IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 11, Issue 3 Ser. I (May. – June. 2019), PP 45-49
www.iosrjournals.org

Modelling of Rain Fade in a Semi Temperate Region

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Abstract: *At frequencies above 10 GHz, a major impediment in the use of various telecommunication applications and platforms is attenuation of electromagnetic waves by rain, especially in tropical regions. In order to combat signal attenuation, systems engineers and designers use the rain attenuation model for the regiontodevelop fade mitigation techniques.This paper presents the modelling of rain attenuation in Jos(9.896^{0}N, 8.858^{0}E, 1,192 m)a semi temperate regionof Nigeria. Signal performance was measured along a DTH (Ku-band) satellite link with its antenna look-up angle of 56.5^o, and analysedfor the months of April through October 2014. The models derivedhave very high correlationpercentages above 80%between the rain rate and rain-induced attenuation for all the months. As such, the models can be used to predict monthly rain-attenuation for the region. The resultsof this study provide additional information to communication system designers, and communication service providers for the planning, design and deployment of satellite systems in the tropical countries and particularly in Nigeria. However, longer periods of study are required to provide more reliable statistics and characterisation.*

Key words: *Modelling, rain-induced attenuation, Ku-band, Telecommunication planning.*

Date of Submission: 30-04-2019 Date of acceptance: 15-05-2019

I. Introduction

Rain fade is the absorption of microwaves radio frequency (RF) signal by atmospheric rain, snow or ice, and losses which are especially prevalent at frequencies above 10 GHz. It is also the degradation of a signal caused by the electromagnetic interference of the leading edge of a storm front. Rain fade can be caused by precipitation at the uplink or downlink location. Rain fade depends on the frequency, polarization, elevation angle, temperature, size distribution of rain drops, and on their fall velocity. However, it does not need to be raining at a location for it to be affected by rain fade, as the signal may pass through precipitation many miles away, especially if the satellite dish has a low look angle and elevation (that is, the orientation of an antenna in azimuth. Durodola (2016) showed that totalsignal outage iscaused by rain on the uplink or downlink antenna reflector, random or feed horn. Rain fade is not limited to satellite uplinks or down links, it also can affect terrestrial point to point microwave links.According to Ajayi et al., (1983) tropical regions often experience very heavy rainfall regimes which cause several problems, such as signal fading, depolarization and co-channel polarization due to scattering along the slant path. .

Telecommunication researchers andengineersare taking steps to provide solution toattenuation of electromagnetic waves due to degradations by hydrometeors such as rain, hail, cloud, and melting layer. To overcome this major impedimentespecially at frequencies above 10 GHz engineers provide allowances or margins commensurate to attenuation levels, in the design of satellite communication links.They use rain attenuation model for the region todevelop fade mitigation techniques. Other possible ways to overcome the effects of rain fade are site diversity, uplink power control, variable rate encoding, receiving antennas larger i.e. higher gain than the required size for normal weather conditions, and hydrophobic coatings.Communication engineers need to employ the most suitable model or rather, develop absolute prediction model for the tropical region.

Rain attenuation modelling on satellite paths has been vigorously researched for over four decades.Most of the studiescarried out in developed countries (such as Moupfouma et al., 1995, Moupfouma., 1998) have employed the use of satellite beacon experiments, but tropical regions are stillfaced with signal outage. Again, attenuation increases with rain rate and frequency in tropical regions; with vertical polarization producing less attenuation than horizontal polarization at millimetre wave bands (Tat-Soon Yeo, et al; 2005).Rain fading channel is a function of frequency, elevation angle, polarization angle, rain intensity, raindrop size distribution and rain temperature (Cheon-in, et al; 2006).Afahakan et al.,(2016) categorized slant path models into two namely:

1. Mathematical models, which attempt to define the physics of the process and model, the constituents of storm cells, etc., and

2. Empirical approaches, which are mainly based on real-time measurements with simplified assumptions.
As a result of inadequate global information on many of the physical inputs necessary for providing accurate results using mathematical models, the empirical models seem to be used most often and with better results.

