry days can be harmful to crops since there is no water or moisture available to crops.

The maximum number of dry spell occurrences in a season during the 1981 to 2019 period was extracted for each pixel to get an idea of their spatial distributions. The observed maximum number of dry days have been given in Fig. 6. The maximum number of dry spell days was considered to be the total number of executive days an area received no rainfall from 1981 to 2019. Few areas were observed to have the longest number of dry spells of more than 60 days. These were observed along the southern part of the lake shore. The lowest length of dry spells days was experienced in the northern and some parts of the southern regions. Some of these areas are Chitipa, Mzimba and Rumphi, Northwest Lake Shore, part of Mulanje and Zomba. Just as it was the case with dry

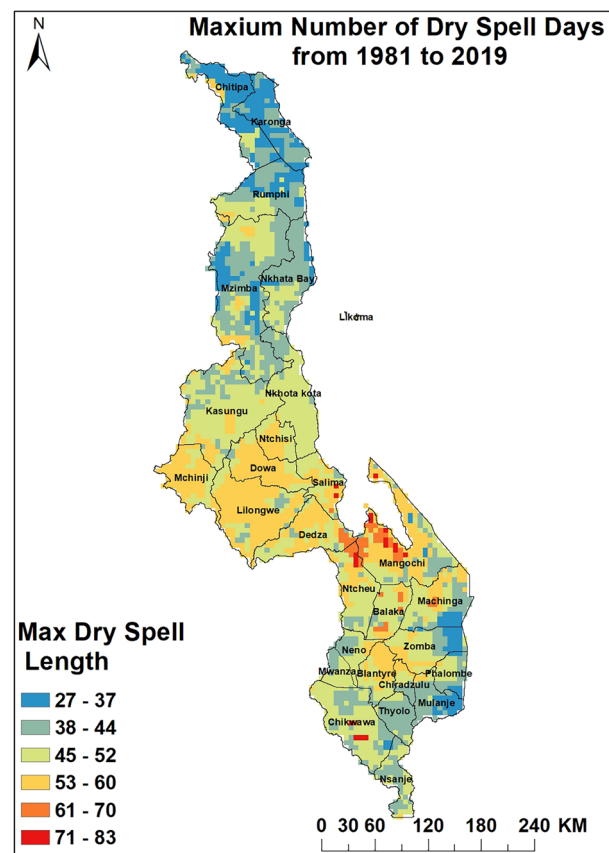


Fig. 6 Maximum Dry Spell Length from 1981 to 2019

spell spatial variability, the areas with lower maximum number of dry spells are those with high topography. This agrees with study by [38] who showed that high topography contributes to high amount of rainfall and longer rainfall duration for Malawi.

3.6 Trend for maximum dry spells

Trend analysis of the maximum values per pixel was also carried out. The MK test at a significance level of 5% was used to study the temporal trends of the maximum days of dry spells from 1981 to 2019 and the results have been shown in Fig. 7. The results show an increase in trend in maximum number of days for some parts of central region and southern region of the study area. The increase in trend indicates an increase in the maximum number of dry spell days. This increase in trend is not necessarily attributed to the change in rainfall amount but it is due to change in the rainfall patterns, the rainfall period has become shorter due to late onset and early cessation of the rainfall. The delay in the onset of rainfall and an early cessation of rainfall makes the dry days to be longer and concurs with studies by [38]. The positive trend in parts of

the southern region also concurs with the study by [39], who found that shortest growing period was shorter for Lower Shire due to late onset and early cessation of rainfall.

Time series trend for the number of occurrences of dry spells were calculated for Lilongwe, Chiradzulu and Karonga districts. These areas were considered since they had significant trend for maximum dry spell days. The trends in these areas were estimated for whole period of 1981 to 2019 and results are shown in Fig. 8. The line graph is the total number of occurrences for each threshold for each year and these were calculated for 7, 10 and 15 days thresholds. The results show an increase in trend for number of occurrence as you move from lower dry spell threshold to higher threshold of 15 days. A good correlation between the rainfall and number of dry spells can be observed in 7 days dry spell for all the three locations, thus depicting the intra seasonal rainfall variability. Significant increase in trend for 7, 10 and 15 days dry spells are observed in Lilongwe, indicating an increase in occurrences of dry spells. However no significant trend could be observed for Karonga and Chiradzulu which correlates with the variability and no trend in rainfall amount of which similar relationships were observed in eight agricultural development divisions by [46].

