Rain fade characteristics at Ku- and Ka-bands in some parts of Nigeria

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Abstract

Rain fade characteristics at Ku- and Ka-bands in parts of North-eastern (Damaturu, Bauchi and Maiduguri) and South-western (Abeokuta, Ibadan and Ikeja) regions of Nigeria is presented in this work. 33 years (1983-2015) rainfall data were collected from the Nigerian Meteorological Agency (Nimet) for the locations. ***.*** *Chebil rain rate model was used to compute the point rainfall rate, while ITU-R P.618-12 model was used to compute the rain-induced attenuation at frequencies of 11 GHz, 14 GHz, 20 GHz, and 40 GHz. Point rainfall rate of 85.24 mm/h, 98.20 mm/h and 99.30 mm/h were obtained at Damaturu, Maiduguri and Bauchi respectively, while higher rainfall rate of 99.70 mm/h, 104.8 mm/h and 108.20 mm/h, were recorded at Abeokuta, Ibadan and Ikeja respectively. Three elevation angles were considered: 23º, 42.5º and 55º. The results obtained show that rain-induced attenuation for the Southwestern region varied from 20.56 dB to 41.00 dB at 23º elevation angle, 12.85 dB to 26.44 dB at 42.5º elevation angle and 10.61 dB to 22.34 dB at 55º elevation angle at Ku band, while the rain-induced attenuation computed for the Northeastern region varied from 18.59 dB to 37.65 dB at 23º elevation angle, 11.61 dB to 23.46 dB at 42.5º elevation angle and 9.59 dB to 20.52 dB at 55º elevation angle for exceedance time percentage of 0.01% at Ku-band. For the Ka-band, the rain-induced attenuation for the Southwestern region ranged between 59.71 dB and 183.75 dB at 23º elevation angle, 40.39 dB and 133.48 dB at 42.5º elevation angle and 35.12 dB and 122.11 dB at 55º elevation angle, while the rain-induced attenuation computed for the Northeastern region ranged between 54.06 dB and 168.97 dB at 23º elevation angle, 36.50 dB and 120.79 dB at 42.5º elevation angle and between 31.71 dB and 111.76 dB at 55º elevation angle for same 0.01 percentage of time exceedance.*

Keywords: Elevation Angle, Ka-Band, Ku-Band, Rain-Induced Attenuation, Rain Rate.

1. Introduction

Rainfall is a natural and time varying phenomenon that changes from location-to-location and from year-to-year. Above a certain threshold frequency, attenuation due to rainfall becomes one of the most important limits to the performance of line-of-sight (LOS) microwave links (Das and Maitra, 2016). In temperate climates this frequency threshold is about 10 GHz, while in the tropical and equatorial climates, the incidence of rainfall on radio links becomes serious for frequencies as low as 7 GHz since the tropical and equatorial climates experiences higher rainfall intensities of larger raindrops than the temperate climate (Rakshit *et al,.* 2017). In order to successfully estimate rain attenuation along the link path, the point rainfall rate characteristics must be available in the location of interest. For such rainfall rate characteristics, information such as integration time, average rainfall cumulative distribution, and worst-month rainfall rate distribution are all required by a radio link planner in order to estimate path loss (Sujan *et al.,* 2017).

Igwe *et al.* (2019) evaluated some rain attenuation prediction models for satellite communication at Ku and Ka bands. It was observed that rain attenuation at Ka-band (19.45GHz) was significantly higher than at Ku-band (12.675GHz) for all the elevation angles. The predicted rain attenuation by ITU-R model exceeded for 0.001 % of the time is as high as 52 dB, 54 dB and 75 dB at 55°, 42.5° and 23° respectively. Also, at 0.01 % of time, the rain attenuation predicted varies between 37 dB and 47 dB at the Ka-band frequency for the three elevation angles.

Also Igwe *et al.* (2021) obtained 5-minutes integration time rainfall data for the North central region of Nigeria from the Tropospheric Data Acquisition Network (TRODAN) Anyigba, Nigeria. One minute integration time rainfall was measured at Minna, Nigeria. To obtain the best performing rain rate model suitable for the region, two globally recognised rain rate models were evaluated and compared with the 1-minute measurements. These are the Lavergnat-Gole (L-G) and ITU-R P.837-7 models. The results obtained showed that the ITU-R P.837-7 and L-G models respectively underestimated the measured rain rate by 7.3 mm/h and 9 mm/h at time percentage exceedance of 0.1%, while they underestimated the measured rain rate by 23.4 mm/h and 13 mm/h respectively at 0.01%. At 0.001%, the measured rain rate was overestimated by the ITU-R P.837-7 and L-G models by 27.4 mm/h and 3 mm/h respectively. Further performance evaluation of the predefined models was carried out using different error metrics such as sum of absolute error (SAE), mean absolute error (MAE), root mean square error (RMSE), standard deviation (STDEV) and Spearman's rank correlation. The results obtained adjudged the Lavergnat-Gole model as the best rain rate prediction model for this region.

