International Journal of Scientific & Engineering Research, Volume 5, Issue 1, January-2014
ISSN 2229-5518

Equivalent 1-Minute Rain Rate Statistics and Seasonal Fade Estimates in the Microwave Band for South-Western Nigeria

O.O. Obiyemi, T.J. Afullo and T.S. Ibiyemi

Abstract— The knowledge of 1-minute integrated cumulative rain rate distribution is required for predicting the attenuation induced by rain on satellite and terrestrial microwave and millimetric links. In this paper, conversion coefficients are derived for estimating the equivalent 1-minute rain rate statistics from those available in 5 and 30-minutes over Akure, South-Western Nigeria. The derivation is based on the power-law relationship existing between equiprobable rain rate statistics, while comparison is made with estimates available for other locations. Apparent in the result is the significant variation in the values estimated for similar observation periods over the years and across different locations. Form the evaluation of the coefficients derived for Akure, the 5-minute conversion provides a more satisfactory performance and hence more suitable for estimating the equivalent 1-minute rain rate statistics for Akure. Quantifying the seasonal precipitation variability, the point rain rates for wet (raining) and dry (harmattan) seasons are 80 and 20 mm/h respectively and the resultant impact on NIGCOMSAT 1-R link reveals that an additional fade margin of 4 and 1.7 dB would be required to meet a 99.99% system availability objective in the wet season, specifically at 12 and 10 GHz respectively.

Index Terms— Rain rate statistics, rain induced attenuation, rain fade margin, conversion coefficient, link availability

1 Introduction

OVER the years, rain rate statistics logged in short integration time have been considered most relevant for monitoring the resultant impairments induced by rain on radio links, particularly at frequencies beyond 10GHz. The dearth of the 1-minute rain rate statistics required for estimating rain-fade margin is still a major concern, especially for wireless communication design purposes in most tropical, sub-tropical and equatorial climates, where rainfall data obtainable from national weather bureaus are mostly available in high integration time – typically between 5, 30 and 60 minutes or even daily in some cases.

Although several efforts have been documented on the prediction of the 1-minute rain rate statistics [1-7], significant variation has been observed in the conversion factors derived across different locations with suitability varying from one location to the other [8-13].

On the seasonal influence of precipitation on fade margins and the corresponding effect on the availability of communication systems, efforts have been made to quantify likely variation over an average year. For instance, the seasonal fade margins estimated for Sub-tropical South-African climates [14, 15] clearly indicates the need to consider seasonal variability in the planning of communication systems. Similarly, the temporal rain attenuation variability was also recently quantified [16, 17] using the Stratiform/Convective (SC) EXCELL model [18]. These contributions however present the need for more efficient propagation planning, based on the use of monthly rain attenuation statistics in the design and operation of advanced communication systems.

In this study, we derive the representative conversion factors for Akure, South-West Nigeria using the cumulative rain rate statistics available in 1, 5 and 30-minute over a 2-year precipitate measurement campaigns. The suitability of the conversion coefficients derived is investigated based on the prediction error inherent in the estimation of the equivalent 1-minute rain rate statistics. Seasonal influence of rainfall intensity on link availability objectives is also investigated based on the equivalent 1-mimute rain rate statistics estimated from the most suitable conversion coefficient over the chosen location.

2 Experimental Sites and Data Collection

The precipitate data employed for this study comprises rain rate statistics for 1, 5 and 30-minute integration time over Akure, South-West Nigeria. The 1-minute statistics is measured using a vertically looking micro rain radar (MRR) and a tipping spoon rain gauge – part of the Davis Vantage Vue electronic weather station, both co-located at the pilot site (7.17^0 N, 5.18^0 E). The 5-minute rain rate data collected from a secondary source had been measured using a tipping bucket rain gauge setup at the experimental site of Nigeria Environmental and Climatic Observatory (NECOP) – also situated within the same premises at the Department of Physics, Federal University of Technology, Akure. The 30-minute statistics, also obtained from a secondary source had been measured using a tipping bucket rain gauge, which is part of the Davis Vantage Pro electronic weather station. This experimental setup is at Iju – about 11.5 km away from the pilot site. The rain rate statistics for a 2-year observation period is sorted from the available precipitate data captured from the various in-situ measurement campaigns over Akure.

