JOURNAL OF METEOROLOGY & CLIMATE SCIENCE
J. Met & Clim. Sci. 10(1):16-21 (2012)

N.Met.S
Nigerian Meteorological Society

MODERATE AND INTENSE RAINFALL RATES AND TOTAL RAIN ACCUMULATION OVER THE NORTHERN AND SOUTHERN NIGERIA

J.S. OJO[1]*, A. OLULEYE[2] AND O.L OJO[1]
[1]Department of Physics, Federal University of Technology, Akure, Ondo State
[2]Department of Meteorology, Federal University of Technology, Akure, Ondo State
ojojs_74@futa.edu.ng; olalekan_bisi2005@yahoo.com

Abstract: This paper is concerned with the statistical investigation of rainfall intensities for 30-years (1975-2004) over Southern and Northern Nigeria. The average rainfall intensity was analyzed to study the diurnal, monthly, and annual variation of total rain accumulation. The study has shown that the northern part of Nigeria (Kano) with the lowest amount of average precipitation recorded the highest percentage of convective rainfall of ~76.7% while 23.3% were for stratiform in terms of the total duration and intensity of the rain events. The southern part (Calabar) recorded the highest number of rain events of about 186 with percentage of convective rainfall of about 67.3% and 32.7% stratiform. The southern oscillation values were low in 1975, 1981, 1984, 1989, 1996 and 1999. The variations in the rainfall fields are due to the dynamic nature of the inter-tropical convergence zone (ITCZ). These results are vital for hydrological processes and radio propagation.

Keywords: Rainfall intensities, ITCZ, ENSO, hydrological processes and radio propagation.

INTRODUCTION

For applications in meteorology and hydrology, moderate and intense rainfall rates and total rain accumulation analysis plays an important role. For example, the rainfall distribution within the year is one of the basic characteristics of the rainfall regime in a certain location while the temporal rainfall accumulation varies from year to year (Hardas and Kutiel, 2010). In addition, the analysis also plays an important role in assisting the radio wave propagation scientists to estimate signal fading and its statistics (Mandeep, 2010). For frequencies greater than 10 GHz, rain is considered to be the main factor of attenuation especially for tropical and equatorial countries that experience high rainfall rate throughout the year such as Nigeria. Also, Adimula et al., [2005] reported that the lack of symmetry of the rain drops causes the rain drops to be capable of supporting two distinct modes of waves and the depolarizing effect of the drops has made frequency reuse by means of dual polarization techniques at microwave and millimeter wave frequencies difficult.

Rain is a natural phenomenon, which varies from location-to-location and from year-to-year. Thus for a geographic location, adequate measurements should be made to create the needed data base.

The major systems that control the spatial and temporal characteristics of the climate of the region include the Intertropical convergence zone (ITCZ), subtropical anticyclones, monsoon wind systems, the African and Tropical Easterly Jet (TEJ and AEJ) streams, easterly/westerly waves, tropical cyclones, and teleconnections with regional and large-scale quasi-periodic climate systems like the quasi-biennial oscillation (QBO), intraseasonal waves, and El Niño—Southern Oscillation (ENSO), among others (Ajayi, 1982). For the ITCZ, its dynamic nature leads to the variations in the rainfall fields; which varies in spatial scale as much as 40° to 45° of latitude north or south of the equator based on the pattern of land and ocean circulation. Variation in the location of the Intertropical zone drastically affects rainfall in many equatorial regions, resulting in the wet and dry seasons of the tropics rather than cold and warm seasons of higher latitudes. In Africa, the system ITCZ is not stationary. The position changes in the course of a year (Ajayi, 1982). Adedoyin (1989) reported that Sea Surface Temperature (SST) anomalies of the Indian, North Atlantic and South Atlantic Oceans are correlated with total rainfall and number of rainy days while the anomalies of the tropical East Pacific may have influence on rainfall intensity at the beginning of the rainy season. However, the work of Mandeep (2010) showed that the probability of exceeding any given rain rate is significantly greater during the Northeast monsoon season and greater during La Nina years than in El Nino years.