Although theoretical and experimental studies of rain attenuation can be found in many literatures (such as Ojo et al 2008, Omotosho et al 2009, Owolawi, 2011, Semire et al, 2012, Durodola et al, 2014) measured rain attenuation data is still insufficiency for estimating the link within the individual regions(Yussuff, 2016). For temperate regions, rain attenuation increases inversely with elevation angle due to large rain cell size while for tropical regions, attenuation is directly proportional to elevation angle for the same rain ratesChakravarty & Maitra, 2009). This necessitates the need to model the propagation factors for tropical regions. Consequently, this paper will focus on the modelling of rain attenuation in Jos(9.896^{0}N, 8.858^{0}E, 1,192 m) a semi temperate regionof Nigeria.

II. Method

Rain attenuation in this work was measured and analyzed from data collected over a Ku-linkco-located with a Davis weather station at Gold and Base (9.896^{0}N, 8.858^{0}E, 1,192 m) near Airforce Military School, Jos. The weather station is equipped with an integrated sensor suite. Jos has an average annual temperature of 22.8^{o}C and average annual rainfall of1160mm (Durodola, 2016).Daily rainfall data were collected from the Davis weather station Jos, Nigeria for a period of one year (April to October 2014). Jos Plateau is located in the North - Central tropical Nigeria. The Earth-space slant path from satellite (L) was computed usingexpression (1) derived by Bryant*et al*,, (2001):

$$L= \frac{H-\Phi}{Sin\theta} \quad (1)$$

Where H is the rain height, Φ is the station altitude and θ is the look up angle.Davis weather station Jos has its rain height of 4.86km, station altitude of 1.192km and antenna look up angle of 56.5^0 respectively. Substituting these into the slant path expression given by (Durodola 2016) as:

$$L = \frac{4.86km - 1.192km}{Sin\ 56.5^\circ} = 4.399km \quad (2)$$

The modelling was achieved using micro-soft excelstatistical means to find the probability of exceedance of each of the rainfall rate value in the data.The power levels of the datafor each month was reorganized and converted to the same units of power in dBm. The attenuation was plotted against rain rate in order to come out with a model for each of the month and also a combined model for the year 2014. From the monthly model, a combined model was derived.The table of monthly models was computed using this expression for each month:

$$A = KR^{\beta} \quad (3)$$

Therefore $$\gamma = \frac{A}{L} = \frac{K}{L} R^{\beta} = \alpha R^{\beta} \quad (4)$$

III. Results

Figures 1to 6 presentthe Modelling of rain attenuation as function of rain rate for April through October, 2014, while Figure 7presents the Modelling of rain attenuation as function of rain rate for the combined months, 2014..

3.1 Modelling ofmonthly Attenuation

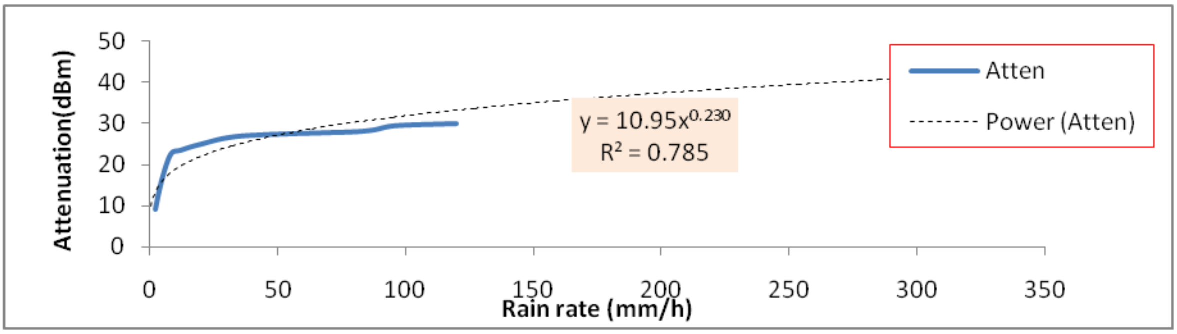

Figure1: Model – Rain attenuation as function of rain rate, Apr 2014.