2. Methodology

Daily rainfall data of 33 years (January, 1983 to December, 2015) was acquired from the Nigerian Meteorological Agency (NIMET), Chebil rain rate model outlined in equation (5) was used to compute the rain rate, while ITU-R P.618-12 rain attenuation model was employed to calculate the rain-induced attenuation. Some of the input parameters needed for the ITU-R P. 618-12 model are: point rainfall rate for the location for 0.01% of an average year (mm/h), height above sea level of the Earth station (Km), elevation angle (degree), latitude of the Earth station (degree), frequency (GHz) and effective radius of the Earth (8500 Km).

2.1 Rain Rate Computation

2.2 Rain Attenuation Computation

The step by step procedure for calculating the attenuation distribution is given below:

Step 1: Determine the rain height, H_R as:

$$H_R = h_o + 0.36 \text{ (km)} \qquad (1)$$

where h_o is the 0°C isotherm height above mean sea level of the location.

Step 2: Determining the slant-path length, L_S, below the freezing rain height as obtained by:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \text{(km)} \qquad (2)$$

where θ is the elevation angle and h_S is the height of the location above sea level.

For $\theta < 5^{\theta}$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \right)\frac{2(h_R - h_s)}{R_e}^{1\backslash 2} + \sin\theta} \text{ (km)} \qquad (3)$$

If h_R - h_S is less than or equal to zero, the predicted rain attenuation for any time percentage is zero and the following steps are not required.

Step 3: Calculate the horizontal projection, L_G, of the slant-path length from:

$$L_G = L_S \text{Cos}\,\theta \quad \text{(Km)} \qquad (4)$$

Step 4: Determine the point rainfall rate $R_{0.01}$ (mm/h) exceeded for 0.01% of an average year. This is obtained using Chebil rain rate model given as:

$$R_{0.01} = \alpha M^{\beta} \qquad (5)$$

where, α and β are regression coefficients defined as α = 12.2903; and β = 0.2973, while M is the annual average rainfall.

Step 5: Obtain the specific attenuation, γ_R using the frequency-dependent coefficients given in Recommendation ITU-R P.618-10 and the rainfall rate, $R_{0.01}$ determined from step 4, by using:

$$\gamma R = k(R_{0.01})^{\alpha} \quad \text{(dB\km)} \tag{6}$$

where Parameters k and α are determined as functions of frequency in GHz as given in ITU-R P. 618-12

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$ for 0.01% of the time given as:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G \gamma R}{f}} - 0.38\left(1 - e^{-2L_G}\right)} \tag{7}$$

Where f is the frequency in GHz.

Step 7: Calculate the vertical adjustment factor, $V_{0.01}$, for 0.01% of the time given as:

$$\zeta = Tan^{-1}\left(\frac{h_R - h_S}{L_G r_{0.01}}\right) \quad \text{(degrees)} \tag{8}$$

$$For \zeta > \theta, L_R = \frac{L_G r_{0.01}}{\cos\theta} \quad \text{(km)} \tag{9}$$

else,

$$L_R = \frac{(h_R - h_S)}{\sin\theta} \quad \text{(km)} \tag{10}$$

If $|\varphi| < 36^\circ$, $\quad$ x = 36 - $|\varphi|$ (degrees)

else, $\quad$ x = 0 degree

$$V_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+x))}\right)\frac{\sqrt{L_R \gamma_R}}{f^2} - 0.45\right)} \tag{11}$$

Step 8: The effective path length through rain, L_E (Km), is calculated as:

$$L_E = L_R V_{0.01} \tag{12}$$

Step 9: The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma R L_E \quad \text{(dB)} \tag{13}$$

Step 10: The estimated attenuation to be exceeded for the other percentages of an average year, in the range 0.001% to 10%, may be estimated from the attenuation to be exceeded for 0.01% for an average year by using:

$$A_P = A_{0.01}\left(\frac{p}{0.01}\right)^{-\left(0.655 + 0.033\ln(p) - 0.045\ln(A_{0.01}) - \beta(1-p)\sin\theta\right)} \quad \text{(dB)} \tag{14}$$

where p is the percentage probability of interest and β is given by:

If $P \geq 1\%\ or |\varphi| \geq 36^\circ \quad \beta = 0$

If $P < 1\%$ and $|\varphi| < 36^\circ\ and\ \theta \geq 25^\circ$: $\quad \beta = -0.005(|\varphi| - 36)$

otherwise:

$\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25\ sin\theta$

where;

$$\beta = \begin{Bmatrix} 0 if \geq 1\% or / \varphi / \geq 36° \\ -0.005(/\varphi/ - 36°) if, p < 1\% and / \varphi / < 36° and \theta \geq 25° \\ -0.005(/\varphi/ - 36°) + 1.8 - 4.25 \sin\theta, otherwise \end{Bmatrix}$$

2.3 Study Locations

The study location is parts of two geographical zones of Nigeria. These include the Southwestern region and the Northeastern region of Nigeria. The Southwestern States are Abeokuta, Ibadan and Ikeja, while the Northeastern region include Damaturu, Bauchi and Maiduguri States.

3. Results

The point rainfall rate calculated using Chebil model is presented in Table 1.

Table 1: Point Rainfall Rate for the Study Locations.

Location	Damaturu	Maiduguri	Bauchi	Abeokuta	Ibadan	Ikeja
$R_{0.01}$ (mm/hr)	85.20	98.20	99.30	99.70	104.80	108.20

The results from Table 1 shows that higher rainfall rates at 0.01 percentage time exceedance was experienced in Abeokuta, Ibadan and Ikeja than in Damaturu, Bauchi and Maiduguri. Hence, higher rain-induced attenuation is expected in Southwestern part than in Northeastern part of the country. Table 2 shows the geographical and experimental parameters used for the computation of rain-induced attenuation in the study locations.

Table 2: Geographical and experimental parameters for the study locations.

Station	Damaturu	Bauchi	Maiduguri	Abeokuta	Ibadan	Ikeja
Longitude (°N)	11.9	9.8	13.2	3.55	3.90	3.33
Latitude (°E)	11.7	10.3	11.8	6.42	7.43	6.58
Altitude (m)	451	616	320	66	230	129
Isotherm Height (Km)	4.412	4.416	4.416	4.410	4.400	4.390
Frequency (GHz)	11, 14, 20 & 40	11, 14, 20 & 40	11, 14, 20 & 40	11, 14, 20 & 40	11, 14, 20 & 40	11, 14, 20 & 40
Elevation Angles	23°, 42.5° & 55°	23°, 42.5° & 55°	23°, 42.5° & 55°	23°, 42.5° & 55°	23°, 42.5° & 55°	23°, 42.5° & 55°
Polarisation Angles	Vertical, Circular & horizontal	Vertical, Circular & horizontal	Vertical, Circular & horizontal	Vertical, Circular & horizontal	Vertical, Circular & horizontal	Vertical, Circular & horizontal

The predicted rain-induced attenuation at 23^0 elevation angle for horizontal, circular and vertical polarisations for the study locations is presented in Tables 3-5

Table 3: The predicted rain-induced attenuation at 23^0 elevation angle for horizontal polarisation

Frequency (GHz)	Damaturu	Bauchi	Maiduguri	Abeokuta	Ibadan	Ikeja
11.00	21.22	22.74	23.45	23.45	24.88	25.58
14.00	34.14	36.45	37.65	37.66	39.88	40.99
20.00	62.94	66.96	69.30	69.56	73.52	75.58
40.00	156.66	162.57	168.97	170.56	178.91	183.75

Table 4: The predicted rain-induced attenuation at 23^0 elevation angle for circular polarisation

Frequency (GHz)	Damaturu	Bauchi	Maiduguri	Abeokuta	Ibadan	Ikeja
11.00	19.89	21.30	21.98	21.99	23.32	23.98
14.00	31.95	34.06	35.19	35.25	37.28	38.31
20.00	58.25	61.83	64.05	64.36	67.92	69.81
40.00	148.09	155.55	161.72	163.31	171.22	175.85

Table 5: The predicted rain-induced attenuation at 23^0 elevation angle for vertical polarisation

Frequency (GHz)	Damaturu	Bauchi	Maiduguri	Abeokuta	Ibadan	Ikeja
11.00	18.59	19.89	20.54	20.56	21.80	22.42
14.00	30.10	32.00	33.10	33.21	35.08	30.04
20.00	54.06	57.26	59.36	59.71	62.93	64.67
40.00	141.56	148.57	154.52	156.10	163.58	167.99

