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Six Years Result of Rainfall Rate Measurement at Covenant University, Southwest, Nigeria

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Abstract. The scattering and absorption of communication signal propagated through the troposphere by rainfall is a major cause for attenuation. For a proper mitigation of this impairment, an adequate understanding of rain rate must be carried out. Hence a 6-years of one-minute rain rate and four years measurement at Ota, Southwest, Nigeria (6^{o} 42N, 3^{o} 14E), using a wireless Davis Vantage Pro2 Weather Station is presented. The rainfall rate data span from April 2012 to December 2015 has been analysed. One-minute rainfall rate is required for the prediction and modelling of rain attenuation at microwave frequencies for a region like the Nigeria at various percentage of time. International Telecommunication Union – Recommendation (ITU-R) divided the world into rainfall zones of which Nigeria falls into the P zone. However, the maximum rainfall rate at 0.01% of time in the P zone is 145 mm/hr of which Ota is overestimated. The measured yearly averaged maximum one-minute rainfall rate for 2012, 2013, 2014, 2015, 2016 and 2017 are 157.7 mm/h, 148.0 mm/h, 241.2 mm/h, 157.3 mm/h, 140.6 mm/h and 250.8 mm/h respectively.

Keywords: Electromagnetic wave, Rainfall rate, attenuation, satellite communication, earth-space path

1. Introduction

For an effective and reliable satellite communication, attenuation - a major impairment has to be overcome due to growing usage of satellite particularly at very high frequency, 10 GHz and above [1]. Therefore, both the subscriber's antenna and the transmitting satellite receive and transmit signal through wireless technology respectively [2]. One of the major challenges of transmitting at this frequency is attenuation, which is caused by rain, atmospheric gases, cloud, scintillation, snow, ice etc. The most severe attenuation is caused by rain which strongly contributes to the reduction in signal level received and transmission losses as a result of absorption and scattering [3-5]. However, rain attenuation is generally based on the distribution of one-minute rain rate statistics for planning and designing of satellite communication in the earth-space path [6-7]. Also, the number of locations at which the rainfall is directly measured with one-minute time intervals over a long term is limited [8]. Therefore, a long-term ground data may provide better solution to the duration of rain fade rate and time of occurrence.

Many researchers have developed several rainfall rates model which have been used to predict rainfall attenuation models. Most of these models were developed in the temperate regions of the world where stratiform type of rainfall exist [9-11]. Hence choosing the right prediction model from the existing ones for the location of interest is a major challenge due to the temporal and spatial variability of rain in the climate. Therefore, measurements from the tropical regions need to be known in order to test them against the predicted models for proper satellite planning [5]. The Cumulative Distribution Function (CDF) of rainfall intensity is the most suitable as input for most prediction models of propagation impairments for frequencies above 10 GHz. It provides comprehensive information of the meteorological characteristics of the site of interest. Since there is a wide difference in terms of rain type between the temperate and tropical region, specific local measurements should be preferred as input to rain attenuation model. One of the most striking aspects of rainfall is its variability both in space and time.

Rainfall rate statistics with a 1-min integration time are required for the prediction of rain attenuation in terrestrial and satellite links. A cumulative probability distribution or exceedances curve is preferred in the analysis of rain rate. Several models on rain attenuation predictions in tropical region, like Nigeria is not accurate because data used in the process are obtained from the temperate region. Therefore, more researches and studies are required in the equatorial region in order to predict impact of rain on radio wave propagation on earth-space paths in Nigeria.

Rain rate R mm/h can be used to calculate attenuation A dB using the relationship given by

$$A = aR^{b}L \qquad (1)$$

where a and b are coefficients determined by the kinds of Drop Size Distribution (DSD), frequency, elevation angle, temperature and polarization of the radio wave signal. L is the equivalent path length of the rainy region.

