# Agroclimatic Zonning of Nigeria Based on Rainfall Characteristics and Index of Drought Proneness

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**Abstract**
Nigeria, a country in sub-Saharan West Africa that depends largely on rainfall distribution for its agricultural practices has been categorised into three major climatic zones based on its rainfall characteristics and drought-proneness analysis. The data used comprises of daily rainfall of thirty years (1983 to 2012) for the thirty-eight climatic stations spread over the country. Rainfall characteristics such as onset dates, cessation dates, length of rainy season and rainfall amount within the seasons for thirty years were extracted over each of these stations for the analysis. Rainfall distribution during the rainy season was also investigated by using two-state Markov chain analysis of order one and two.
The result is useful in making some pre-sowing decisions such as site selection for a particular crop and specie selection for a particular zone. The first zone has earliest rainfall onset dates, latest cessation dates and hence, having longest length of rainy season in the country. It also has the highest (lowest) Markovian probability of a wet (dry) week after a previously wet week and hence least prone to drought occurrence. Therefore, this zone is tagged “rain-forest” (Guinea). Followed closely is the zone II which is the “Savannah” and lies on the north of the zone I. On the northern part of zone II is the zone III with the shortest length of rainy season termed “Sahel”. Despite the fact that Sahel zone has the latest onset, earliest cessation and hence shortest length of rainy season, it is most prone to drought occurrence, while Savana has moderate values between those of zones I and III.
**Keywords**: Rainfall onset, rainfall cessation, length of rainy season, drought-proneness, zones.

## 1 Introduction

Sustainable agricultural practices and food security can be enhanced if some necessary agro-meteorological information are timely made available to decision makers, agricultural and water resources sectors. The key components of rainfall characteristics in West Africa in general and Nigeria in particular that modulate the growth and development of crops include the timing of onset and cessation of rainfall as well as length of rainy season, annual rainfall amount and distribution of rainfall during the rainy season. Due to the large spatial variation of rainfall on inter- and intra-seasonally time scales, such information are better given to area with similar rainfall characteristics. Hence, failure of accurate forecast, timely and adequate dissemination of information of these characteristics may have severe impacts on agro-hydrological systems as well as on human health.

Nigeria, a country in West African sub-region spans through a latitudinal belt of 10 degrees (from 4$^{o}$N to 14$^{o}$N) and a longitudinal belt of 12 degrees (from 3$^{o}$E to 15$^{o}$E) and covers a land area of 923,768 km$^{2}$. Area south of 10$^{o}$N in the country has a bimodal rainfall distribution while area to north of 10$^{o}$N has a modal, therefore such a country will definitely be too big as a single zone for such agrometeorological information. For effective and efficient utilization of agrometeorological information for sustainable agricultural practices and food security, the country has to be properly categorised based on the general climatological behaviour of the respective climatic stations in response to rainfall distribution and characteristics.

Agricultural planning, practices and operations in Nigeria like all other parts of West Africa are highly dependent on rainfall characteristics. These characteristics are rainfall onset and cessation, length of rainy season, number of rain days, amount of rainfall as well as the distribution of rainfall during the season. The most important of these properties are the onset of rainfall, length of rainy season (or cessation of rainy season in which its difference in days from onset gives the length of rainy season), annual rainfall amount and its distribution both in space and time. The fact that rainfall distribution is more important than total amount of rainfall leads us to the term “effective rainfall”. Effective rainfall is a relative term, having different definitions and applications to different professions. For an agriculturist, it can be defined as the daily (or weekly) rainfall amount that meets the daily (or weekly) soil-crop-water requirements. For example, a rainfall amount of 2 mm falling daily for 10 consecutive days is more useful to plants and soil than a day with rainfall of 20mm followed by 9 consecutive days of dryness, despite that the total rainfall amount over 10 days in both cases is 20 mm. This indicates there is a need to focus on rainfall patterns and dry periods within the rainy season.

The term drought or dry spell has drawn worldwide attention over the years because of its widespread occurrences and its associated socio-economic effects in various parts of the world (Ahmed, 1991; Le Barbé and Lebel 1997; D’Amato and Lebel 1998; Le Barbe et al., 2002 and recently, Nicholson, 2013). To zone a big country like Nigeria for effective application of agrometeorological information, detailed and systematic study of rainfall characteristics and the associated dry/wet spell occurrences during the rainy season

will be an invaluable approach. Among the most frequently stochastic/statistical methods used for the analysis of wet/dry occurrence is two-states Markov chains of different orders. The first successful application of such scheme was by Gabriel and Neumann (1962) for Tel-Aviv. Additional evidence to indicate the feasibility of using a Markov chain for dry/wet spell analysis (to mention a few) thereafter has been presented by Caskey (1963), Weiss (1964), Hopkins and Robillard (1964), Torodovic and Woolhiser (1975), Martin-Vide and Gomez (1999) and Banik et al., (2002).

In Nigeria, the usage of Markov chains for rainfall analysis were those of Fasheun (1983) as well as Stern and Coe (1984). They analysed and fitted a set of daily rainfall data using a two-state Markov chain of different orders for possibilities of using it for farm operations and planning. They both found out that over the various areas of their studies in Nigeria, daily rainfall is Markovian and concluded that Markov chain can therefore be used for daily rainfall analysis for agricultural planning and operations over the country. The work of Jimoh and Webster (1996) also over five of Nigerians stations was to determine the optimum of the order to which Markov chain can be applied for daily rainfall analysis by comparing its performance with two other statistical methods. They concluded that Markov chain of order zero, one and two are very good in representing the characteristics of the historical sequence of dry and wet periods. This study therefore employed the Markov chain, index of drought proneness and the characteristics mentioned to zone Nigeria for effective utilization of agrometeorological information.

## 2 Data and Methodology

### 2.1 Description of Observation Data Used

Daily rainfall amount of thirty years spanning from 1983 to 2012 over thirty-eight climatic stations in Nigeria were collected from the Archive unit of the Nigerian Meteorological Agency (NIMET) and analysed for the study. These stations used have consistent and continuous daily rainfall data and well spread over the entire country. Table I gives the alphabetical list of the names of all the stations used with their respective coordinates (longitudes and latitudes), the identification numbers, elevations above mean sea level and the abbreviations used for the stations in the subsequent figures and throughout the study. Figure 1 shows the map of Nigeria with its constituent states and the geographical locations of all the thirty-eight climatic stations used for the study.

### 2.2 Methods of Analysis

#### 2.2.1 Rainfall Characteristics

Nigeria as a country like every other part of West Africa has two distinct major seasons: the wet (rainy) season and dry (harmattan) season. Therefore, analysis for the present study is on the rainy season, since this is the only time agricultural activities take place in the country. The definition of onset of rainfall used to determine the onset in this study was 'the beginning of the first two rains totalling 20mm or more, within 7 days, followed by 2 – 3 weeks each with at least 50% of the weekly crop-water requirement' after Omotosho et al., (2000). This definition receives general acceptability in West African sub-region. It is in use in African Centre of Meteorological Applications for Development (ACMAD), Nigerian Meteorological Agency, (NIMET), Department of Meteorological Services in Mali, Chad and Niger as well as several researchers like Omotosho (2007), Adefisan and Omotosho (2014) and Moussa et al., (2014). Likewise, the cessation of rainfall after Omotosho (2000) also defined as 'any day from 1 September after which there are 21 or more consecutive days of rainfall less than 50% of the crop-water requirement'. Length of rainy season (LRS) is the difference between the days of year (DOYs) of onset and cessation dates. Dates of onset and cessation of rainfall as well as the LRS, total annual rainfall and the sum of rainfall within the LRS termed seasonal rainfall were determined for each year and average over the thirty years period for each station was determined.

