Rain attenuation models at ka band for selected stations in the southwestern region of Nigeria

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ABSTRACT

Rain is the major factor in radio propagation analyses that is responsible for outage on terrestrial point-to-point and point-to-multipoint radio communication systems at millimeter wave bands. This hampers radio wave signal transmission in the tropics. This paper investigates the performance of ITU-R P.530-16, Silver Mello, Moupfouma and Abdulrahman rain attenuation prediction models using locally-sourced data. The aim is to determine their suitability or otherwise in tropical Nigeria. Two years daily rainfall data were sourced from the Nigerian Meteorological Services (NIMET) for six different stations in southwestern Nigeria. Southern Nigeria is predominantly influenced by the southwest monsoon wind from the Atlantic Ocean due to its proximity to the coastal belt. The data were analyzed using these prediction models by comparing with measured data. The ITU-R P.530-16 rain attenuation prediction model closely matched the measurement value for $p \geq 0.1\%$ of the time but over-estimated it at $p<0.1\%$ while Abdulrahman and Silver Mello proposed prediction models generally over-estimated for $p<0.01$ of time exceeded. Overall, Abdulrahman proposed prediction model presented the best performances; it was closely followed by Silver Mello, ITU-R and Moupfouma prediction models respectively. These results further accentuate the need for urgent review of the ITU-R P.530-16 prediction model or alternatively, the development of a separate rain attenuation prediction model specifically for the stations in the tropical region.

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1. INTRODUCTION

The tremendous advancement in the telecommunication and broadcasting industry is driven by the increasing demand for high speed broadband communication in multimedia services. This subsequently led to increased demand for bandwidth. Since the use of frequency band below 10 GHz such as L, S, C, and X bands in signal transmission results in congestion, microwave designers were compelled to adopt higher frequencies [1], such as Ku band (12 to 18 GHz), Ka band (26.5 to 40 GHz), and V band (40 to 75 GHz) [2]. Some of the attraction of operating at higher frequency includes large bandwidth, increased frequency reuse, and a wide range of spectrum availability [3]. Electromagnetic wave interference on rain drops includes absorption, scattering and depolarization, which are the major culprits of rain attenuation. This eventually results in loss of signal strength at the receiver, wastage of transmission power in attempt to overcome attenuation or total loss of signal at the receiver in extreme cases [4].

Rain attenuation has been reported to be a major problem that is being experienced in tropical stations, where heavy rainfall with large size of water drops predominates [5]. Rain structure and rain drops size in temperate and tropical regions are quite distinct, with temperate regions experiencing predominantly stratiform rainfalls while convective rainfalls (with large rain drop sizes) prevails for tropical regions. Large rain drops results in higher attenuation exceedances.

Although several works have been carried out on rain attenuation predictions globally, most were carried out in temperate stations (data collected from Europe and America), the application of these rain attenuation prediction models to tropical stations have largely produced poor performances [6]. However, the International Telecommunication Union–Radio communication Sector (ITU-R) which is the globally accepted model for predicting rain attenuation on any terrestrial radio link is hindered since the prediction was founded on data collected from the temperate region. Furthermore, the ITU-R model is premised on the assumption of simplified models for the rain field affecting the propagation path; such as the assumption that the non-uniform rainfall along the propagation path can be modeled by an equivalent cell of uniform rainfall rate. The terrestrial prediction method as provided in ITU-R P.530-16 [7] assumes that an equivalent cylindrical cell of uniform rain can intercept the link at any position with equal probability. An effective path length is thus calculated as the average length of the intersection between the cell and the propagation path. Consequently, the effective path length was found be smaller than the actual path length [8], and this is the motivation that led to the introduction of a path reduction factor. This approach compensates for the non-homogeneity of rainfall and rain rates. Consequently, there is urgent need to deepen research in tropical regions in order to produce a reliable rain attenuation prediction models that will reliably model rain attenuations in tropical (and equatorial) climates.

