CrossMark

ORIGINAL PAPER

Variations in the sequences of daily rainfall across Nigeria

Christopher Uche Ezeh[1] · Michael Chukwuma Obeta[1] · Raymond N. C. Anyadike[1]

Abstract The study compared the sequences of daily rainfall over coastal southern and semi-arid northern Nigeria. Daily rainfall occurrences for 41 years (1971–2011) over four meteorological stations in Lagos, Rivers, Borno, and Katsina were analyzed using frequency analysis and Markov chain model. Findings indicate that the coastal area had a predominance of 2–4-day wet spells while the semi-arid area showed a wet spell distribution that is geometric in nature with 1-day spell predominance. The dry spell behavior was nearly the opposite of the wet spell occurrence. The coastal region showed a dry spell of 1–4-day spell predominance while the semi-arid region showed a predominance of higher dry spells of 2–6 days. Accumulation of the amount of rainfall in each spell also showed that much rainfall from the coastal area was obtained from rains of spells of 3 days and above while the semi-arid had more of its rain from spells of 1–3 days. The mean annual rainfall was 1423.75 mm (Lagos), 2173.56 mm (Rivers), 517.50 mm (Katsina), and 578.34 mm (Borno). The wettest month was June (274.08 mm) in Lagos, September (378.18 mm) in Rivers, and August in Katsina and Borno (172.98 and 184.81 mm, respectively). The driest months were January for Lagos and Rivers (15.77 and 18.96 mm, respectively) and November–February for Katsina and Borno (0–0.06 mm). This showed that the coastal areas had nearly three times the volume of rain in the semi-arid area. The study further showed that onset of rain for the coastal area was March/April while the cessation of rainy season was October/ November. On the other hand, the onset of rainy season in the semi-arid area was May/June and cessation of rainy season was September. Findings portend drier days for the semi-arid area due to dry spell persistence and hence, the consequent challenges of providing artificial water supply for agriculture and other purposes especially from October to May.

Keywords Wet and dry spells · Variation · Rainfall sequences · Agriculture · Climate change

Introduction

Rainfall in Nigeria varies temporally and spatially. Its onset and end, frequency, intensity, amount, and sequences of spells also vary greatly. The knowledge of the climatology and the variability of its attribute of wet and dry spells are essential to climatologists, environmentalists, other scientists, and most especially farmers. This is so, as rainfall is a vital natural resource that is paramount to economic development of any nation. The analysis of its behavior is increasingly important in many areas especially given the ravages of climate change. With the expansion in industry and population explosion, such analysis is important to planning and decision making. Since the early part of the twentieth century, research on rainfall behavior, particularly the sequence of wet and dry spells, had been successfully carried out by a number of scientists. Among them is one of the pioneer scientists, Williams (1952), who studied the distribution of wet and dry sequences and suggested a logarithmic series distribution (LSD) for data from England. Gabriel and Neumann (1957, 1962) introduced geometric distribution (GD) to wet and dry sequences in Tel Aviv and found that the distribution of the length of each type of spell fitted GD well. Foufoula and Lettenmaier (1987) applied a Markov renewal model to predict the occurrence of rainfall. Basak (2014) applied Markov chain model to predict rainfall in West Bengal and found that the first order Markov

✉ Christopher Uche Ezeh
christopher-uche.ezeh@unn.edu.ng; uchextop@yahoo.com

[1] Geography, University of Nigeria, Nsukka, Enugu 410001, Nigeria

🍃 Springer

chain model is the best for forecasting rainfall. Kannan and Farook (2015) worked with Markov-mixed exponential model and found that it is suitable for simulation of precipitation processes. Nogue-Paegle and Mo (1997) applying orthogonal function analysis of outgoing longwave radiation (OLR) anomalies, filtered to retain variations longer than 10 days which revealed a meridional seesaw of dry and wet conditions over tropical and subtropical South America. Pena and Douglas (2002) using reanalysis data, upper air wind and OLR data discovered that wet spells over Nicaragua, Costa Rica, and Panama are associated with weaker trade winds over the Caribbean and stronger winds across the equatorial flow northwards over the eastern Pacific. Brooks and Carruthers (1953) proposed the Polya distribution (PLD) to the wet and dry sequence of daily rainfall occurrences. Berger and Goossens (1983) later applied this to the distribution of wet (dry) spells in Belgium and showed that PLD successfully fitted the observed data. Similar findings were obtained by Theoharatos and Tselepidaki (1990) who studied the sequence of wet days in the Aegean Area. Graphical procedure has also been used to assess wet and dry spells based on monthly rainfall amounts (Bazuhair et al. 1998). This can be used to depict change of duration with their numbers within a given record length. A linear regression formulation is described on a log—log plot between spell durations and numbers (Bazuhair et al. 1998). It showed that longest durations of wet periods occur in the south eastern part of the kingdom of Saudi Arabia. This coincides with the area of the highest elevation in the kingdom.