Table 3 shows that the Northeastern region (Damaturu, Bauchi and Maiduguri) recorded rain-induced attenuation values for horizontal polarisation that ranged between 21.22 dB and 23.45 dB at 11 GHz downlink frequency, while values ranged between 34.14 dB and 37.65 dB at 14 GHz uplink frequency. For the Southwestern region (Abeokuta, Ibadan and Ikeja) rain-induced attenuation values varied from 23.45 dB to 25.58 dB at 11 GHz downlink frequency, while values varied from 37.66 dB to 40.99 dB at 14 GHz uplink frequency of Ku-band. For the Ka band, the Northeastern region recorded attenuation values for the range between 62.94 dB and 69.30 dB at 20 GHz downlink frequency, while values ranged between 154.66 dB and 168.97 dB at 40 GHz uplink frequency. The Southwestern region recorded rain-induced attenuation values that ranged between 69.56 dB and 75.58 dB at 20 GHz downlink frequency, while values ranged between 170.56 dB and 183.75 dB at 40 GHz uplink frequency at 0.01% time exceedance.

As observed in Table 4, the rain-induced attenuation for circular polarisation, recorded values that varied from 19.89 dB to 21.98 dB at 11 GHz downlink frequency, while values varied from 31.95 dB to 35.19 dB at 14 GHz uplink frequency for the Northeastern region. The Southwestern region recorded attenuation values that ranged between 21.99 dB and 23.98 dB at 11 GHz downlink frequency, while values ranged between 35.25 dB and 38.31 dB at 14 GHz uplink frequency at 0.01% time exceedance at Ku band. The Northeastern region recorded rain-induced attenuation values that ranged between 58.25 dB and 64.05 dB at 20 GHz downlink frequency, while values ranged between 148.09 dB and 161.72 dB at 40 GHz uplink frequency. For the Southwestern region recorded attenuation values varied from 64.36 dB to 69.81 dB at 20 GHz downlink frequency, while values varied from 163.31 dB to 175.85 dB at 40 GHz uplink frequency at Ka-band.

From Table 5, the Northeastern region recorded attenuation values for vertical polarisation that ranged between 18.59 dB and 20.54 dB at 11 GHz downlink frequency, while values ranged between 30.10 dB and 33.10 dB at 14 GHz uplink frequency. The rain-induced attenuation values varied from 20.56 dB to 22.42 dB at 11 GHz downlink frequency, while values varied from 33.21 dB to 36.04 dB at 14 GHz uplink frequency of the Southwestern region at 0.01% time exceedance at Ku band. Rain-induced attenuation values varied from 54.06 dB to 59.36 dB at 20 GHz downlink frequency, while values varied from 141.56 dB to 154.52 dB at 40 GHz uplink frequency for the Northeastern region. The Southwestern region recorded rain-induced attenuation values that ranged between 59.71 dB and 64.67 dB at 20 GHz downlink frequency, while values ranged between 156.10 dB and 167.99 dB at 40 GHz uplink frequency at 0.01% time exceedance at Ka band.

Figures 1-4 show the graphical comparison of rain attenuation at downlink and uplink frequencies of Ku- and Ka- bands at horizontal polarisation for the study locations at 42.5° elevation angle for different percentages of time exceedance.