- *Obiseye O. Obiyemi is a lecturer at Osun State University Nigeria and He is currently working towards his Ph.D at the University of Ilorin, Nigeria. Obiseyeobi@gmail.com*
- *Thomas J. Afullo is a Professor at the Department of Electrical, Electronic & Computer Engineering, University of KwaZulu-Natal (UKZN), Durban, South Africa*
- *Tunji S. Ibiyemi is a Professor at the Department of Electrical and Electronic Engineering, University of Ilorin, Nigeria*

International Journal of Scientific & Engineering Research Volume 5, Issue 1, January-2014
ISSN 2229-5518

3 Power-Law Coefficient and Conversion Factors

The power law relationship defined **between two** equiprobable rain rates by Flavin [2], Ajayi and Ofoche [3] and Burgueno et al. [5] is defined as:

$$R_\tau(P) = aR_T(P)^b \tag{1}$$

where $R_T(P)$ is the available rain rate in T integration time, $R\tau(P)$ is the equivalent 1-minute rain rate, while a and b are the power-law coefficient and exponent respectively. Taking the logarithm of both sides of (1), the values of a and b can be easily estimated between any T time rain rate statistics and the corresponding τ time statistics. The power-law fit is therefore established with a Log-log plot of the equiprobable rain rates between any two comparable statistics, that is:

$$Log(R_\tau) = Log(a) + bLog(R_T) \tag{2}$$

The power-law coefficient a and the exponent b are obtained based on the line that best fits the equiprobable rain rates from the available statistics for Akure. The cumulative

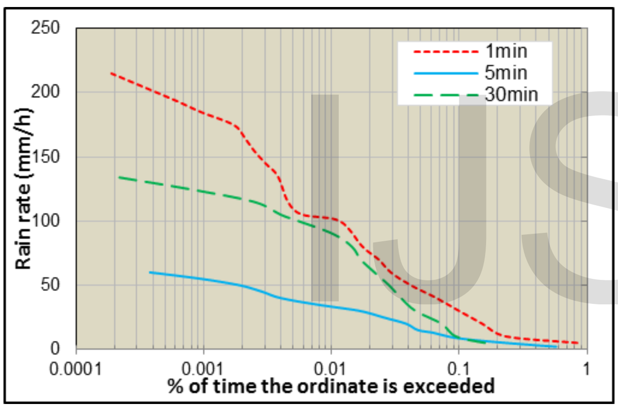

Fig. 1. Cumulative rain rate distribution for 1, 5 and 30-minute statistics over Akure

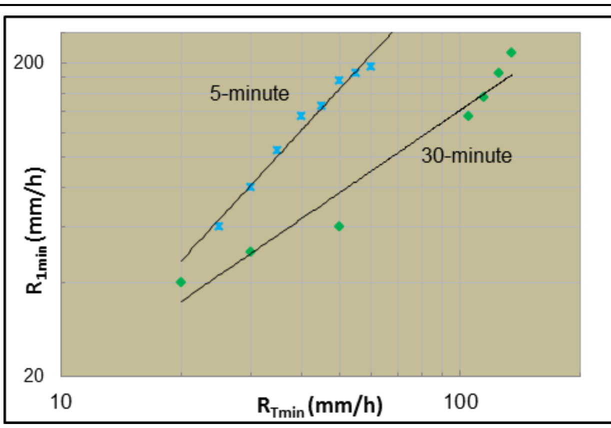

Fig. 2. Equiprobable rain rate statistics between 5, 30 and the 1-minute statistics over Akure

TABLE 1
Coefficients for a and b for τ =1 minute

Locations in Nigeria	T (Min)	a	b	Locations outside Nigeria	T (Min)	a	b
Ile-Ife [3]	5	0.991	1.098	Korea [19]	5	0.934	1.032
Ogbomoso [13]	5	0.797	1.195	China[19]	5	1.110	1.010
Akure	5	0.749	1.380	Brazil [19]	5	0.929	1.036
Ife [3]	30	--	--	Spain [5]	5	0.795	1.081
Akure	30	2.566	0.871	Korea [19]	30	0.723	1.062
Ogbomoso [13]	30	--	--	Brazil [19]	30	0.554	1.331

