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Dry Spells and Probability of Rainfall Occurrence over Tanzania, East Africa

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ABSTRACT

Agriculture is the pillar of Tanzania's economy, employing a large portion (65%) of the population, however, agriculture is affected by probability of rainfall distribution and dry spells occurrence. In this study, the Markov chain approach employed to analyze the probability of rainfall and dry spells occurrence by using daily datasets of varying length from 1981 to 2019. The length of the maximum dry spells was obtained by using the Instat statistics package (v3.36) based on the longest period of consecutive days with less than 1.0 mm (R<1.0 mm) and the length of a dry spells is the sum of the number of dry days in a sequence. The Mann-Kendall's (MK) test employed for analyzing time series data and detecting trends of maximum dry spells and Sen's slope to estimate the rate of change (Q_2) in days per month. MK test results show insignificant decrease in the length of the maximum dry spells in March at 7 stations out of 9. For the month of April and May, the length of a maximum dry spells is observed to be increasing over most stations although not statistically significant at the 5% significance level. The probability of 8-days of dry spells is high across all stations (42.2%-82.0%) in October, November, and December. Climate change is a significant factor contributing to the occurrence of dry spells in Tanzania. Understanding these causes is essential for the development of adaptation and mitigation measures, that could be water conservation and management, climate-resilient agriculture, ecosystem restoration, and policy support.

Keywords: Agriculture, Dry spells, Rainfall, Climate-resilient

INTRODUCTION

Rainfall holds significant importance in East Africa due to its vital role in sustaining ecosystems, agriculture, water resources, and overall livelihoods in the region [1-3]. Given the significant importance of rainfall, the region faces considerable challenges related to climate change [2]. The changes in weather and synoptic-scale events poses challenges in agriculture and socioeconomic over Sub-Saharan Africa countries such as Tanzania, growing crops become more difficult, the areas where plants grow shift and creating new agricultural challenges [4,5]. For example, less than a 1.0 mm of rain has fallen during the period of 1999 for 249 days across Dodoma region in Tanzania during the long rains season, Dodoma, central of the country famous for farming and wine production, 249 days is the one among of the longest dry spells in Tanzania since the record began [6]. Changing climate patterns can lead to shifts in rainfall distribution, including the onset and duration of rainy seasons [3,7]. Rising temperatures and altered weather patterns can also exacerbate the intensity and frequency of dry spells [8,9]. In East Africa, including countries such as Tanzania, projections of dry spells indicate a complex and varied future influenced by multiple factors such as climate change, natural climate oscillations, and regional geography [10]. While it is challenging to precisely predict the timing and intensity of future dry spells, a synthesis of climate models and observational data provides valuable insight into potential patterns and trends [11,12]. Climate change is expected to impact rainfall patterns in East Africa, potentially leading to more frequent and severe dry spells in some regions [2]. Projections of rainfall anomaly in East Africa indicate potential shifts in precipitation patterns, including changes in the timing, intensity, and distribution of rainfall [13,14]. A mean number of prolonged dry spells days and 5 years return of maximum dry spells days as well as very wet days (r95p) and extremely wet days (r99p) are projected to significantly to increase. However, mean number of dry spells will decrease along the tropic in mid- century 2041-2070 and in the end of the century 2071-2100 [15,16]. Rainfall is the primary water source for rainfed agriculture

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in Tanzania, synoptic or large-scale weather events will continue to cause socioeconomic losses in agriculture in many developing countries, which have the low adaptive capacity [17-19]. The changing climate and weather variability have significant adverse effects across various sectors in East Africa regions, including Tanzania. These impacts manifest critical in agriculture, for example, erratic rainfall patterns and prolonged dry spells can lead to crop failures, reduced agricultural productivity, and food insecurity [20,21]. The changing climate pattern and variability have been evidently linked to the intensification of extreme precipitation and more associated with the intensification of extreme events [22].

Furthermore, on longer timescales, total precipitation received during the "long rains" season of March to May (MAM) has been reported to be in decline in recent decade over parts of Tanzania [23-25]. But, for the October to December (OND) short rain season has increased throughout northern party of the country, as well as fractional significant increase of rainfall toward the end of the century [26,27]. In addition to these, increasing temperatures, longer dry spells and more frequent and intense rains put crop and livestock production in Tanzania at risk [28]. A prolonged dry spell in MAM has been significant increase as compared to the OND rain season [29-32]. Little change in overall rainfall; slight decrease from 1961-2013, mainly from March to June [33]. Rainfall is the primary water source for rainfed agriculture in Tanzania, this variability of seasonal rainfall has profound impacts to the farmers who depend on the precipitation for their livelihood activities. Tanzania, like many other countries in East Africa, faces the significant challenge of decreasing soil moisture due to changing climate patterns and weather variability [34]. Prolonged dry spells and reduced precipitation can lead to soil moisture deficits, particularly in rain-fed agricultural areas [35-37]. Addressing the impacts of decreasing soil moisture on agricultural production in Tanzania requires a comprehensive and multi-sectorial approach, involving government agencies, research institutions, and local communities.

A recent study on future climate using average of the 34 Global Climate Models (GCMs), observing some differences in rainfall across Tanzania [38]. With projections suggesting that the north could become slightly wetter by the 2040s and the south slightly drier. For rain season (OND), a critical time for agriculture, a possibility of increased rainfall of up to 9%, for (MAM), a possibility dries of up to 9%. In spite of the efforts, the study of dry spells and the probability of rainfall occurrence over Tanzania are vital for the sustainable development and resilience of the country. By harnessing scientific knowledge and advanced forecasting techniques, Tanzania can better prepare for and adapt to the challenges posed by dry spells and variability in rainfall patterns, ultimately contributing to the well-being of its people and the environment.

Therefore, the aim of this study is to address and identify the current status on dry spells and probability of rainfall occurrence across Tanzania, despite the progress on different studies but the gap still exists on the trends of maximum dry spells length, Probability of rainfall occurrence, and probability of dry spells during the rainy season. In Tanzania, we're used small farmers, they need to feed more people as the population continues to grow, this information is necessary to make sure that supply chains exist as well as this information will be relevant for policymakers, irrigation development planners, and research communities.

METHODOLOGY

Study area

Tanzania is a country located in the Eastern part of Africa (Figure 1). It is bordered by Kenya and Uganda to the north, Rwanda, Burundi, and the Democratic Republic of the Congo to the west, Zambia, Malawi, and Mozambique to the south, and the Indian Ocean to the east. Its capital is Dodoma. Tanzania has an area of 947,300 square kilometres, 46% of which is arable land [39,40]. The current population is 61.7 million people and is expected to increase to 130 million people by 2050 [41,42]. Tanzania is located by latitudes between 1°S to 12°S and longitudes between 29°E to 41°E. The main physical feature in Tanzania includes water bodies such as Lake Victoria, Tanganyika, and Mountain Kilimanjaro etc.