#### 2.2.2 Drought Proneness analysis

The dry spell within the rainy season is analysed using two-state, Markov chains of first and second orders. A dry week is a week with total rainfall amount less than the weekly crop-water requirements. The weekly crop-water requirement used throughout in this study is 8.0 mm. Let $X_0$, $X_1$, $X_2$,…, $X_n$, be random variables distributed identically and taking only two values (two-state), namely 0 and 1, with probability one, that is,

$$X_n = \begin{cases} 0 & if \quad the \quad nth \quad week \quad is \quad dry \\ 1 & if \quad the \quad nth \quad week \quad is \quad wet \end{cases}$$

Firstly, we assume that,

$$P(X_{n+1} = x_{n+1} | X_n = x_n, X_{n-1} = x_{n-1}, ..., X_0 = x_o) \qquad = P(X_{n+1} = x_{n+1} | X_n = x_n). \qquad (1)$$

where $x_0, x_1, ..., x_{n+1} \in \{0,1\}$. In other words, it is assumed that probability of dryness of any week depends only on whether the previous week was wet or dry. Given the event on previous week, the probability of dryness is assumed independent of further preceding weeks. Therefore, the stochastic process $\{X_n, n = 0,1,2,....\}$ is a Markov chain (Cox and Miller 1965, Medhi 1981, and Banik et al., 2002). Consider the matrix

$$\begin{pmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{pmatrix}$$

where: $P_y = P(X_1 = j | X_0 = i) i, j = 0,1$ Note $P_{00} + P_{01} = 1$ and $P_{10} + P_{11} = 1$.

Let p = $P(X_0 = 1)$. Here p is the absolute probability of a day being wet during the rainy season (within LRS), clearly,

Table 1: Alphabetic list of the 38 stations used with their respective abbreviations, coordinates, elevations and WMO identification codes.

| S/ No | Station Name | Station Abbr. | WMO ID | Latitude (°N) | Longitude (°E) | Elevation (m) |
|---|---|---|---|---|---|---|
| 1 | Abeokuta | ABK | 65213 | 7.17 | 3.33 | 104.0 |
| 2 | Abuja | ABJ | 65125 | 9.00 | 7.00 | 343.1 |
| 3 | Akure | AKR | 65232 | 7.28 | 5.30 | 375.0 |
| 4 | Bauchi | BAU | 65055 | 10.28 | 9.82 | 609.7 |
| 5 | Benin | BEN | 65229 | 6.32 | 5.10 | 77.8 |
| 6 | Bida | BID | 65112 | 9.10 | 6.02 | 144.3 |
| 7 | Calabar | CAL | 65264 | 4.97 | 8.35 | 61.9 |
| 8 | Enugu | ENU | 65257 | 6.47 | 7.55 | 141.8 |
| 9 | Gombe | GOM | 65075 | 10.28 | 11.15 | 204.0 |
| 10 | Gusau | GUS | 65015 | 12.17 | 6.70 | 463.9 |
| 11 | Ibadan | IBD | 65208 | 7.43 | 3.90 | 227.2 |
| 12 | Ibi | IBI | 65145 | 8.18 | 9.75 | 110.7 |
| 13 | Ijebu-Ode | IJB | 65210 | 6.83 | 3.93 | 77.0 |
| 14 | Ikeja | IKJ | 65201 | 6.58 | 3.33 | 39.4 |
| 15 | Ikom | IKM | 65273 | 5.97 | 8.70 | 119.0 |
| 16 | Ilorin | ILR | 65101 | 8.48 | 4.58 | 307.4 |
| 17 | Jos | JOS | 65134 | 9.87 | 8.75 | 1290.0 |
| 18 | Kaduna | KAD | 65019 | 10.60 | 7.45 | 645.4 |
| 19 | Kano | KAN | 65046 | 12.05 | 8.20 | 472.5 |
| 20 | Katsina | KAT | 65028 | 13.02 | 7.68 | 517.6 |
| 21 | Lokoja | LOK | 65243 | 7.78 | 6.73 | 62.5 |
| 22 | Maiduguri | MAI | 65082 | 11.85 | 13.08 | 353.8 |
| 23 | Makurdi | MAK | 65271 | 7.73 | 8.53 | 112.9 |
| 24 | Minna | MIN | 65123 | 9.62 | 6.53 | 256.4 |
| 25 | Nguru | NGR | 65064 | 12.88 | 10.47 | 343.1 |
| 26 | Ogoja | OGJ | 65275 | 6.67 | 8.80 | 117.0 |
| 27 | Ondo | OND | 65222 | 7.10 | 4.83 | 287.3 |
| 28 | Oshogbo | OSH | 65215 | 7.78 | 4.48 | 302.0 |
| 29 | Owerri | OWR | 65252 | 5.48 | 7.00 | 91.0 |
| 30 | Port Harcourt | P/H | 65250 | 4.85 | 7.02 | 19.5 |
| 31 | Potiskum | POT | 65073 | 11.70 | 11.03 | 414.8 |
| 32 | Shaki | SHK | 65108 | 8.67 | 3.38 | 425.0 |
| 33 | Sokoto | SOK | 65010 | 13.02 | 5.25 | 350.8 |
| 34 | Uyo | UYO | 65260 | 5.50 | 7.92 | 38.0 |
| 35 | Warri | WAR | 65236 | 5.52 | 5.73 | 6.1 |
| 36 | Yelwa | YEL | 65001 | 10.88 | 4.75 | 244.0 |
| 37 | Yola | YOL | 65167 | 9.23 | 12.47 | 186.1 |
| 38 | Zaria | ZAR | 65030 | 11.10 | 7.68 | 110.9 |

$$P(X_0 = 0) = 1 - p.$$

$P_{11}$ gives the probability of a week to be wet given that the previous week was also wet. When $P_{11}$ is large, the chance of sequences of wet weeks is also large, but a small value of $P_{11}$ may not necessarily indicate high drought proneness. However, large values of $P_{01}$ imply large number of short wet spells that can prevent occurrence of drought. Hence, an index of drought proneness (DI) was defined by Banik et al., (2002) as:

$DI = P_{11} \times P_{01}$ (2)

Zero and one bound this index of drought. The higher the value of DI, the lower will be the degree of drought-proneness.

Table II lists the averages of all these rainfall characteristics and the DI for each station as estimated.