TABLE 2
Values of $C_E(R)$ for T=5 minute and τ =1 minute – for sites in South-Western Nigeria

Location	Rain rate (mm/h)						
	30	40	50	60	70	80	90
Ife [3]	0.59	0.57	0.4	0.3	0.17	0.10	0.08
Ogbomoso [12]	0.37	-	-	0.28	-	-	0.16
Akure	0.11	0.04	0.025	-	-	-	-

distribution of the respective rain intensities are estimated as presented in Figure 1. Figure 2 shows the equiprobable rain rates between the 1-minute cumulative rain rate distribution, 5 and 30-minute distributions for Akure.

The conversion factors considered by Watson et al [1], has also been broadly employed over the years. Representative values for Akure is also determined using the equation given as [1]:

$$C_e(R) = \left(e_T \big/ e_\tau \right) \tag{3}$$

$$C_R(t) = \left(R_T \big/ R_\tau \right) \tag{4}$$

where $C_R(t)$ refers to the ratio of rain rates exceeded for a given percentage of time t as measured by rain gauges with integration times T and τ, while $C_e(R)$ is the ratio of exceedances for a given rain rate R measured using rain gauges with integration times T and τ.

4 Result and Discussion

The conversion coefficients for predicting the required point rainfall rate have been derived for Akure using three sets of rainfall intensity statistics – the 1, 5 and 30-minute rain rate statistics. The equiprobable rain rates were selected from the cumulative distribution of rainfall intensity and the representative conversion coefficients have been derived. The data employed for the comparison in Figure 3(a) and 3(b) were obtained directly from equiprobable rain rate estimates at defined percentages of time for Ile-Ife [3] and Ogbomoso [12, 13], sites also geographically situated within the South-Western part of Nigeria.

International Journal of Scientific & Engineering Research Volume 5, Issue 1, January-2014
ISSN 2229-5518

TABLE 3
VALUES OF $C_R(T)$ FOR T =1 MINUTE – FOR SITES IN SOUTH-WESTERN NIGERIA

Location	T (Min)	C_R (0.01)	$R_{0.01}$ (mm/h)	C_R (0.001)	$R_{0.001}$ (mm/h)	Remarks
Ile-Ife	5	0.68	80	0.64	130	2-year, 4-month data for Ile-Ife [3]
Ogbomoso	5	0.42	24	0.53	77	2-year data for Ogbomoso [13]
Ogbomoso	5	0.64	90	--	--	10-month data for Ogbomoso [12]
Akure	5	0.33	105	0.29	175	2-year data for Akure
Akure	30	0.83	60	0.68	185	2-year data for Akure

The relationship derived for the chosen location- Akure is therefore given as;

$$R_1 = 0.749 R_5^{1.3804} \tag{5}$$

$$R_1 = 2.5657 R_{30}^{0.8709} \tag{6}$$

$$R_5 = 1.7794 R_{30}^{0.6813} \tag{7}$$

As presented in Table 1, these coefficients vary significantly across the locations.

Comparing the numerical values derived for the ratio of exceedances at given rain rates ($C_e(R)$) across South-Western Nigeria, the observed variation is presented in Table 2 for the 5-minute conversion. The Highest value is obtained at Ile-Ife, while Akure has the lowest value.

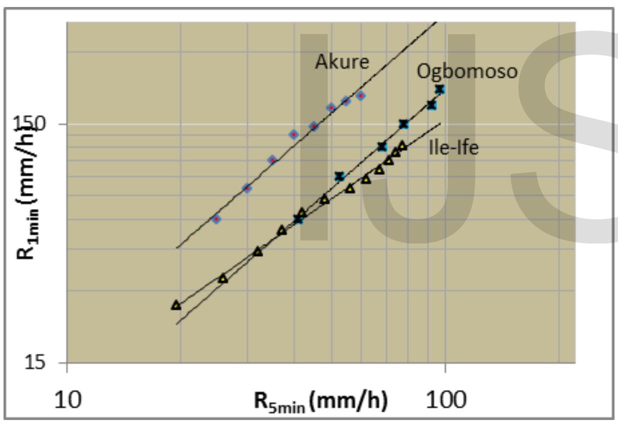

Fig. 3(a). Power-law relationship for equiprobable rain rates between 1and 5-minute statistics for Ile-Ife, Ogbomoso, and Akure.

