IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Environmental and Earth Sciences Research Journal
Vol. 9, No. 1, March, 2022, pp. 1-7
Journal homepage: http://iieta.org/journals/eesrj

Spatio-Temporal Analysis of Dry Spell for Agricultural Decision Support in North-Central Nigeria

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https://doi.org/10.18280/eesrj.090101

Received: 3 January 2022
Accepted: 18 February 2022

Keywords:
dry spell after onset, dry spell at end of the season, geospatial, temporal, north central

ABSTRACT

This study aims to examine the trend and geospatial variability of dry spells for agricultural decision support. Daily precipitation data spanning from 1981 to 2020 was analyzed using the Instat climatic software to calculate rainfall onset, onset plus 50, length of the growing season, cessation, dry spell 1, and dry spell 2. Multiple regression analysis was used to analyze the trend in maximum dry spell length. Kriging method in Surfer 13 software was used to interpolate and plot dry spell distribution into a spatial grid in the study region. Based on records of daily rainfall data obtained from eight meteorological stations, the spatial distribution of dry spells was generated for the beginning and end of the season. The results obtained revealed a decreasing trend for maximum dry spell length during onset, meaning its recurrence is declining except in Bida, Minna, and Jos that show a positive trend. While the trend for maximum dry spell length at end of the season appears to be positive except for Lafia and Minna that shows a negative trend. The result further indicates that dry spells towards the end of the season are more severe than dry spells at beginning of the season.

1. INTRODUCTION

A period of three consecutive days or more due to lack of rainfall during the wet season is termed as a dry spell, while a pentad dry spell is a consecutive five dry days of no rainfall during the wet season.

The characteristics of dry spell observed in an arid or semi-arid region determines to a great extent what becomes of the few, scanty, and poorly distributed rains usually observed in such areas [1, 2]. Its impact on the environment cannot be overemphasized. Its occurrence and distribution over an area impinge and heavily undermines the effect of the previous rainfall occurrences [3]. Furthermore, it also accounts for the usual and subsequent heat interactions and exchanges within such an environment. Dry spells are usually associated with a high rate of evaporation and transpiration, high demand for water among human beings and animals [4]. The knowledge of the hazards associated with such prevailing drought conditions or spells makes it imperatively necessary to carefully study its characteristics to provide useful information for its management [1, 5, 6].

According to the study [7], precipitation does not usually occur daily during the rainy season. Subsequently, there are breaks in between rain spells, when these breaks become prolonged, plants may wilt or die. In 1919 the British meteorological agency delineated periods of non-rainfall during the rainy season. Mzezewa and Gwata [8] established a dry spell on the length of consecutive dry days with less than 1.0 mm of rainfall, while a dry spell is three (3) consecutive days with less than 1.0 mm of rainfall. Similarly, Adefolalu [7] considered days with less than 2 mm of rainfall as dry days while dry days of equal to or more than three pentads as dry spells.

Mzezewa and Gwata [8] opined that dry spells are dry days having less than 1 mm of rainfall consecutively as a sequence of dry days bracketed by wet days on both sides. Sawa [9] suggested the determination of dry spells based on the Nigerian meteorological agency standard of 2010, which used a rainfall amount equal to or greater than 1 mm as a benchmark for a wet day while days with rainfall less than 1 mm are regarded as dry days. Similarly, 5 consecutive dry days (pentads) are regarded as dry spells.

Sawa and Ibrahim [10] developed "dry spell parameters using a forecast model for the yield of millet and sorghum in the semi-arid areas of northern parts of Nigeria." Their findings indicate that dry spells are critical in the development stages of millet and sorghum during their growing period, as the occurrence of dry spells at some phonological phases of sorghum is beneficial at some development stages and increases its yield.

On the other hand, in Africa and Nigeria in particular, the emphasis of many scholars in the study of tropical climatology has been the consideration of precipitation features, like rainfall total, period, and its intensity. The various precipitation characteristics have been studied in terms of their distributions over space and time, trends, periodicities, planting period (onset), retreat, probabilities [11-15]. Rainfall is highly variable in Nigeria as compared with temperature, which appears to have imbued more relevance to the former as the major component in the study of climate in the region [16-18]. The highly variable nature of the rainfall in the region as compared with the relatively stable nature of the temperature appears to have imbued more relevance to the former as the major component in the study of climate in the region [16-18].