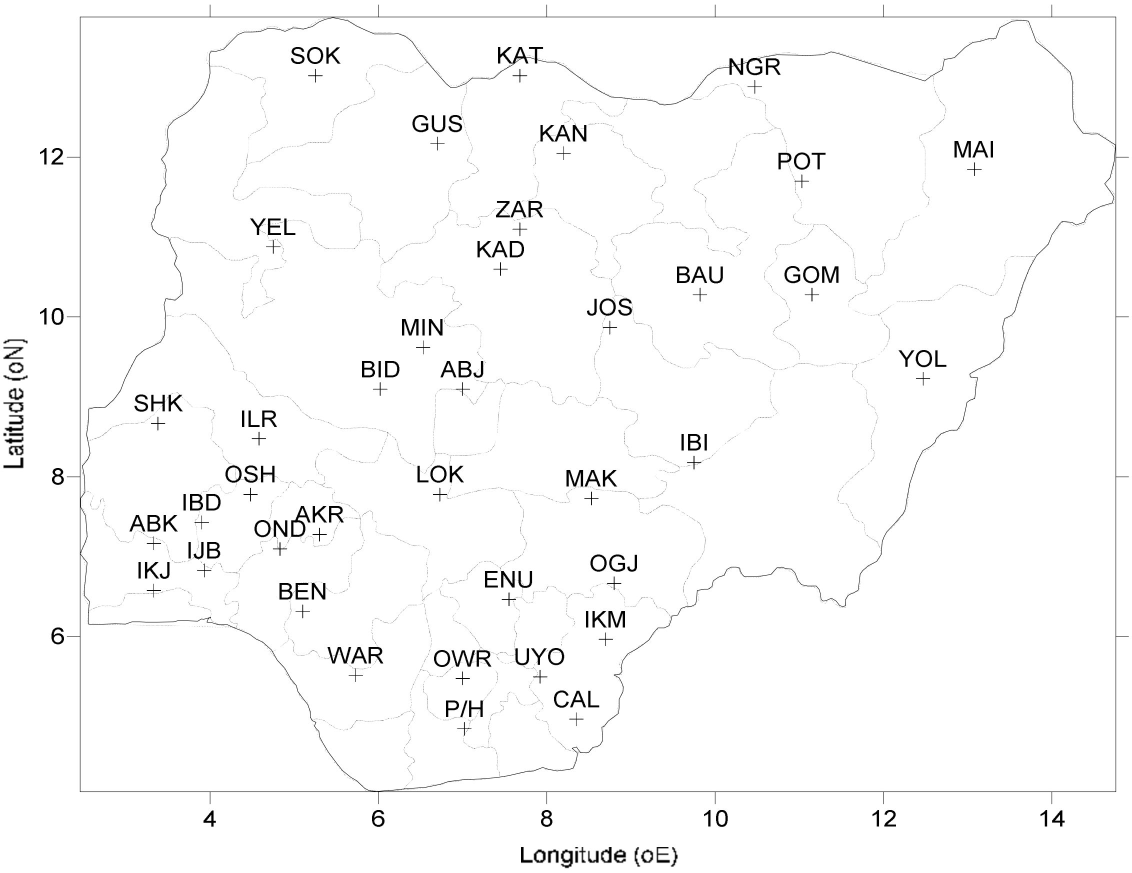

Figure 1: Map of Nigeria with its thirty-six states and the federal capital showing the locations of the thirty-eight climatic stations used.

## 3. Results and Discussions

### 3.1 Rainfall Onset Dates (ROD).

The averages of rainfall onset dates and its respective days of year (DOY) as listed for each station in columns 3 and 4 respectively of Table II were plotted to display the spatial distribution of mean rainfall onset dates over the entire country as shown in Figure 2. The contours are drawn at interval of 7 days (1 week). The mean ROD over the country varies from DOY 40 (09-Feb) over Owerri (OWR) in the south-eastern part to DOY 178 (27-Jun) over Nguru (NGR) in the north-eastern part. ROD therefore has an average range of 135 days over the country. Expectedly, the stations to the southern part of the country experience early rainfall onset compared to other parts of the country following the pole ward migration of the inter-tropical discontinuity (ITD) as south-westerly wind advances further inland. From Owerri up to contour 89, there is a strong meridional gradient suggesting that the stations in this zone have same pattern of ROD. These stations are Owerri, Calabar, Ikom, Uyo, Port-Harcourt, Enugu, Ogoja, Warri, Benin, Akure, Ondo, Oshogbo, Ibadan, Ijebu-Ode, Ikeja, and Abeokuta. Generally, the rainfall onset dates of the stations in this zone range between middle of February to end of March but on the average are mostly in March (DOY labelled 47 to 89). Using the behaviour of the contours and a time step of five weeks from north of isoline 89 in Figure 2 to isoline 124 is another zone, this comprises of stations like Ilorin, Lokoja, Markudi, Ibi, Abuja, Bida, Jos, Minna, Yola, Kaduna and Zaria. It should be noted here that Jos that is farther north of Bida, Minna, Yola, has ROD earlier than these stations. This is most likely due to high elevation of Jos (elevation in Table I) which allows orographically induced precipitation earlier in the season than its neighbouring stations. This supports the fact that zoning a region for agricultural purposes cannot be achieved using arbitrary straight latitudinal bands but proper analysis of the rainfall distribution. From isoline 124 to its northern part gives another zone of uniformly distributed isolines and this comprises of the remaining stations. This last area or zone has ROD ranging from 124 to 166, therefore has a range of 42 days.

3.2. Rainfall Cessation Dates (RCD).

The mean rainfall cessation dates (RCD) over the country vary from about DOY 259 (16-Sep) over Nguru in the north-eastern part to DOY 326 (22-Nov) over Calabar in the south-eastern part of the country as shown in Figure 3 and listed in columns 5 and 6 of Table II. The mean rainfall cessation date over the country has a spatial range of about 67 days. The distribution of the RCD over the country is in agreement with the pole ward retreat of the ITD and the smaller range over the country compares to that of ROD further proves that ITD moves faster when retreating from pole than when advancing towards the pole. The first zone identified in section 3.1 above is bound to the south of isoline (DOY) 301 as shown in Figure 3 including all the stations mentioned except the exclusion of Shaki. North of this contour 301 up to contour 280 comprises of all stations listed in the second zone as identified in section 3.1 above but now with exclusion of Zaria and inclusion of Yelwa. North of isoline (DOY) 280 lies the remaining stations and are bound in the northern part by isoline 266 over Sokoto at the north-western part and 259 over Nguru which is in the north-eastern part of the country.

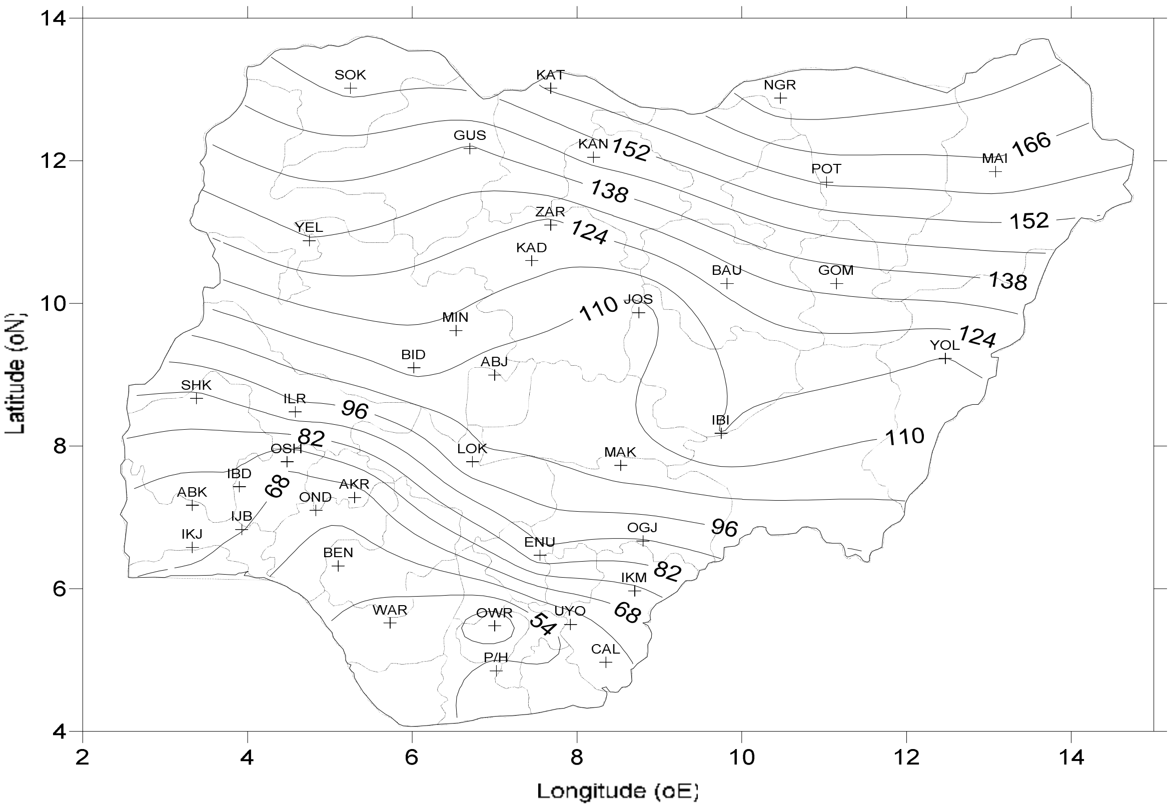


Figure 2: Spatial distribution of mean rainfall onset dates (ROD) over Nigeria with contours drawn at intervals of 7 days (1 week).