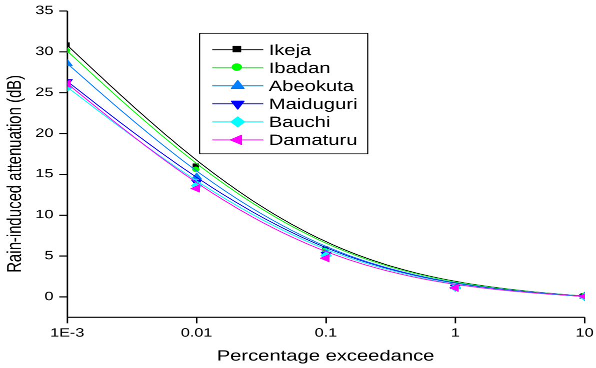

Figure 1: Rain-induced attenuation at 11 GHz downlink, horizontal polarisation

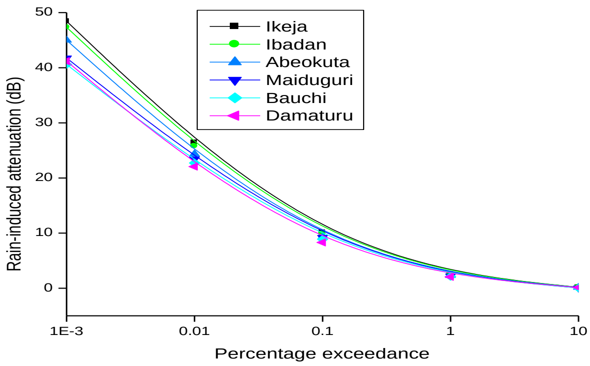

Figure 2: Rain-induced attenuation at 14 GHz uplink, horizontal polarisation

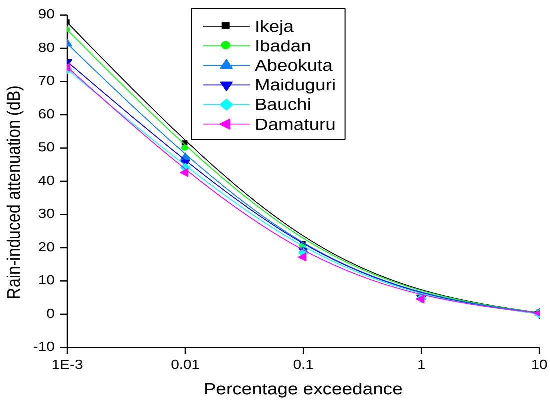

Figure 3: Rain-induced attenuation at 20 GHz downlink, horizontal polarisation

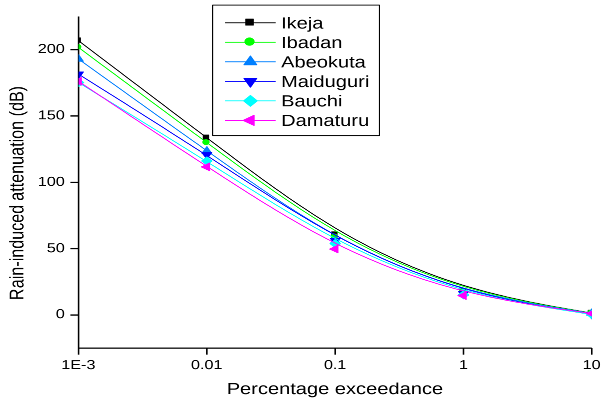

Figure 4: Rain-induced attenuation at 40 GHz uplink, horizontal polarisation

Figures 1-4 revealed that the rain-induced attenuation values for horizontal polarisation ranged between 13.26 dB and 14.04 dB at 11 GHz downlink, while values ranged between 22.07 dB and 23.46 dB at 14 GHz uplink frequency for the Northeastern region. The Southwestern region recorded rain-induced attenuation values that varied from 14.66 dB to 15.95 dB at 11 GHz downlink frequency, while values varied from 24.35 dB to 26.44 dB at 14 GHz uplink frequency of Ku-band. The Northeastern region recorded rain-induced attenuation values that varied from 42.62 dB to 45.68 dB at 20 GHz downlink frequency, while values varied from 111.63 dB to 120.79 dB at 40 GHz uplink frequency. Rain-induced attenuation for the Southwestern region recorded values that ranged between 47.17 dB and 51.30 dB at 20 GHz downlink frequency, while values ranged between 123.57 dB and 133.48 dB at 40 GHz uplink frequency at 0.01% time exceedance at Ka-band.

Figures 5-8 show the graphical comparison of rain attenuation at downlink and uplink frequencies of Ku- and Ka- bands at circular polarisation for the study locations at 42.5° elevation angle for different percentages of time exceedance.