The Spatio-temporal analysis of dry spells frequencies is one of such approaches aimed at studying the variability, duration, and spatial distributions of dry spells, especially within the growing season, to provide useful information required for effective crop planning and subsequent drought monitoring. Therefore, the purpose of this study is to better understand the variability of dry spells and the frequency of their occurrence by mapping the spatial distribution of north-central dry spells to determine the trend.

2. DRY SPELL INDICATORS

2.1 Dry sequences at the beginning of the season (Onset)

The Start of the Growing Season (SGS) at a given place is defined as the date after 1st May, when rainfall amount over three consecutive days is at least 20 mm, with no dry spell exceeding seven days during the following 30 days [19] Therefore, a dry spell at the beginning of the season (dry spell 1) is the consecutive number of long dry days at the first 50 days of the start of the season. This dry sequence usually occurs after the establishment of the onset. However, the dry days are being calculated from day one after the onset of the season has been established.

2.2 Dry sequences at the end of the season (Cessation)

The End of the Growing period (EGP) is the date in a particular place or station after 1st day of September when the soil moisture down to 60 cm depth is zero with daily potential evapotranspiration of 5 mm [20]. To consider the last rains, useful for crops production, in the calculation of EGP, the soil containing 100 mm water holding capacity [21] rather than 60 mm proposed by Li et al. [20].

The end of the growing season dry spell (dry spell 2) which usually occurs in August and September, is the longest dry sequence towards the end of the season, that is to say over the period taking into account the critical periods of heading-flowering and maturation of the crops, can be done, for example from the 50th day after the calculated start date of the season until the end date.

In general, a dry day is defined as a day with a rainfall value of less than 0.85 mm. Nevertheless, the threshold values for dry days are not fixed values threshold, some authors have used different threshold values to define a dry day for their work. Dry spell description is further elaborated in Table 1 below.

Table 1. Index descriptions

Index Name	Explanation
Dry day (DD)	A day with rainfall of <0.85 mm in a day in a year
Dry spell length after Onset (DSL1)	Dry days of three or more consecutive days in June & July.
Dry Spell Length at the End of the Season (DSL2)	Two or more consecutive dry spells in August September
Mean dry spell (MDS)	Is the average or expected dry spell

3. MATERIAL AND METHOD

3.1 Data

Daily climatic rainfall data for forty years (1981-2020) was used for this study. The data were collected from the operational Head Quarters of the Nigerian Meteorological Agency (NiMet). Data collected were subjected to quality control and standardization, before analyses.

3.2 Description of the study area

The north-central part of Nigeria is located between 8°N &10°N latitude and longitude 3°E and 10°E [21]. North-central is characterized by a Tropical Continental Climate marked by a wide variation of annual temperature regime and restricted rainfall, with temperatures and rainfall varying with location and period of the year. The Mean annual temperature ranges from 24°C to 37°C, while the mean annual rainfall is between 100 and 200 cm^3 [22]. The climate of north-central Nigeria is characterized by a rainy season, which extends from April to October, and a dry season that starts in December and lasts till March of the following year. The recession of harmattan for the rains is heralded by the moist Tropical Maritime Air Mass of the Southwest Trade winds. This point is usually marked by hot sunny days with temperatures being highest about March to April.

Soil resources of the area are either friable, porous, coarse-grained sandy or lateritic usually grey or reddish in color, generally low in fertility [22]. The soil supports a wide variety of crop species including cereals such as Maize, Rice, Millets, and Sorghum. These crops supply much of the average farm family's subsistence food requirements as well as a marketed surplus for income. FCT, Benue, Kwara, Nasarawa, Niger, Bida, Plateau, and Kogi station were selected to represent the region. Details of stations considered were presented in Table 2 and Figure 1 below.