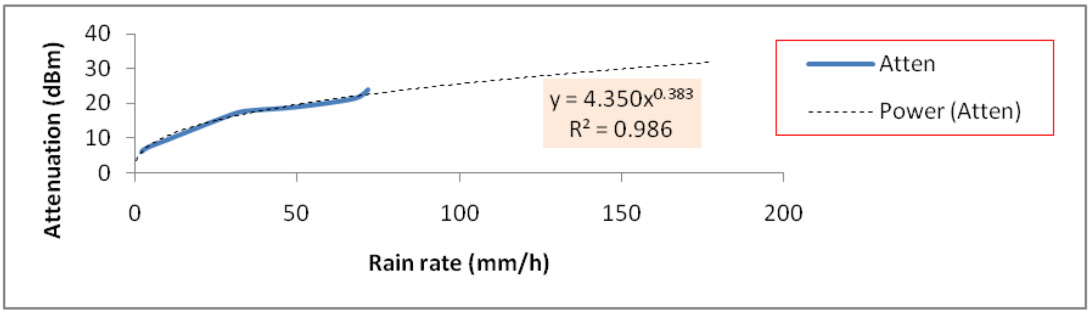

Figure 2: Model– Rain attenuationas function of rain rate for May2014.

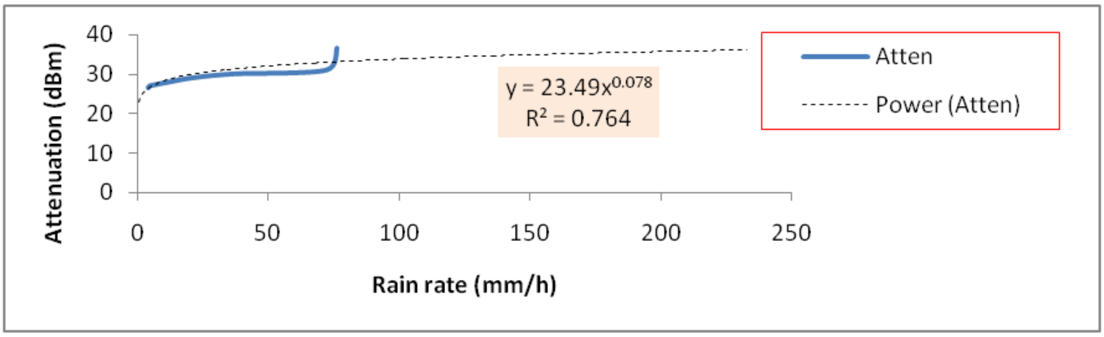

Figure 3: Model– Rain attenuationas function of rain rate Jun2014.

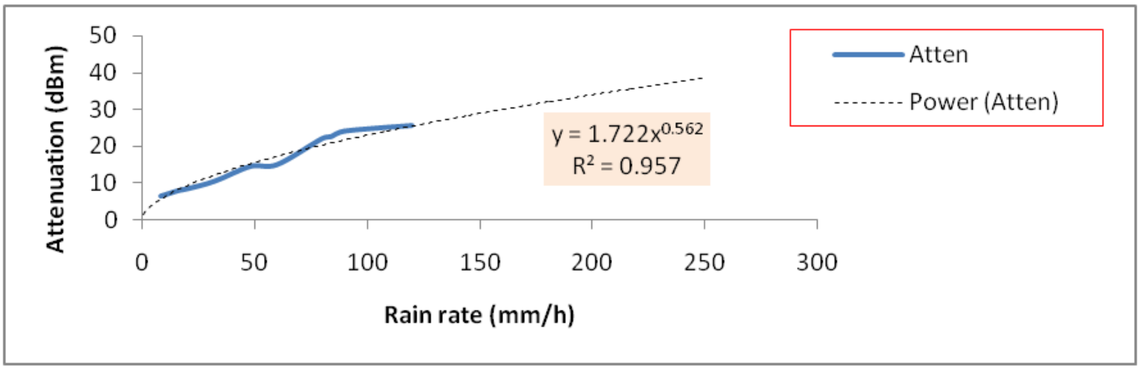

Figure 4: Model of rain attenuationas function of rain rate Jul2014.