The tropical coastal region of Nigeria spans over latitude 6.5° N and Longitude 12° E with an altitude of 62 m above sea level. It has a long term mean temperature of 27.1°C. It enjoys a typical equatorial climate and a rainfall average of 2864.22 mm. Its coastal and relatively low-level location no doubt affects its climatic characteristics (Ojo, 2009). The Northern region also span over latitude 12° N and Longitude 9° E and on altitude of 480m above sea level. The interannual variability of rainfall in the northern part of Nigeria is large; typically over 20% of the annual values (Oladapo, 1995) while an annual average rain accumulation is less than 1000 mm.

In this article, hourly rainfall data measured in different locations in Nigeria over a period of 30 years (1975 to 2004) are analyzed for tropospheric effects on microwave and millimeter wave signals. The study also includes the analyses of the diurnal, monthly and annual variation of total rain accumulations. In addition, rain rate analysis for a 30-year period is studied to investigate changes in rain structure during the monsoon seasons. The rain rates are also analyzed for the El niño years. Such studies are vital to quantify how rainfall patterns are dependent on various natural hydrological processes such as daily convectional cycles as well as radio propagation.

STUDY SITE AND METHOD

The long-term daily rainfall data were obtained from the Nigerian Meteorological Stations for a period of 30 years (1975 to 2004) over the northern and southern regions of Nigeria. The data were obtained from rain gauge measurements in each station and recorded on a chart in accordance with the Nigerian Meteorological Agency standard and documented in the Meteorological Form of Met/111/2. The precipitation data are taken from measurements made in locations from the Southern region; Akure (7.17° N, 5.18° E), Calabar (4.58° N, 8.21° E) and Lagos (6.35° N, 3.2° E) and the Northern region; Minna (9.37° N, 6.32° E) and Kano (12.03° N, 8.32° E). Table 1 shows the site characteristics. For application of the results of this work to radio propagation purposes, the 30-years rainfall intensity was converted to rain rate of 1-minute integration using the Moupfouma and Martin's model (Moupfoma and Martins, 1995).

Table 1: Site characteristics of the study locations.

Station	Latitude (° N)	Longitude (° E)	Altitude (m)	Average Annual Rainfall (mm/year)	ITU-R Rain Zone	Highest monthly Precipitation (mm/month)	Regional climate
Akure,	7.17	5.18	358	1485.57	P	463.8	Rain forest
Ikeja	6.35	3.20	129.0	1425.21	P	619.5	Coastal
Calabar	4.58	8.21	61.9	2864.91	P	796.6	Coastal
Minna	9.37	6.32	281.1	1196.75	N	409.0	Semi-arid
Kano	12.03	8.32	475.8	924.85	N	604.7	Savannah

Table 2: Rain types observed over the period of 30 years in the study locations

Observation period	1975 – 2004				
Locations	Akure	Ikeja	Calabar	Minna	Kano
Average number of rainy events	89	100	186	77	53
Convective rain (%)	70	62.9	67.3	72.9	76.7
Stratiform rain (%)	30	37.1	32.7	27.1	23.3
Average rainfall amount (mm)	1485.57	1425.21	2864.91	1196.75	924.85

The model is good for both tropical and temperate climate and can be expressed as:

$$P(R \geq r) = 10^{-4}\left(\frac{R_{0.01}}{r+1}\right)^{b} \exp(u[R_{0.01} - r]) \quad (1)$$

where r (mm/h) represents the rain rate exceeded for a fraction of the time, $R_{0.01}$ is the rain intensity exceeded during 0.01 percent of time in an average year (mm/h) and b is approximated by the following expression:

$$b = \left(\frac{r - R_{0.01}}{R_{0.01}}\right) \ln\left(1 + \frac{r}{R_{0.01}}\right) \quad (2)$$

The parameter u in equation (1) governs the slope of rain rate cumulative distribution and depends on the local climatic conditions and geographical features. For tropical and sub-tropical localities

$$u = \frac{4\ln 10}{R_{0.01}} \exp\left(-\lambda\left[\frac{r}{R_{0.01}}\right]^{\gamma}\right) \quad (3)$$

where $\lambda = 1.066$ and $\gamma = 0.214$.