Table 2. Station details

Stations	Longitude	Latitude	Elevation (m)
Abuja	7.2	9	360
Bida	6	9.8	132
Ilorin	4.58	8.48	343
Jos	8.9	9.87	1220
Lafia	8.45	8.5	205
Lokoja	6.73	7.8	89
Makurdi	8.5	7.7	91
Minna	6.54	9.56	256

3.3 Data analysis

INSTAT Climate Guide [23] was used in this study. Instat is a general interactive statistics package for microcomputers). Instat's macro facilities were limited for agro-climatic analyses, where data from many stations were used for the analyses. An unconditional dry sequence was adopted which allows having the maximum duration of dry sequence (number of consecutive days without rain with a threshold value of (P <= 0.85 mm) from a given date and for a duration data) for both the dry spell 1 and dry spell 2. Regression analysis where perform to see the trend of the dry spells in each station.

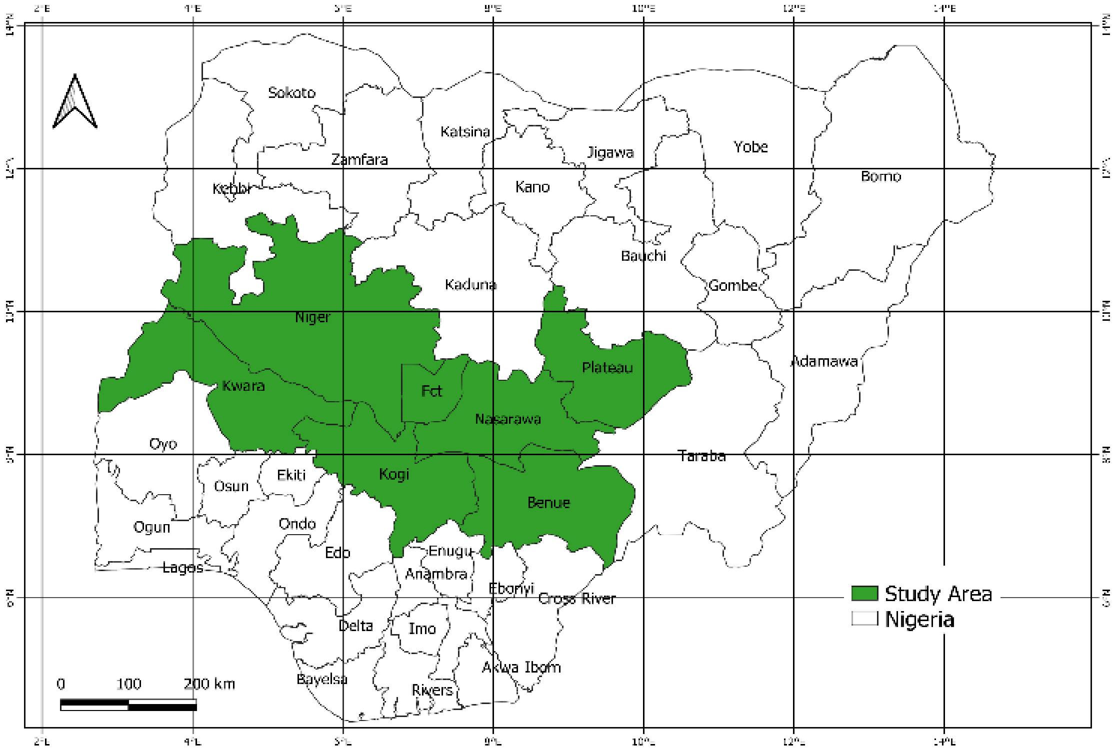


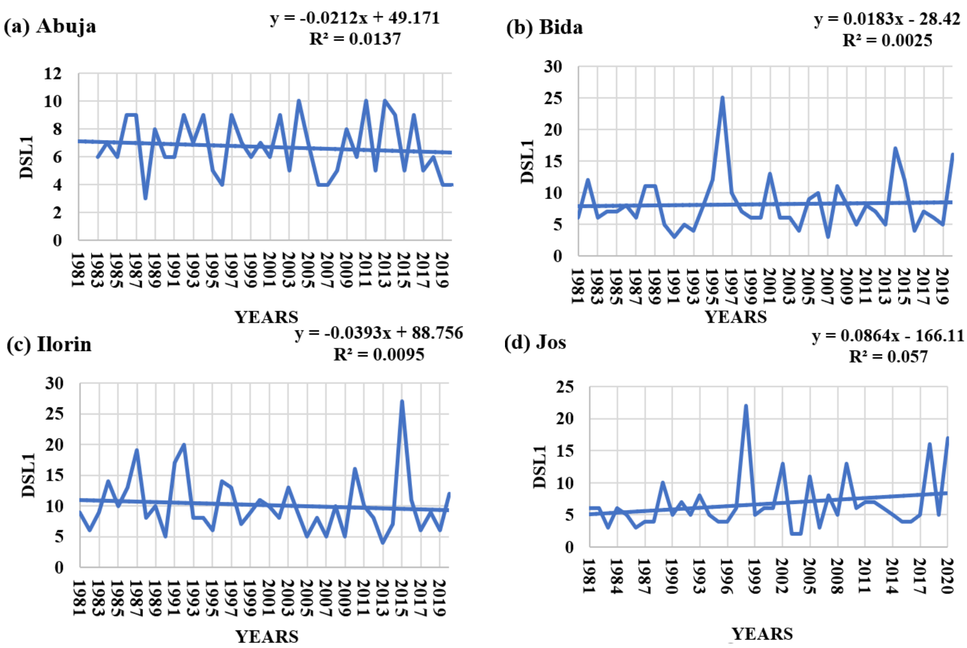
Figure 1. Map Nigeria showing study area

4. RESULTS AND DISCUSSION

4.1 Temporal analysis of dry spell

Plots of the records for maximum consecutive dry spell length for the study area over time in years for the first dry spell.

Figures 2 a-h below presented maximum dry spells length at beginning of the season. Maximum dry spell length of 25, 22, and 16 dry days are the highest recorded within the study period in Bida, Jos, and Minna in the year 1996, 1998, and 2005 respectively. It is interesting to note from Figures b, d, and h (Bida, Jos, and Minna) indicates that the frequency of occurrence of maximum consecutive dry days in the study area is slightly increasing. The best fit line equation is positive (y= 0.0848x-162.9), (y= 0.0864x-166.11) and (y= 0.0271x-46.96) respectively implying an increasing trend in its occurrence. While other locations from Figure 2 a, c, e and f (Abuja, Ilorin, Lafia and Makurdi) shows that the trend line is negative best fit line equation y=(-0.0212x+49.171), (y=-0.0393x+88.756), (y=-0.0573x+122.44) and (y-0.0283x+66.175). The pattern of occurrence of maximum dry spells length trend is decreasing, as a result of ng its frequency is decreasing as indicated in Figures 2 a, c, e, and f. The year, 1973 had the highest incident of dry spell.