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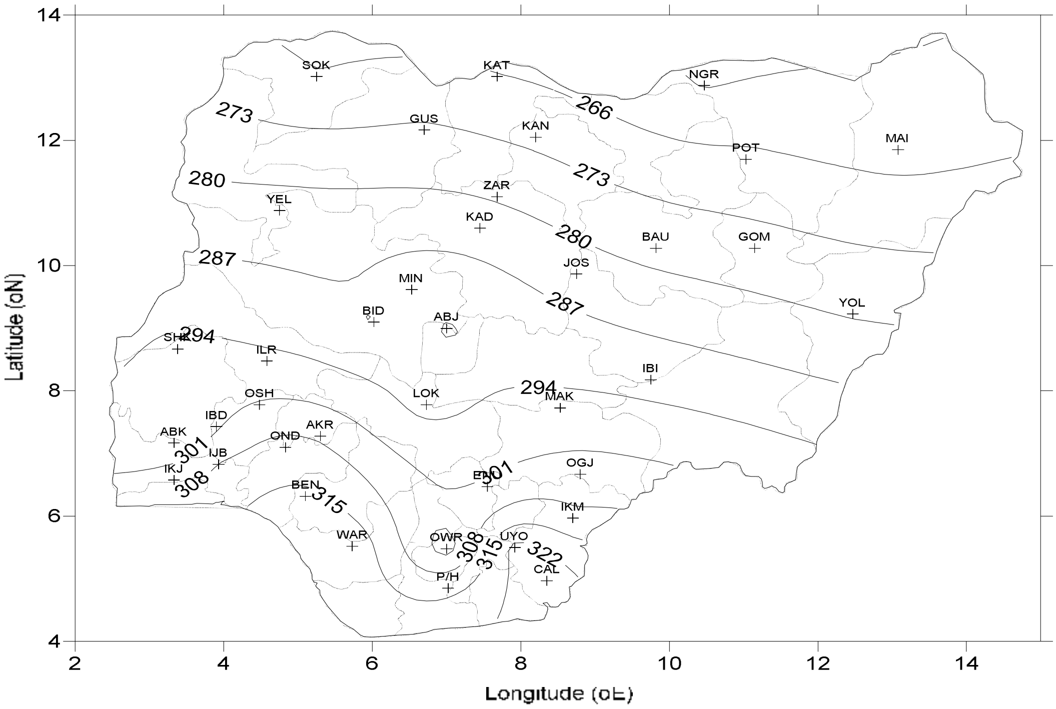


Figure 3: Spatial distribution of mean rainfall cessation dates (RCD) over Nigeria with contours drawn at intervals of 7 days (1 week).

Table 2: Mean rainfall characteristics and drought-prone analysis for the stations

| S/No | STN | ROD-date | ROD- | RCD-date | RCD- | LRS | SSrr | P11 | P01 | DPI |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ABK | 10-Mar | 69 | 21-Oct | 294 | 226 | 1155 | 0.83 | 0.72 | 0.60 |
| 2 | ABJ | 16-Apr | 106 | 22-Oct | 295 | 190 | 1264 | 0.93 | 0.73 | 0.68 |
| 3 | AKR | 04-Mar | 63 | 03-Nov | 307 | 244 | 1382 | 0.88 | 0.78 | 0.68 |
| 4 | BAU | 07-May | 127 | 05-Oct | 278 | 152 | 1043 | 0.90 | 0.72 | 0.63 |
| 5 | BEN | 27-Feb | 58 | 12-Nov | 316 | 260 | 2125 | 0.90 | 0.75 | 0.67 |
| 6 | BID | 22-Apr | 112 | 14-Oct | 287 | 175 | 1077 | 0.90 | 0.75 | 0.68 |
| 7 | CAL | 27-Feb | 58 | 22-Nov | 326 | 269 | 2788 | 0.95 | 0.61 | 0.58 |
| 8 | ENU | 28-Mar | 87 | 29-Oct | 302 | 216 | 1712 | 0.95 | 0.71 | 0.66 |
| 9 | GOM | 13-May | 133 | 03-Oct | 276 | 144 | 825 | 0.87 | 0.81 | 0.70 |
| 10 | GUS | 16-May | 137 | 01-Oct | 274 | 138 | 899 | 0.91 | 0.79 | 0.71 |
| 11 | IBD | 15-Mar | 74 | 27-Oct | 300 | 227 | 1314 | 0.86 | 0.77 | 0.66 |
| 12 | IBI | 27-Apr | 117 | 19-Oct | 292 | 175 | 1012 | 0.85 | 0.85 | 0.72 |
| 13 | IJB | 09-Mar | 68 | 04-Nov | 308 | 241 | 1533 | 0.88 | 0.65 | 0.57 |
| 14 | IKJ | 11-Mar | 70 | 01-Nov | 305 | 236 | 1386 | 0.82 | 0.65 | 0.53 |
| 15 | IKM | 14-Mar | 73 | 05-Nov | 309 | 237 | 2163 | 0.96 | 0.67 | 0.64 |
| 16 | ILR | 03-Apr | 93 | 22-Oct | 295 | 203 | 1124 | 0.86 | 0.77 | 0.66 |
| 17 | JOS | 17-Apr | 107 | 10-Oct | 283 | 177 | 1209 | 0.94 | 0.74 | 0.69 |
| 18 | KAD | 30-Apr | 120 | 11-Oct | 284 | 165 | 1009 | 0.93 | 0.69 | 0.64 |
| 19 | KAN | 28-May | 148 | 29-Sep | 272 | 125 | 1017 | 0.91 | 0.66 | 0.60 |
| 20 | KAT | 09-Jun | 160 | 23-Sep | 266 | 107 | 505 | 0.81 | 0.64 | 0.52 |
| 21 | LOK | 11-Apr | 101 | 19-Oct | 292 | 191 | 1140 | 0.88 | 0.75 | 0.66 |
| 22 | MAI | 13-Jun | 164 | 21-Sep | 264 | 100 | 515 | 0.83 | 0.73 | 0.59 |
| 23 | MAK | 16-Apr | 106 | 23-Oct | 296 | 191 | 1150 | 0.86 | 0.77 | 0.66 |
| 24 | MIN | 25-Apr | 115 | 18-Oct | 291 | 177 | 1177 | 0.92 | 0.77 | 0.71 |
| 25 | NGR | 27-Jun | 178 | 16-Sep | 259 | 82 | 318 | 0.76 | 0.69 | 0.52 |
| 26 | OGJ | 30-Mar | 89 | 31-Oct | 304 | 217 | 2025 | 0.92 | 0.70 | 0.63 |
| 27 | OND | 04-Mar | 63 | 07-Nov | 311 | 249 | 1612 | 0.91 | 0.69 | 0.62 |
| 28 | OSH | 10-Mar | 69 | 29-Oct | 302 | 234 | 1274 | 0.88 | 0.67 | 0.58 |
| 29 | OWR | 09-Feb | 40 | 25-Oct | 298 | 259 | 2103 | 0.92 | 0.59 | 0.56 |
| 30 | P/H | 28-Feb | 59 | 09-Nov | 313 | 255 | 1994 | 0.91 | 0.73 | 0.66 |
| 31 | POT | 09-Jun | 160 | 25-Sep | 268 | 109 | 572 | 0.85 | 0.75 | 0.65 |
| 32 | SHK | 28-Mar | 87 | 23-Oct | 296 | 209 | 1113 | 0.87 | 0.83 | 0.72 |
| 33 | SOK | 03-Jun | 154 | 23-Sep | 266 | 114 | 588 | 0.85 | 0.83 | 0.70 |
| 34 | UYO | 25-Feb | 56 | 20-Nov | 324 | 269 | 2317 | 0.96 | 0.78 | 0.74 |
| 35 | WAR | 20-Feb | 51 | 16-Nov | 320 | 270 | 2740 | 0.94 | 0.70 | 0.66 |
| 36 | YEL | 11-May | 131 | 10-Oct | 283 | 153 | 913 | 0.86 | 0.74 | 0.64 |
| 37 | YOL | 27-Apr | 117 | 06-Oct | 279 | 164 | 834 | 0.88 | 0.75 | 0.65 |
| 38 | ZAR | 02-May | 122 | 06-Oct | 279 | 158 | 999 | 0.92 | 0.68 | 0.61 |