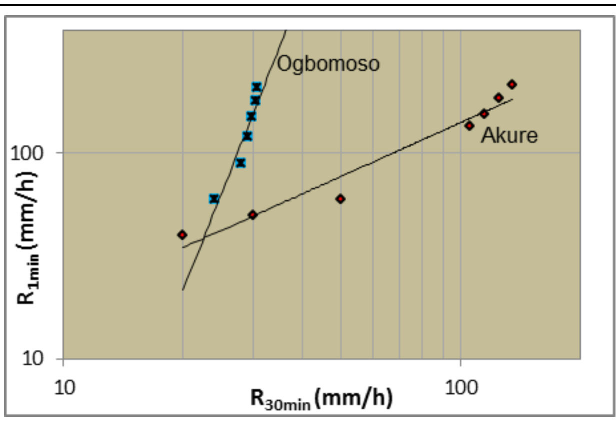

Fig. 3(b). Power-law relationship for equiprobable rain rates between 1and 30-minute statistics for Ogbomoso and Akure

A similar Comparison on the $C_R(t)$ obtained for the conversion of 5-minute rain rate statistics in South-West Nigeria also indicate that the numerical values obtained for Akure is relatively lower than estimates determined in [3] for Ile-Ife (170.2 km from Akure) and in [13] for Ogbomoso (105.5 km from Akure). Ogbomoso is about 110.7 km away from Ile-Ife. This is as shown in Table 3.

It is apparent from comparison that the coefficients derived based on the power-law relationship actually vary significantly from one location to another. Although the observation period is around 2-years across sites (Ile-Ife, Ogbomoso and Akure), the sensitivity of the rain gauges and MRR differ and this might introduce some form of bias, and could be responsible for the observed variation. Moreover, the distance between the pilot site (FUT Akure) and Iju could as well introduce some biases on the 30-minute conversion for Akure. However, it could be negligible since the conversion coefficients are actually defined on statistics. The spatial variability of rainfall characteristics could also be accountable for this apparent variation in the conversion factors.

4.1 Performance assessment

Since the new data available at the sites are not substantial for the validation of the derived coefficients, their performance is therefore assessed based on how good the fit on the initial data is. Hence, to determine the most suitable conversion coefficient for Akure, the equivalent 1-minute rain rate statistics is predicted from the knowledge of 5 and 30-minutes statistics and is then compared with the measured 1-minute statistics available for Akure. The cumulative distribution of the predicted and measured rainfall intensities is shown in Figure 4 (a) for the 5-minute conversion, while Figure 4 (b) presents the cumulative rain rate distribution for the 30-minute conversion.

It is obvious from comparison that the equivalent 1-minute rain rate statistics is underestimated based on the conversion factors derived for this location. However, they remain vital prediction tools for estimating the cumulative rain rate distribution and the point rainfall rate required for calculating the equivalent fade margin for communication system designs, especially in scenarios where the required 1-minute statistics is hard to come by. The prediction error is subsequently quanti-

International Journal of Scientific & Engineering Research Volume 5, Issue 1, January-2014
ISSN 2229-5518

fied so as to determine the most suitable conversion and rain rate statistics that best predicts the equivalent 1-minute statistics for Akure. The prediction error at different percentages of the time is calculated using [11]:

$$\varepsilon = 100\left(\frac{R_P - R_M}{R_M}\right) \tag{8}$$

where R_M is the measured 1-minute rain rate and R_P is predicted 1-minute rain rate at any given probability of occurrence. The prediction errors, quantified on the performance of the conversion coefficients indicate that the 5 to 1-minute conversion provides satisfactory performance over Akure. However, the performance of the 30-minute statistics is verified further by converting it to the equivalent 5-minute statistics using (7), and the 1-minute statistics estimated thereafter. Although the 30-5-1-minute conversion recorded the least error at 0.01% of the time, the direct 5-minute conversion is still the most preferred due to the good performance recorded at higher and lower percentages of the time. Figure 4 (c) shows the prediction error estimated at 0.001 – 1% of the time for the conversion coefficients derived from rain rate statistics over Akure.