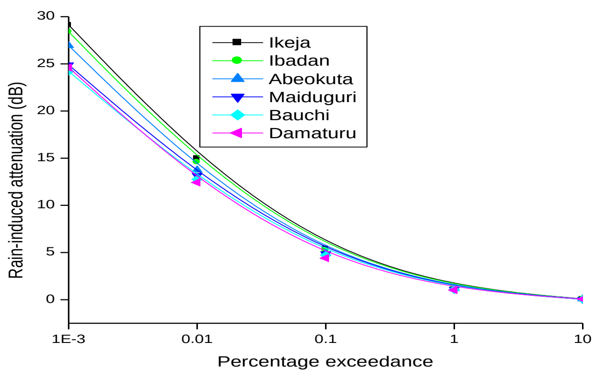

Figure 5: Rain-induced attenuation at 11 GHz downlink, circular polarisation

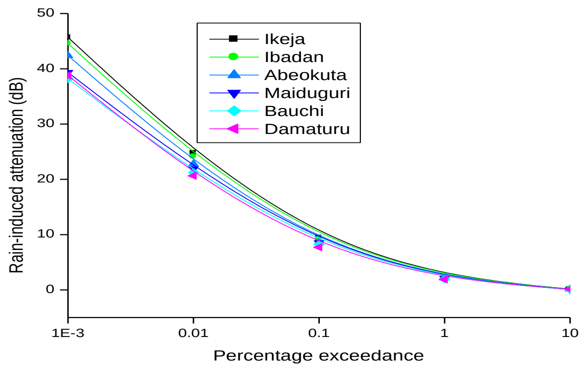

Figure 6: Rain-induced attenuation at 14 GHz uplink, circular polarisation

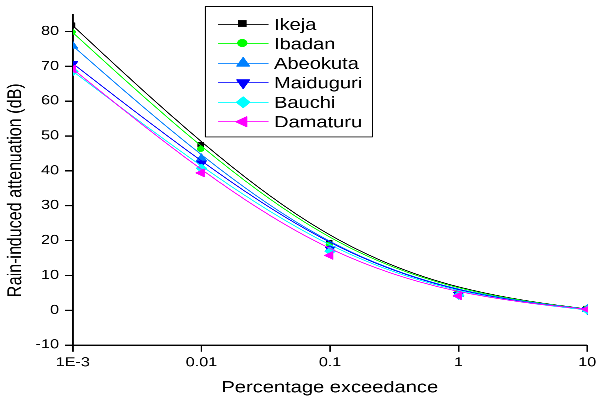

Figure 7: Rain-induced attenuation at 20 GHz downlink, circular polarisation

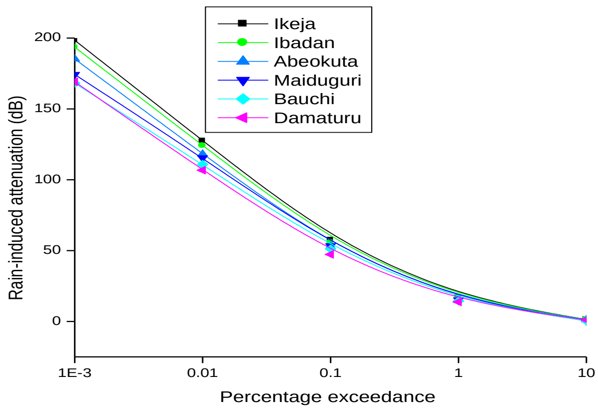

Figure 8: Rain-induced attenuation at 40 GHz uplink, circular polarisation

As observed from Figures 5-8 rain-induced attenuation computed for circular polarisation for the Northeastern region recorded values that varied from 12.43 dB to 13.17 dB at 11 GHz downlink, while values varied from 20.64 dB to 21.93 dB at 14 GHz uplink frequency. The Southwestern region recorded attenuation values that ranged between 13.74 dB and 14.99 dB at 11 GHz downlink frequency, while values ranged between 22.79 dB and 24.78 dB at 14 GHz uplink frequency at Ku-band. For Ka band, the Northeastern region recorded attenuation values that ranged between 39.39 dB and 42.21 dB at 20 GHz downlink, while values ranged between 106.70 dB and 115.45 dB at 40 GHz uplink frequency. The Southwestern region recorded attenuation values that varied from 43.59 dB to 47.34 dB at 20 GHz downlink frequency, while values varied from 118.12 dB to 127.54 dB at 40 GHz uplink frequency at 0.01% time exceedance.

Figures 9-12 show the graphical comparison of rain attenuation at downlink and uplink frequencies of Ku- and Ka- bands at vertical polarisation for the study locations at 42.5° elevation angle for different percentages of time exceedance.