Keys: ROD = Rainfall Onset Date; RCD = Rainfall Cessation Date; DOY = Day of Year
LRS = Length of rainy season; SSrr = Seasonal rainfall amount; DI = Index of drought-proneness
P01 (P11) = Probability of wet week given that the previous week is dry (wet).

 

*3.3* Length of Rainy Season (LRS)

As earlier mentioned, length of rainy season (LRS) is the difference between the days of year of ROD and RCD. Column 7 of Table II lists the respective mean LRS over the stations while Figure 4 shows the mean spatial distribution of LRS over the country with contours drawn at interval of ten days. The Figure showed that mean LRS over the country varies from 81 days over Nguru in the north-eastern part and about 110 days over Sokoto in the north-western part to 267 days over Calabar in the south-eastern part thereby having a spatial range of 186 days over the country. Contour labelled 210 bound the first zone identified in ROD and RCD sections above to the coastline, thereby making the average LRS to range from 267 to about 220days over the zone. North of this first zone up to contour labelled 160 gives the stations in the second zone identified in ROD section but now excluding Zaria and also the stations identified in RCD section but without Yelwa. The last zone is to the north of isoline 160 and these are stations with LRS less than 160days.

3.4.Annual and Seasonal Rainfall Amount

The discussion since has been on the onset, cessation and length of rainy season for agro-meteorological applications, it is therefore imperative to use the rainfall within the rainy season bound by the ROD and RCD termed the seasonal rainfall in this study. Adefisan (2015) has shown that the seasonal rainfall accounts for between 93% and 97% of the total annual rainfall across the country and the contour of one is a replica of the other. The spatial distribution of seasonal rainfall amounts as listed in column 8 over the stations are as shown in Figure 5 and the contours drawn at interval of 150 mm. The seasonal rainfall amount has the minimum value of 318mm over Nguru and maximum of 2788 mm over Uyo. Each of Uyo, Port-Harcourt and Warri has local maximum, this may be due to the additional rainfall from the sea breeze phenomenon due to their closeness to the large water body.

The first zone earlier identified in the previous sub-sections has very close contours hence strong meridional gradient of seasonal rainfall amount and bounded together from these local maxima to isoline 1250 mm in Figure 5. Very close to this isoline are Makurdi and Lokoja. The second zone that has always been observed in previous sections is observed to be within 1250 and 1100 mm and the remaining stations always in the third zone were found to be within 950 mm and 350mm with very weak gradient. Objectively, from the spatial distribution of the seasonal rainfall amount, it is obvious that the country can easily be classified into two major zones; these are the area with less than 1250 mm with weak isohyet gradient and area with more than 1200 mm of seasonal rainfall amount with strong isohyet gradient.

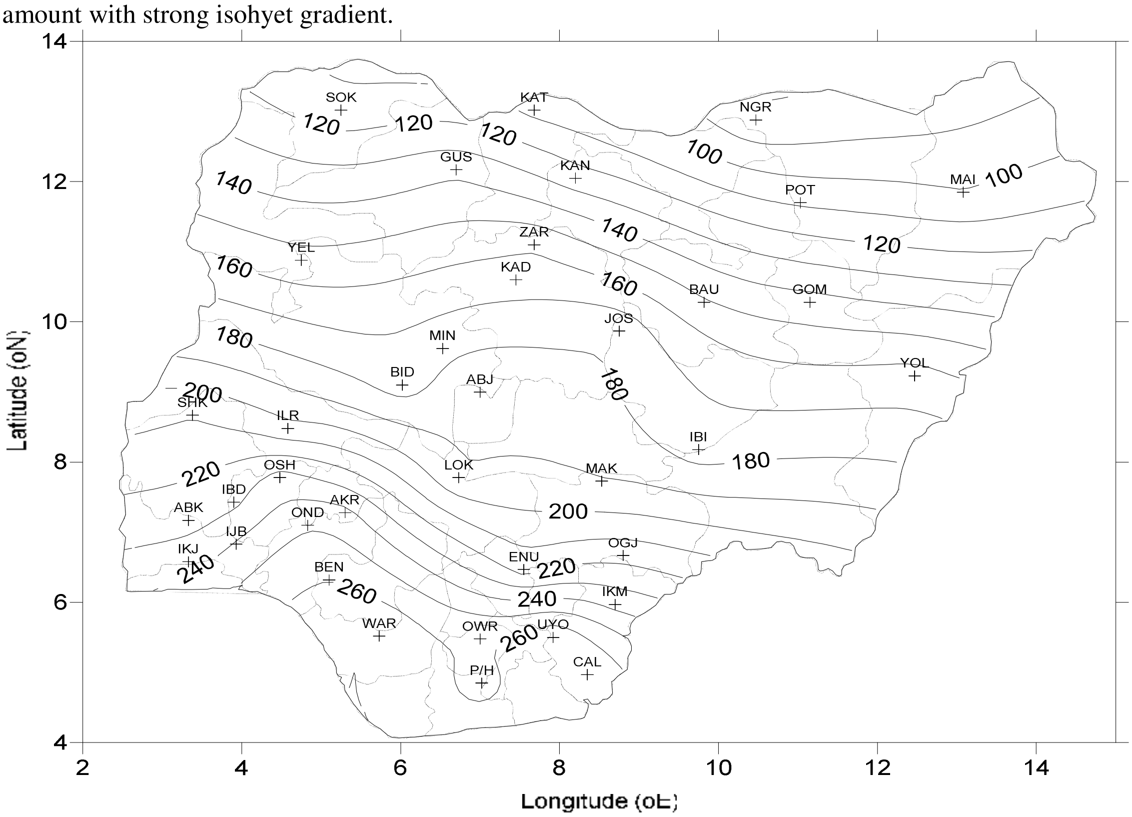


Figure 4: Distribution of average length of rainy season (LRS) over the country with contours drawn at interval of 10 days.