4.2 Seasonal variation of rainfall attenuation

Nigeria enjoys a truly tropical humid climate which is dominated by the West African monsoon system. Two main seasons are experienced in Nigeria and they are: the wet and the dry seasons. The wet season is characterised with high rainfall events and usually observed between March and October i.e. the raining season, while the dry season is characterised with little and in some cases, no rain event. This is usually observed from November through February [20]. The seasonal rainfall variation is influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ) [21], where the moisture-laden South-Westerly wind from the Atlantic brings cloudy and rainy weather, whereas the dry North-Easterly wind from the Sahara brings dusty and fair weather – often referred to as harmattan, usually experienced in the dry season.

The 1-minute rain rate statistics predicted from the available 5-minute statistics is used in quantifying the equivalent point rain rate across the seasons in Nigeria. Figure 5(a) shows the monthly variation of the equivalent 1-minute statistics over the observation period. As shown, the months of January, March, April and December 2011 recorded no rain event and the wettest months for the entire observation period are October for 2011 and June for 2012. The point rainfall intensity $R_{0.01}$ (mm/h) for the wet season is 80 mm/h while the estimate for the dry season is 20 mm/h. Figure 5(b) shows the seasonal cumulative distribution of the rainfall intensity over the observation period.

Rain induced attenuation on the satellite downlink is subsequently estimated using the global ITU-R model [22] for transmission in the Ku band (10 and 12 GHz) based on the specific attenuation [23] and effective path length [22] calculated for digital satellite television reception at the pilot site (7.17^0 N, 5.18^0 E) in Akure, using a horizontally polarized antenna as a typical TV receive-only earth station terminal for

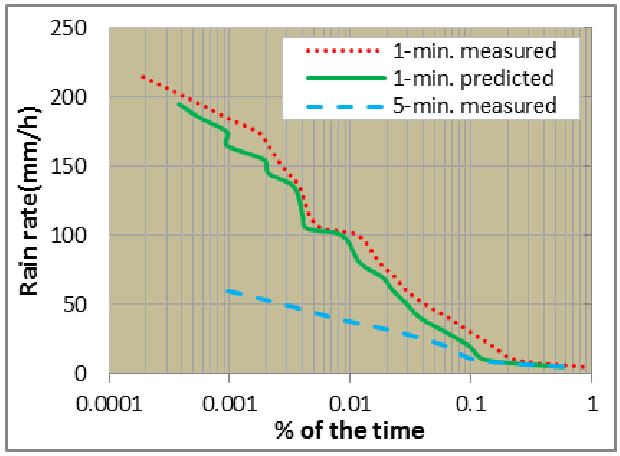

Fig. 4(a). Cumulative rain rate distribution for the predicted 1-minute statistics – from 5-minute

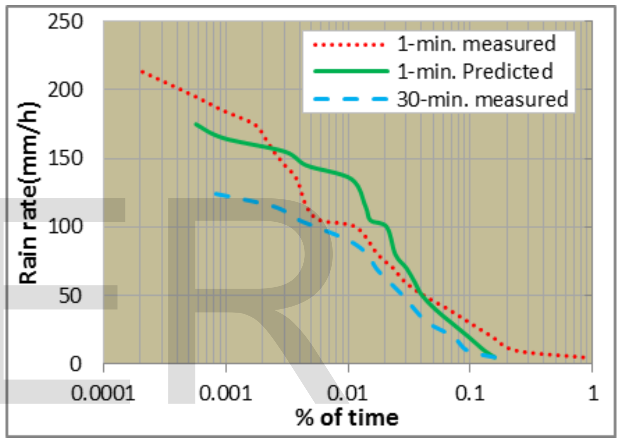

Fig. 4(b). Cumulative rain rate distribution for the predicted 1-minute statistics – from 30-minute