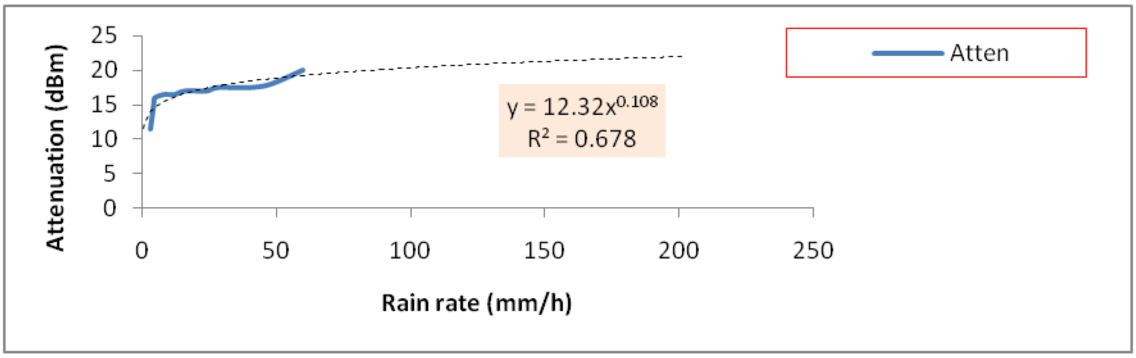

Figure 5: Model - Rain attenuationas function of rain rate, Sep2014.

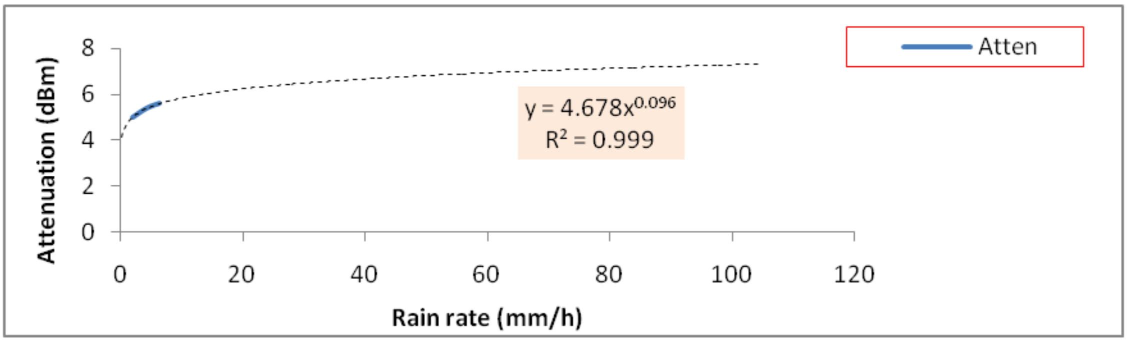

Figure 6: Model -Rain attenuationas function of rain rate, Oct 2014.

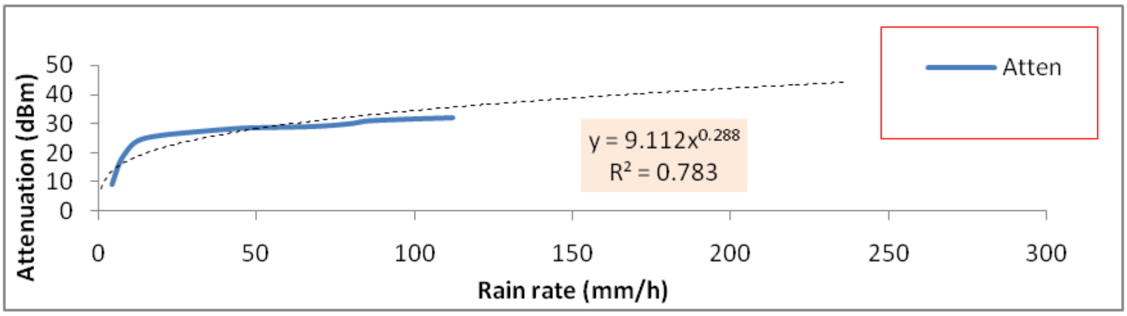

Figure 7: Model – Rain attenuationas function of rain rate for the year 2014.