2. METHODS AND DATA ANALYSIS

The four years rainfall data used for this research work were obtained from the Davis Wireless vantage Pro2 weather station installed at Covenant University, Ota, Nigeria with geographical coordinates 6.7^{o}N, 3.23^{o}E to measure meteorological data such as temperature, pressure, wind speed, humidity, water vapour etc. The receiver antenna is pointed towards the ASTRA satellite located at 36^{o}E in the geostationary orbit. The satellite transmitted power is 50.8 dBW and the stability of the power over time is 98%. The beacon signal frequency is 12.245 GHz and it is vertically polarized. The tipping bucket type rain gauge is used which is connected to the Weather station to obtain rainfall data, all in one package called Integrated Sensor Suite. A sensor interface module (SIM) collects outside data from the ISS and transmits the data to a vantage Pro console via a low power radio at a frequency of 868.0 – 868.6 MHz with a maximum line-of-sight range of 300 m. The beacon measurement was taken through a signal transmitted from the operational transponder. The output signal of the Low Noise Block Converter (LNB), at the satellite dish, was connected to a data logger via personnel computer (PC).

The data logger was programmed to stored data every second continuously which was recorded as averaged data every 1- minute. The one-minute rain rate experimental data obtained were used to analyze rain rate variation from April 2012 to December 2017.

3. RESULT AND DISCUSSION

A. Highest number of rainy days

Variation in the number of rainy days all through the year from 2012 to 2017 is presented. From observation, there was rainfall all through the year although January, February, March, April, November and December recorded fewer rainy days. May indicated the beginning of rainfall with an increase in the number of rainy days ranging between 10 and 14 for 2012, 2013, 2014, 2015 and 2016 respectively except for 2017 which recorded just 5 days of rainfall. The months with increased number of rainy days is from May to October for each year under consideration and Covenant University, Ota experienced high rainfall during this period. The total numbers of rainy days for each year are 116, 127, 159, 114, 135 and 107 for 2012, 2013, 2014, 2015, 2016 and 2017 respectively and it rains on an average of 126 days of the year. This shows that in an average year the total number of rainy days is less non-rainy days. The maximum number of rainy days was recorded in 2014. The months with the highest number of rainy days varied between July and October. The influence of the inter-tropical convergence zone (ITCZ) could be linked to the increased in rainfall during the wet months which falls between May and October.

B. Yearly Variation of One – minute Rainfall Rates

The estimation of a proper fade margin for a location of interest to mitigate the effect of signal degradation requires the study of the cumulative distribution of rain rate derived from the ground measurement of precipitation in that locality. The exceedance curves of rainfall rate computed using 6-year one-minute rainfall records is presented. The percentage of time of the year that a given rain-rate would be exceeded is represented on the x-axis usually known as *'p%'*.The estimate for the rainfall rate exceeded at 0.01% of the time is 137.0 mm/h, 135.0 mm/h, 150.0 mm/h, 114.0 mm/h, 115.2 mm/h and 110.8 mm/h for 2012, 2013, 2014, 2015, 2016 and 2017 respectively.

Rainfall rate is the most important meteorological statistic when planning a radio system exceeded for different percentage of time especially at 0.01% of the time i.e. $R_{0.01}$%. The rainfall rate is a function of the geography of the location of interest. In temperate regions, $R_{0.01}$% can be around 30 mm/hr while for arid regions it is only few mm/hr. It's quite different in tropical regions where high rainfall and rainfall rates are experienced. The value of $R_{0.01}$% in a tropical region could be as high as 150 mm/hr [12].

Rainfall rate at 1-minute interval on daily basis was recorded monthly from 2012 to 2017. The daily data obtained for one month was converted to complementary cumulative distribution (CCDF) at time and the monthly CCDF was converted to an annual CCDF at time in percentage. The OriginPro8 software was used to plot the CCDF graph. Figure 1 shows the yearly cumulative distribution of rainfall rate which is required to predict outage on yearly basis from 2012 to 2017. The rainfall rate was analysed monthly for the rainy events. From the CCDF graph, the measured rainfall rates at 0.001%, 0.01%, 0.1% and 1% in time was determined as presented in Table 2. The average rainfall rate for the six years (Table 3) was obtained and compared with ITU-R values.