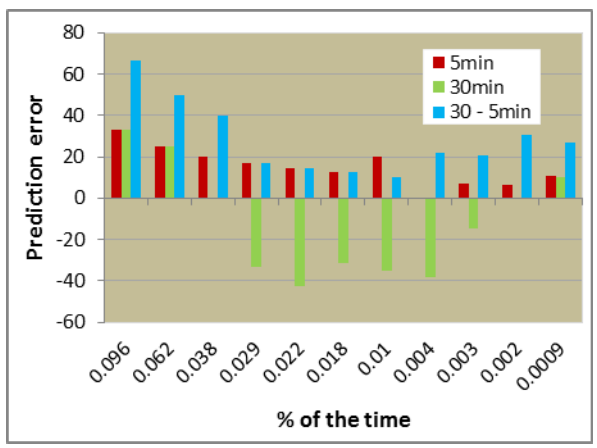

Fig. 4(c). Prediction error estimated from conversion

International Journal of Scientific & Engineering Research Volume 5, Issue 1, January-2014
ISSN 2229-5518

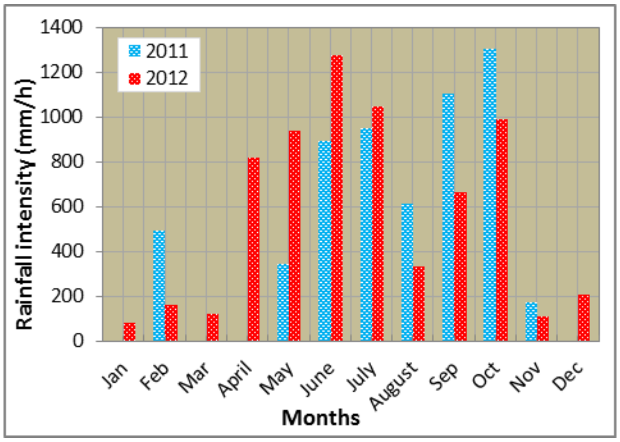

Fig. 5(a). Monthly accumulations of rainfall intensity over the observation period

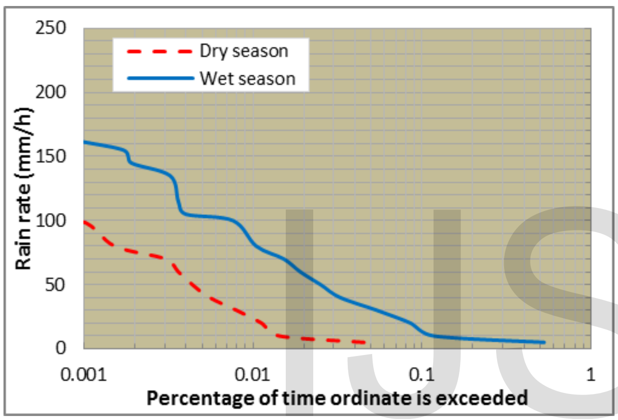

Fig. 5(b). Seasonal distribution of rain rate in Akure over the observation period

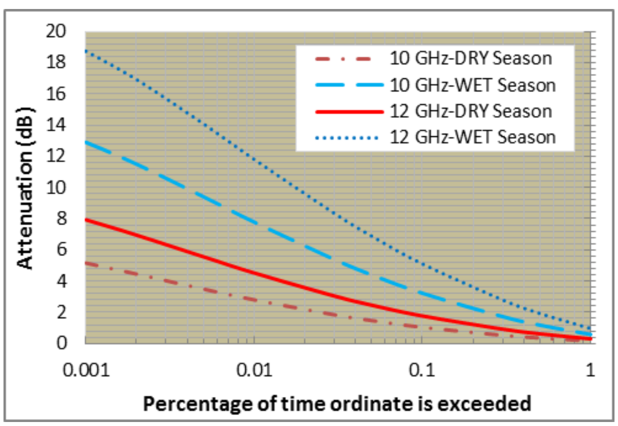

Fig. 5(c). Seasonal distribution of rain attenuation in Akure between 2011 and 2012

the recently launched NIGCOMSAT 1-R satellite, which is geostationary at 42.5^{0}E.

Results from the seasonal cumulative distribution in Figure 5(c) indicate that rain attenuation is strongly dependent on the seasonal point rain rate estimates. The high rainfall intensity recorded in the wet season accounts for the correspondingly high rain attenuation distribution over this season. Observations in the dry season however indicate lower rain attenuation distribution as a result of the low rain rate recorded over the harmattan season.