The use of most of the above methods is made difficult in most developing countries due to paucity of data. However, Markov chain model has been widely adopted for stochastic studies because of its useful application to real life problem and the ease of interpretation. It is easily applied to daily rainfall records available in developing countries where rainfall intensity among other indices required by other models is difficult to come by (Ajayi and Olufayi, 2002). In this regard, Admasu et al. (2014) used the Markov model to explain the long-term frequency behavior of wet or dry spell during the main rainy season in Dhera region Ethiopia. Shahraki et al. (2013) employed markov chain analysis to model sequences of spells in order to understand the drought proneness of the area. N'guessanbi et al. (2014) work at Sinfra, central Cote'di voire used markov chain to develop a model to analyze and forecast precipitation that reflected up to 83 % accuracy. As a result, the Markov chain model was applied in this study to simulate the trend or pattern of rainfall occurrences and their effect on agriculture in the study area.

Studies in Nigeria such as Ezenekwe et al. (2013) on rainfall characteristics over Kano using time series analysis found that fluctuations in rainfall in Kano are not an indication of climate change. Fasheun (1983) using Markov chain rule to model monthly rainfall data for Ibadan reported an exponential relationship between frequency of dry spell and their duration. Ajayi and Olufayo (2002) used the Markov chain to model the sequences of wet and dry days in Ibadan and Onne, Nigeria. They found out that the system assumes state of stability after 4 days in August in Ibadan.

Dry spells have become an important topic as climatic models indicate increasing frequency of summer droughts under global warming in regions where drought was hitherto unknown or was a rare event (Aamlid et al. 2000; Seneviratne et al. 2002; Solberg 2004; Maracchi et al. 2005; Good et al. 2006). Caloiero et al. (2015) applied it in their study of southern Italy and found that lower probabilities of long dry spells occur in the main reliefs of the region. In the same way, interest in wet spells have increased significantly especially following the recent incidences of devastating floods in Europe (Frei et al. 2000; Palmer and Raisanen 2002). It is, however, instructive that African agriculture is predominantly rainfed and the vagaries of climate pose significant challenge to agriculture in the continent (Speranza 2010; Nzeadibe et al. 2012). In this era of climate change, it is imperative to take a new look at the sequences of rainfall in order to be able to develop an effective strategy against climate change impact on agriculture. A sound scientific knowledge of Nigeria's climate and weather using historical data as well as possible impacts of its variability and change on the various socio economic sectors cannot be over-emphasized (NIMET 2010). Despite the existence of previous studies on the variations of daily rainfall in Nigeria (Anyadike 1993; Ezenekwe et al. 2013; Ajayi and Olufayo 2002), this research uses data from four climatologically contrasting locations to ascertain and compare the sequences of daily rainfall in order to examine its implication for agricultural production in Nigeria.