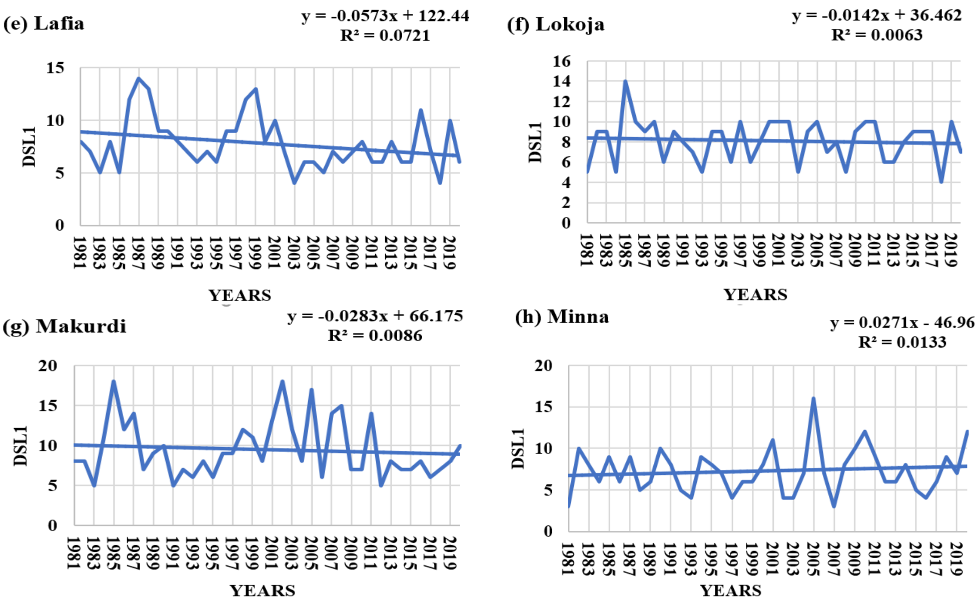


Figure 2. Dry spell 1 in (a) Abuja, (b) Bida, (c) Ilorin, (d) Jos, (e) Lafia, (f) Lokoja, (g) Makurdi and (h) Minna

