Rain Fade Analysis at C, Ka and Ku Bands in Nigeria

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Abstract
Rain fade has continued to be a major concern to communication systems designers. The effect of these dynamic fluctuations of the received signal due to rain is very pronounced in the tropical region. This paper pertains to the analysis of rain fades at C, Ku and Ka bands at some selected stations covering the main geographical zones of Nigeria. The ITU-RP propagation model was used to calculate the fade depth at 6 GHz, 8 GHz, 12 GHz, 16 GHz, 20 GHz, 30 GHz and 40 GHz. The rain fade correlate with signal attenuation. Attenuation distributions for percentages of time for signal unavailability were also estimated. The results show that values of attenuation for vertically and circularly polarized signals are less than those of the horizontal polarization at all the frequencies. It is found that rain fade is less severe in the Northern part of the country and is most severe in the southern part of Nigeria, with Port Harcourt, Lagos and Nsukka experiencing the highest rain impairment.
Key words: Propagation, rain rate, attenuation, rain fade, communication links
DOI: 10.7176/JEES/9-3-16
Publication date:March 31st 2019

1. Introduction

Telecommunication systems are continuing to move to higher frequencies due to the congestion at the lower frequency bands. However, rain attenuation and the associated rain fade have continued to pose serious challenges to communication at microwave frequencies. In the design of telecommunication systems, the dynamic characteristics of fading due to atmospheric effects are essential in order to optimize system capacity and meet quality and reliability of signal reception (Shoewu and Edeko 2011).

Rain fade is majorly caused by signals attenuated as a result of scattering and absorption when a radio wave encounters a rain droplet. A non-uniform transmission medium (the raindrops in the atmosphere) causes energy to be absorbed or dispersed from its initial travel direction thereby leading to outages.

Several efforts have been made by many researchers to estimate the level of degradation of terrestrial and satellite signals by rain in Nigeria based on ITU models (Malinga, Owolawi, and Afullo 2013), (Alao 2013). However, most of the investigations are based on the cumulative distribution of rain –induced attenuation while very limited investigations have focused on fade dynamics of rain attenuation statistics.

Ojo and Ajewole, worked on dimensional statistics of rainfall signature and fade duration for microwave propagation (Ojo, and Ajewole 2011). Among other researchers who have also reported their findings are Lee, et al [8]. Their findings have been very useful for communication planning and system design as they suggested various ways of overcoming the rain fade in their research on understanding rain dynamics and feasible countermeasures against rain fading in Singapore. They got conflicting results which potentially suggest that the available rain models might not provide an accurate prediction of rain attenuation for tropical areas; thereby suggesting fade mitigation techniques.

Omotosho investigated the effect of propagation impairments such as rain, cloud, gases and tropospheric scintillation on fixed satellite communication link on earth-space path for frequencies between 10 and 50 GHz at Ku, Ka and V bands in Nigeria. He concludes that tropospheric scintillation is very high in the SS region [Omotosho 2008).

More recent research efforts have focused on determining attenuation statistics at higher percentages of time, say 10 percent to 0.1 percent, since these correspond to the reliabilities and the 1 to 3 dB fade margins that very small aperture terminal (VSAT) systems and other low margin the services provide (Adetan 2014).

Radar measurements have shown that typical dimensions of strong rain rate cells range from 2 to 5 km (Adimula,

Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) DOI: 10.7176/JEES
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Falaiye and Willoughby 2005). The height of the rain cell (rain height) is an important parameter in the calculation of slant path attenuation. It is generally considered that the rain system reaches a maximum height equal to the 0^0 C isotherm, above this precipitation it is assumed to have the form of ice, snow, or melting snow (ITU-R 2008).

However, E. O. Ogunti (Ogunti 2016) studied the effect of rain fade in satellite communication in his paper: Making Sense from knowledge Management Concept where he Suggested the use of questionnaire for collection of data, to be carried out by meeting with consumers of this the particular service to ask them the questions that would be needed to proffer solution to this rain fade problem.

This paper has however been able to establish the depth of rain fades, the percentages of availabilities and the effect on communication links in the major geographical zones of Nigeria. It has also shown correlation with the work of some researchers in Nigeria, establishing the fact that the Northern part of the country is more prone to rain fades.