Data and method

The study area and data

Lagos, Rivers, Katsina, and Borno are among the states in Nigeria. They were chosen to represent climatologic contrasts between the Southern and Northern parts of the country where livelihoods depend significantly on water and agriculture. Four stations were used in this study and they are Lagos (Ikeja), Rivers (PortHarcourt), Katsina (Katsina), and Borno (Maiduguri). Lagos lies between latitude 6° 19′ N and 6° 41′ N, and between longitude 2° 44′ E and 4° 20′ E; Rivers lies between latitude 4° 19′ N and 5° 44′ N, and between longitude 6° 24′ E and 7° 33′ E; Borno lies between latitude 10° 03′ N and 13° 44′ N, and between longitude 11° 35′ E and 14° 44′ E while Katsina lies at latitude 11° 08′ N and 13° 20′ N, and between longitude 6° 50′ E and 9° 00′ E (Fig. 1). Lagos is at a height of 36 m, Rivers is at a height of 19 m, Katsina is at 517.50 m, and Borno is at a height of 348 m above sea level.
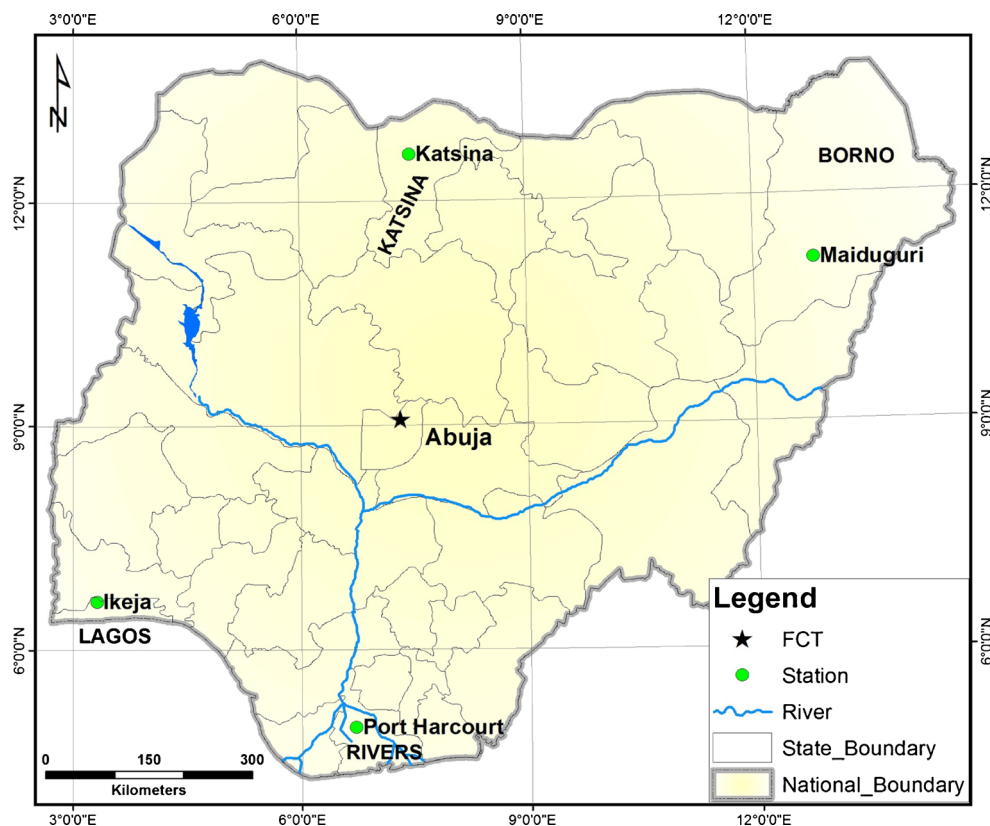
The locations are in areas of the dominant effect of the Azores anticyclones in the north and the St. Helena Anticyclones in the south that affect the nation's climate. Katsina and Borno are in the semi-arid (BSh) climatic zone whereas Lagos and Rivers are in the Equatorial (Af) climatic zone. They represent areas of short rainy season and long dry season and vice versa, respectively. Rainfall data for the stations were obtained from the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos for the period of 41 years (1971–2011).

Distribution of rainfall

The distribution of rainfall is shown in Table 1. From the Table 1, it is apparent that only Lagos has somewhat double maxima in June and September. Rivers has a unique rainfall distribution that increases progressively till August and September when the peak is reached, then diminishes till December. A high volume is received in Rivers from June to September but the highest volume is received in September. The semi-arid region represented by Borno and Katsina has its peak in August.

General description of the rainfall statistics

Table 2 shows the frequency distribution/statistical parameters of the distribution of wet/dry days and spells. In this paper, a wet day is defined as a day with recorded rain of at least 0.1 mm. A wet spell is defined as a consecutive group of rainy days and a dry spell as the period between two rain spells (Ochola and Kerkides 2003; Deni and Ibrahim 2008). The total number of wet days is 4079 (Lagos), 6231 (Rivers), 1798 (Katsina), and 1847 (Borno). The total number of days is 14,975. The probability of a day being wet is Pw = 0.28, 0.48, 0.12, and 0.12, respectively. The probability of a day being dry 1−p or Pd = 0.72, 0.52, 0.88, and 0.88, respectively. The frequency distribution of wet and dry spells was based on the threshold of 0.1 mm of daily rainfall event. We denoted wet spell with "w" and dry spell with "d." These frequency distributions of the number of wet and dry spells are shown in Table 2. This is necessary in order to generate the probability of sequences of the spells (Table 3). This inherent variability in rainfall is a prelude to the prediction of future occurrences. To compare the observed frequencies with the expected frequencies, a theoretical distribution is needed to be fitted to the data. The Markov model was used to predict the likelihood of future occurrences of wet and dry spells in the areas. Also, Anyadike's (1992) onset method was used to evaluate the onset/cessation of rainy season in the areas. The persistence of rainfall also called Besson's coefficient (rB) was evaluated for the four areas.