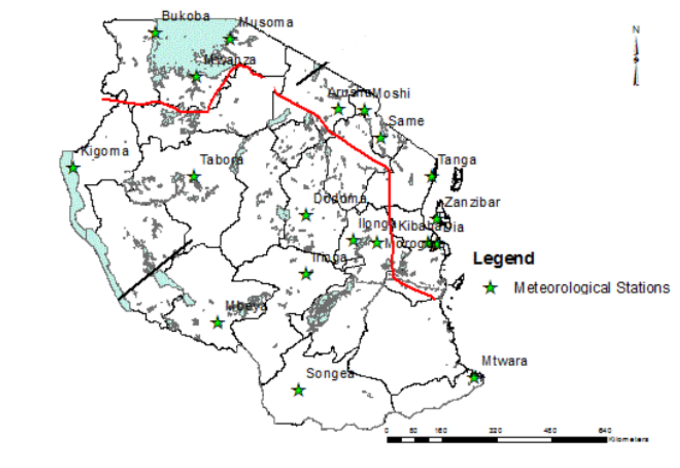

Figure 1: Map showing location of Tanzania in Africa and its elevation ranges and meteorological stations. **Note:** (★)Meteorological stations- (a) Bukoba; (b) Musoma; (c) Mwanza; (d) Arusha; (e) Moshi; (f) Same; (g) Kigoma; (h) Tabora; (i) Tanga; (j) Dodoma; (k) Zanzibar; (l) Ilonga; (m) Kibaha; (n) Morogoro; (o) Iringa; (p) Mbeya; (q) Songea; (r)Mtwara;

Throughout the year, Tanzania experiences two distinct rainfall patterns, bimodal and unimodal. The short rain ("Vuli") in October to December and the long rains ("Masika") in January or February to May [43]. The amount of rainfall is usually 50 mm to 200 mm per month but southwestern, central, southern and western parts of Tanzania received unimodal pattern rainfall that starts in October and continue through April or May [44]. However, regions in the north, northern coast, Lake Victoria basin, north-eastern as well as the Island of Zanzibar used to receive two distinct seasonal rainfall (bimodal)-the short rainfall seasonal ("Vuli") that's start in October continues throughout December (OND) and the long rain ("Masika") that starts in January or February continue through May (MAM) [45].

During the wet season, the Inter-Tropical Convergence Zone (ITCZ) moves southward, bringing moist air and rainfall to Tanzania, the seasonal migration of the ITCZ is sensitive to shifts in Indian Ocean sea-surface temperature and vary from year to year, hence the onset, duration and intensity of the rainfall vary considerably inter-annually [46,47]. The monsoon wind is characterized by a reversal of the prevailing wind direction in the summer months, bringing moisture and rainfall to surrounding the Indian ocean, also causes seasonal variability, as well as the areas outside the tropics (extra-tropical) characterized by variable weather conditions and frequent storms [48]. While the monsoon and extra tropic regions are distinct meteorological phenomena, but they can interact with each other. Land surface heterogeneity can cause local circulation systems by biophysical and topography whereby can cause the impacts on variability of rainfall [29,49].

Data

Daily observed rainfall data for the period (1981-2019) from Tanzania Meteorological Authority (TMA) has employed on this study, the data obtained from first-order meteorological stations across Tanzania, these stations are maintained by professional weather observers from TMA. Data were loaded and archived using Climpact an R Software (v3.1.5) package that calculate Expert Team on Sector-Specific Climate Indices (ET-SCI). To inspect no error are present in station data, the process of quality data check was commenced. On account of processing of the available information twelve (12) stations were subjected to preliminary quality assessment: (Arusha, Kagera, Dodoma, Kigoma, Mahenge, Mbeya, Morogoro, Mtwara, Mwanza, Songea, Tabora, and Tanga).

Despite some data gaps the data available for at least more than 10 months in every year. The missing data in some stations filled according to the World Meteorological Organization, where by recommending that the missing daily data should be filled [50]. Based on the nearby sites the missing value was filled based on linear regression, with neighbouring stations that have high correlated rainfall records due to its non-complexity [51]. Mahenge station had large gap in historical records which failed to meet required recommendation for gap filling, therefore remaining 11 stations chosen for further analysis (Figure 1).

The Grubs test for outliers is a statistical test used to detect outlier in a Univariate data set [52]. The Grub's test was used as a primary for identify a single outlier that is significantly different from the rest of the data points, daily climate data observed from eleven station were used for outlier's test. The test assumes that the data follows a normal distribution.

Also, the Shapiro-Wilk test was used to test the normality of the data. It tests the null hypothesis that a sample comes from a normally distributed, the alternative hypothesis is that the sample does not come from normal distribution could be caused by external factors such as human error, and technical problems (during the observation and collection of the data), these could be avoided if the tests are conducted before the analysis of the data. The test is based on the correlation between the observed data and corresponding expected values if the data were normally distributed at a 5% significant level [53]. By Wijngaard et al. stated that, data inhomogeneity if not considered properly, could largely impact the robustness of the study [54]. At the 5% level, the data was drawn from a normally distributed with data point 121 for Shapiro-wilk. Finally, nine (9) stations satisfied the criteria mentioned above and were chosen for further analysis on this study which are: Arusha, Kagera, Dodoma, Kigoma, Mtwara, Mwanza, Tabora, Morogoro, and Songea.

Spatio-temporal trend and variability analysis of rainfall

The total rainfall time series from 1981 to 2019, was calculated from the daily rainfall of nine (9) meteorological stations across the country. Several statistical methods used to analyse spatio-temporal trend.

The Mann-Kendall test is a non-parametric test used to determine if there is a trend in a time series. It was first proposed by Mann HB, the Mann-Kendell test used in this study to detect trends in Maximum dry spell days and annual rainfall [55]. The Mann-Kendall test is commonly used in climatology to detect trends in variables such as rainfall and temperature, the test used to detect upward, downward or no trend in data. The test works by comparing the differences between each pair of values in the time series and the test allows it to confirm the existence of a trend in any data against null hypothesis of no trend. The test then calculates a statistic called the Kendall tau rank correlation coefficient and the autocorrelation performed using the modified non-parametric trend test, which is suitable for auto correlated data, the Mann-Kendall (MK) test statistic was performed at a 5% significant level to observe the trend in data, if the differences are mostly positive or mostly negative, then these suggest the trend in the data, but it is important to note that it cannot determine the cause of the trend [56]. The Mann-Kendall test is a useful tool for identifying trends in time series data, various studies have employed MK tools for trend analysis, for example; in water quality analysis, for temperature and rainfall analysis [57-60]. To assess the significantly of the trends the Mann-Kendall (MK) test used, 'n' time series value (x_1-x_n) is replaced by their relative ranks (R_1-R_n) is starting from as the lowest rank and considered as the highest rank. The test statistics of the MK for the time series x is computed as a sum of the signs of the slope [61]. Which is given at Eq. (1) and MK trend was calculated by Eq. (2) below:

$$S = \sum_{i=1}^{n-1} + \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i) \quad \text{..........(1)}$$

$$\begin{aligned} \operatorname{sgn}(X_j - X_i) &= 1 if (X_j - X_i) > 0 \\ \operatorname{sgn}(X_j - X_i) &= 0 if (X_j - X_i) = 0 \\ \operatorname{sgn}(X_j - X_i) &= -1 if (X_j - X_i) < 0 \end{aligned} \quad \text{..........(2)}$$