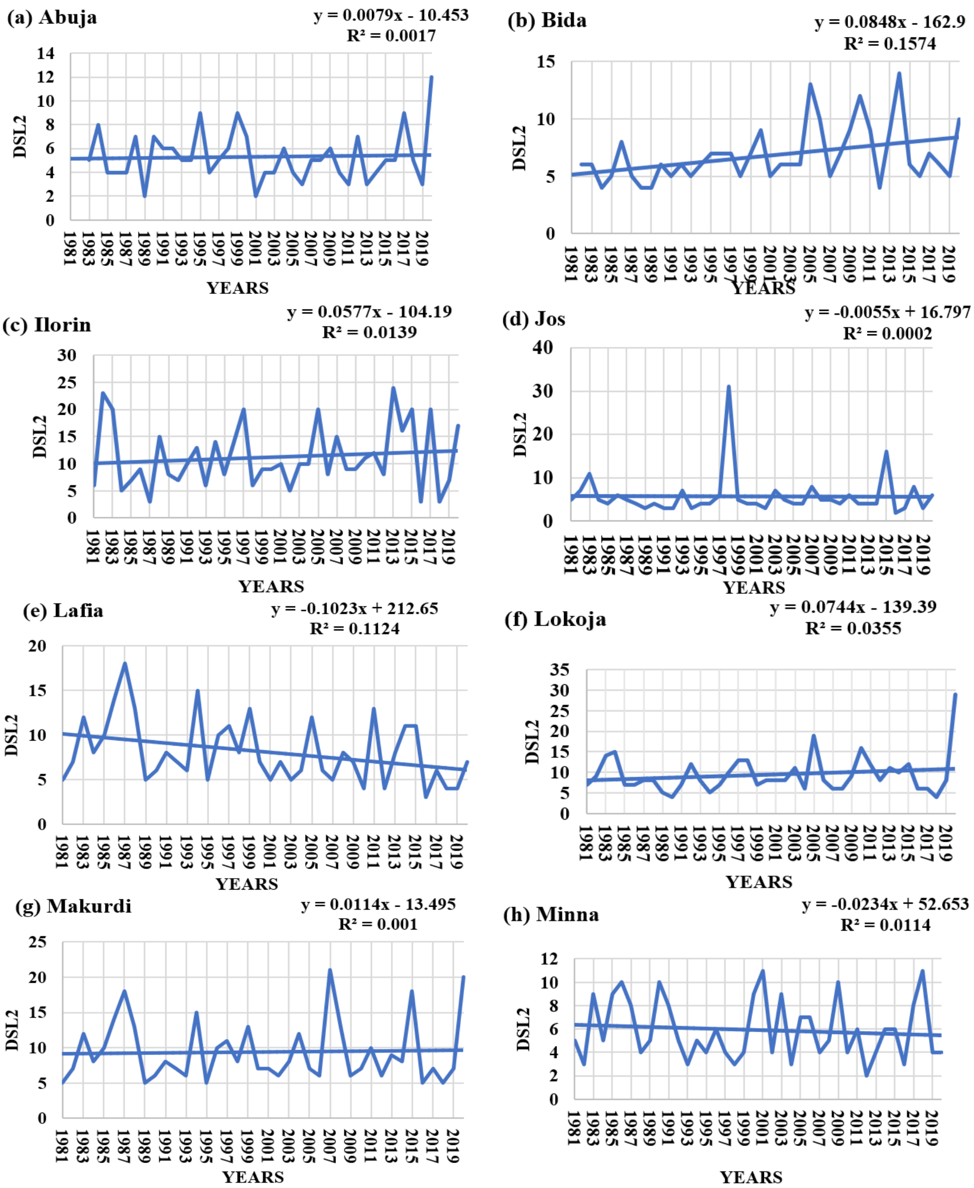


Figure 3. Dry spell 2 in (a) Abuja, (b)Bida, (c) Ilorin, (d) Jos, (e) Lafia, (f) Lokoja, (g) Makurdi and (h) Minna

Figures 3 (a-h) presents the maximum dry spell length at the end of the season. It is seen that the maximum dry spell length of 29, 24, 21, 18, 12, and 11 consecutive dry days were the highest recorded in Lokoja 2020, Ilorin 2013, Makurdi 2007, Lafia 1987, Bida 2014, Abuja 2020, and Mina 2018 respectively. Positive best fit trend line equations showed in Abuja (y= 0.0079x-10.453), Bida (y=0.0848x-162.9), Ilorin (y=0.0577x-104.19), Lokoja (y=0.0744x-139.39) and Makurdi (y= 0.0114x-13.495) respectively. The pattern of occurrence of maximum dry spell length in these stations indicates an increasing trend meaning the frequency of occurrence of maximum dry spell length towards the end of the season upsurge as indicated in Figures 3 (a-h). Lokoja has the longest length of a dry spell of 29 consecutive days recorded in 2020, while on the other hand Lafia and Minna recorded the highest length of a maximum dry spell of 18 in 1987 and 11 in 2018 respectively within the period under review. However, the trend line equation shows a negative best fit line in Lafia (y= -0.1023x+212.65), Jos (-0.0055x+16.797) and Minna (y= -0.0234x+52.653) the pattern of occurrence of maximum dry spells length in this location within the study area displays a decreasing trend line as a result of its frequency is declining as shown in Figure 3d, e, and has well as in Table 3 below.

4.2 The geospatial analyses of dry spell