Figures 1 (a, b, c, d, e and f) present the measured annual complementary cumulative distribution (CCDF) of rainfall rate obtained for Ota at 6.7°N, 3.23°E over six years in-situ experimental 1-minute measurement. The cumulative distribution is based on rain intensities and percentages of time. It was observed that in 2012, at the lowest percentage of 0.001% exceedance, rainfall rate of about 215.0 mm/h was continually exceeded. At the higher percentage exceedance time of 0.01%, the rainfall rate of about 137.0 mm/h was continuously exceeded. Also, at 0.1%-time, 60.0 mm/h of rainfall rate was exceeded and at 1%-time, the rainfall rate of 4.0 mm/h was exceeded. Therefore, the rain intensity for time percentage differences between 1% to 0.01% is 211.0 mm/h.

It was observed that in 2013, at the lowest percentage of 0.001% exceedance, rainfall rate of about 251.0 mm/h was continually exceeded. At the higher percentage exceedance time of 0.01%, the rainfall rate of about 135.0 mm/h was continuously exceeded. Also, at 0.1%-time, 49.0 mm/h of rainfall rate was exceeded and at 1%-time, the rainfall rate of 3.0 mm/h was exceeded. Therefore, the rain intensity for time percentage differences between 1% to 0.01% is 248.0 mm/h.

It was observed that in 2014, at the lowest percentage of 0.001% exceedance, rainfall rate of about 249.0 mm/h was continually exceeded. At the higher percentage exceedance time of 0.01%, the rainfall rate of about 150.0 mm/h was continuously exceeded. Also, at 0.1%-time, 56.0 mm/h of rainfall rate was exceeded and at 1%-time, the rainfall rate of 4.0 mm/h was exceeded. Therefore, the rain intensity for time percentage differences between 1% to 0.01% is 245.0 mm/h.

It was observed that in 2015, at the lowest percentage of 0.001% exceedance, rainfall rate of about 237.0 mm/h was continually exceeded. At the higher percentage exceedance time of 0.01%, the rainfall rate of about 114.0 mm/h was continuously exceeded. Also, at 0.1%-time, 38.0 mm/h of rainfall rate was exceeded and at 1%-time, the rainfall rate of 3.0 mm/h was exceeded. Therefore, the rain intensity for time percentage differences between 1% to 0.01% is 234.0 mm/h.

It was observed that in 2016, at the lowest percentage of 0.001% exceedance, rainfall rate of about 235.2 mm/h was continually exceeded. At the higher percentage exceedance time of 0.01%, the rainfall rate of about 115.2 mm/h was continuously exceeded. Also, at 0.1%-time, 27.6 mm/h of rainfall rate was exceeded and at 1%-time, the rainfall rate of 1.6 mm/h was exceeded. Therefore, the rain intensity for time percentage differences between 1% to 0.01% is 233.6 mm/h.

It was observed that in 2017, at the lowest percentage of 0.001% exceedance, rainfall rate of about 338.8 mm/h was continually exceeded. At the higher percentage exceedance time of 0.01%, the rainfall rate of about 110.8 mm/h was continuously exceeded. Also, at 0.1%-time, 21.0 mm/h of rainfall rate was exceeded and at 1%-time, the rainfall rate of 1.6 mm/h was exceeded. Therefore, the rain intensity for time percentage differences between 1% to 0.01% is 337.2 mm/h.

The cumulative distributions obtained were based on rainfall rates and its equivalent percentage of time. It is seen that rainfall rate is inversely proportional to the percentage of time which shows that higher rainfall rate occurs at lower percentage of time exceeded while the lower rainfall rate occurred at higher percentage of time. Generally, the results show yearly variation in rainfall rate as observed in CU. The rainfall rates observed here in CU, Ota is higher than that obtainable in temperate regions, hence communication signals are more prone to high rain attenuation.