Where, x_j and x_i are value of sequence and "i^th^" and "j^th^" terms, and "n" is the length of the time series and, documented that the statistic "S" is approximately normally distributed when n ≥ 8 [55]. For identifying the trend, a hypothesis is set as follows; the null hypothesis (H_0) signified no trend in the data being tested. Alternative hypothesis (H_1), indicated the presence of a trend, either increasing or decreasing monotonic trend. As well as the mean and variance of statistics "S" as follows;

$$E(S)=0 \quad \text{..........(3.1)}$$

$$Var(S) = n(n-1)(2n+5) - \sum_{i=1}^{m} T_i i(i-1)(2i+5) \quad \text{.........(3.2)}$$

Where, T_i is the amount of data in the tied and m is the number of groups tied ranks. Probability associated with s and the sample size; n was calculated to assess the significance of the trend. The significance of the trend was also being assessed using Z values, where negative and positive scores of Z denoted downward and upward trends respectively. For a two-tailed test, at a given\ varvecα level of significance, (H_1) is accepted if $|Z| > z_1 - \frac{\alpha}{2}$, whereby, $z_1 - \frac{\alpha}{2}$ was calculated from standard normal distribution tables. Statistically quantity, the significant of the trend computed from the probability associated with MK and sample size "n". The normalized test statistic; then Z can be calculated using Eq. (4):

$$\begin{aligned} Z &= S - 1\frac{ifs}{V_s} > 0 \\ Z &= 0 ifs = 0 \\ Z &= S + 1\frac{ifs}{V_s} < 0 \end{aligned} \quad \text{..........(4)}$$

If Z is negative the trend is considered decreasing and the other way round is true.

The Sen's estimator or the median slope, is a non-parametric method for estimating the slope of a linear relationship between two variables, from these study Sen's slope was used by taking all possible pairs of data points and calculating the difference in their values for both X and Y variable, when the data contain outliers or be non-normally distribute, the median difference is then taken as the estimator for the slope of the linear relationship [62]. This method is robust to outlier because the median is less sensitive to extreme value than other measure of central tendency. WMO (World Meteorological Organization) recommends this test as a part of the detection of trend in hydro meteorological data [50]. The Sen's slope test (Q_2) is given in Eqs. (5) and (6) as follows:

$$Q_i = j_{(X_i, X_j)} - 1$$
$$i = 1,2,3,....,N \qquad ....(5)$$

Where, (i=1,2,3,4,...-i,N), X_j and X_i are presenting data values at the time j and\varveci (>\varveci) respectively. If there are n(n−1) n values of X_j in time series, there will be N=n(n-1)/2 slope estimates, also N value of Q_i is slotted from smallest to largest. Overall, Sen's slope used median Q_i (Q_{med}) at a confidence interval of 90% and 95% which given by the Eq. (6) below;

$$Q_{med} = Q_{2N+1}, ifN = odd$$
$$Q_{med} = Q_{2N} + Q_{2N+1}, ifN = even \qquad ....(6)$$

The Sen's estimator is computed by the top part of the Eq. (6) if N is odd, and by the lower if is the N is even.

Probability of dry spells occurrence

During dry spells, there is typically a period of little or no rainfall events. Consequently, the rain season is defined as a succession of wet spells and dry spells [63]. The beginning of the first wet spells in short rain, in October, marks the beginning of the rain season, whereas, the end of the last wet spells in the long rain in May marks the end of the rain season. For determining the length of the dry spell's statistics package Instat v3.36 was adopted at this study [64]. From the studies carried out in Tanzania; less than 1.0 mm daily rainfall for dry, and greater than 1.0 mm for a wet day, is the threshold values that was adopted. In Tanzania, the occurrence of dry spells can vary greatly depending on the location and time of the year [6]. The Instat climatic tool and direct method was employed to determine the length of a maximum dry spells during the rainy season for every year by using daily rainfall data [8]. Followed by, the maximum length of a dry spells of each year was determined as the longest consecutive dry days for a station. In addition, Mann-Kendall's test statistics (MK) at a 5% significant level and Sen's slope test (Q_2) was used to detect trends (rate of change) in the series of the maximum dry spells.

In contrast, Markov chain is a mathematical model that describes a sequence of events where the probability of the current rainfall event depends only on the state of the previous rain event and is best relate if in sequential order [65]. In order to estimate probability events occurrence of rainfall and dry spells as usually used in the analysis of daily rainfall, the first order Markov chain modeling approach was utilized in different studies, for example; extensively used in daily rainfall occurrence detection by Kottegoda et al. and Schoof et al. [66,67]. A rain condition is well-defined as a 24-hour period with the total quantity of rain. Otherwise, the state considered sunny. Rainfall occurrence is well described by the first-order Markov process as it is stochastic [68]. The assumptions based on main stochastic events is that, rainfall received for any given day follows a random distribution, only dependent on two scenarios that, the day is either dry (P(rd)) or rain (P(rr)) as described by [65]. In the context of modelling, a first- order Markov chain can be used to describe a process where the distribution of the forthcoming state y_{n+1} depends only on the current state y_n and doesn't depend on the previous ones y_{n-1}, y_{n-2}..., y_1. The characteristics of rainfall are well described by a sequence of dry (y_i=0) or wet (y_j=1) days in a given year (Q_1) as defined by [8].

The Eq. (7) provides the rainfall in a given year and the probability is given by the Eqs. (8) and (9) as following:

$$Q_1 = \{y_1, y_2, y_3, y_4, \ldots, y_{i-1}\}$$
$$RepresentQ_1 = \{1,2,3,4,\ldots,i-1,\ i\} \qquad ....(7)$$

Where, "i" is the number of years and "j" is the day number of the year. The probability of a day being rain after a dry day can be obtained as:

$$P(rd) = Prob(y_{j=1}, y_{j-1=0}) \quad \text{Thus;}$$
$$P(rd) = \sum_{Q=i}^{Q=i}(y_{j=1}, y_{j-1=0})$$
$$P(rd) = \sum_{Q=1}^{Q=1}(y_{j-1=0}) \qquad ....(8)$$

The probability of a rainy day following a rainy day can be described with Eq. (9):

$$P(rr) = \sum_{Q=i}^{Q=i}(y_{i=1}, y_{j-1=1})$$
$$P(rr) = \sum_{Q=1}^{Q=1}(y_{j-1=1}) \qquad ....(9)$$
$$P(rr) = prob(y_{j=1}, y_{j-1=1}) \quad \text{Thus;}$$

Furthermore, the Fourier analysis function was used to estimate probability, F-test of three harmonics level was used to determine the best fit function for models of the stations. Ordinary Kriging interpolation technique from ArcGIS10.4.1 was used to generate raster surfaces [69].