In climatology, spatial analyses are very useful since they ease the handling of large sets of data and they allow the appreciation of a phenomenon at a broader scale. To examine how the recent reduction in seasonal rainfall has affected the other seasonal indicators we are interested in the Onset and Cessation, we calculated the mean values of each station. Afterward, Surfer version 13 was used to plot the spatial distribution of dry sequence in the selected station in the region using the kriging module was applied to interpolate these values into a spatial grid. furthermore, we generated dry spell length for each of the seasonal indicators (Onset and Cessation) based on the records of 8 stations that are considered. These sequences were plotted to envisage changes and departure from normal in each dry spell indicator from 1981 to 2010 and long term respectively.

The distribution of maximum dry spell length during the onset in Figure 4 shows a progressive increase in dry days over the region the mean average values for each station from 1981 to 2010 indicate a range of dry spells varies between 7 to 9 days. The lowest mean average dry spell length of 7 days was recorded over areas in and around Abuja and Ilorin with an average dry spell of 7 days (areas in yellow). Normal dry spell was observed in Lafia, and Minna with average dry spell length of 8 days while Makurdi, Lokoja & Bida respectively recorded the longest average dry spell length of 10 days (areas in red colour).

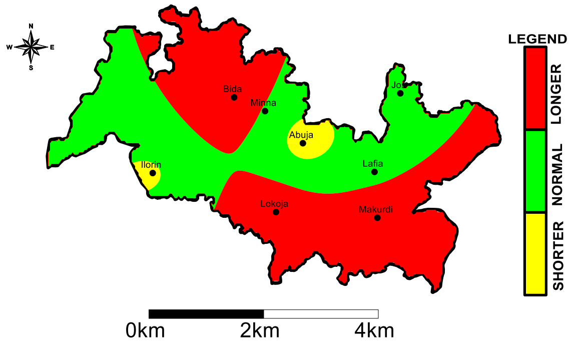


Figure 4. Distribution of Mean average dry spell length during onset from 1981-2010