$$\text{Onset/end} = \text{Dm}\left(\frac{0.083TR-AC}{Rm}\right) \tag{1}$$

Table 1   Monthly distribution of rainfall in the study area

| | Monthly mean rainfall (mm) | | | |
| | Equatorial clim | | Semi-arid clim | |
	Lagos	Rivers	Katsina	Borno
Jan	15.77	18.96	0	0.04
Feb	40.01	83.50	0	0
Mar	66.85	110.13	0.71	0.25
Apr	137.41	155.93	5.73	6.34
May	191.83	240.03	30.28	31.99
Jun	274.08	269.76	72.03	80.93
Jul	198.25	330.35	148.48	154.70
Aug	82.42	372.10	172.98	184.82
Sept	179.56	378.18	82.85	100.43
Oct	142.98	256.89	12.66	13.20
Nov	78.34	123.18	0	0
Dec	21.79	21.63	0	0.06
Total annual rainfall distribution (41 years) in millimeter				
Total	58,373.90	89,116.00	21,217.40	23,711.80
Mean	1423.75	2173.56	517.50	578.34
Max	2019.90	2581.70	776.30	1076.30
Min	894.7	256.90	259.80	263.50
St Dev	270.25	388.42	138.00	162.97
Skew	−0.06	−3.05	0.02	0.54
Kurt	−0.76	14.11	−0.79	1.06

Dm is the number of days in the month containing the average, TR is the total annual rainfall, and Rm is the total rainfall of the month containing the average,

Table 2   Frequency Distribution of wet and dry spells

| | Frequency | | | |
	Rivers	Lagos	Borno	Katsina
W	6231	4079	1847	1798
1w	1149	1347	939	863
2w	3854	1794	541	571
3w	2501	827	173	308
D	8745	10,896	13,128	13,177
1d	1165	753	395	397
2d	5660	7701	14,006	13,026
3d	4416	6507	11,207	10,546
MLWS	5.42	3.03	1.97	2.08
MLDS	7.51	14.47	33.19	33.24

W is the number of wet days, 1w is the occurrence of wet spell of 1 day, 2w is wet spell of 2 days and so on. D is the number of dry days, 1d is the occurrence of dry spell of 1 day and so on. MLWS is the mean length of wet spells in days; MLDS is the mean length of dry spells in days

Table 3   Probability distribution of wet and dry spells

| Conditional probabilities | | | | |
State	Lagos	Rivers	Katsina	Borno
P	0.28	0.42	0.12	0.12
1−p	0.78	0.58	0.88	0.88
2 days				
P(ww)	0.60	0.62	0.32	0.29
P(wd)	0.40	0.38	0.68	0.71
P(dd)	0.71	0.65	0.91	0.91
P(dw)	0.29	0.35	0.09	0.09
3 days				
P(www)	0.46	0.66	0.46	0.32
P(wwd)	0.54	0.34	0.54	0.68
P(ddd)	0.81	0.78	0.93	0.93
P(ddw)	0.19	0.22	0.07	0.07

AC is accumulated rain up to the month before the month in which the value (TR × 0.083) falls in.

$$rB = \frac{1-p}{1-p1} - 1. \tag{2}$$

$$T = \begin{pmatrix} Pww & Pwd \\ Pdw & Pdd \end{pmatrix} \tag{3}$$

Note: p is the probability that a day will be wet. $1-p$ is the probability of a day being dry, Pww is the probability of two consecutive wet days, pwd is the probability of a wet day being followed by a dry day, pdw is the probability of a dry day followed by a wet day, and pdd is the probability of having dry day given that the previous day was dry. P1 = pww or pdd. The parameter p usually ranges from 0 to 1.

The study also aims at investigating the persistence of wet and dry spell. Persistence is a measure of the probability of the occurrences of an event on a given day. Singh et al. (1981) suggested that wet (dry) persistence can be defined as follows: wet persistence is pww–pw and dry persistence is pdd–pd.

Where, pw is the probability of a wet day and pww is the conditional probability of a wet day given that the previous day was wet. pd is the probability of a dry day and pdd is the conditional probability of a dry day given that the previous day was dry.

Results

Characteristics of the areas

The major characteristics of the study areas are shown in Table 4. Rivers and Lagos have higher mean rainfall intensity of 14.2 and 13.6 mm per day than Katsina and Borno with just 5.3 and 6.9 mm per day, respectively. This is due to higher annual rainfall recorded in the south as well as the fact of being in the equatorial

Table 4 Major characteristics of wet and dry spells

Station	State	Lat. (N)	Long (E)	Height (m)	MAR (mm)	MRI (mm/day)	LWS	LDS	P	1–P	WP	DP
Ikeja	Lagos	6° 35′	3° 20′	37	1459.35	13.6	10	113	0.27	0.73	0.33	0.01
PHarcourt	Rivers	04° 51′	7° 01′	19	2227.9	14.2	28	123	0.42	0.58	0.20	0.07
Katsina	Katsina	13° 01′	7° 4′	517	517.50	5.3	10	246	0.12	0.88	0.20	0.03
Borno	Maiduguri	11° 51′	13° 1′	348	578.34	6.9	8	245	0.12	0.88	0.17	0.03