RESULTS AND DISCUSSION

Rainfall climatology

From Figures 2 and 3, the figures show the monthly cycle of the rainfall and measure of drought over nine (9) stations by using SPEI-24 months across Tanzania for the range period from 1981-2019. From the results, Kagera, and Mwanza stations (northern), the stations show that there is fairly significantly increase in annually rainfall. Songea (southern) has shown the statistically significantly decrease of annually rainfall. Furthermore, Dodoma and Morogoro (Central), Dodoma has showing there is no trend in the annually rainfall, since Morogoro has showing statistically significantly increasing of annually rainfall with Sen's slope of 0.001 and p=0.001. Mtwara (southeastern) station has showing slightly increase of the annually rainfall. Kigoma and Tabora stations which are presenting (western party), the results reveal statistically significantly decrease of the annually rainfall. The long rainfall seasonal peaks centered on April for (MAM) rainfall season, and short rainfall season around December for (OND) rainfall season, MAM and OND are the major period for rainfall over most parts of Tanzania [44]. The North, North- East and Coastal areas of Tanzania are characterized by a bimodal rainfall pattern. The so called 'short rains' ("Vuli") occurring from October to December and the 'long rains' ("Musimu") last from January or February to May. The rest of the country has a unimodal rainfall pattern with rainfall occurring from March to May ("Masika") [70]. Throughout all stations, indicate that the peak of the first rain season is indicated to occur in April and usually associated with above average rainfall amount across most parts of the country (Figure 2), during these months most influential rainfall driver is the Inter Tropical Convergence Zone (ITCZ), during these time ITCZ move towards northern hemisphere and allowing low- level moisture convergence across the equator [71].

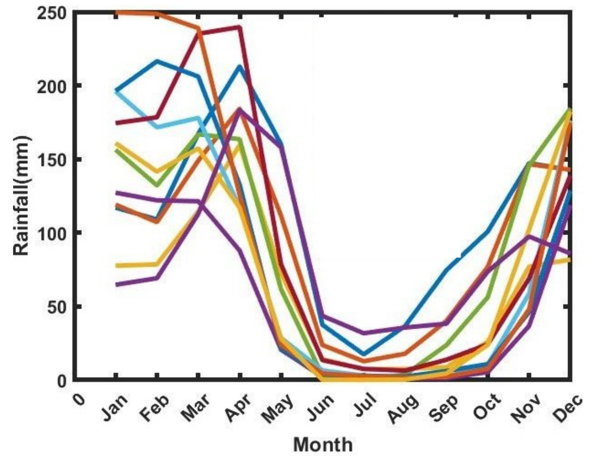

Figure 2: Monthly time cycle of rainfall for meteorological stations over Tanzania (1981-2019). **Note:** (▬) Kagera; (▬) Mwanza; (▬) Arusha; (▬) Dodoma; (▬) Kigoma; (▬) Mbeya; (▬) Morogoro; (▬) Mtwara; (▬) Songea; (▬) Tabora; (▬) Tanga.

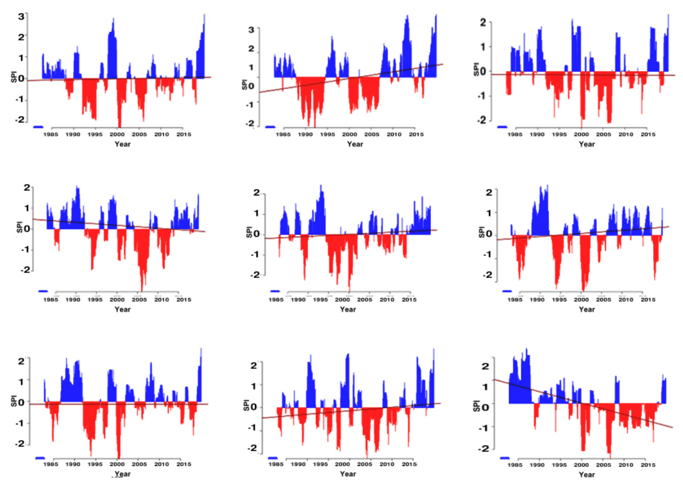

Figure 3: Measure of drought over 9 meteorological stations across Tanzania using SPI 24. **Note:** (▬) rainfall season; (▬) short rainfall season- (a) Arusha-SPI 24, (b)Kagera- SPI 24, (c) Dodoma- SPI 24, (d) Kigoma- SPI 24, (e) Mtwara- SPI 24, (f) Mwanza- SPI 24, (g) Tabora- SPI 24, (h) Morogoro- SPI 24, (i) Songea- SPI 24.

During June-July-August-September, this period of the month is considered as the dry and cold season, is a relatively period of suppressed rainfall, however, an average from 0.0 mm to 50 mm of rainfall is received from 1981 to 2019 as indicated in Figure 2. Kagera is the station receives the highest rainfall during OND season and Mwanza during MAM season both stations located at northern party of the country with comparison to other stations, might be due to its location in the north of Lake Victoria basin which is influenced by the ITCZ movement Southward and linked to the relative stability of the northeast and southerly trade wind regimes in boreal summer and winter [72].

Trends of the length of maximum dry spell days in rain months

As per results of Mann-Kendall's (MK) trends analysis for maximum dry spells in rain months MAM and OND are indicated in Table 1. From the table, results show that, the maximum dry spells days in March in rain season (MAM), has been decrease in the station of Arusha, Dodoma and Mwanza. Although, the decrease is statistically insignificantly with p=0.28, p=0.21, and p=0.44, respectively. For the same month, in the stations of Kagera, Kigoma, and Songea the result showing no rate of changes for the maximum dry spells days. Furthermore, for the month of April, the result of MK trend indicates that, the length of maximum dry spells days has increase at Songea station, statistically insignificantly with p=0.11 and insignificantly rate of change of (Q_2=0.15 day per month). As well as, an insignificantly decreasing trend of maximum dry spells days in April has showed at Dodoma station with p=0.27 and insignificantly rate of change of (Q_2=-0.08 day per month).

For the month of May, the result shows that, the MK trends for maximum dry spells days have increase statistically significantly at Dodoma station with p=0.05 and insignificantly rate of change of (Q_2=0.25 day per month), but, Kigoma and Mtwara stations showing the rate of increase in May is insignificantly at the rate of (Q_2=0.09 day per month and Q_2=0.07 day per month), respectively. Furthermore, Morogoro and Tabora stations, the result indicate that the MK trend has showing the decrease insignificantly for the maximum dry spells days at both stations.

Generally, April is the peak month for the rain season MAM (Figure 2), therefore the decrease in the length of maximum dry spells days is anticipated in between April and May. June, July, August, and September considered as a dry and cold season throughout the country [6,44]. Since (p>0.05) for the months of June, July, August, and September, this month did not show statistical important in increase or decrease trend. From the end of September or the early October usually is the beginning of the short rain season (S/OND) but frequently considered as (OND rain season) occurs in north, north western and coastal regions [43]. The results obtained from the study showed an increase significantly MK trend in the length of maximum dry spells days in October at Morogoro with p=0.01 and insignificantly rate of change Q_2=0.37 day per month and remaining stations Arusha, Mtwara, and Mwanza showed a statistically insignificantly decrease trend of the maximum dry spell days. In November Arusha station showed statistically insignificantly increase trend of the maximum dry spells days, while Morogoro and Mwanza stations on the same month has showed statistically insignificantly decrease trend of the maximum dry spells days at (p=0.63 and p=0.09), and significantly rate of change of (Q_2=-0.04 days per month) and insignificant rate of change of (Q_2=-0.07 days per month), respectively. Furthermore, the result indicates that, there are statistically significantly decrease trends in December in the maximum length of a dry spells days at Kigoma station with p=0.02 and significantly rate of change of (Q_2=-0.03 days per month). It is observed that Kagera, Morogoro, and Mtwara stations has showed statistically MK insignificantly increase of the maximum length of a dry spells days at (p=0.17, p=0.36, and p=0.62) and with significantly Sen's slope of 0.034 and 0.053 day per month at Kagera and Mtwara, respectively, since Morogoro indicate insignificantly rate of change.