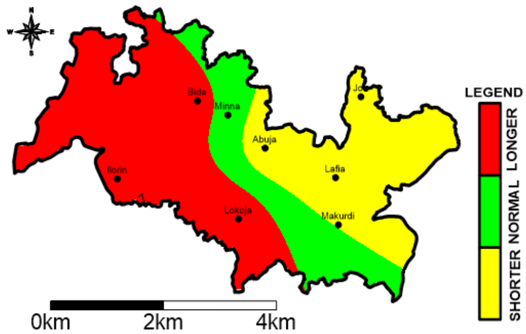


Figure 5. Long-time Deviation of dry spell length during onset from 1981-2010

Table 3. Statistics of maximum dry spell length 2

Stations	Variable	Equation: Y=	Intercept	Slope	R2=
Abuja	Dry spell 2	0.0079x-10.453	0.0079x	-10.453	0.0017
Bida	Dry spell 2	0.0848x-162.9	0.0848x	-162.9	0.1574
Ilorin	Dry spell 2	0.0577x-104.19	0.0577x	-104.19	0.0139
Jos	Dry spell 2	-0.0055x+16.797	0.0055x	16.8	0.0
Lafia	Dry spell 2	-0.1023x +212.65	-0.1023x +	212.65	0.1124
Lokoja	Dry spell 2	0.0744x-139.39	0.0744x	-139.39	0.0355
Makurdi	Dry spell 2	0.0744x-139.39	0.0744x	-139.39	0.001
Minna	Dry spell 2	-0.0234x +52.653	-0.0234x	52.653	0.0114

Table 4. Statistics of maximum dry spell length 1

Stations	Variable	Equation: Y=	Intercept	Slope	R2=
Abuja	Dry spell 1	-0.0212x+49.171	-0.0212x	49.171	0.0137
Bida	Dry spell 1	0.0183x-28.42	0.0183x	-28.42	0.0025
Ilorin	Dry spell 1	-0.0393x+88.756	-0.0393x	88.756	0.0095
Jos	Dry spell 1	0.0864x-166.11	0.0864x	-166.11	0.057
Lafia	Dry spell 1	-0.0573x+122.44	-0.0573x	122.44	0.0721
Lokoja	Dry spell 1	-0.0142x+36.462	-0.0142x	36.462	0.0063
Makurdi	Dry spell 1	-0.0283x+66.175	-0.0283x	66.175	0.0086
Minna	Dry spell 1	0.0271x-46.96	0.0271x	-46.96	0.0133

The distribution of dry spell departure from normal as compared to the 30 years average during the start of the rain in Figure 5 above shows that Lokoja, Ilorin, and Bida had positive departures which indicate longer than normal dry spell while Abuja, Jos, Lafia, and Makurdi were however experienced a negative departure from normal (below normal). Moreover, normal dry spell departure was recorded in Mina Niger state.

The spatial analysis of long term mean average dry spell length at the end of the season in Figure 6 below shows longer dry spell prevailed mostly in the southern part of central states Ilorin, Lokoja, Lafia, and Makurdi (areas in red colors) while stations in the northern part (Abuja and Jos) experienced shorter dry spell (areas in yellow). Minna and Bida in the western part of the region recorded mean average normal dry spell respectively.

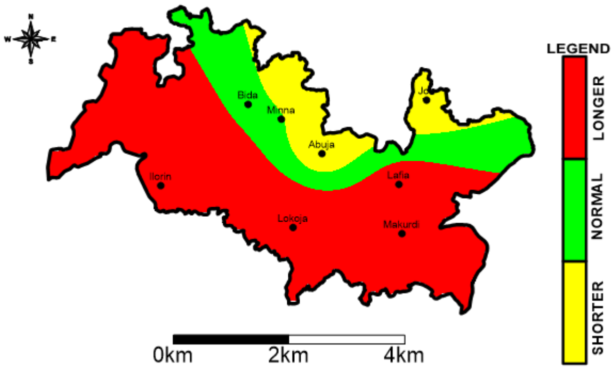


Figure 6. Distribution of mean average dry spell length during the end of the season from 1981-2010