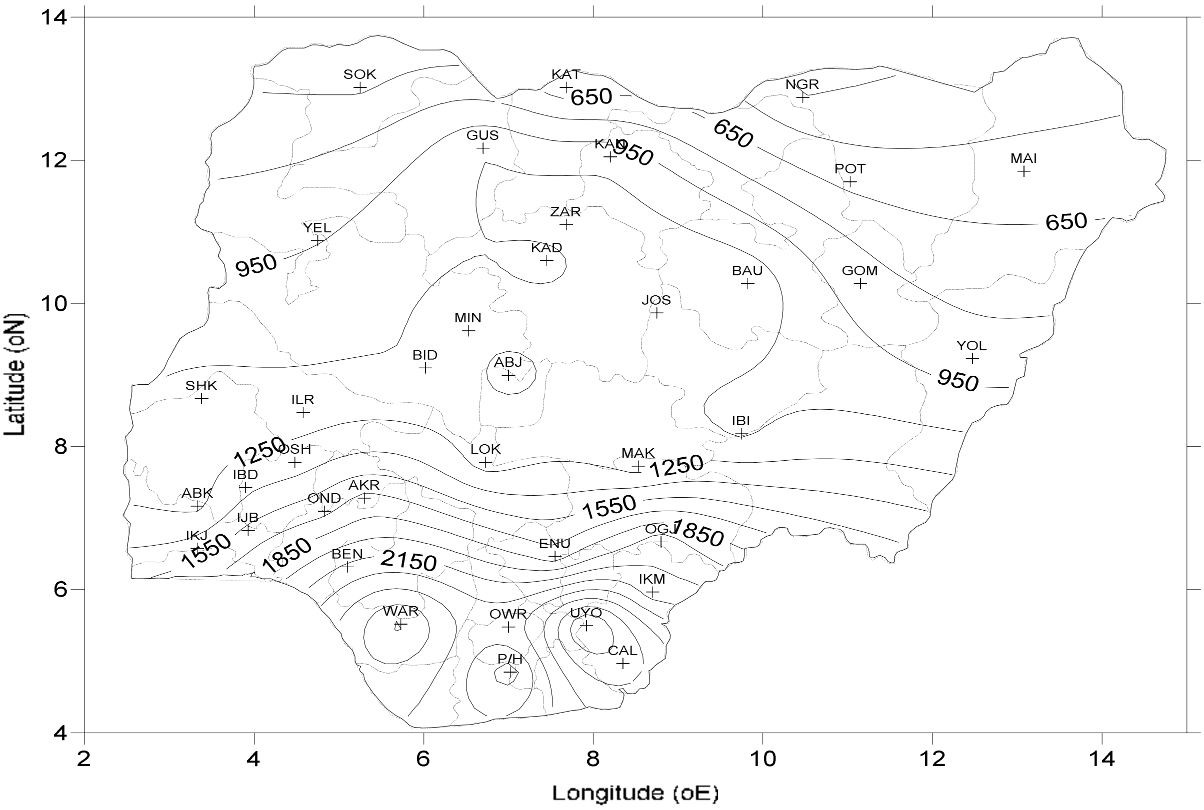


Figure 5: Mean seasonal rainfall amount over the country. Contours are at interval of 150mm.

## 3.5. Drought Analysis

As already pointed out in the earlier section, the distribution of rainfall within the rainy season is very crucial in order to meet the daily/weekly soil-atmosphere crop water requirements. This can best be investigated by analysing the dry/wet days within the rainy season. Figure 6 showed the distribution of Markovian probabilities of having a wet week after a previously wet week while Figure 7 showed that of a wet week after a previously dry week during the rainy season. Columns 9 and 10 respectively list these probabilities of Figure 6 and 7. For these two cases, a wet day is a day with minimum rainfall amount of 1.0 mm and by extension, a wet week is a week with a total rainfall of at least 7.0 mm and any week with rainfall amount less than 7.0 mm is regarded a dry week. The contours of spatial distribution of a wet week after a previously wet week in Figure 6 are drawn at interval of 0.015. The Figure shows that the probability of having a wet week after a previously wet week over the entire country is high with minimum of 0.76 over Nguru and 0.9 and above in the middle part to south-eastern part of the country. Despite the fact that Nguru which has the latest ROD, earliest RCD and hence shortest LRS is still having the lowest probability. Sokoto, Katsina, Maiduguri and some northern parts of the country with late ROD, early RCD and hence short LRS have lower probability compared to other parts of the country. This implies that rainfall is not evenly distributed over these areas within the rainy season despite their short LRS and low seasonal rainfall amount. These areas might not be able to completely support rain fed agricultural practices thus, complementing the rainfall with irrigation practices for viable agricultural practices should be put in place. Over Jos (Kaduna and Abuja), Warri, and Ikom, are some centres of high probabilities, showing that rainfall distribution of wet week after a previously wet week over these areas are evenly distributed and hence can completely support rain fed agricultural practices.

Contour interval in Figure 7 is 0.025 with centres of minimum values over areas where centres of maximum values were observed in the just presented Figure 6. Generally, this probability of a wet week after a previously dry week within the rainy season is low over the entire country. The probability is low towards the southern part despite the fact that this area experiences a “little dry season” phenomenon between July and August. In Figures 6 (and 7), the first zone still has the highest (lowest) probability of a wet week after a previously wet (dry) week and therefore completely supports a rain fed agricultural practices. The second zone still serves as the intermediary between the first and the third zones with values between that of the first and third zones. The third zone has the lowest (highest) value of the Markovian probability of a wet (dry) week after a previously wet week.

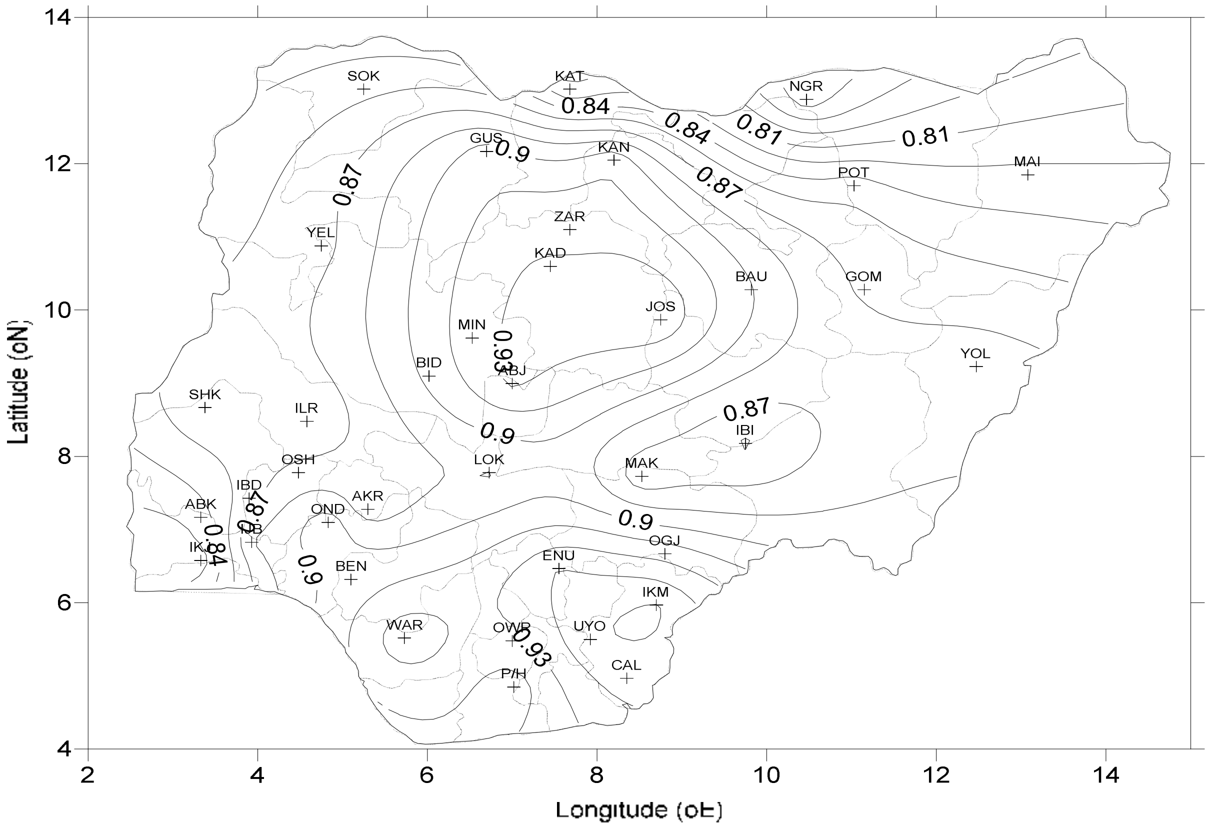


Figure 6: Markovian probabilities of a wet week after a previously wet week. Contours are at interval of 0.015.