Finally, the result showed that, there are statistically insignificantly increase trends in January and February in the maximum length of dry spells days at Arusha and Dodoma stations. It is observed that Morogoro, Mwanza, and Songea stations has showed statistically MK insignificantly decrease of the maximum length of a dry spells days and with insignificantly rate of change for Morogoro, and Mwanza.

The analysis of probability of dry spells occurrence

The general message of this chapter is to provide an awareness of the current status into dry spells occurrence over Tanzania, the probability of dry spells occurrence of 8, 11 and 14 days after the start of the first season (day 61) of the year and second season (day 274) that access to detailed daily rainfall from 1981 to 2019. An event is a characteristic of interest for which there is a single observed value each year 64. Some examples: The length of the dry spells (in given year); and the date of the start of the rains. The analysis of probability of dry spells is obtained straight forward from daily rainfall data from 9 stations. The start of rain season is based on amount exceeding 20 mm in 1 or 2 days after 1st March and 1st October.

The results of the analysis are presented in Figure 4. The result indicates that, for the season (MAM) in Tanzania early March (Day 61) of the year, at the start of the season the probability of 8-day dry spells is the highest at all stations. The probability of dry spells ranges from 62.7% at Arusha station, 39.9% at Dodoma station, 24.7% at Morogoro station, 15.6% Mtwara, 8.5% at Tabora station, and 3.1% at Songea station. The highest probabilities occurred by the first 6 days of March observed at Arusha and Dodoma stations. With bimodal rainfall, Mwanza and Kagera indicate the lowest dry spells probability of 5.8% and 0.8% respectively. Furthermore, as the rains progress towards the end of March, the probability of 8-days dry spells increased at Dodoma, Tabora, and Songea with dry spells probability of 92.2%, 67.7%, and 69.9%, respectively and decrease across Arusha, and Kagera with 46.5% and 1.0% dry spells probability occurrence, respectively.

Table 1: Mann-Kendall's test and Sen's slope (Q_2) results of the trend of the maximum dry spell during the rainy season (March-April-May and October-November- December)

Stations	Variable	March	April	May	June	July	August	September	October	November	December
Songea	S	-	1.47	30	-	-	-	-	-	-	-
	P	0.96	0.11	0.75	-	-	-	-	-	-	-
	Q_2	0	0.14	0	-	-	-	-	-	-	-
Arusha	S	-100	-27	-39	-	-	-	-	-128	73	12
	P	0.282	0.777	0.679	-	-	-	-	0.168	0.434	0.905
	Q_2	-0.091	0	-0.04	-	-	-	-	-0.435	0.067	0
Kagera	S	-16	-106	37	-	-	-	-	152	19	125
	P	0.869	0.245	0.694	-	-	-	-	0.097	0.843	0.172
	Q_2	0	0	0	-	-	-	-	0.042	0	0.034
Dodoma	S	-117	-103	176	-	-	-	-	-	-	-
	P	0.207	0.267	0.05	-	-	-	-	-	-	-
	Q_2	-0.071	-0.08	0.25	-	-	-	-	-	-	-
Kigoma	S	-96	-102	171	-	-	-	-	11	-106	204
	P	0.289	0.266	0.064	-	-	-	-	0.913	0.245	0.021
	Q_2	0	0	0	-	-	-	-	0	0	-0.025
Mtwara	S	31	-18	64	-	-	-	-	-71	-19	47
	P	0.743	0.853	0.494	-	-	-	-	0.447	0.845	0.617
	Q_2	0	0	0	-	-	-	-	-0.077	0	0.053
Mwanza	S	-72	-76	-15	-	-	-	-	-85	-156	-16
	P	0.439	0.412	0.879	-	-	-	-	0.361	0.089	0.868
	Q_2	-0.029	0	0	-	-	-	-	-0.045	-0.071	0
Tabora	S	-72	-76	-15	-	-	-	-	-85	-156	-16
	P	0.439	0.412	0.879	-	-	-	-	0.361	0.089	0.868
	Q_2	-0.029	0	0	-	-	-	-	-0.045	-0.071	0
Morogoro	S	-3	-34	-102	-	-	-	-	251	-45	85
	P	0.983	0.719	0.272	-	-	-	-	0.007	0.632	0.361
	Q_2	0	0	-0.095	-	-	-	-	0.371	0.04	0.115