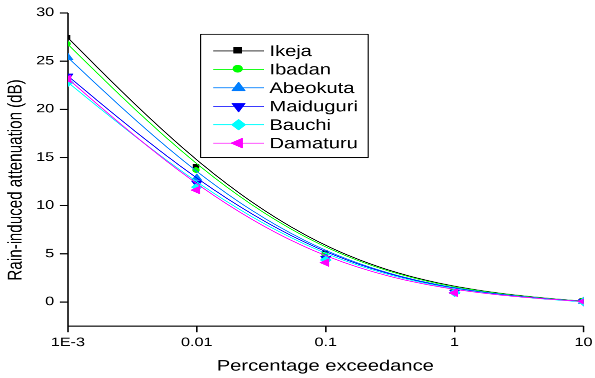

Figure 9: Rain-induced attenuation at 11 GHz downlink, vertical polarisation

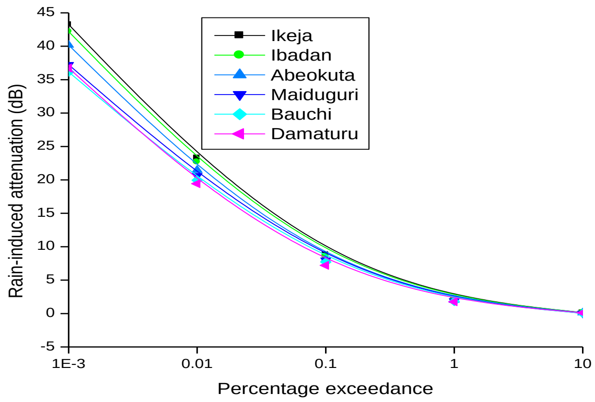

Figure 10: Rain-induced attenuation at 14 GHz uplink, vertical polarisation

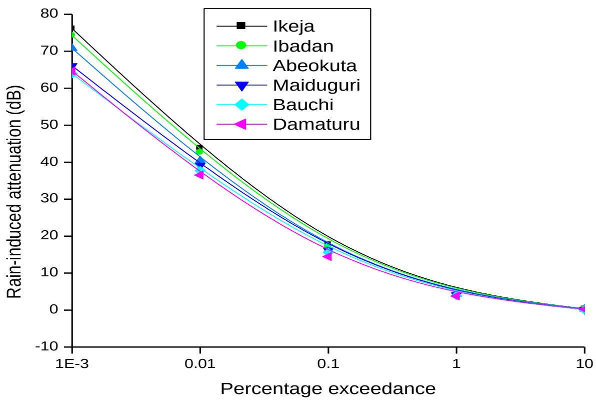

Figure 11: Rain-induced attenuation at 20 GHz downlink, vertical polarisation

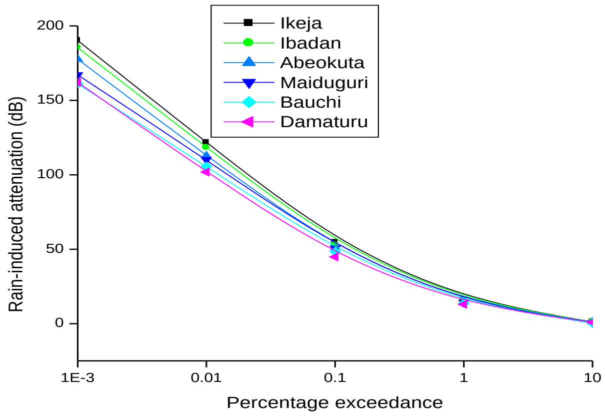

Figure 12: Rain-induced attenuation at 40 GHz uplink, vertical polarisation

It is observed from the Figures 9-12 that the Northeastern region recorded attenuation values computed for vertical polarisation that ranged between 11.61 dB and 12.31 dB for 11 GHz downlink frequency, while values ranged between 19.43 dB and 20.64 dB for 14 GHz uplink frequency. For the Southwestern region rain-induced attenuation values varied from 12.85 dB to 14.01 dB at 11 GHz downlink, while values varied from 21.47 dB to 23.31 dB at 14 GHz uplink frequency at 0.01% of time exceedance at Ku-band. The Northeastern region recorded attenuation values for vertical polarisation that varied from 36.50 dB to 39.10 dB at 20 GHz downlink, while values varied from 101.81 dB to 110.14 dB at 40 GHz uplink frequency. Rain-induced attenuation for the Southwestern region had values that ranged between 40.39 dB and 43.81 dB at 20 GHz downlink, while values ranged between 112.71 dB and 121.64 dB at 40 GHz uplink frequency at 0.01% of time exceedance at Ka-band.

The predicted rain-induced attenuation at 55^0 elevation angle for horizontal, circular and vertical polarizations for the study locations is presented in Tables 6-8

Table 6: The predicted rain-induced attenuation at 55^0 elevation angle for horizontal polarisation

Frequency (GHz)	Damaturu	Bauchi	Maiduguri	Abeokuta	Ibadan	Ikeja
11.00	10.94	11.73	12.09	12.09	12.83	13.19
14.00	18.60	19.86	20.52	20.53	21.73	22.34
20.00	37.05	39.49	40.37	41.03	43.40	44.63
40.00	101.77	107.28	111.76	112.89	118.72	122.11

Table 7: The predicted rain-induced attenuation at 55^0 elevation angle for circular polarisation

Frequency (GHz)	Damaturu	Bauchi	Maiduguri	Abeokuta	Ibadan	Ikeja
11.00	10.26	10.98	11.33	11.34	12.03	12.37
14.00	17.40	18.54	19.17	19.21	20.32	20.88
20.00	34.23	36.39	37.72	37.91	40.05	41.18
40.00	97.19	102.37	106.70	107.83	113.35	116.58

Table 8: The predicted rain-induced attenuation at 55^0 elevation angle for vertical polarisation