MAR mean annual rainfall, *MRI* mean rainfall intensity, *LWS* longest wet spell, *LDS* longest dry spell, *Wp* wet persistence, *DP* dry persistence, *m* meters above sea level, *N* north, *E* east, *Lat* latitude, *Long* longitude

climatic belt. The highest volume of rain recorded in a day in Lagos was 237.3 mm on June 23rd, 1997; Rivers was 185.3 mm on August 12th, 2002, 85.8 mm on 21st June 2010 in Katsina and 94.8 mm on July 24th, 1999 in Borno. Rainfall intensities during the longest runs of wet spells were evaluated. Findings indicate highest rainfall intensity of 41.4 mm per day occurred in Lagos during the 9-day wet spell from 24th June to 2nd July 1972 with accumulated rain of 372.4 mm. In Rivers, it was 18.0 mm per day during the 25-day wet spell from 20th July to 13th August 1972 with accumulated rainfall of 450.8 mm. In Katsina, it was 23.8 mm per day during the 7-day wet spell from 25th to 31st August 1975 with accumulated rain of 96.5 mm and in Borno, it was 20.2 mm per day during the 6-day wet spell from 13th to 18th August 2011 with accumulated rainfall of 121 mm. Lagos and Rivers have no dry month. That is, it rains throughout the year whereas Katsina and Borno experience severe dry season with no rain in 4 months. Wet persistence is higher in Lagos and Rivers while the Dry persistence is higher in Katsina and Borno. The longest wet spell experienced in Rivers was 28 days with accumulated rainfall of 377.5 mm from 13th August to 9th September, 1994, Lagos and Katsina experienced the same longest wet spell duration of 10 days while for Borno it was 8 days wet spell with accumulated rainfall of 52.4 mm from 15th to 22nd August 1999. However, Lagos had the longest wet spell of 10 days on four occasions but Katsina was once. The highest accumulated rain during the longest wet spell in Lagos was 231.1 mm from September 13th to 22nd, 1984 while in Katsina it was 70.5 mm from July 16th to 25th, 2006. The month with the highest rain in Lagos is June with a total of 11,237.2 mm, September in Rivers with a total of 15,505.5 mm, August in Katsina and Borno with a total of 7092

and 7577.5 mm, respectively. The distribution of rainfall is presented in Table 1. The longest dry spells in the stations also vary from 246 days (October 1st, 1972–June 3rd, 1973 in Katsina), 245 days in Borno from 25th September 1986 to 27th May 1987, to 123 days in Rivers from 17th November 1982 to March 19th, 1983 and 113 days (December 7th, 1982–March 29th, 1983) in Lagos. These periods much nearly correspond to the period of sahelian droughts (Mortimore 1973, Nicholson 1986).

Rainfall season in the stations

The seasons in the stations are divided into wet and dry seasons. The length of each season in the stations varies considerably. The dates of onset and end of rainy season vary from year to year and from place to place. Such information is important especially to the farmers since our agricultural practices are still rainfed. The dates of onset and cessation of rainy season are displayed in Figs. 2, 3, 4, and 5.

The mean date for the onset of rainy season in the stations are 13th April (Lagos), 10th April (Rivers), 13th June (Katsina) and 11th June (Borno) while for the cessation of the rainy season are 10th October (Lagos), 13th October (Rivers), 13th September (Katsina and Borno). The earliest date for the onset of rainy season in the sites are 15th February (Lagos), 3rd March (Rivers), 1st May (Katsina), and 3rd May (Borno) (Figs. 2, 3, 4, and 5) while the latest is April 28th (Lagos, in 2003), April 30th (Rivers, in 1990), 5th July (Katsina, in 1986), and 4th July (Borno, in 1986). The earliest date for the end of rainy season is 1st September in 1987 (Lagos), 3rd October in 2008 (Rivers), 1st August in 1982 (Katsina), and 6th August in 1991 (Borno). The latest
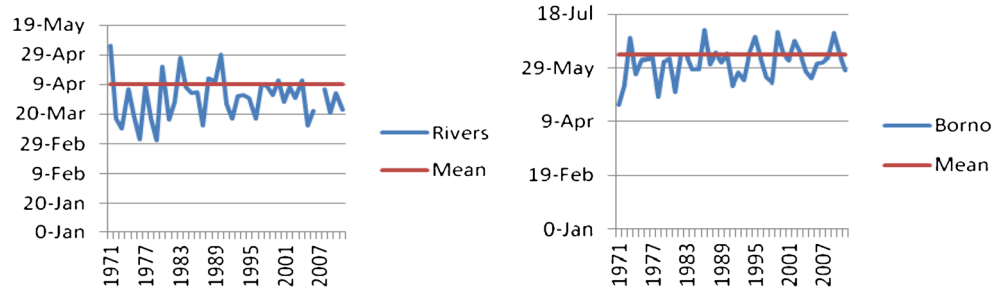