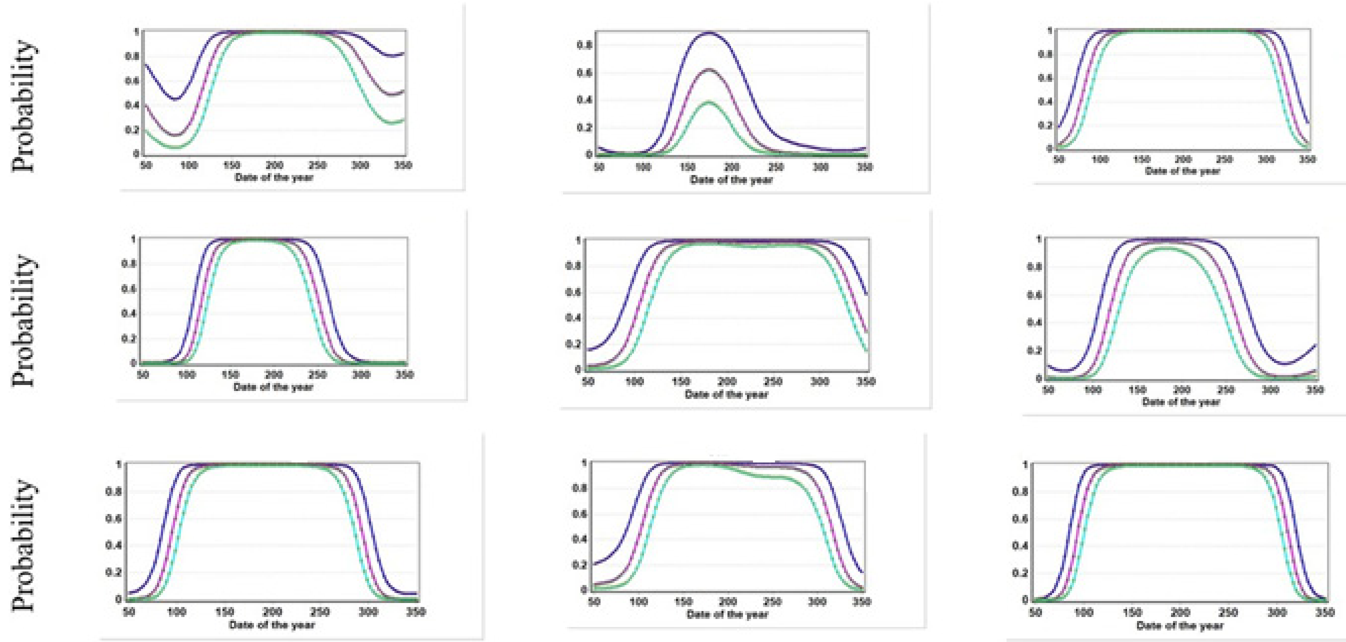

Figure 4: The risk of the long dry spells in 30 days following planting (rainfall) seasons March-October (day 61-day 274) for 9 stations across Tanzania. **Note:** (blue) sp8; (magenta) sp11; (cyan) sp14- (a) Arusha station, (b)Kagera station, (c) Dodoma station, (d) Kigoma station, (e) Mtwara station, (f) Mwanza station, (g) Tabora station, (h) Morogoro station, (i) Songea station.

This time looking at the first MAM rainfall season, we looked the distribution of the 11-days probability of the dry spells. The results show that, 11-day dry spells are fairly moderate over most stations raging between 26.2% and 1.2%. Moreover, Kigoma, Kagera, and songea stations continued to show the moderate probability of 0.001%, 0.2% and 0.3% for 11-days dry spells, respectively. Finally, the chances of 14-day dry spells are low (<4.0% probability) across the stations.

While, the second season OND, the chances of dry spells occurrences over 9 stations depending on the climatological zones, the result showing that 3 stations out of 9 which are Kagera and Mwanza showed the lowest 8-day probability of dry spells in October in the range of 7.2% and 4.7% (Table 1 and Figure 5), respectively. Since, Tanzania experiences two distinct rainfall patterns, this stations which are located in northern and northern west receive rainfall in two main rain seasons (MAM and OND). October is the beginning of the OND rain season in Tanzania, but due to high 8-days of dry spells across Arusha, Dodoma, Morogoro, Mtwara, and Tabora rainfall is not attainable. This tendency continuous up to the fourth week of November. The result indicates that, the probability of 8-days dry spells decreased to 61.3%, 36.6%, 14.5%, 13.6%, 5.4%, 3.0%, 2.1% and 0.5% at Dodoma, Mtwara, Mwanza, Morogoro, Tabora, Songea, and Kigoma, respectively. The second week of December, the probability of 8-days dry spells shows the significantly fall throughout the country. Arusha stations show higher probability of 8-days dry spells in the OND season. Generally, the probability of 11-days dry spells shows the lower occurrence as 0.001%, 0.3%, 0.6%, 2.1% and 2.7% at Kigoma, Kagera, Tabora, Songea, and Mwanza stations, respectively and probability of 11-days dry spells is moderate over all remaining stations at the ranging between 49.2%, 36.6%, 28.2% and 13.6% at Arusha, Mtwara, Dodoma, and Morogoro stations, respectively. The estimated chances of 14-dry spells show that, in the OND season are very low as less than 4.1% at Kagera, Kigoma, Tabora, Songea, Mwanza, and Morogoro, yet, Arusha, Dodoma and Mtwara reveal the moderate probability of 25.7%, 16.6% and 11.3% respectively, for 14-days dry spells at 13th December since the start of the OND season. In the northern and west region of Tanzania probabilities of 8-days dry spells are relatively low during the OND season show the tendency of bimodal rainfall system, but, northern eastern highland, southern eastern and central regions which include Arusha, Dodoma and Mtwara shows highly probabilities of 8-days dry spells during the OND season. By the first week of October, at Mwanza, Kagera, and Kigoma stations, the probabilities of 8-days dry spells of these stations remained less than 17.8% and the probabilities of 11 days and 14 days' dry spells less than 6%.

The aim of this study has been to encourage the full use of climatic data in rainfed agriculture. Rainfed production dominates agriculture in Tanzania, covering about 46% of total cropland and accounting for more than half of the world's food production [40]. Mainly wheat that can barely survive without extra irrigation and irrigation contribution to global crop yields remain uncertain, to divert water that's already scarce due to the impacts of the climate change such as drought and dry spells during the crop growing season, it would be better to switch efforts to sustainable agriculture to attain its potential contribution [73]. The dry spells occurrence within sowing season plays vital role in determining productivity of rainfed crops [74]. Dry spells of 8-days during March-October on major rainfed crops across Tanzania has cumulative impact on crop growth and yield. Furthermore, dry spells above 11 days and 14 days have economic impacts on Tanzanians across the entire country by depriving them of food and water, dry spells they are a devastating natural disaster causing deaths for livestock and affecting food security and increase poverty and much of the damage is done to agriculture which bears up to 80% the economic cost of drought in developing country [75]. Climate change is already intensifying dry spells and increasing their frequency across East Africa [11]. The traditional response of climate change which cause the dry spells occurrence is not enough to meet sustainable development goals, the response to a proactive approach that reduces impact build resilience and allow farmers to cope with dry spells and allow food production to continue. In East Africa region, dry spells probabilities of 5 days-10 days are more common and raging from 4% to 31% during the first month of both rain seasons [76]. In Africa, 90% of the main food production is from rainfed agriculture; generally, with low yields and a high risk of crop failure and one of the reasons for crop failure is the occurrence of dry spells during the sowing and growing season [77]. The study from 8 by using Markov chain process to obtain meteorological dry spells and by using rainfall data (daily) in a simple water balance to obtain agriculture dry spells. The meteorological dry spells analysis showed a minimum probability of 20% of dry spells exceeding 10 days at both sites, increasing to 70% or more depending on onset of season. The agriculture dry spells analysis showed that maize was exposed to at least one dry spells of 10 days or longer in 74%-80% of seasons at both sites. Understanding probabilities of dry spells is a defining sustainable development across the country. Its impacts can be distressing and affect the whole community, but not all dry spells distribution is the same. They vary in the size of the area affected, intensity and how long they last.

In fact, our environment is vulnerable during the dry spells' occurrence. From the result shows that, Northern eastern highland area, and central dry spells occurrence is highly throughout first and second rain season, some parts of the country show moderate and fairly lower probability of occurrence. With Tanzania changing climate, dry spells are expected and may be more intense to these areas.

The overall probabilities of rainfall occurrence

The beginning of the OND rain season has nearly two weeks of interannual variation across the different agro climatic regions of Tanzania with comparison to MAM rain. By the middle of February and the beginning of March and further to April strengthening of rain conditions over all the station observed, this clarifies Tanzania has two peaks of probabilities of rain in a year (Figure 6). The first rain season MAM across all the stations, range between 22%–62% which is on average between day 50 (February 19th) and day 90 (March 31st) and conditions maybe intensifies or moderate in the beginning or at the end of day 100 (April 10th) (Figure 6). The second rain season OND varies great from one station to another, maximum probabilities of rain across the stations ranges between less than 18%–58%, which occurs approximately on day 274 of the year (1st October).