Table 1 shows the different rain climatic zones with different rainfall rate the world has been divided into [13] of which Nigeria was classified into the P zone. Table 2 presents the comparison between the yearly CDF of rainfall rate with the ITU-R predicted measurements. Cumulative distribution of rainfall rate shows that the rainfall rate at the 0.001% (lower percentage) of time observed in 2013 and 2017 was greater than ITU-R prediction compared to other years. At 0.01% of time, the highest recorded in 2014 was greater than ITU-R prediction compared to other years which recorded lower values.

Based on ITU-R recommendation of the acceptable unavailability of communication signal, 2014 would have experience a severe attenuation since its value at 0.01% of time is higher than that predicted by ITU-R. At 0.1% and 1% of time, the recorded rainfall rates for all the years are lower than ITU-R predicted values. Table 4.18 shows the percentage difference between the average rainfall rate and that predicted by ITU-R. The result shows that ITU-R climatic zone recommendation underestimated the rainfall rate at 0.001% exceedance of time by -0.02% for CU, Ota. It overestimated the rainfall rate at 0.01%, 0.1% and 1% exceedance of time by about 0.14%, 0.55% and 3.18% respectively for CU. The six years of the experimental results indicated that the measured $R_{0.01}$ rainfall rate at Ota is 127 mm/h compared to 145 mm/hr. recommended by ITU-R. This clearly shows that ITU-R P. underestimated the measured rainfall rate at lower percentage of time and overestimated at higher percentage of time for Ota. It is therefore necessary to redefine the ITU-R regional climatic zones for CU, Ota based on the measured ground/local data.

Table 1: ITU climatic zones (ITU-R P.530-7/8)

S/N	Percentage of time → Rain regions	1	0.3	0.1	0.03	0.01	0.003	0.001
1	A	0.12	0.8	2.0	5.0	8.0	14.0	22.0
2	B	0.5	2.0	3.0	6.0	12.0	21.0	32.0
3	C	0.7	2.8	5.0	9.0	15.0	26.0	42.0
4	D	2.1	4.5	8.0	13.0	19.0	29.0	42.0
5	E	0.6	2.4	6.0	12.0	22.0	41.0	70.0
6	F	1.7	4.5	8.0	15.0	28.0	54.0	78.0
7	G	3.0	7.0	12.0	20.0	30.0	45.0	65.0
8	H	2.0	4.0	10.0	18.0	32.0	55.0	83.0
9	J	8.0	13.0	20.0	28.0	35.0	45.0	55.0
10	K	1.5	4.2	12.0	23.0	42.0	70.0	100.0
11	L	2.0	7.0	15.0	33.0	60.0	105.0	150.0
12	M	4.0	11.0	22.0	40.0	63.0	95.0	120.0
13	N	5.0	15.0	35.0	65.0	95.0	140.0	180.0
14	**P**	**12.0**	**34.0**	**65.0**	**105.0**	**145.0**	**200.0**	**250.0**
15	Q	24.0	49.0	72.0	96.0	115.0	142.0	170.0

Table 2: Rainfall rate for each year and different percentage of time

	Rain rate, 1-min, mm/h			
Year	Rp(0.001%)	Rp(0.01%)	Rp(0.1%)	Rp(1%)
2012	215.0	137.0	60.0	4.0
2013	251.0	135.0	49.0	3.0
2014	249.0	150.0	56.0	4.0
2015	237.0	114.0	38.0	3.0
2016	235.2	115.2	27.6	1.6
2017	338.8	110.8	21.0	1.6
ITU R	250.0	145.0	65.0	12.0