Fig. 2 Onset of rainy season for Lagos and Katsina
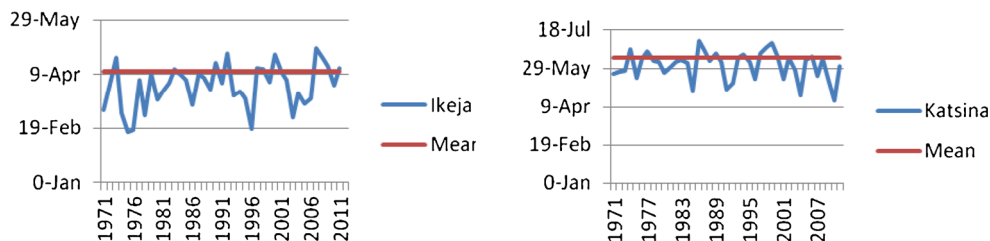
Fig. 3 Cessation of rainy season for Lagos and Katsina
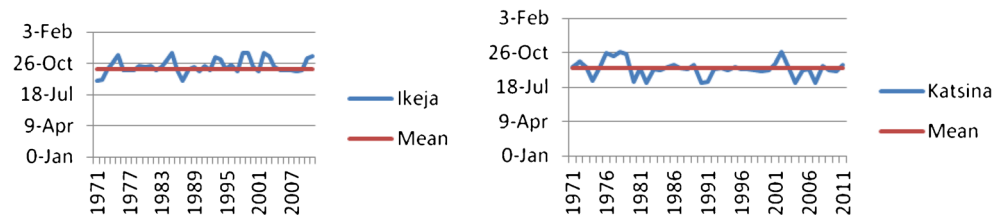
Fig. 4 Onset of rainy season for Rivers and Borno

date for the cessation of rainy season is 29th November in 1998 and 2002 (Lagos), 30th November in 1973 and 1976 (Rivers) but 30th October in 1978 and 2002 (Katsina) and 28th October in 1976 (Borno). Also, the number of rainy days during the rainy seasons varies between the stations and with years. The years with the longest are 1979 (134 days in Lagos), 1975 (189 days in Rivers), 1998 (57 days in Katsina), and 2008 (56 days in Borno). The years with the shortest duration of rainy days are 1998 (78 days in Lagos), 1978 (90 days in Rivers), 1987 (33 days in Katsina), and 1983 (30 days in Borno). The coefficient of persistence of rainfall (rB) is 0.80 for Lagos, 0.52 for Rivers, 0.29 for Katsina, and 0.24 for Borno.

Prediction of wet and dry spells

Markov chain model was used to simulate the likelihood of future occurrences of wet and dry spells. It is constructed into a 2-way, 2-state (3-state) conditional matrixes. This conditional probability is an independent transitional probability since the two conditional probabilities sum to unity. This implies that none of the state is dependent on the other. The

conditional probabilities for the stations are presented in Table 3. The predictions for 2, 3, and 4 years are given in Table 5.

Table 5 shows that in the next 2 years, the conditional probability of having a wet day followed by another wet day is 0.33 in Lagos, 0.52 in Rivers, but 0.16 in Katsina and 0.15 in Borno.

Conclusion

The analysis of daily rainfall occurrence is of high climatological interest, globally, as it provides useful knowledge and information for many areas particularly agriculture, irrigation, water resource management, engineering and also in hydrological activities. This study has focused on providing the contrasts between the semi-arid (Katsina and Borno) and coastal (Lagos and Rivers) rainfall climatology. The study has shown that the stations have longest wet spells of 8 days (Borno), 10 days (Lagos and Katsina), and 28 days (Rivers) which also vary in terms of accumulated rain during the period. Rivers and Lagos have more accumulated rain during the period than Katsina and Borno.

Fig. 5 Cessation of rainy season for Rivers and Borno. Source: authors' computation and plotting
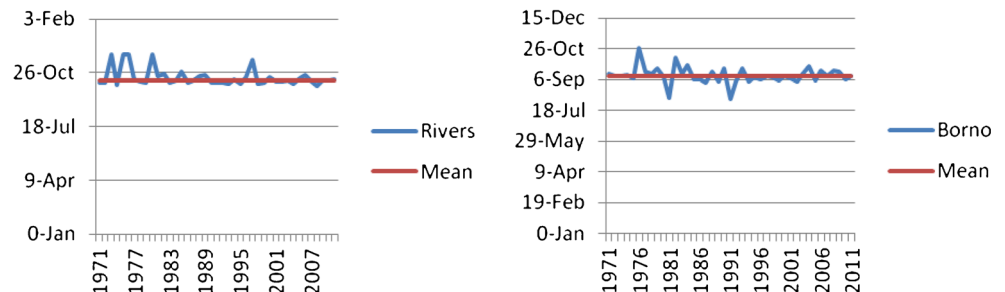
Table 5　Simulating the probability of wet and dry spells at given annual intervals