Results therefore reveal that an additional fade margin would be required to guarantee system availability during wet season. For instance, about 13 dB of fade margin is required for planning 99.999% system availability in the dry season while additional 6 dB is required on the 12 GHz link in the wet season. In order to meet 99.99% availability objective, 7.8 dB is required for link designs in the dry season while additional 4 dB would be required to cater for signal disruptions due to rain in the wet season at 12 GHz. On the 10 GHz link, 2.8 dB is required to meet 99.99% availability objective in the dry season while additional 1.7 dB would be required for optimal link design in the raining season.

Hence, fade margin estimates for communication link design varies considerably with seasons of the year. This is similar to observations reported for seasonal fade margins in [14] and seasonal estimates for specific rain attenuation in [15] for variations across summer, autumn, winter and spring seasons over South Africa. The monthly attenuation estimates in [16] also confirms similar variation, although with predictions based on the recently proposed SC EXCELL model [18]. Considering the empirical nature of the ITU-R model and its dependence on yearly rain rate statistics, the application for season prediction in this work is based on careful estimate of the seasonal cumulative distribution of the rainfall intensity as shown in Figure 5 (b).

5 Conclusions

Based on available rain rate statistics from measurement campaigns in Akure, South-West Nigeria, representative conversion coefficients have been derived for the prediction of the equivalent 1-minute statistics, which is the most relevant input for estimating the attenuation induced by rain on microwave and millimetric communication links.

The power-law regression coefficients for Akure was compared with conversion coefficients derived for other locations in South-Western Nigeria and in other locations outside Nigeria, where similar approach have been employed. Apparent in the result is the significant variation in the values obtained from one location to another – within and outside Nigeria. The prediction errors from the conversions were quantified and result shows that the 5-minute conversion provides satisfactory performance and hence more suitable for estimating the 1-minute rain rate statistics required for propagation planning over Akure.

The seasonal rainfall attenuation was estimated using the point rainfall rates estimated for the dry and wet seasons at 10 and 12 GHz. Results reveal the seasonal variability of rainfall intensity and the corresponding impact on link designs on the basis of service availability objectives. It is clear from the results obtained that a larger fade margin is required for communication system planning in the wet season, hence showing an additional fade margin of 4 dB, and 1.7 dB for 99.99% link

ISSN 2229-5518

availability on the 12 and 10 GHz respectively. It is therefore obvious that conversion coefficients are site specific and are mostly defined on statistics.

ACKNOWLEDGMENT

The authors would like to thank Professor M.O. Ajewole of the Centre for Space Research and Applications (CESRA), Federal University of Technology (FUT), Akure for granting access to the MRR data. They would also like to appreciate Dr. J.S. Ojo and Dr. A.T. Adediji (both of the Department of Physics, FUT Akure) for the providing the precipitation data from NECOP (FUT, Akure) and the measurement campaign at Iju (Akure).

REFERENCES

[1] P. Watson, V. Sathiaseelan, and B. Potter, "Development of a Climatic Map of Rainfall Attenuation for Europe," 1981.

[2] R. Flavin, "Rain attenuation considerations for satellite paths in Australia," *ATR Australian Telecommunication Research,* vol. 16, pp. 11-24, 1982.

[3] G. O. Ajayi and E. B. C. Ofoche, "Some tropical rainfall rate characteristics at Ile-Ife for microwave and millimeter wave applications," *Journal of Applied Meteorology,* vol. 23, pp. 562-567, 1984.

[4] B. Segal, "The influence of raingage integration time, on measured rainfall-intensity distribution functions," *Journal of Atmospheric and Oceanic Technology,* vol. 3, pp. 662-671, 1986.

[5] A. Burgueño, M. Puigcerver, and E. Vilar, "Influence of rain gauge integration time on the rain rate statistics used in microwave communications," *annales des telecommunications,* vol. 43, pp. 522-527, 1988.

[6] P. A. Owolawi, "Rainfall rate probability density evaluation and mapping for the estimation of rain attenuation in South Africa and surrounding islands," *Progress In Electromagnetics Research,* vol. 112, pp. 155-181, 2011.