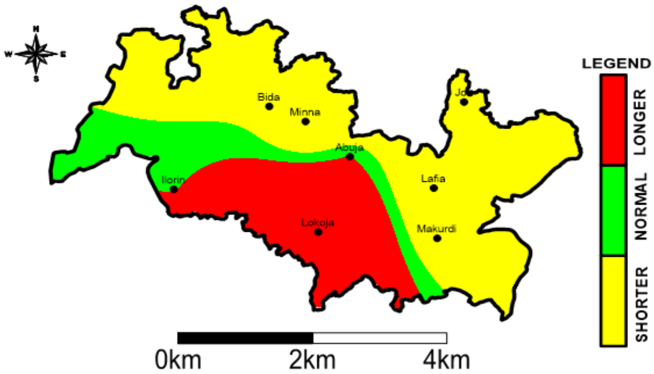


Figure 7. Long-time Deviation of dry spell length at end of the season from 30 years' average

Figure 7 above indicates a spatial pattern of long time deviation from normal for dry spell length at end of the season which showed that dry spell was within below normal dry spell bracket. However, a few locations had deviations from normal, such areas include Lokoja and Ilorin which was noticeably longer than a normal dry spell.

4.3 Dry spell analysis for agricultural decision support

The results of the maximum dry spell length analysis are presented in Table 4. In this paper, a dry spell is defined as a period in which the rainfall threshold value is below 0.85 mm or no rainfall amount recorded in a day. The average dry spell for forty years long term during the onset in the study areas varies from station to station and ranges between 10-8 that is between the month of (May-July). While the highest annual maximum dry spell length recorded at the beginning of the season is 25, 22, and 16 dry days in Bida, Jos, and Minna. Dry spell anomaly was computed for both dry spell one and two and can be seen in Table 5 ranging between -2 to 10 and -1 to 20 respectively. However dry spell length can extend up to ten days and beyond during the start of the season at these early stages of planting. Crops require adequate rainfall and moisture within the soil therefore, the occurrence of maximum dry spells between the month of May-July indicates little or no rainfall as a result of low soil moisture content during these critical periods, which leads to crop failure, disturb vegetative developmental and subsequently poor yield will be recorded, this finding corroborates with Sawa and Adebayo [24].

The occurrence of maximum dry spells length or more dry days in August and September (dry spell 2) can harm the growth and development of the plant, because of this, August and September are the periods when certain crops grains are produced, ripen and harvested in the study area. Therefore, at this period, crops require sufficient rainfall to effectively develop grains. Furthermore, dry spells incidences at this period will, therefore, significantly affect soil moisture content which will subsequently affect the development of the grains and reduce the yield of the crops as well. This is also in line with the study [24].

Table 5. Maximum dry spell anomaly

	Dry spell One		Dry spell Two	
Station	Normal	2020 Anomaly	Normal	2020 Anomaly
Abuja	7	-3	5	7
Bida	10	6	6	4
Ilorin	7	6	10	7
Jos	8	-2	5	1
Lafia	8	-2	8	-1
Lokoja	9	10	9	20
Makurdi	9	1	9	1
Minna	8	4	6	-2

5. CONCLUSIONS

Rainfall is the most significant climatic parameter in agricultural production in Nigeria and hence can be used as an index of climate change. Rainfall is an element of climate required by man in moderate form; surplus rainfall causes flood which can destroy settlement and farmland while its deficit results in dry spell leading to a drought of varying magnitudes which can pose a serious threat to agriculture and water resource. These climatic extremes have numerous adverse effects on man and his daily activities. Therefore, the study is examining the maximum consecutive dry spell length variability in the north-central region of Nigeria in the context of their historical evidence and Geospatial analysis. The study is relevant because it will assist researchers to understand the future consequences of rainfall variation over the study region.

The studies suggested that the study area is becoming more prone to dry spells therefore drought resistant and early maturing varieties of seeds should be made available and affordable to farmers, Sensitization and awareness on the use of weather and climate information in the region become imperative and soil management practices such as moisture conservation and other indigenous practices should be adopted. However, the study further recommends the analysis of maximum wet spells for future studies.

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