Condition	2 years				3 years				4 years			
	Ikeja	Rivers	Katsina	Borno	Lagos	Rivers	Katsina	Borno	Lagos	Rivers	Katsina	Borno
Pww	0.33	0.52	0.16	0.15	0.33	0.49	0.13	0.12	0.32	0.48	0.12	0.12
Pwd	0.67	0.48	0.84	0.85	0.67	0.51	0.87	0.88	0.68	0.52	0.88	0.88
Pdd	0.68	0.44	0.89	0.11	0.67	0.47	0.88	0.11	0.68	0.48	0.88	0.11
Pdw	0.32	0.56	0.11	0.89	0.33	0.53	0.12	0.89	0.32	0.52	0.12	0.89
Pwww	0.31	0.51	0.25	0.15	0.27	0.44	0.17	0.11	0.26	0.42	0.14	0.10
Pwwd	0.69	0.49	0.75	0.85	0.63	0.56	0.83	0.89	0.64	0.58	0.86	0.90
Pddd	0.76	0.32	0.93	0.09	0.75	0.36	0.93	0.09	0.74	0.38	0.92	0.10
Pddw	0.24	0.68	0.07	0.91	0.25	0.64	0.07	0.91	0.26	0.62	0.08	0.90

Source: authors' computation

Borno and Katsina have longer dry spells than Lagos and Rivers. The coastal stations have higher rain intensity than the semi-arid station. The likelihood of having more rain is higher in the coastal stations.

The findings so far conform to the general view that rainfall amount decrease from south to north. This implies that aridity increases with distance inland. Therefore, there is greater likelihood of higher floods in the coastal stations than the semi-arid stations. There is a greater chance of having rain in any day irrespective of what the previous day was (whether wet or dry) in Rivers and Lagos than in Katsina and Borno.

Agriculture in Nigeria is largely rainfed which makes it subject to the vagaries of weather and climate. The study also discovered that dry spells have higher probability of occurrence than the wet spell. This shows that there is long uninterrupted period of dryness during the dry season, an indication for water scarcity during this period and a need for irrigation agriculture and borehole drilling for efficient and prompt water supply. Findings portend drier days for the semi-arid area due to dry spell persistence and hence the consequent challenges of providing artificial water supply for agriculture and other purposes. To achieve the objectives of the agricultural Transformation Agenda of Nigeria of increasing the income of small holder farmers, much attention need to be given to spell persistence and dates of onset of rainy season to avoid much losses to farmers due to drought and variations in rainfall.

Further analysis should be conducted to determine the best fit theoretical distributions of wet and dry spells in Nigeria on a seasonal and geographical basis.

References

Aamlid D, Torseth K, Venn K, Stuannes AO, Solberg S, Hylen G, Christopherson N, Framstad (2000) Changes of forest health in Norwegian boreal forests during 15 years. J Ecol Manag 127:103–118

Admasu et al (2014) Markov chain Analysis of dry, wet weeks and statistical analysis of weakly rainfall for agricultural planning at Dhera, Central rift valley region. Afri J Agric Res. Pp 2205–2213

Ajayi AE, Olufayo AA (2002) The sequence of wet and dry days at Ibadan and Onne (sub-humid zone of Nigeria). Niger J Technol 21(1):38–44

Anyadike RNC (1992) Regional variations in fluctuations of seasonal rainfall over Nigeria. Theor Appl Climatol 45(4):285–292

Anyadike RNC (1993) Seasonal and rainfall variations over Nigeria. Int J Climatol 13:1–4

Basak P (2014) On the Markov chain models for monsoonal rainfall occurrence in different zones of West Bengal. Indian J Radio Space Phys 43:349–354

Bazuhair AS, AL-Gohani A, Sen ZS (1998) Determination of monthly wet and dry periods in S/Arabia. Inter J Climate 17(3):303–311

Berger A, Gossens C (1983) Persistence of wet and dry spell at Uccle (Belguim). J of Clim 3:21–34

Brooks CEP, Carruthers N (1953) Handbook of statistical methods in meteorology. Her majesty's stationary office, London, p. 412

Caloiero T, Coscarelli R, Ferrari E, Sirangelo B (2015) Analysis of dry spells in southern Italy (Calabria). Water 7:3009–3023. doi:10.3390/w7063009 www.mdpi.com/journal/water