It is generally difficult to record and measure rainfall of high intensity experimentally. Moreso, it is highly variable from year-to-year. However, in system design, it is the highest rainfall rates that are of great interest. Short integration-time rainfall rate is the most essential input parameter in the prediction models for rain attenuation. A rain event is not evenly distributed in an area; and the contribution of rain effect on a transmitted signal is such as to impede propagation of electric fields. Rainfall is structurally inhomogeneous in both vertical and horizontal direction of propagations. Although tropical climates are more impacted negatively by vertical variability (where the 0ºC isotherm is high), horizontal variability affects all climates (particularly areas that experience heavy precipitations with its characteristic localized nature) [9].

The product of path reduction factor and the physical path length of a microwave link is the effective path length, defined as the intersection between the rain cell and propagation path. It is confirmed that the effective path length is often smaller than the actual physical path length leading to introduction of a path reduction factor [8], [10].

Several rain rate and rain attenuation prediction models abound in the literature. These include the revised version of the Crane's two-component model [11], Excell model [12], Bryant model [13], Flavin model [14], DAH model [15], simple attenuation model (SAM) by Stutzman and Yon [16].

2. RESEARCH METHOD

2.1. Data Collection and Measurements

Daily rainfall data were collected from the Nigerian Meteorological Agency (NIMET) for the six states in rain forest zone (South-West) of Nigeria for a period of two years (January 2011 to December 2012). Measurement setup at the metrological station consists of the bucket type rain gauge having 0.5mm sensitivity per tip. Also, the setup in the main measurement site is made up of the indoor and the outdoor units. The indoor unit comprises the spectrum (Trlytic) field strength meter (BK Precision 26.40 GHz) and a satellite tracker, while the outdoor unit consist an ISS (Integrated Sensor Suite) unit. Shown in Table 1 are the climatological parameters of the various stations under consideration.

Chebil and Rahman's proposed rain rate conversion model was adopted for converting the hourly data to the equivalent one-minute rainfall rate values. Detailed discussion of this procedure can be obtained in [17], [18] as follow:

$$CF_{60} = \frac{R_{1(p)}}{R_{60(p)}} = ap^b \tag{1}$$

$$CF_{60} = ap^b + c * exp(dp) \tag{2}$$

where a, b, c and d are regression coefficients derived from Segal proposed conversion model [19] using Gauss-Newton technique for the evaluation [18]. From (2), we obtain:

$$CF_{60} = 0.772 * p^{-0.041} + 1.141 * exp(-2.57 * p) \tag{3}$$

where CF_{60} is the rain rate conversion factor, defined as the ratio of rain rates $R1(p)$and $R60(p)$ for a given percentage of time p with an integration time of 1 min and 60 min respectively. Although this model is applicable for the range$0.001\% \leq p \leq 1.0\%$; nonetheless, if $R_{60(p)}$ is known, then $R_{1(p)}$ can be derived as:

$$R_{1(p)} = R_{60(p)} * CF_{60} \tag{4}$$

Table1. One-minute rain rate for selected locations

Stations	Abeokuta (3.09km)	Ado-Ekiti (2.45km)	Akure (3.1km)	Ikeja (3.34km)	Ibadan (2.85km)	Oshogbo (2.97km)
Long.(°N)	3.2	5.12	5.18	3.2	3.59	4.29
Lat.(°E)	7.1	7.39	7.17	6.35	7.22	7.47
Ave. Annual	129.4	127.5	126.3	124.8	122.3	119.1
Rainfall (mm)	1299.0	1425.0	1450.7	1686.7	1488.8	1384.1
$R_{0.001}$ (mm/h)	50.66	52.07	52.35	54.75	52.76	51.62

The specific attenuation $\gamma_R$for any percentage of time is given by:

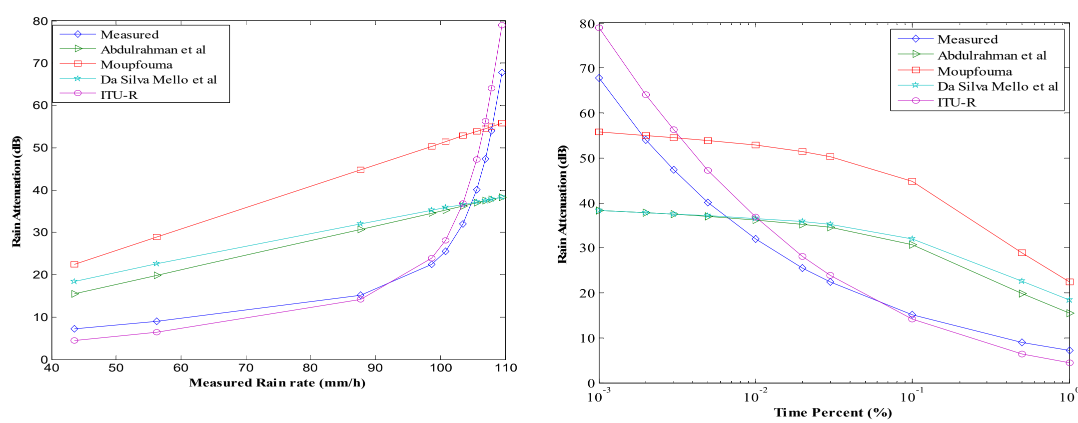
$$\gamma = kR_{\%p}^{\alpha}(dB/km) \tag{5}$$

Parameters k and α are frequency, rain temperature and polarization dependent regression coefficients, which can be determined locally or alternatively obtained from ITU-R P.838-3 [20].

ITU-R P.530-16 [7], Abdulrahman et al. [21], Silver Mello et al. [22] and Moupfouma [23] prediction models were tested with locally-sourced data, and the results of the simulated data are thereafter compared with the measurement data. The analysis and comparison are presented and discussed in the section below.

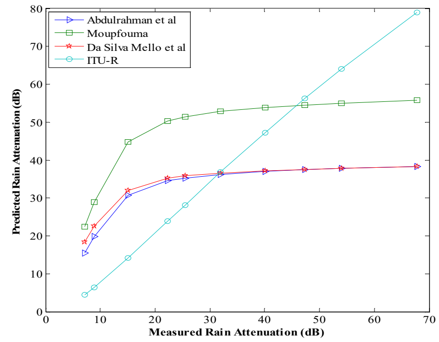
3. RESULTS AND ANALYSIS

At Abeokuta Figures 1 (a) through (c), ITU-R is the closest to the measured value at 1.0%, 0.1%, and 0.01%. However, ITU-R overestimated the measured at$p < 0.01\%$. Abdulrahman and Da Silva Mello models presented closely matched values to the measurement at $0.01\% < p < 0.007\%$, while Moupfouma performed well at $p = 0.002\%$. Overall, Abdulrahman exhibited the best performances followed closely by Da Silva Mello as seen in Table II (see Appendix).



(a) (b)

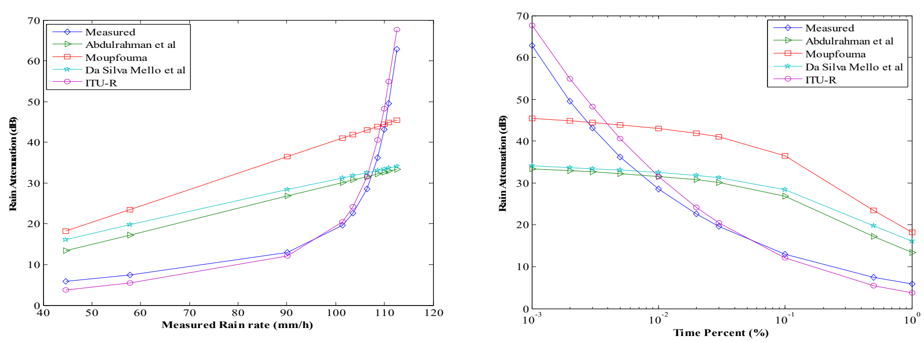
Figure 1. Comparisons of (a) rain rates and (b) rain attenuation CDs for Abeokuta



(c)

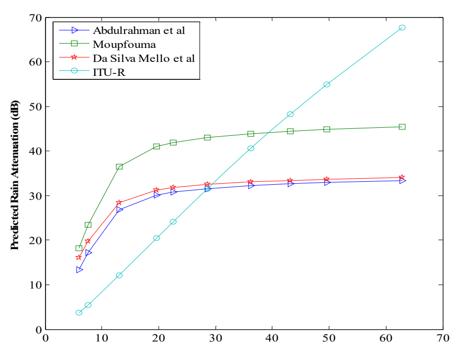
Figure 1 (c). Predicted against measured rain attenuation for Abeokuta