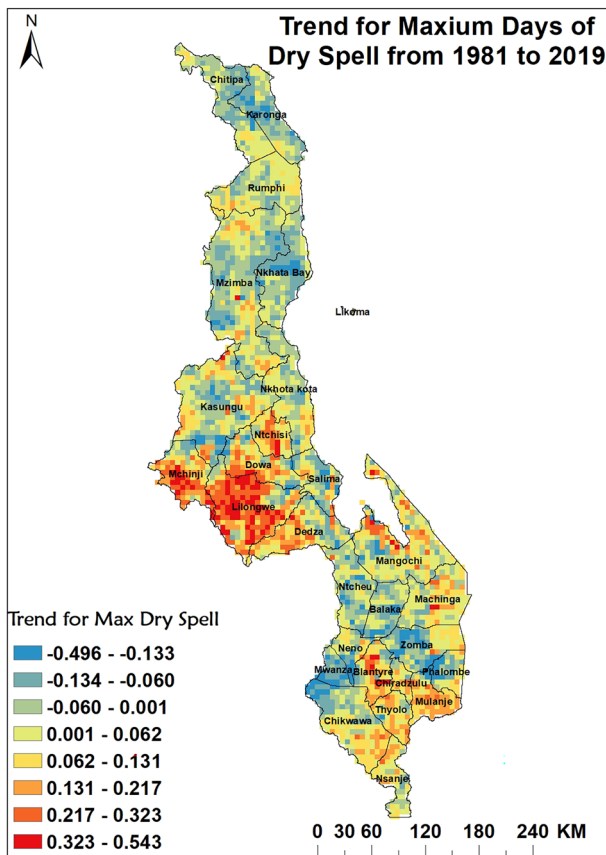


Fig. 7 Trend for Maximum dry spell from 1981 to 2019

3.7 Return period of dry spells

Understanding the return period of a dry spell helps in proper planning of crops and water management. Return period helps in describing the possibility of dry spell happening. Since dry spells of 7 and 10 days length can also have an impact on plant growth depending on soil depth and retention capacity [5] the return period was calculated for 7, 10 and 20 days dry spell length. The calculation was done for each pixel. Figure 9 shows the return period for dry spells with length 7, 10 and 20. The 7 days dry spell length has a higher return period than all the thresholds. The probability of dry spell events over 7 days ranged from 3.6–11% and the probability of dry spell events over 10 days ranged from 2.2–7.5% and 20 days ranged from 0.3 to 3.0% for 2, 5 and 10 years return periods. The highest probability of occurrence is in the southern western part of Malawi and the lowest odds is in the northern part of the country. For instance, there is 1.5–1.8% chance that a 20 day dry spell length will return within 2 years in the southern tip of the country. On the other hand, there is a 0.3% chance for 20 days spell to occur in northern part of the country. Similar to number of occurrence the probability of dry spell occurring is related to the rainfall patterns, onset and cessation of rainfall. Ngongondo et al. [44] established that Nchalo area, which is in the southern western part of the country, had the lowest mean annual rainfall, which could attribute to high probability