Thus, the Moupfouma model requires three parameters; λ, γ and $R_{0.01}$. The first two parameters have been provided. However, these two parameters had been modified in our previous work where our new coefficients provided lower variability in predictions -measured by the standard deviation and mean of the error variable (Ojo et al., 2009) .To estimate $R_{0.01}$, the use of Chebil and Rahman's model appears suitable, it allow the usage of long-time mean annual accumulation, M, at the location of interest. The power law relationship of the model is given by

$$R0.01 = \alpha M^{\beta} \quad (4)$$

where the regression coefficient α and β are defined as

$$\alpha = 12.2903 \quad \text{and } \beta = 0.2973 \quad (5)$$

Thus, using the refined Moupfouma model and Chebil and Rahman's model, the 1-minute rain-rate cumulative distribution is fully determined from the long-term mean annual rainfall data.

RESULTS AND DISCUSSIONS

Table 1 shows the site characteristics while Table 2 gives the detail rain types observed for 30 years over the study locations. The results show distinct inter-annual variations in which Calabar consistently recorded the highest monthly precipitation, with the peak of 796.6 mm. Over these years, Ikeja recorded the second highest of 619.5 mm in the same year, while Minna has the least record of highest monthly record of 409 mm. It could also be noticed that that the classification according to international Telecommunication union differs according to the region. The differences in the rain cell structure accounts for the lower total average rainfall amount in Ikeja (Adimula et al., 2005). Figure 1 also presents a typical graph of total annual rainfall accumulation over the northern and southern region of Nigeria. The cumulative rainfall distribution also shows distinct inter-annual variations, with Calabar having an average annual rainfall of about 2864 mm and the ratio of standard deviation to mean of 0.12, while Kano has an average annual rainfall of about 925 and the ratio of standard deviation to mean is 0.4. Although, the two stations showed distinct variation in the pattern of their rainfall, year 1984 (2167 and 480 mm for Calabar and Kano respectively) had significantly low rainfall relative to other years. Correspondingly, the SOI values are negative indicating a possible influence of an El Niño event. This is in good agreement with the work of Mandeep, (2010).

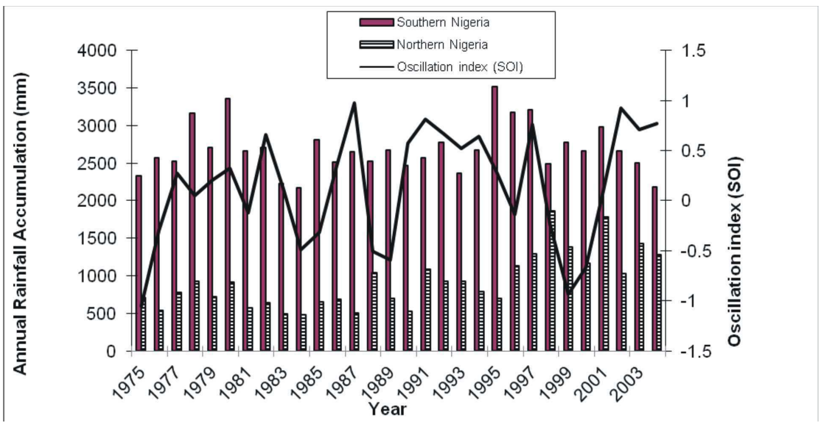

Figure 1: Highest monthly accumulation of Rainfall (mm) over northern and southern Nigeria

Fig 1 shows that over the last 30 years, El Niño, which represents SOI (Ogallo, 1988; Obasi, 1991) occurred six times (1975-1976, 1981-1982, 1984-1985, 1989-1990, 1996-1997, and 1999-2000).