Frequency (GHz)	Damaturu	Bauchi	Maiduguri	Abeokuta	Ibadan	Ikeja
11.00	09.59	10.26	10.59	10.61	11.26	11.56
14.00	16.38	17.42	18.03	18.09	19.11	19.64
20.00	31.71	33.64	34.90	35.12	37.05	38.10
40.00	92.65	97.51	101.68	102.80	108.01	111.10

From Table 6, the Northeastern region recorded rain-induced attenuation values computed for horizontal polarisation that ranged between 10.94 dB and 12.09 dB at 11 GHz downlink frequency, while values ranged between 18.60 dB and 20.52 dB at 14 GHz uplink frequency. The attenuation values varied from 12.09 dB to 13.19 dB at 11 GHz downlink frequency, while values varied from 20.53 dB to 22.34 dB at 14 GHz uplink frequency for the Southwestern region at 0.01% time exceedance at Ku band. Rain-induced attenuation for horizontal polarisation, values varied from 37.05 dB to 40.37 dB at 20 GHz downlink frequency, while values varied from 101.77 dB to 111.76 dB at 40 GHz uplink frequency for the Northeastern region. The Southwestern region recorded rain-induced attenuation values ranged between 41.03 dB and 44.63 dB at 20 GHz downlink frequency, while values ranged between 112.89 dB and 122.11 dB at 40 GHz uplink frequency at 0.01% time exceedance of Ka band.

Table 7 shows that the Northeastern region recorded attenuation values for circular polarisation that ranged between 10.26 dB and 11.33 dB at 11 GHz downlink frequency, while values ranged between 17.40 dB and 19.17 dB at 14 GHz uplink frequency. For the Southwestern region attenuation values varied from 11.34 dB to 12.37 dB for 11 GHz downlink frequency, while values varied from 19.21 dB to 20.88 dB at 14 GHz uplink frequency at Ku-band. For the Ka band, the Northeastern region recorded attenuation values for ranged between 34.23 dB and 37.72 dB at 20 GHz downlink frequency, while values ranged between 97.19 dB and 106.70 dB at 40 GHz uplink frequency. The Southwestern region recorded attenuation values ranged between 37.91 dB and 41.18 dB at 20 GHz downlink frequency, while values ranged between 107.83 dB and 116.58 dB at 40 GHz uplink frequency at 0.01% time exceedance.

The results from Table 8 indicates that values of rain-induced attenuation for vertical polarisation varied from 09.59 dB to 10.59 dB at 11 GHz downlink frequency, while values varied from 16.38 dB to 18.03 dB at 14 GHz uplink frequency for the Northeastern region. The Southwestern region recorded attenuation values in the range of 10.61 dB and 11.56 dB at 11 GHz downlink frequency, while values ranged between 18.09 dB and 19.64 dB at 14 GHz uplink frequency at 0.01% time exceedance at Ku band. The Northeastern region recorded rain-induced attenuation values for circular polarisation that ranged between 31.71 dB and 34.90 dB at 20 GHz downlink frequency, while values ranged between 92.65 dB and 101.68 dB at 40 GHz uplink frequency. For the Southwestern region recorded attenuation values that varied from 35.12 dB to 38.10 dB at 20 GHz downlink frequency, while values varied from 102.80 dB to 111.10 dB at 40 GHz uplink frequency at Ka-band.

4. Conclusion

The statistics of rainfall attenuation for earth-space communication links at Ku-and Ka-bands have been investigated based on local input data. Rain-induced attenuation values were computed for 0.001%–10% time exceedance using ITU-R P.618-12 rain-induced attenuation model for locations studied. The results revealed that, for the rain-induced attenuation predicted for 0.01 percentage of time exceedance, availability of signal is possible at 42.5° and 55° elevation angle but impossible at 23° elevation angle at Ku-band.
For Ka-band, the predicted rain-induced attenuation values for 0.01 percentages of time exceedance

have shown that availability of signal is impossible at all three elevation angles. This implies total signal fade out during such rainfall events in the regions.

As observed from the computed rain-induced attenuation, the horizontal polarisation had highest amount of rain-induced attenuation followed by the circular polarisation, while the vertical polarisation had the least amount of rain-induced attenuation at all the operational frequencies of Ku- and Ka-bands and elevation angles. The Northeastern States showed a moderate rain-induced attenuation prediction due to low amount of rainfall intensity in the region. It implies that satellite communication signals will experience more rain-induced attenuation in the Southwestern region than the Northeastern region.

From the results obtained, it shows that increase in frequency leads to corresponding increase in attenuation, attenuation is also a function of frequency.

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