Furthermore, the mean rain per day for each day of the year used for fitting the 3 dialogues (Figure 7). The result shows the fitted model, the estimated chance are higher probabilities of receiving rain if the previous day was rain (Prr) and chance are lower probabilities of receiving rain if the previous day was dry (Prd).

The result show that the chance of a planting season of more than one set of months, March-May and October-December, for the region characterized by bimodal pattern as displayed in Figure 7, Kagera and Mwanza stations show a high probability of rain occurrence. Within the OND season, rainfall has increased and showing to increase in future on these areas, meaning the risk of dry spells through OND season might be dropped at Kagera and Mwanza [44]. This result can help in determining agriculture strategies and can be utilized in crop management. Agriculture depends on a stable climate with predictable seasons and weather patterns. The periods of June-July-August-September indicate reduction in rainfall probabilities for 6 out of 9 stations, that shows the period is relatively dry, but Kagera station indicate highly probabilities of rainfall. This means this period is best for crop harvesting, drying and other post-harvest activities. Late September is early suggested as the time for field preparation for the next farming season across larger area of the country.

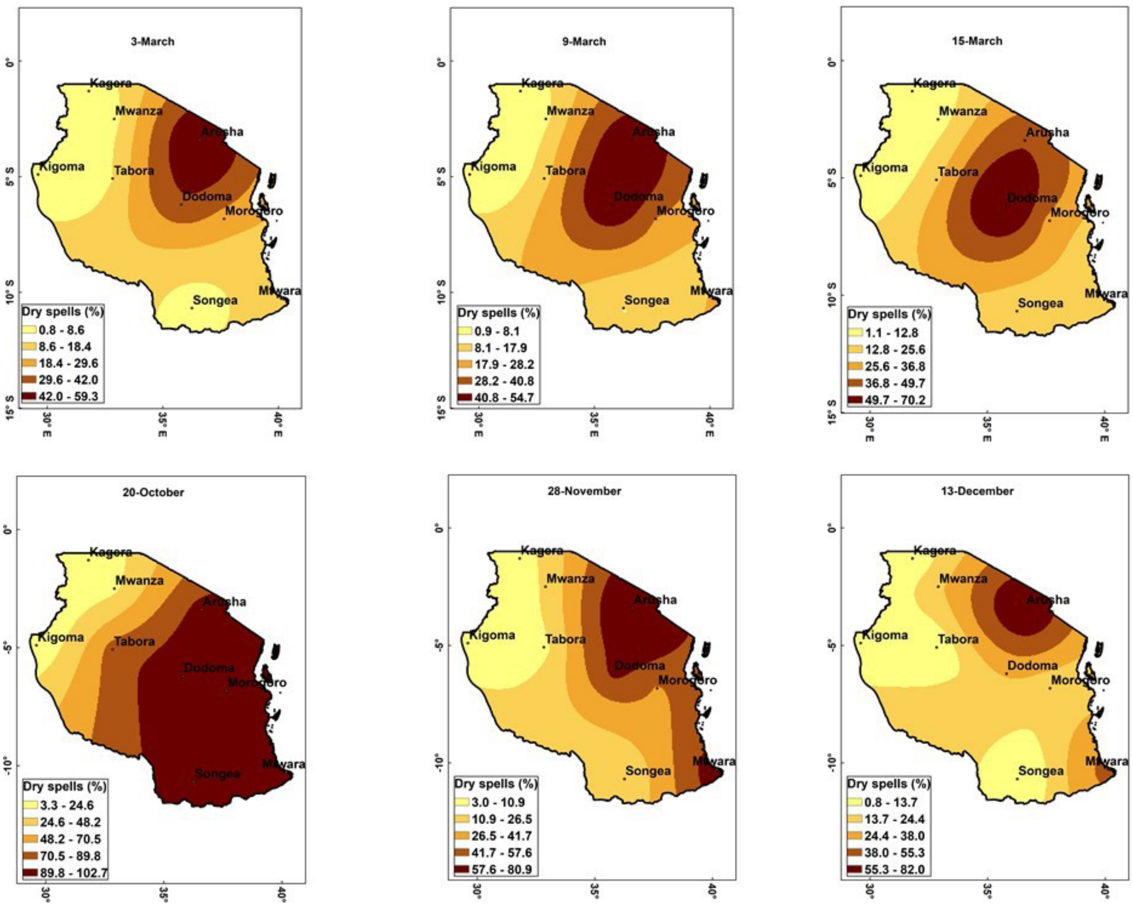

Figure 5: Spatial distribution of 8-day dry spells for March, October, November, and December.

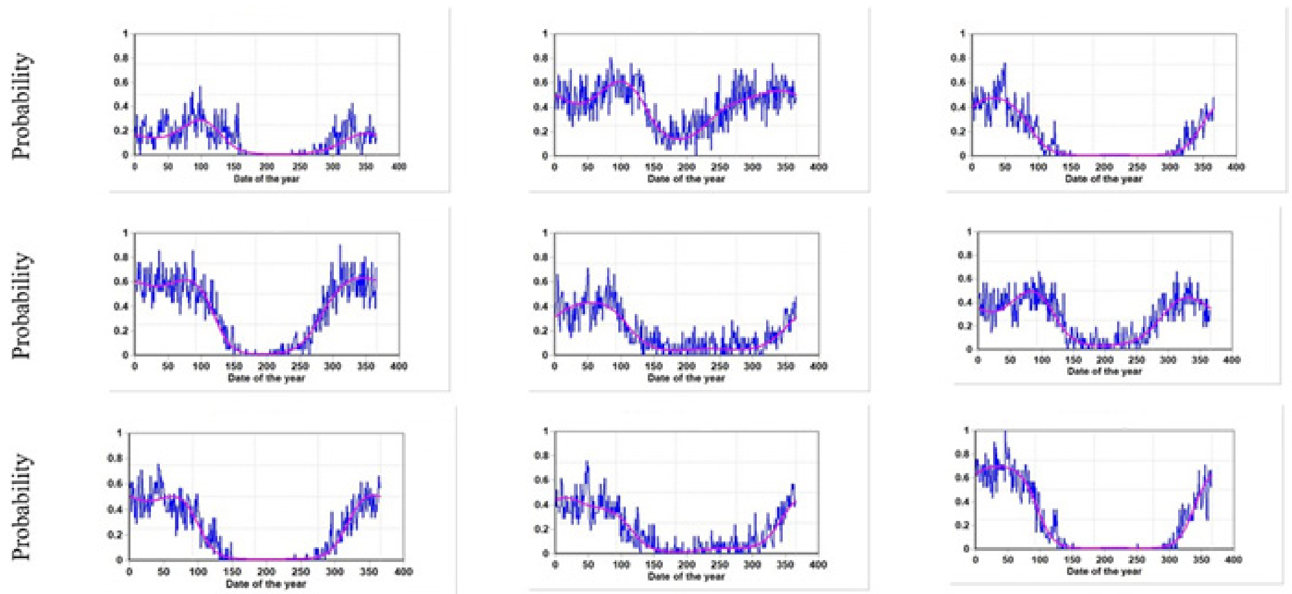

Figure 6: Probabilities of rainfall occurrence over 9 stations across Tanzania. **Note:** (blue) P_r; (pink) P_rr- (a) Arusha station, (b)Kagera station, (c) Dodoma station, (d) Kigoma station, (e) Mtwara station, (f) Mwanza station, (g) Tabora station, (h) Morogoro station, (i) Songea station.