Rain in the tropics, in most cases, occurs in form of cells which are a mixture of stratiform and convective rain types with the convective rain accounting for ~ 70% or more of the total rain in most cases (Adimula, 2005). This statement was confirmed using the analysis of Table 2, which presents the statistics of the rain events (observed over the 30 years), in terms of the total time duration and the intensity of the rain events. The convective rains, which account for ~70% of the measurements, occurred in the form of heavy showers, with intensities over a wide range and accompanied by rapid changes in intensities and rain temperature. From the table, it could be seen that the highest percentage of convective rain was observed in Kano and the lowest in Ikeja. Results from Table 2 also shows that, of all the rain events for the period of observation, Kano with the lowest amount of average precipitation over the period of study recorded the highest percentage of convective rainfall of ~76.7% while 23.3% were for stratiform in terms of the total duration and intensity of the rain events. This agrees with the work of Omotosho, (1985) which investigated the separate contributions of squall lines, thunderstorms and the monsoon to the total rainfall in Nigeria. The results indicated that convective rain tend to occur most frequently in the northern Nigeria and that this contribution decreases from north to south. The corresponding figures for the other stations are as shown in Table 2. The highest number of rain events recorded was 186 in Calabar, while the lowest was 53 in Kano, though; this site recorded the highest percentage of convective rainfall but the number of rainy events was the least because of the climatic nature of the region. In general there are more rainy events recorded in Calabar. We can therefore deduce that two kinds of rainfall are observed during the period of observation. The strong showers with high rain rates due to convective rain which occur for a short time and over a limited area and the Stratiform rain which characterized by medium and low intensities with long duration, and which extended over all the locations of measurement.

Figure 2 shows the average monthly rainfall accumulations during the observation period. The average monthly rainfall depends on the effects of movement of the Intertropical Convergence Zone (ITCZ). Nigeria has two seasons, dry (Nov., Dec., Jan., and. Feb) season and wet (the rest of the calendar year) season. ITCZ advances further North during the wet season, intensifying rainfall during the season.

It could also be observed from the figure that each location has different month of peak average monthly rainfall accumulation. Calabar consistently records the highest (March – November) average monthly rainfall accumulation throughout the period of observation, with a peak of ~ 434 mm in the month of July. Over the period, Ikeja, which is in the same climatic region, recorded the peak average monthly rainfall accumulation of ~ 257 mm in June. Akure also recorded its peak average monthly rainfall accumulation of 208 mm in the month of July. However, Kano which is located in the northern region records its peak average monthly rainfall accumulation of ~313 mm in the month of August along with Minna with the peak of ~ 263 mm. The rain in the coastal region during the dry season is due to the local effects like sea breeze while in the other locations may be due to the presence of high altitude (Oluleye, 2009). For example, little amount of shower was observed in the semi-arid region (Minna); however, no traces of rainfall were observed in the savannah region (Kano) during the dry season especially in December and January throughout the period of observation.

The mean total rainfall for the coastal (coast to latitude 7^{o} N) and the savannah (latitude 9^{o} N to 14^{o} N) over Nigeria is presented in Figure 3. It could be observed that in the coastal region, there was always a sharp drop in the amount of precipitation in the month of August due to what is locally called 'August break' or 'little dry season', however at this period, the arid region recorded the peak amount of rainfall. The result is in good agreement with the earlier work of Ajayi [1982].

From the analysis, one can, therefore, notice that the 'worst months' in terms of excess amount rainfall are between April and October. This is very important for determining the quality objectives of telecommunication systems. Although within these months, the worst month still varies from one location of observation to another.