[7] J.-H. Lee, Y.-S. Kim, J.-H. Kim, and Y.-S. Choi, "Empirical conversion process of rain rate distribution for various integration time," *Microwave Conference, 2000 Asia-Pacific,* pp. 1593-1597, 2000.

[8] J. Chebil and T. Rahman, "Rain rate statistical conversion for the prediction of rain attenuation in Malaysia," *Electronics Letters,* vol. 35, pp. 1019-1021, 1999.

[9] T. Boonchuk, N. Hemmakom, P. Supnithi, K. Tanaka, K. Igarashi, M. Iida, *et al.*, "Rain attenuation of satellite link in Ku-band at Bangkok," *Proc. Fifth International Conference on Information, Communications and Signal Processing,* pp. 1093-1096, 6-9, Dec. 2005.

[10] C. Capsoni and L. Luini, "1-min rain rate statistics predictions from 1-hour rain rate statistics measurements," *Antennas and Propagation, IEEE Transactions on,* vol. 56, pp. 815-824, 2008.

[11] J. Mandeep and S. Hassan, "60-to 1-min rainfall-rate conversion: Comparison of existing prediction methods with data obtained in the Southeast Asia region," *Journal of Applied Meteorology and Climatology,* vol. 47, pp. 925-930, 2008.

[12] F. Semire and T. Raji, "Characteristics of Measured Rainfall Rate at Ogbomoso, Nigeria for Microwave Applications," *Journal of Telecommunications and Information Technology,* pp. 85-89, 2011.

[13] F. A. Semire, R. Mohd-Mokhtar, T. V. Omotosho, I. Widad, N. Mohamad, and J. Mandeep, "Analysis of Cumulative Distribution Function of 2-year Rainfall Measurements in Ogbomoso, Nigeria," *International Journal of Applied Science and Engineering,* vol. 10, pp. 171-179, 2012.

[14] M. O. Odedina and T. Afullo, "Characteristics of seasonal attenuation and fading for line-of-sight links in South Africa," in *Proc. of SATNAC*, 2008, pp. 203-208.

[15] A. A. Alonge and T. J. Afullo, "Seasonal analysis and prediction of rainfall effects in Eastern South Africa at microwave frequencies," *Progress In Electromagnetics Research B,* vol. 40, pp. 279-303, 2012.

[16] C. Capsoni and L. Luini, "The SC EXCELL model for the prediction of monthly rain attenuation statistics," in *Antennas and Propagation (EuCAP), 2013 7th European Conference on*, 2013, pp. 1382-1385.

[17] L. Luini and C. Capsoni, "A Unified Model for the Prediction of Spatial and Temporal Rainfall Rate Statistics," 2013.

[18] C. Capsoni, L. Luini, A. Paraboni, C. Riva, and A. Martellucci, "A new prediction model of rain attenuation that separately accounts for stratiform and convective rain," *Antennas and Propagation, IEEE Transactions on,* vol. 57, pp. 196-204, 2009.

[19] M.-W. Jung, I.-T. Han, M.-Y. Choi, J.-H. Lee, and J.-K. Pack, "Study on the empirical prediction of 1-min rain rate distribution from various integration time data," *Microwave Conference, KJMW 2007. Korea-Japan. 2007,* pp. 89-92, 2007.

[20] J. S. Ojo and M. O. Ajewole, "Dimensional Statistics of rainfall Signature and Fade Duration for Microwave Propagation in Nigeria," *xxxth URSI Genaral Assembly and Scientific Symposium, 13 - 20th August, Istanbul*, 2011.

[21] C. M. A. Karmalkar, M. New and G. Lizcano, "UNDP Climate Change Country Profiles: Nigeria," 2006.

[22] I. T. U. Radiowave Propagation Series, "Propagation Data and Prediction Methods Required for the Design of Earth-Space Telecommunication Systems," in *Recommendation ITU-R P.618-10*, ed: I TU-R, Geneva, 2009.

[23] I. T. U. Radiowave Propagation Series, "Specific attenuation model for rain for use in prediction methods," in *Recommendation ITU-R P.838-3*, ed: ITU-R, Geneva, 2005.