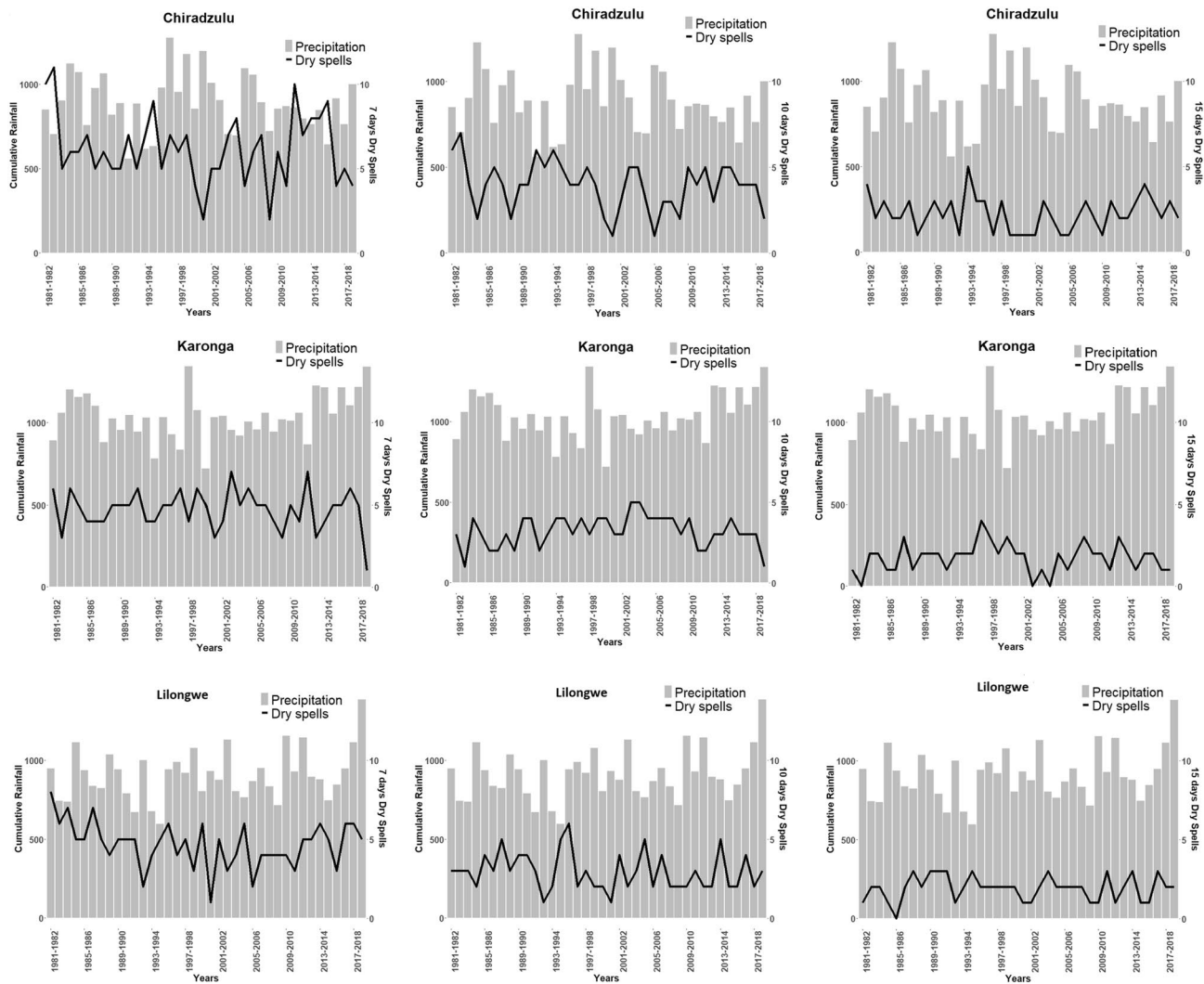


Fig. 8 Time series trends for 7, 10, and 15 days dry spell for Karonga, Chiradzulu and Lilongwe districts

of dry spell occurrence in the area. On the other hand, the north especially Chitipa has early onset and late cessation of rainfall contributing to the low probability of dry spell occurrence.

4 Conclusion

This study analysed spatial–temporal characteristics of dry spells over Malawi using CHIRPS precipitation data sets from 1981 to 2019. The results suggest that overall, the southern region experiences the highest number of dry spells for all thresholds of 7, 10, 15 and 20 days. The occurrence of these dry spells was also influenced by the topography of the areas, which in turn influences precipitation of the area. This was also evident from a negative correlation between elevation and number of dry spells, whereby the

high elevation had low number of dry spells. In addition, there is an increase in trends for maximum number of dry spells in central region, which is greatly affected by the delayed start of rains and early cessation of rains. On the other hand, the northern region showed less amount of maximum dry spell length. The northern region also experiences lower number of dry spells, while other low dry spell areas are scattered across Malawi, in high plateau areas of Dedza Mountains, and the southernmost tip of Malawi (lower Shire valley). In relation to time of occurrence for dry spells, the number of occurrence for 7 days dry spell length is higher throughout the growing season than the other threshold for the country. However, there is an overall increase in number of occurrences before mid-November and towards end of March. Thus, the study concludes that despite the rainy season being considered from November to April, the actual crop growing season