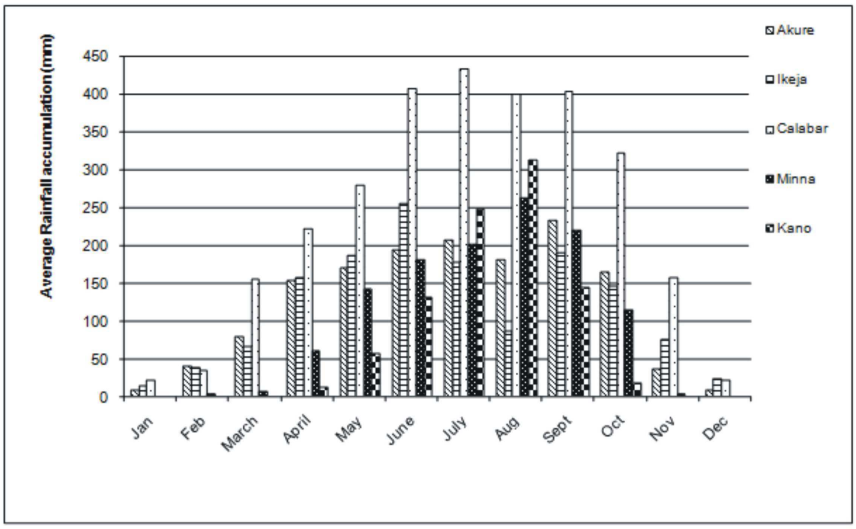

Fig 2: Average monthly rainfall accumulations (mm) over 30 years

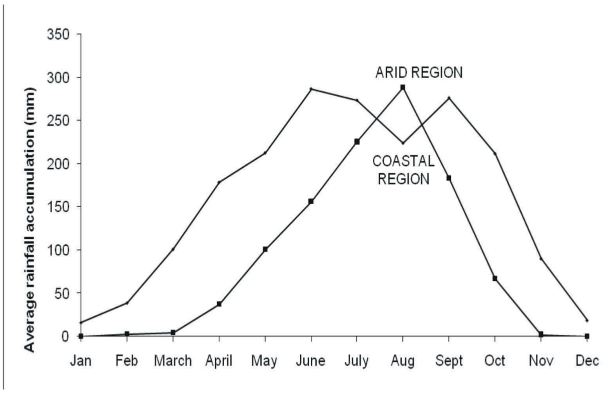

Fig 3: Comparison of the average rainfall accumulation (mm) over the arid and the coastal region of Nigeria

Figure 4 presents the cumulative distribution of 30-year predicted 1-minute rain rate using Moupfouma model for each station in Nigeria. The lower time percentage is characterized by the presence of thunderstorm whose variability is greater than that of the stratiform rain that is observed at higher time percentages; this explains why the values for low probability are much greater than the ones for high probabilities The higher the rain intensity, the lower the corresponding percentage of time recorded and the lower the rain intensity the higher the percentage of time or exceedance probability. For example, at higher time percentage of 0.1%, the rain rate recorded varies between about 47 mm/h and ~ 34 mm/h from the coastal to the arid region of Nigeria; while for the lower time percentage of 0.01%, the rain rate varies between about 130 mm/h and 93 mm/h. Also the rain intensity for time percentage difference between 0.1% and 0.01% ranges between 82.7 mm/h and 59 mm/h from the coastal to the arid region of Nigeria. It could further be observed that, though, Ikeja and Calabar belong to the same coastal region; there is a wide variation between the rain rates. System designer needs to be aware of these differences because they represent an uncertainty in the design of each link. It could, therefore, be concluded that the difference between higher and lower time percentage decreases as one move from the coastal region to the interland and to the savannah region of the country.