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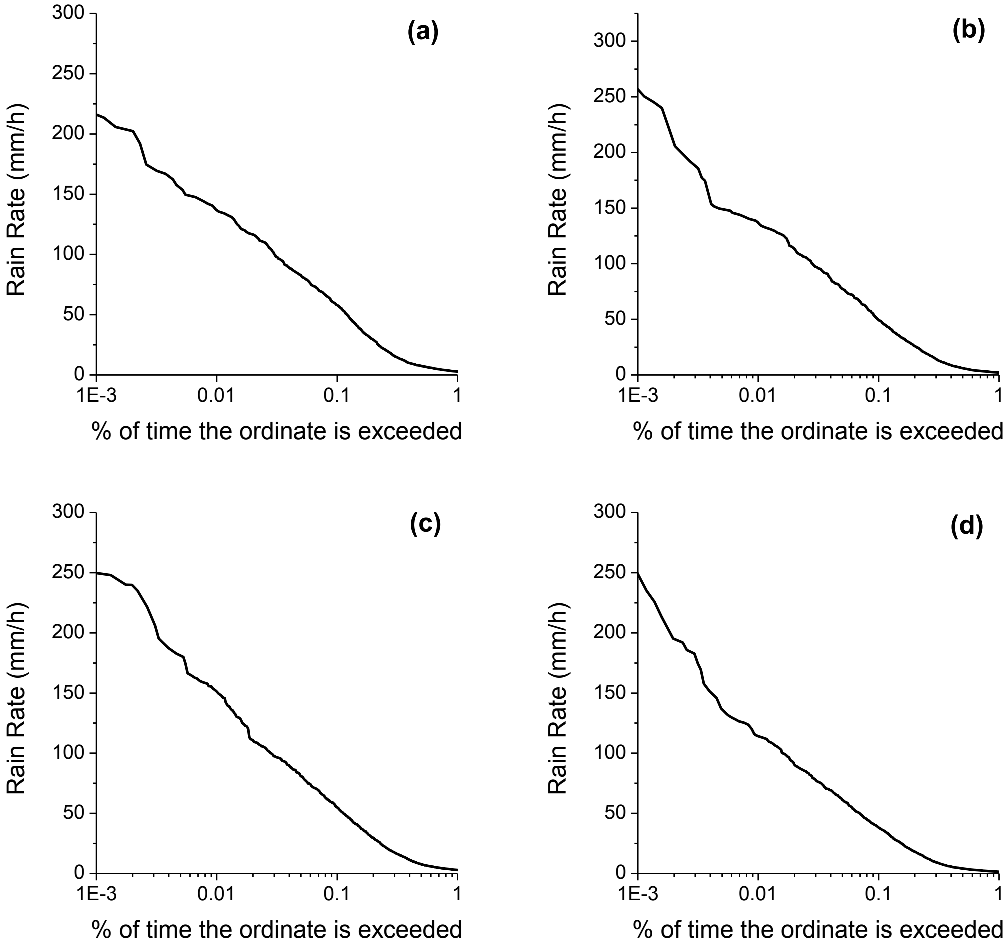
Table 3: Difference between ITU-R P837 and the average for the selected percentage of time

	Rain rate (mm/h), 1-min.			
	Rp (0.001%)	Rp (0.01%)	Rp (0.1%)	Rp (1%)
Average	254.3	127.0	41.9	2.87
ITU R	250.0	145.0	65.0	12.0
% Difference	-0.02%	0.14%	0.55%	3.18%