For Ado-Ekiti (see Figures 2 (a) through (c)), ITU-R also closely matched the measurement at 1.0%, 0.1%, and 0.01%. However, ITU-R overestimated the measured at $p < 0.01\%$. Abdulrahman and Da Silva Mello models gave closely values at $0.01\% < p < 0.008\%$ while Moupfouma performed well at $p = 0.003\%$.



(a) (b)

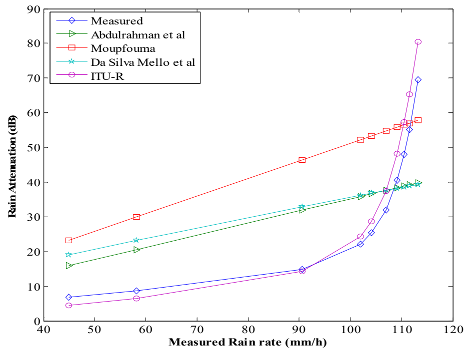
Figure 2. Comparisons of (a) rain rates and (b) rain attenuation CDs for Ado-Ekiti



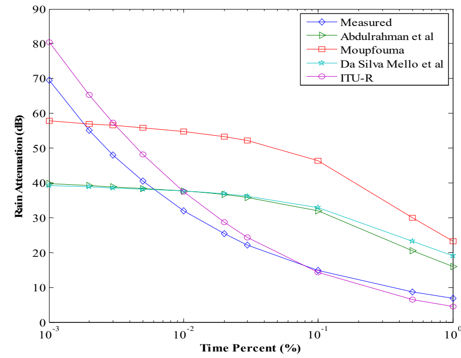
(c)

Figure 2 (c). Predicted against measured rain attenuation for Ado-Ekiti

Furthermore, for Ikeja (Figures 4 (a) through (c)), ITU-R presented the closest to the measured value at 1.0%, 0.1% and 0.05%. It however overestimated the measurement at $p < 0.005\%$. Abdulrahman and Da Silva Mello models gave a closed value at $p = 0.007\%$, while Moupfouma performed well at $p = 0.002\%$.

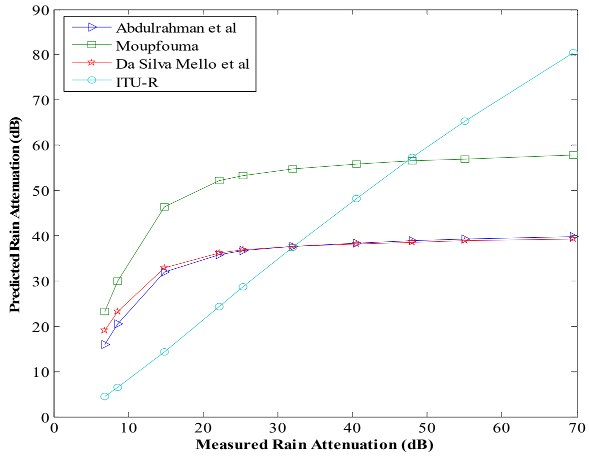


(a)



(b)

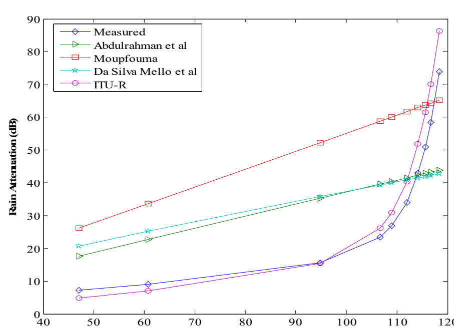
Figure 3. Comparisons of (a) rain rates and (b) rain attenuation CDs for Akure



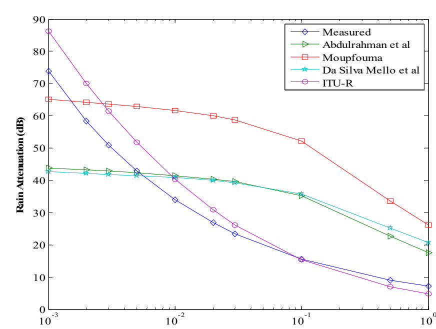
(c)

Figure 3 (c). Predicted against measured rain attenuation for Akure.