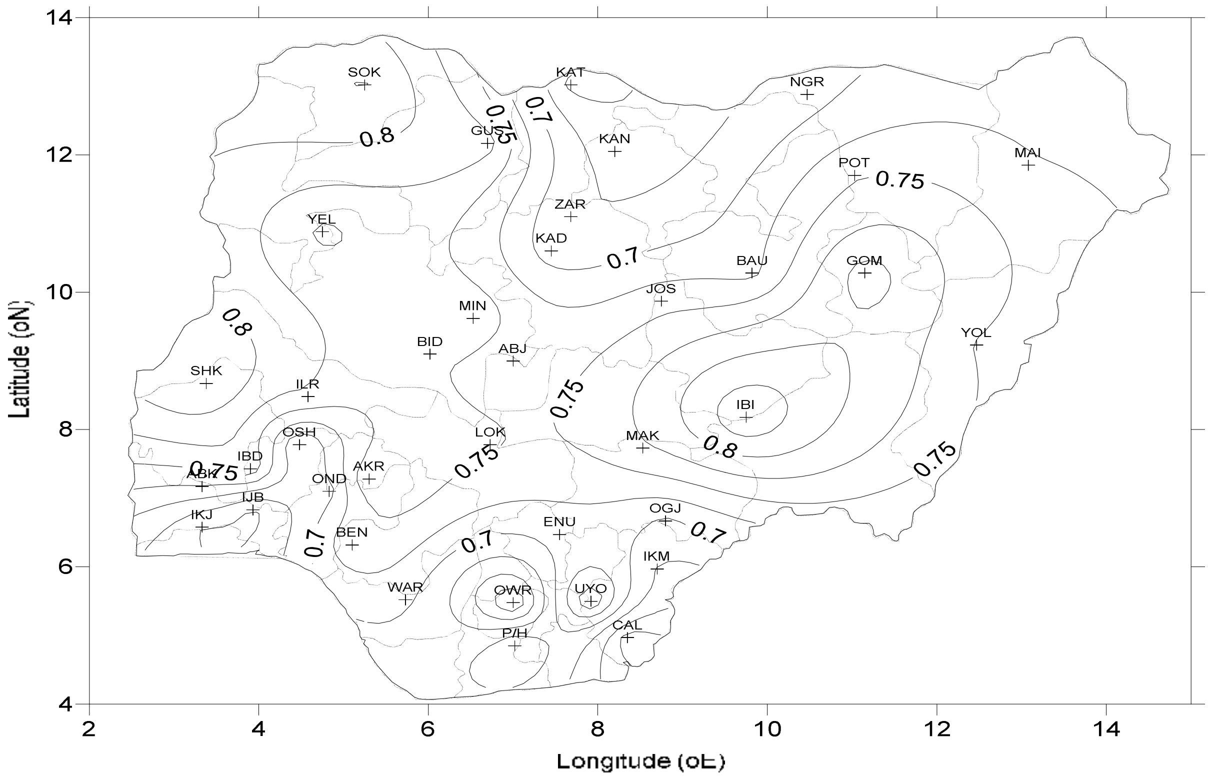


Figure 7: Mean Markovian probabilities of a dry week after a previously wet week. Contours interval is 0.025.

Displayed in Figure 8 is the spatial distribution of drought-proneness index (DI) over the entire country, contours are drawn at interval of 0.02, it is listed in column 11. According to Banik et. al. (2002), the higher this index over an area the less the area is prone to drought and has a range of 0 to +1. Over the country, the lowest value of

0.52 is observed over Nguru and increases southwards with maximum value of 0.74 over Uyo, therefore DI ranges from 0.52 in the north to 0.74 in the south of the country.

Generally, the low DIs are found in the third zone already identified and range from 0.52 to 0.66 except Sokoto and Gusau. This means that despite the fact that this area has the latest ROD, earliest RCD and hence the shortest LRS, it is the most vulnerable area to drought incidence. This is because squall lines and mesoscale convective systems are responsible for more than 90% of the rainfall in this zone (Omotosho 1985; Laurent et al., 1998 and Mathon et al., 2002). Rainfall from these systems are heavy and may be followed by few days of no or very little rainfall if the thermodynamics of the environment do not favour the initiation and propagation/ growth of these systems to maturity, hence lower value of P11 and higher value of P01 compared to other zones.

In the second zone, apart from a maximum DI of 0.72 over Ibi and another two local maxima of 0.70 over Minna and Shaki, the whole zone has DI within 0.66 and 0.68. The zone is less vulnerable to drought and can support rain fed agricultural practices within its LRS. In the first zone, DI has low value towards the western part and a bit high value to its eastern part. The eastern part of the first zone has the highest value of DI. This is largely due to shape of the surface position of inter-tropical discontinuity (ITD) over West Africa, which exposes this area to have more effect of a phenomenon called “little dry season” (LDS) than its eastern counterpart. LDS affects area south of $10^{o}$N and within longitude of $9^{o}$E and $10^{o}$W and it is a phenomenon characterised with little or no rainfall over the affected area in July/August when ITD is at the northernmost position. The eastern part of first zone is the least vulnerable area prone to drought in the whole country, followed by some isolated areas in the second zone like Ibi, Minna, Yelwa and Shaki and then the western part of first zone.

Finally, Figure 9 gives the zones with the climatological mean of the rainfall distribution, its characteristics and the drought-proneness index. In each zone I to III, the range of the rainfall characteristics and seasonal rainfall amount are therefore specified. This Figure provides the basic agrometeorological information needed before planting for necessary pre-sowing activities such as land preparation, tillage, and crops (species) selection. It is also useful for determining how an area being cultivated is prone to drought occurrence within the rainy season. Generally, in all the above Figures and this present Figure 9, it was observed that the western parts from north to south have high probability values than their eastern counterparts. Species of drought-tolerant crops are advisable to be cultivated in zone III, most especially the eastern part of it. The same set of species of crops can be cultivated in the eastern part of northern and southern parts of the country, if the length(s) of growing season of such crop(s) are within the LRS of the northeastern part of the country. The middle part of the country, which has always been referred to as the second zone in this study, has average values of the first and third zones.

## 4. Conclusions

Using daily rainfall data of thirty years over thirty-eight climatic stations in Nigeria, a country in West Africa, effective agrmometeorological information for sustainable agricultural practices have been provided. The country is hereby classified into three major and distinct zones from the analysis of the rainfall characteristics and dry spell carried out. The contours in the first zone namely Guinea for rainfall onset dates (ROD), rainfall cessation dates (RCD) and length of rainy season (LRS) have tight and hence strong gradient while contours of zone III namely Sahel are spacious and hence have weak gradient. Stations in zone II namely Savana do not have uniform gradient thus scattered contour and fall between zones III and I.