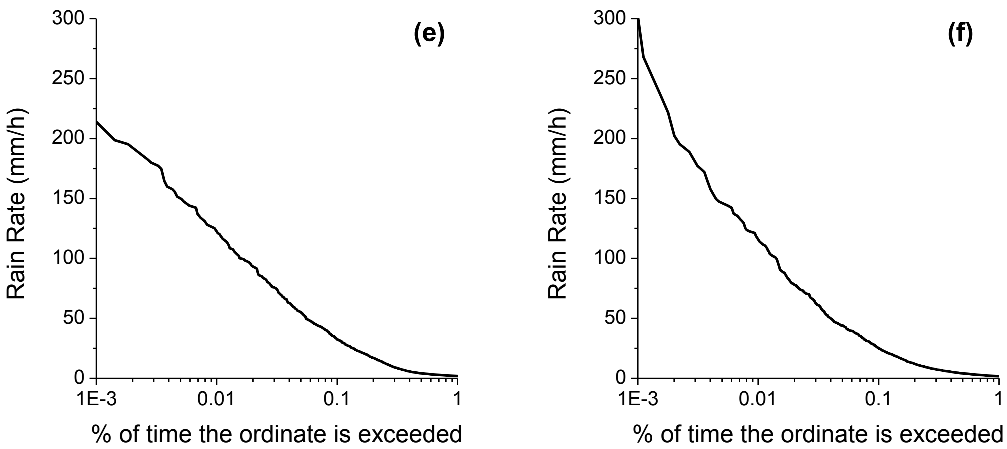


Figure 1: Rain-rate exceedance curve for Ota derived using one-minute rain

4. CONCLUSION

The total numbers of rainy days from 2012 to 2017 are 116, 127, 159, 114, 135 and 107 respectively. The six years of our experiment results indicated that the averaged measured $R_{0.01}$ rainfall rate at Ota is 127 mm/h. The result obtained also indicated that year 2014 had the maximum number of rainy days, maximum total rainfall and maximum rainfall rate which are 159.0, 1348.7 mm and 241.2 mm/h respectively. Therefore, the P region of ITU-R model is overestimated for Ota, a reliable rainfall region of ITU-R model would be more suitable. This result will provide adequate information to the communication engineers about the possible attenuation or link reliability that is likely to occur in Ota. New model of rainfall rate should be developed using the rainfall rate measurement from the place of interest.

Conflict of Interest

The authors declare no conflict of interest.

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References

[1] Zhou, Z. X., L. W. Li, T. S. Yeo, and M. S. Leong (2000), Cumulative distributions of rainfall rate andmicrowave attenuation in Singapore's tropical region, *Radio Science.*, 35(3), 751–756.

[2] Ojo, J.S., and Rotimi, O.C. (2015). Diurnal and seasonal variations of rain rate and rain attenuation on Ku-band satellite systems in a tropical region: A synthetic storm techniques approach. Journal of computer and communications, 3, 1-10.

[3] Crane, R. K., (1996). Electromagnetic Wave Propagation through Rain. John Wiley & Son Series.

[4] Panagopoulos, A. D., P.-D. M. Arapoglou, and P. G. Cottis, Satellite communications at Ku, Ka

and V bands (2004): Propagation impairments and mitigation techniques," IEEE Communications Surveys and Tutorials.

[5] Mandeep, J. S., 2011. Comparison of rain rate models for equatorial climate in south East Asia. Geofizika, 28, 265-274.

[6] Omotosho, T.V, Mandeep, J.S, Abdullah, M and Adeniji, A.T. (2013). Distribution of one-minute rain rate in Malaysia derived from TRMM Satellite data. Annales Geophysicae. 31, 2013-2022.

[7] T. V. Omotosho, O. O. Ometan, S. A. Akinwumi, O. M. Adewusi, A. O. Boyo and M. S. J. Singh, Year to year variation of rainfall rate and rainfall regime in Ota, southwest Nigeria for the year 2012 to 2015, Journal of Physics: Conference Series, 852 (2017)

[8] Mandeep, J. S., 2009. Slant path rain attenuation comparison of prediction models for satellite applications in Malaysia. Journal of Geophysical Research, 114, 1-12.

[9] Ajewole, M.O., Kolawole, L.B and Ajayi, G.O. (1999). Theoretical Study of the effect of satellite types of tropical rain fall on microwave and millimetre-wave propagation. Radio Science, 34, 1103-1124.

[10] Ojo, J.S., Ajewole, M.O and Sarkar, S.K. (2008). Rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria. Progress in Eletromagnetics Research B, 5, 207-223.

[11] Ojo, J.S., and Omotosho, T.V. (2013). Comparison of 1-minute rain rate derived from TRMM satellite data and raingauge data for microwave applications in Nigeria. Journal of Atmospheric and Solar-Terrestrial Physics, 102(27), 17 – 25.

[12] Abdulrahman, A. Y., Rahman, T. A., Olufeagba, B. J. and Rafiqul Islam M. D., 2013a. Using full rainfall rate distribution for rain attenuation predictions over terrestrial microwave links in Malaysia.*Signal Processing Research***2(1)**: 25 – 28

[13] International Telecommunication Union (2003), Characteristics of precipitation for propagation modelling, *Recommendation. ITU-R P.837–4*, Geneva, Switzerland.