Furthermore, for Ikeja (Figures 4 (a) through (c)), ITU-R presented the closest to the measured value at 1.0%, 0.1% and 0.05%. It however overestimated the measurement at $p < 0.005\%$. Abdulrahman and Da Silva Mello models gave a closed value at $p = 0.007\%$, while Moupfouma performed well at $p = 0.002\%$.

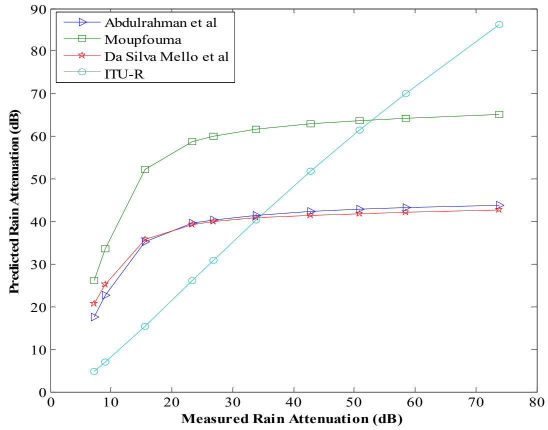


(a)



(b)

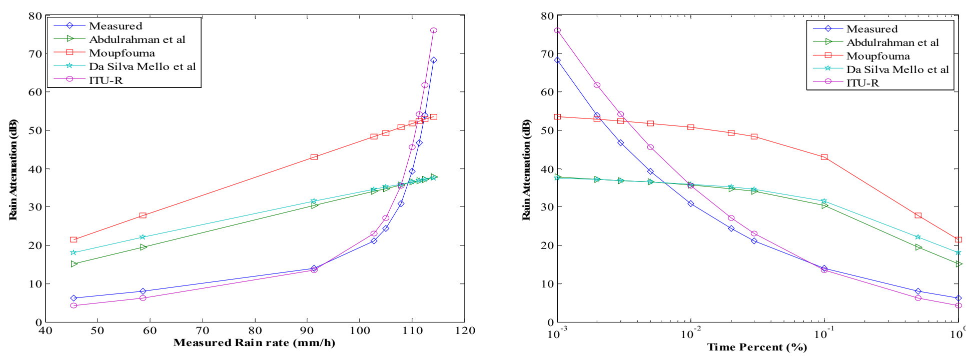
Figure 4. Comparisons of (a) rain rates and (b) rain attenuation CDs for Ikeja.



(c)

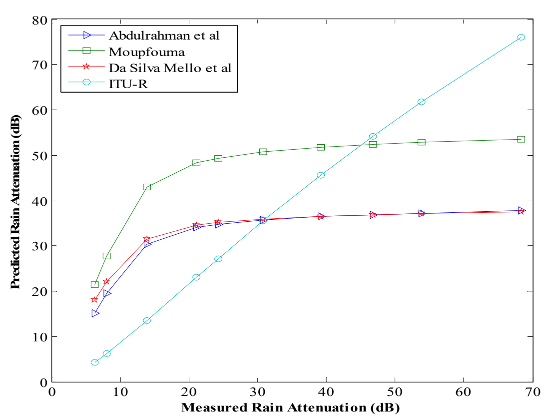
Figure 4 (c). Predicted against measured rain attenuation for Ikeja.

A close look at Figures 5 (a) through (c), reveals that at Ibadan the ITU-R overestimated the measured at$p < 0.005\%$, while Abdulrahman and Da Silva Mello models presented proximate value at $0.005\% < p < 0.008\%$. However, Moupfouma did well at $p = 0.002\%$.