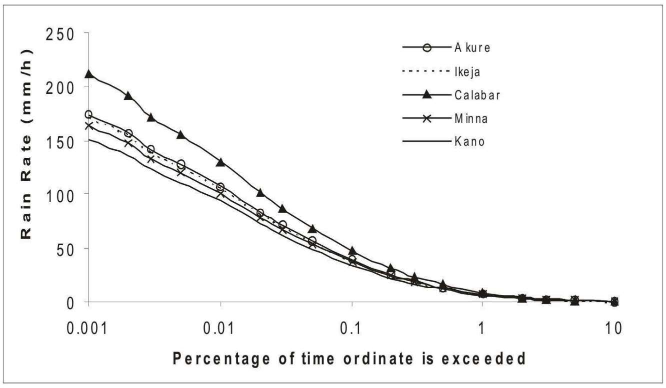

Figure 4 Cumulative distribution of 1-minute rain rate using Moupfouma model.

CONCLUSIONS

Analysis of moderate and intense rainfall rates and total rain accumulation over Northern and Southern Nigeria has been overviewed. The study has shown that the northern part of Nigeria (Kano) with the lowest amount of average precipitation recorded the highest percentage of convective rainfall of ~76.7% while 23.3% were for stratiform in terms of the total duration and intensity of the rain events. The southern part (Calabar) recorded the highest number of rain events of about 186 with percentage of convective rainfall of about 67.3% and 32.7% stratiform. The variations in the rainfall fields are due to the dynamic nature of the inter-tropical convergence zone (ITCZ). These results are vital for hydrological processes and radio propagation.

REFERENCES

Adimula I.A, Falaiye, O.A and Willoughby, A.A (2005): 'Effects of rain on microwave and satellite communications in equatorial and tropical regions', *Nigerian J. Phys.,* Vol. 17, Pp. 66-71.

Ajayi, G.O (1982): Statistical properties of tropical rainfall intensity measured at Ile- Ife, a southern station in Nigeria for microwave and millimetre wave applications, *Annales des Telecom,* Vol. 37, Pp. 477-483.

Chebil J., and T. A. Rahman, (1999). "Development of 1 min Rain Rate Contour Maps for Microwave Applications in Malaysia Peninsula", *Electronics Letts.,* 35**,** 1712-1774.

Hardas.R. and Kutiel, H. (2010): Rainfall uncertainty in the Mediterranean: Intraseasonal rainfall distribution, *Theor Appl Climatol.* Vol.100: 105–121.

Mandeep, J.S. (2010): 'Rain rate analysis and total rain accumulation in the North of Malayan Penisula', *Ann. Telecommun*, DOI 10.1007/s12243-010-0211-1.

Moupfouma, F. and Martin, L. (1995): Modeling of the rainfall rate cumulative distribution for the design of satellite and terrestrial communication systems, *Int. J. of Satellite and Commun.* Vol.13, (2), Pp. 105-115.

Obasi, G. O .P. (1991) Climatic resources of Africa: problems and potentials in their management for increased agricultural productivity and sustainable development. Lecture presented at the First United Nations University (UNU) Programme on Natural Resources in Africa, Orientation/Training Course, Nairobi, 16 August 1991.

Ogallo, L. J. (1988) Relationship between seasonal rainfall in East Africa and the Southern Oscillation Index. J. Climatol., 8, 31–43.

Ojo. J. S. (2009): 'Distribution of Rainfall rates of short integration time and their applications to microwave propagation over Nigeria'. *PhD Thesis, Federal University of Technology, Akure, Nigeria* (unpublished).

Ojo J.S, Ajewole M.O and Emiliani, L.D (2009). "One-minute rain rate contour maps for microwave communication-system planning in a tropical country: Nigeria" IEEE Antenna and Propagation Magazine, Vol. 51(5), 82-89.

Oladapo, E.O. (1995): Some statistical characteristics of drought area variations in the savanna region of Nigeria. *Journal of Theor. Appl Climatol*, Vol. 50, 147-155.

Oluleye A. (2009): Change detection in rainfall anomalies across climatic zones in Nigeria. *J.of Met. & Cli. Sci,* 7: 6-10.

Omotosho J.B. (1985). The separate contributions of squall lines, thunderstorms and the monsoon to the total rainfall in Nigeria. Journal of Climatology 5: 543–552.