Deni SM, Jemain AA, Ibrahim K (2008) The spatial distribution of wet and dry spells over peninsular Malaysia. Theor Appl Climatol 94: 163–173. doi:10.1007/s00704-007-0355-8

Ezenekwe LN, Ezemonye MN, Emeribe CN (2013) An appraisal of the characteristics of rainfall in Kano. Br J Adv Acad Res 2(1):20–28

Fasheun A (1983) Modeling of rainfall sequence for farm operations planning in Ibadan. Niger Meteor J 1:102–109

Foufoula-Georgiou E, Lettenmaier DP (1987) A Markov renewal model for daily rainfall occurrence. Water Res Research 25(5):875–884

Frei C, Davies HC, Gurtz JO, SCHAR C (2000) Modelling wet and dry spells with mixture distribution. Meteorog Atmos Phys 73:245–256

Gabriel KR, Neumann J (1957) On the distribution of weather cycles by length. Quart J Roy Meteor Soc 83:375–379

Gabriel KR, Neumann J (1962) A Markov chain model for daily rainfall occurrence at Te. Aviv. Quart J Roy Meteor Soc 88:90–95

Good P, Barring L, Giannakopolous C, Holt T, Palutikof J (2006) Non-linear regional relationships between climate extremes and annual mean temperatures in model projections for 1961–2009 over Europe. Clim Res 31:19–34

Kannan KS and Farook AJ (2015) Stochastic simulation of precipitation using Markov chain-mixed exponential model. Applied Mathematical Sciences, Vol. 9, 2015, no. 65, 3205–3212 HIKARI Ltd, www.m-hikari.com. http://dx.doi.org/10.12988/ams.2015.54308

Maracchi G, Sirotenko O, Bindi M (2005) Impact of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Climate Change 70:117–135. doi:10.1007/s10584-005-5939-7

Mortimore MJ (1973) Drought in Africa and famine in Hausaland. Savanna 2(2):97–107

Nguessanbi, et al (2014) Markovian approach for analysis and prediction of monthly precipitation field in the department of Sinfra (Central-west of Côte d'Ivoire). Int. J. Engr. Res and Gen Sci. Vol. 2 Issue 1. pp

Nicholson SE (1986) The spatial coherence of African rainfall anomalies: inter-hemispheric teleconnections. J Appl Meteorol 25:1365–1381

NIMET (2010) Demonstration and assessment of climate change in Nigeria and development of adaptation strategies in the key socio-economic sectors: meteorological approach presented by Anthony Anuforo, DG NIMET to the National stakeholders Workshop on Developing National Adaptation strategy and plan of Action for Nigeria, Abuja, 2010

Nogues-Paegle J, Mo KC (1997) Alternating wet and dry conditions over South America during summer. AMS Journal. 125(2):279–291

Nzeadibe TC, Egbule CL, Chukwuone NA, Agwu AE, Agu VC (2012) Indigenous innovations for climate change adaptation in the Niger Delta region of Nigeria. Environ Dev Sustain 14(6):901–914. doi:10.1007/s10668-012-9359-3

Ochola WO, Kerkides P (2003) A Markov chain simulation model for predicting critical wet and dry spells in Kenya: analyzing rainfall events in the Kano plains. Irrig Drain 52(4):327–342

Palmer TN, Raisanen J (2002) Quantifying the risk of extreme seasonal precipitation events in a changing climate. Nature 415:512–514

Pena M, Douglas MW (2002) Characteristics of wet and dry spells over the pacific side of central America during the rainy season. AMS J 130(12):3054–3073

Seneviratne SI, Pal JS, Eltahir EAB, Schar C (2002) Summer dryness in a warmer climate: a process study with a regional climate model. Climate dyn 20:69–85

Shahraki N, Bakhtiari B, Ahmadi MM (2013) Markov chain model for probility of dry, wet days and statistical analysis of daily rainfall in some climatic zone of Iran. 5th International Conference on Air and Water-Components of the Environment, March, 22–23, Cluj-Napoca, Romania, 399–406

Singh SV, Kripalani RH, Shaha P, Ismail PMM, Dahale SD (1981) Persistence in daily and 5-day summer monsoon rainfall over India. Arch Meteor Geophys Bioclim Ser A 30:261–277

Solberg S (2004) Summer drought: a driver for crown condition and mortality of Norway spruce in Norway. For Pathol 34:93–104

Speranza CI (2010) Resilient adaptation to climate change in African agriculture. Bonn, German Development Institute (DIE)

Theoharatos GA, Tselepidaki IG (1990) The distribution of rainy days in the Aegean area. Theor Appl Climatol 42:111–116. doi:10.1007/BF00868217

Williams CB (1952) Sequences of wet and of dry days considered in relation to the logarithmic series. Quart J Roy Meteor Soc 78:511–516