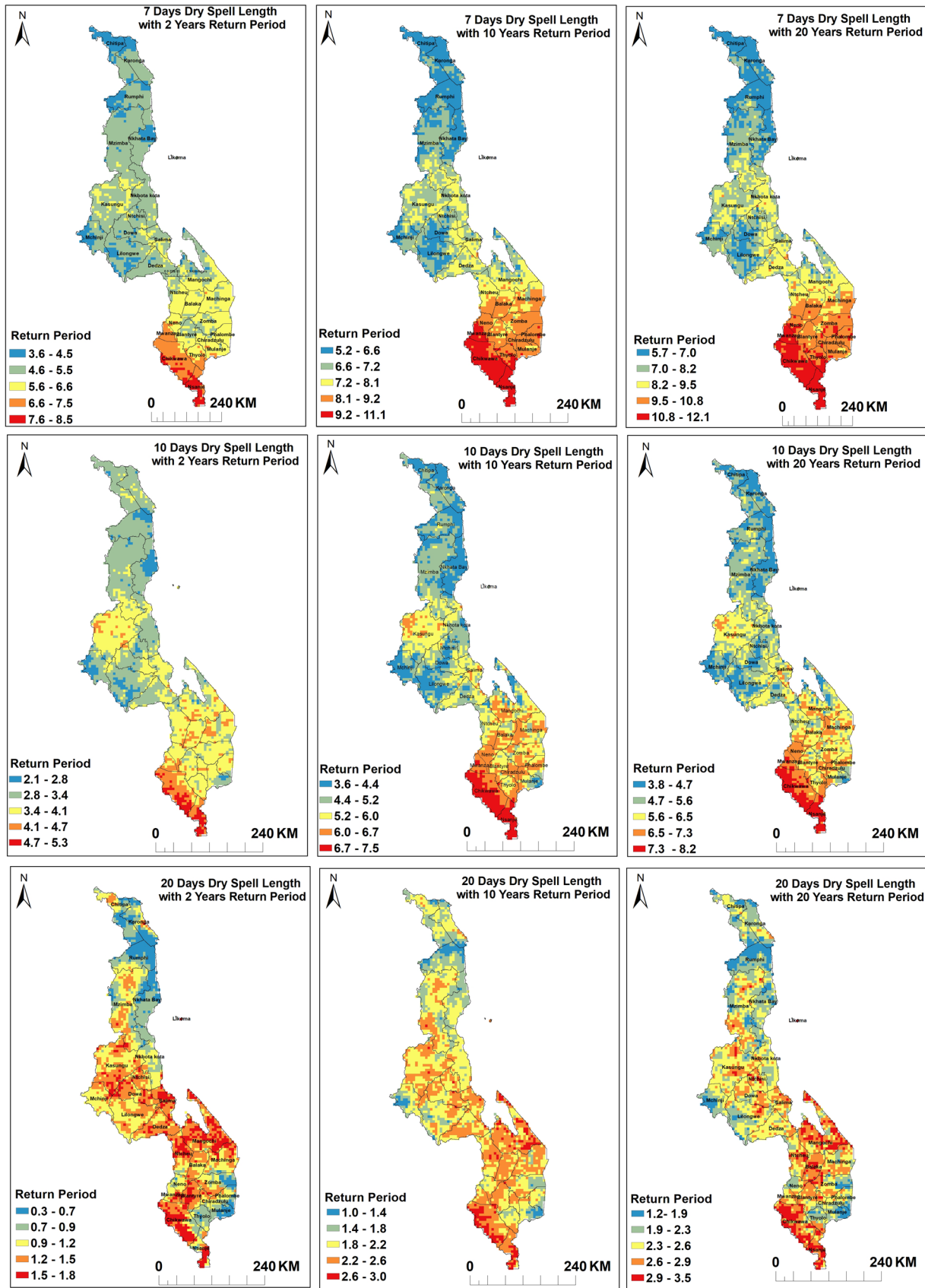


Fig. 9 Return period for dry spell for 7, 10 and 20 dry spell length with 2, 10 and 20 year return period

can be considered to be from mid- November to March as this is the period without many dry spells such that most many crops can grow optimally.

Author contributions EC took lead of the research, analysed data and drafted the initial manuscript. CN took lead in the supervision, guided research direction, and assisted in the writing and editing of the manuscript. BM assisted in data analysis especially coding. CL assisted in data analysis and editing of the manuscript. LE provided research direction, and assisted in the writing and editing of the manuscript. MM provided research direction, and assisted in the writing and editing of the manuscript. The listed authors have made a significant contribution to warrant their being part of authorship and have approved the work.

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Data availability Precipitation data used in this study can be accessed through the following link; ftp://chg-ftpout.geog.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/global_daily/. Material or code used can be provided upon request to the authors if needed.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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