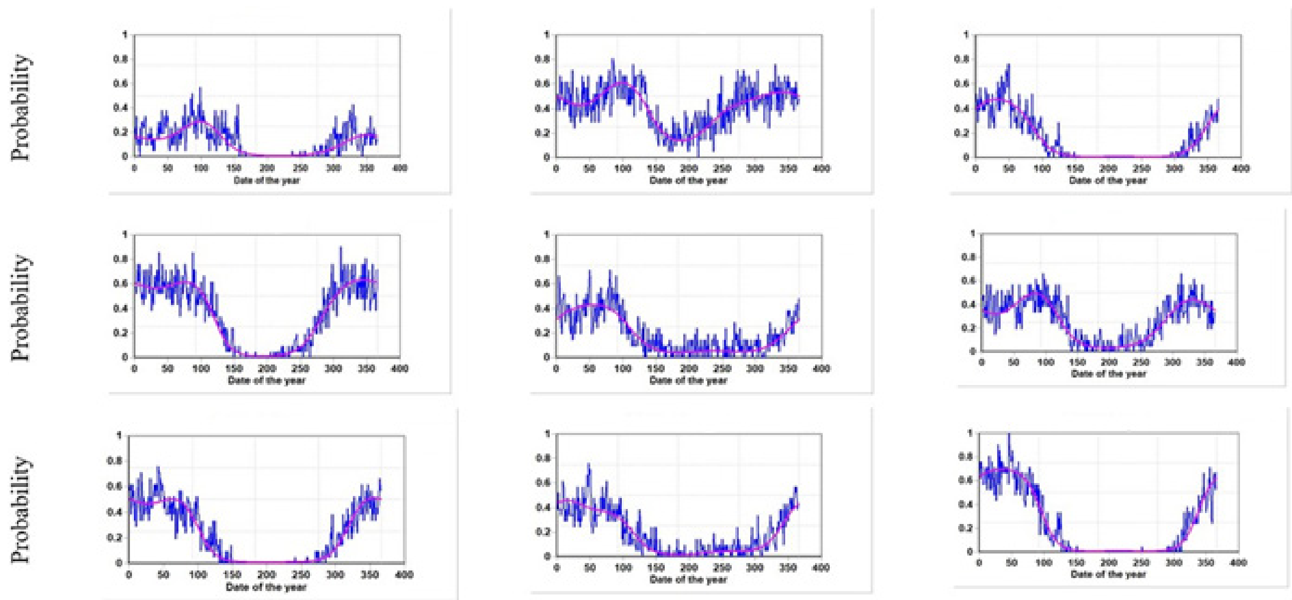

Figure 7: Probabilities of rainfall occurrence during the seasons P(r), and the probability of rain given previous day was dry P(rd) and received rainfall P(rr) given the previous day was wet. **Note:** (blue) P_r; (pink) P_rd; (cyan) P_rr- Overall chance of rain: (a) Arusha station, (b)Kagera station, (c) Dodoma station, (d) Kigoma station, (e) Mtwara station, (f) Mwanza station, (g) Tabora station, (h) Morogoro station, (i) Songea station

CONCLUSION

The study deepening the discussions around the variability of rainfall seasons by look critically at the trends in the length of the maximum dry spell days throughout 9 stations across Tanzania. Maximum dry spells analysis was assessed from daily rainfall based on a threshold of less than 1.0 mm for the dry day. From this study, trend analysis involves collecting the information from accounting period from 1981 to 2019 and plotting it with the objective of finding actionable patterns. Mann-Kendal's trend statistically techniques at a 5% significance level and the rate of change tested by Sen's slope (Q_2). Basically, looking at its interpretations of rainfall occurrence and maximum dry spells occurrence for 8, 11, and 14 days, dry spells was obtained by using a Markov chain property.

The results showed that, Mtwara and Tabora stations for the first month March in the MAM rainfall season, there is an increasing statistically insignificantly trend of the maximum dry spells out of 9 stations table, Furthermore, Arusha, Kagera, Dodoma, Kigoma, Mwanza, Morogoro, and Songea showed decrease trends in the length of the maximum dry spells during the month of March only with statistically insignificantly for both stations. During the month of April, under selected core regions for this study, what has been observed is the persistent statistically insignificantly decline of the maximum dry spells in Arusha, Kagera, Dodoma, Kigoma, Mtwara, Mwanza, Tabora, and Morogoro. But, Songea indicate statistically insignificantly increase of the maximum dry spells during the month of April. Only Dodoma station showed a statistically significantly increase in the length of maximum dry spells in the Month of May, with p=0.01 for the MAM rainfall season.

Moreover, the result shows that in October, for the short rain period of the year there is a statistically significantly increase trend in the length of the maximum dry spells at Morogoro station with p=0.01.

But, Kagera and Kigoma on the same month show the statistically insignificantly increase in the length of the maximum number of dry spells and the rest of the stations showed insignificantly decrease trend of a maximum dry spells in October. January or February to April is specified as the possible very wet periods for the selected stations. The probability (risk) of extreme events such as dry spells is important for agriculture for the farmers for planning their cropping strategy. A conditional analysis at the start of rain season October to December indicate that 8-days of dry spells are higher in the range from 42.2%-82.0% at central, northern eastern highland, and southern eastern coastal area as well as from 0.5%–24.0% at west, northern, and northern west and this decrease as the season progress in most stations. The chances of the probabilities of 11 days and 14 days dry spells after the beginning of the rain season throughout the selected stations are range from 0.2%-25.7% overall risk of dry spells through the season is likely to be lower for the crops that are sensitive to drought at a particular growth stage. The highly probability of dry spells in the OND rain season could be related to a climate pattern known as La Niña usually associated with frequent droughts. Through the study of 43 they investigated historical and projected rainfall in Tanzania, rainfall is highly variable in both space and time due to topographical variations, coastal influences, and the presence of lakes. Maximum rainfall declines during long rain season in the fall (March-May), and an increasing rainfall trend in the north during the short rain season (September-November) this observation is highly correlated with probability of the maximum dry spells' occurrence obtained from this study, since Arusha, Dodoma, and Morogoro stations considering the significantly impacted from water stress based on the overall analysis of dry spells, the trend of the maximum length of dry spells, and probability of rainfall occurrence. Investing in locally specific mitigation and adaptation methods is needed to improve crop production, these methods include reduce forest loss and improve awareness for local farmer. These efforts are projected to increase crop yield during OND rainfall season since the probability of dry spells occurrence during these periods is highly (42.2%-80.2%) also farmers could grow drought-tolerant crops species. If this method combined with combating deforestation in the region, they could move the country toward a resilient from the dry spells' impacts.

DECLARATIONS

Conflict of interest

The authors declare that they have no conflict of interest.

Funding source

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Author contribution

The data search and analysis were done by DSM. The Result analysis by DSM and manuscript writing was done by all authors.

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