This zoning is similar to the agro-ecological zones that have been in use over the country by recent research studies. Some studies similar to this findings where three zones are used over West Africa (Nigeria) are Omotosho and Abiodun, 2007; Abiodun et al., 2012 and Moussa et al., 2014 but with no particular reason for such zoning. Bello (1995) used potential evapotranspiration and rainfall onset only and classified Nigeria into four zones namely; Forest, southern Guinea savannah, northern Guinea savannah and Sudan savannah regions respectively. Odekunle et. al. (2005) used the country as a five-zone area similar to that of Bello (1995) except that the forest region of Bello (1995) was sub-divided into two, namely; rain forest and coastal regions but the source and method of the zoning was not explicitly defined in the work. The classification of WHO (2001) has four zones over Nigeria like that of Bello (1995) but five zones over the entire West Africa up to about latitude $18^{o}$N. According to the study, the four zones over Nigeria are humid, sub-humid humid, sub-humid dry and semi-arid similar to that of Bello (1995). The study is the first known to authors to have given a climatological range of some useful agrometeorological information by zones for efficient agricultural practices and hence food security.

 

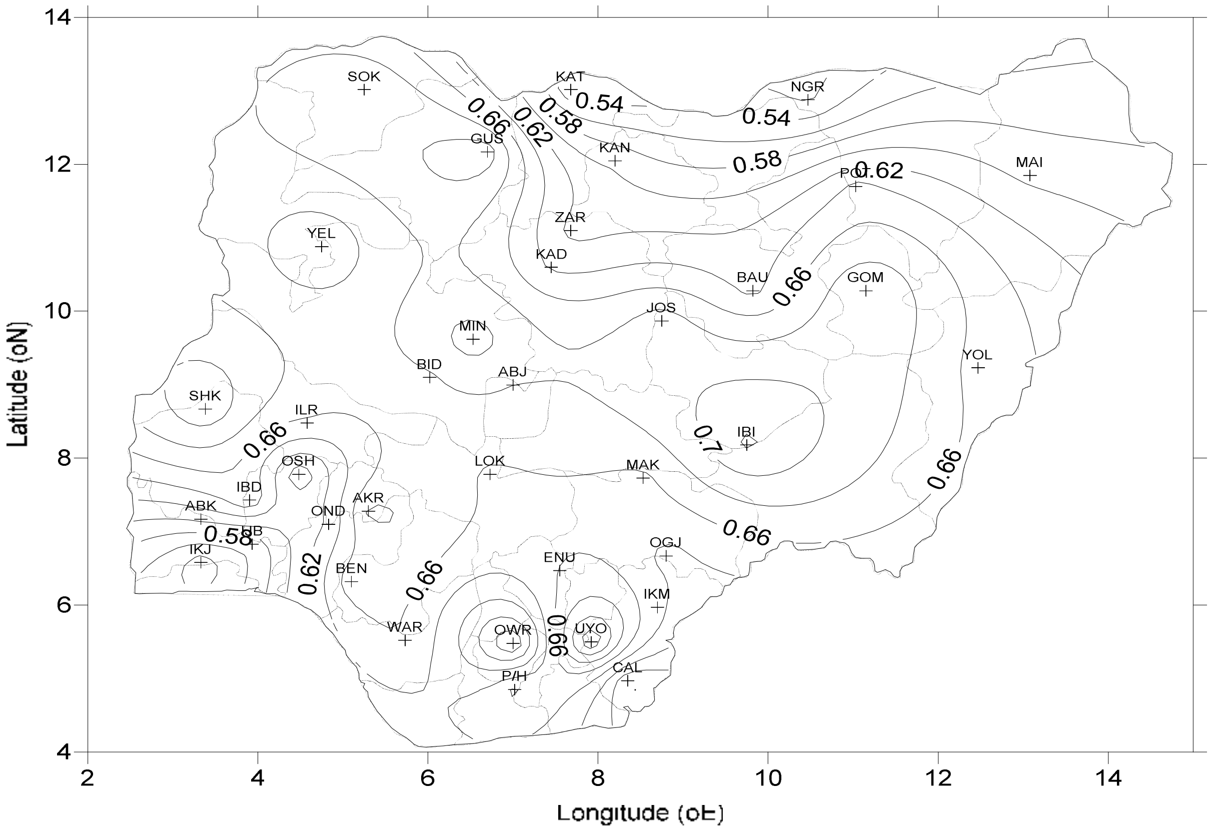


Figure 8: Mean distribution of drought-proneness index over the country with contours interval of 0.02.

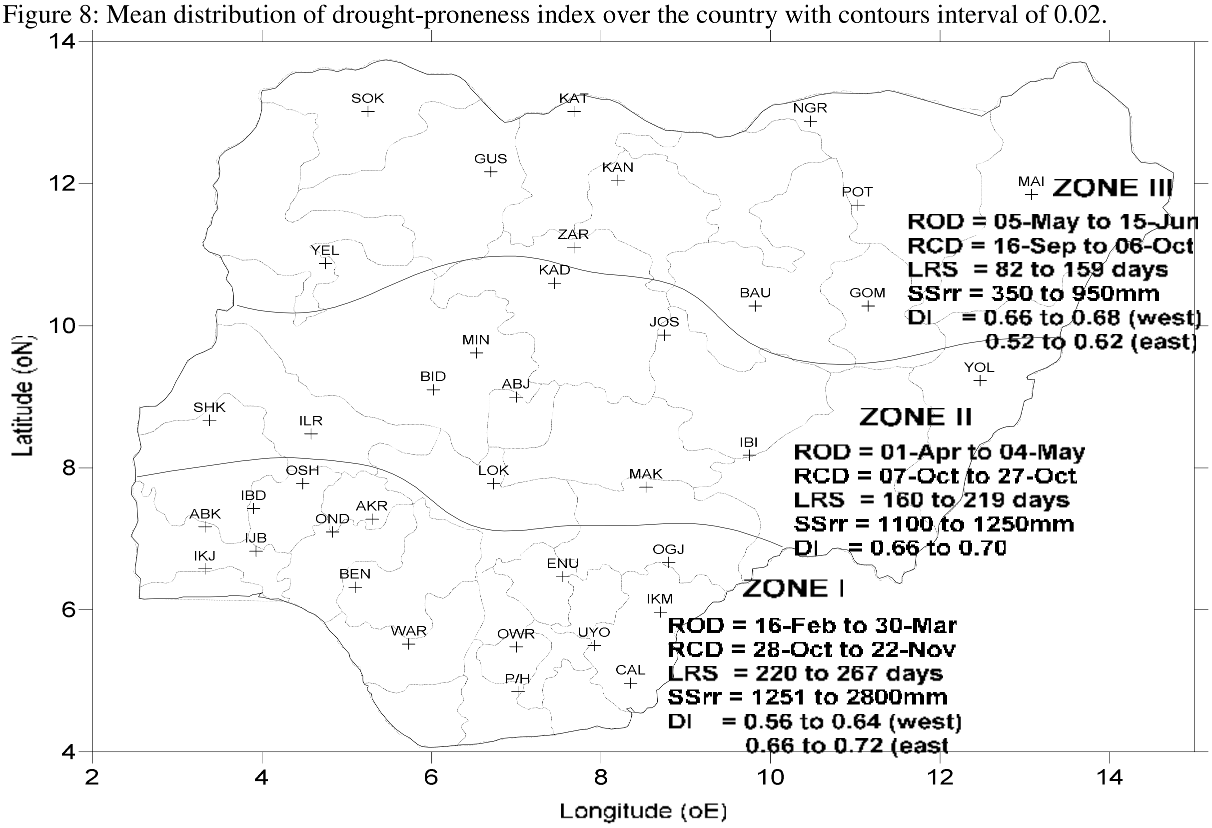


Figure 9: Map of Nigeria showing the three defined major climatic zones and their respective threshold values of agrometeorological information.

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