(a) (b)

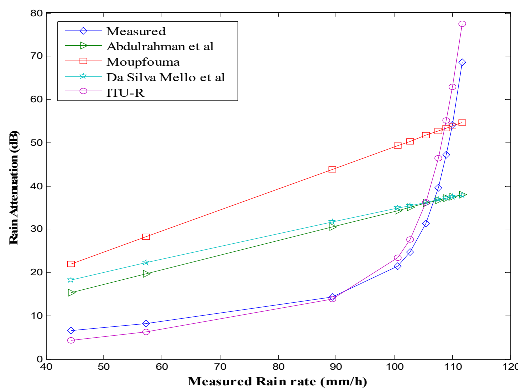
Figure 5. Comparisons of (a) rain rates and (b) rain attenuation CDs for Ibadan



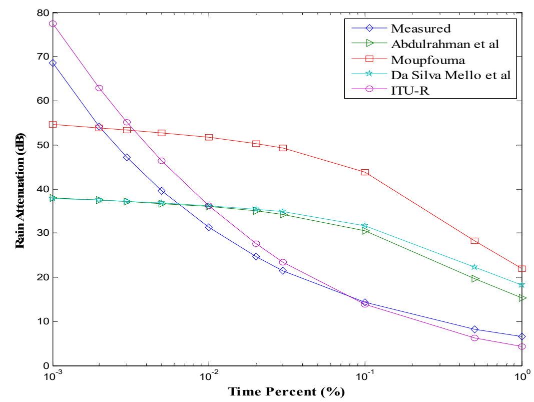
(c)

Figure 5 (c). Predicted against measured rain attenuation for Ibadan.

Finally, at Oshogbo (Figures 5 (a) through (c)), Abdulrahman and Da Silva Mello gave a nearly equal value at $0.006\% < p < 0.008\%$. Moupfouma performedgave a good account at $p = 0.002\%$. Herre, ITU-R model presented the best performance, even though it overestimated the measurement at $p < 0.005\%$.

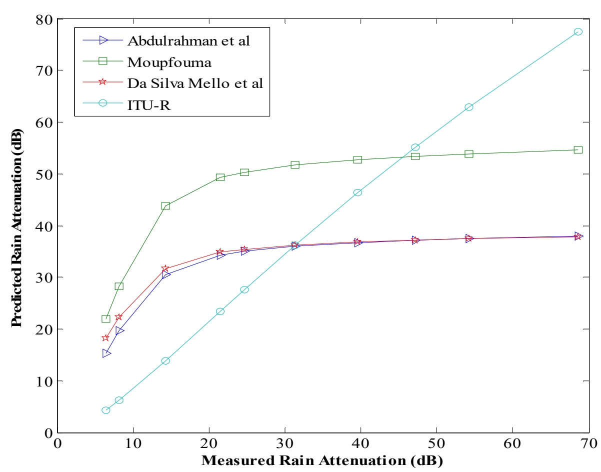


(a)



(b)

Figure 6. Comparisons of (a) rain rates and (b) rain attenuation CDs for Oshogbo



(c)

Figure 6 (c). Predicted against measured rain attenuation for Oshogbo.

4. CONCLUSION

This paper presented the findings of the study of terrestrial rain attenuation for six stations in the southwestern geographical region of Nigeria, which is in the tropical West African continent. Results of this study suggested that at 26 GHz, Abdulrahman proposed prediction model exhibited the overall best performance and was closely follwed by Silver Mello and ITU-R models, respectively. The ITU-R and Moupfouma prediction models over-estimated the measurement; with the Moupfouma proposed model showing the worst performances in all the six stations under investigation. The poor performances of the ITU-R and Moupfouma prediction models may be attributed to the fact that the data used for the formulation of these models were largely sourced from stations located in the temperate region. On the other hand, the impressive performances of Abdulrahman and Silver Mello proposed prediction models can also be attributed to the sources of the data used in their formulations (Malaysia and Brazil respectively; both tropical stations). The ITU-R model only agreed with the measurement value mostly at $p \geq 0.1\%$ of time exceeded. This is a further confirmation of the need for urgent review of the ITU-R Recommendation P.530-16 to accommodate the peculiarity of the precipitations experienced in tropical and equatorial stations.

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