3.2 Computation of Specific Attenuation Parameters

Parameters for specific attenuation, γ for each month were computed as summarised in Table 1:

Table 1: Specific attenuation

Months	**Attenuation Equation (From Graph)**	**Equation of Specific Attenuation** ($\gamma = \frac{A}{L}$)	**α**	**β**	**R**
April	$A = 10.95\ R^{0.230}$	$2.489\ R^{0.230}$	2.489	0.230	0.886
May	$A = 4.350R^{0.388}$	$0.989R^{0.388}$	0.989	0.388	0.993
June	$A = 23.49R^{0.078}$	$5.339R^{0.078}$	5.339	0.078	0.874
July	$A = 1.722R^{0.562}$	$0.391R^{0.562}$	0.391	0.562	0.978
Sep	$A = 12.32R^{0.108}$	$2.801R^{0.108}$	2.801	0.108	0.823
Oct	$A = 4.678R^{0.096}$	$1.063R^{0.096}$	1.063	0.096	0.999
Combined	$A = 9.112R^{0.288}$	$2.071R^{0.288}$	2.071	0.288	0.885
Average Values	–	$2.179R^{0.244}$	2.179	0.244	0.926

IV. Discussion

Regression equations of the graphs in figures 1 t0 7 have very high correlation coefficients, which show that there is a very good correlation between the rain attenuation and rain rate. However, the correlation vary from one month to the other. This is understandable, since the rainfall intensities and rainfall regimes from one month to the other different variations. Such variations could actually be better studied if the experimental measurements covered a longer period of 6 to 20 years. With such elongated data, it would provide a more accurate average value for each month; but this is limited by the lack of equipment.

From the regression curves relevant parameters for computing specific attenuation the various months have been computed as summarised in Table 1. The coefficient of regression (R) shows the relationship between the attenuation and the rain rate. The correlation coefficients in the months range from a minimum of 82% to 100%. The attenuation parameters are useful for modelling specific attenuation in each month at a given rainfall intensity.This is a significant input parameter for systems engineers for computing fade margins, or for designing other fade mitigation techniques such as channel modelling and upper link power control. The results obtained can also be used for preliminary design of the satellite microwave links, satellite–payload design and satellite-coverage analysis.

From the table above, the model coefficient(alpha, α) is the multiplying constant akin to the fade slope; while the index (beta, β) is the shaping constant. Most of the multiplying constants are above unity, except for the month of May and July. This indicates that the value of alpha (α) has the effect of aggravating the specific attenuation. This multiplier effect is highest for the month of June (5.3) which from researched has been found to be worst month for the year Durodola (2017). The minimum value of alpha (α) was 0.39 for July which is unexpected, which suggest that investigations such as this require longer periods of study for reliable statistics and characterisation.

The indexvalues (beta, β) are all less than unity. Mathematically, beta (β) may be related to the variation of rainfall intensity and /or the occurrence of rain regimes in the month varies. Incidentally, the value is highest in the month ofJuly suggesting that the occurrences of rain regimesare highest in the month of July.

V. Conclusion

This paperpresented the modelling of rain attenuation in tropical region – Jos Plateau State, Nigeria.Our models revealed over 80% coefficient of agreement between rainfall intensities and attenuation for each month.The advantage of the rain attenuation model is that it gives additional information and input parameters to system designers, for the design of satellite systems in the tropical country and particularly in Nigeria. However, there is need for longer periods of study to obtain more reliable statistics and characterisation.

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IOSR Journal of Applied Physics (IOSR-JAP) is UGC approved Journal with Sl. No. 5010, Journal no. 49054.

O.M. Durodola " Modelling of Rain Fade in a Semi Temperate Region." IOSR Journal of Applied Physics (IOSR-JAP) , vol. 11, no. 3, 2019, pp. 45-49.