2. Materials and methodology

This project involves analysis of rain fades recorded on the Tropospheric Data Acquisition Network (TRODAN) stations that are located in Mowe, Lagos, Port Harcourt, Minna, Nsukka, Akure, Yola, and Ayingba. (see figure 1)

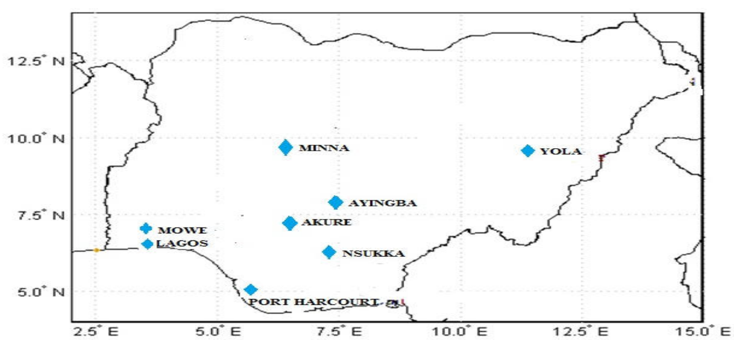


Figure 1.1: Map of Nigeria showing study areas

Table1: The characteristics of locations under study

STATIONS	LATITUDE (^{0}N)	RAIN RATE ($R_{0.01}$)	ELEVATION ANGLE (θ)	HEIGHT ABOVE SEA LEVEL (mm)	AVERAGE ANNUAL RAINFALL (MM/YEAR)	OBSERVATION PERIOD
MOWE	6.8184	74.83	50.5	19.00	430.5	12 months (Jan. 2011- Dec. 2011)
LAGOS	6.5200	110.7246	51.5	10.75	1626.2	12 months (Oct.2007- Nov. 2008
PORT HARCOURT	4.8156	123.47	55.9	7.52	2346.1	12 months (Jan. 2009 – Dec. 2009)
NSUKKA	6.8429	106.51676	56.1	414.40	1427.15	2 years (Jan. 2008- Dec. 2009)
MINNA	9.5836	90.14530	54.2	273.3	814.328	12 months (Jan. 2010 – Dec. 2010)
AKURE	7.3106	107.77	50.4	367.03	1485.6	16 months (Jun. 2010 – Sept. 2010)
YOLA	9.0766	94.32.69	60.7	282.63	948.5	14 months (Nov. 2009– Dec. 2010)
AYINGBA	7.4934	70.1077	55.5	377.42	349.6	12 months (July 2010 – July 2011)

Figure 2: The TRODAN station at Redeemer's University campus at the Redemption Camp, Mowe, Ogun state.

3. Results and Discussion

3.1 Rainfade Calculation

Rain fades vary with frequency, location, polarization and rainfall rate. The depth of fade in decibel (dB) can be calculated from:

$$L_R = \gamma_R D_{Rain} \ldots\ldots$$

L_{RAIN} is the rain loss in dB

γ_R is the specific attenuation (dB/km)

D_{RAIN} is the path length through the troposphere in km,

3.2 Determining the D_{RAIN}

D_{RAIN} is effectively the slant range of the portion of the signal that lies below the freezing point (0 ^{0}C isotherm) in the atmosphere. The assumption is that all rain originates at this level

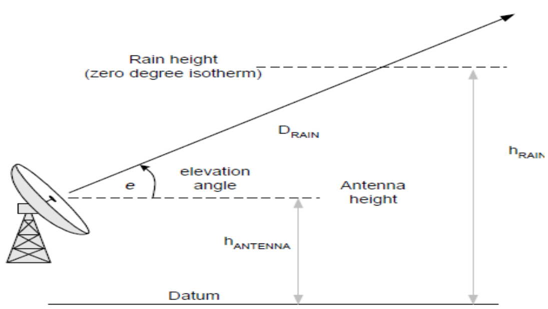


Figure 3: A schematic diagram of earth-space showing the slant range of the portion of the signal that lies below the freezing point (ITU-R 2003).

D_{Rain} can be calculated from simple trigonometry from the above diagram.

$$D_{Rain} = \frac{(h_{rain} - h_{Antenna})}{\sin(e)} \ldots\ldots$$

3.3 Rain Rate Model used

The rain rate model used in this research work is Moupfouma model. Rain rate models are used to predict the point rainfall-rate cumulative distribution of any location.

Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) DOI: 10.7176/JEES
Vol.9, No.3, 2019

Several studies have shown that the Moupfouma model with refined parameters can best describe the one minute rain rate distribution in tropical regions (Khandaker, and Mohammad 2014). Moupfouma found that the one minute rain rate CD could be expressed as:

$$p(R \geq r) = 10\left(\frac{R_{0.01}+1}{r+1}\right)^{b}\exp(u[R_{0.01} - r])$$

where r (mm/h) represents the rain rate exceeded for a fraction of the time, and b is approximated by the following expressions

$$b = \left(\frac{r - R_{0.01}}{R_{0.01}}\right)\ln\left(1 + \frac{r}{R_{0.01}}\right)$$

Data collected at the eight TRODAN stations in Nigeria as presented in Table 2 were processed and analyzed. The rain rate distribution of the stations showing the average monthly rainfall accumulations during the observation period is as shown in Figure 4.1

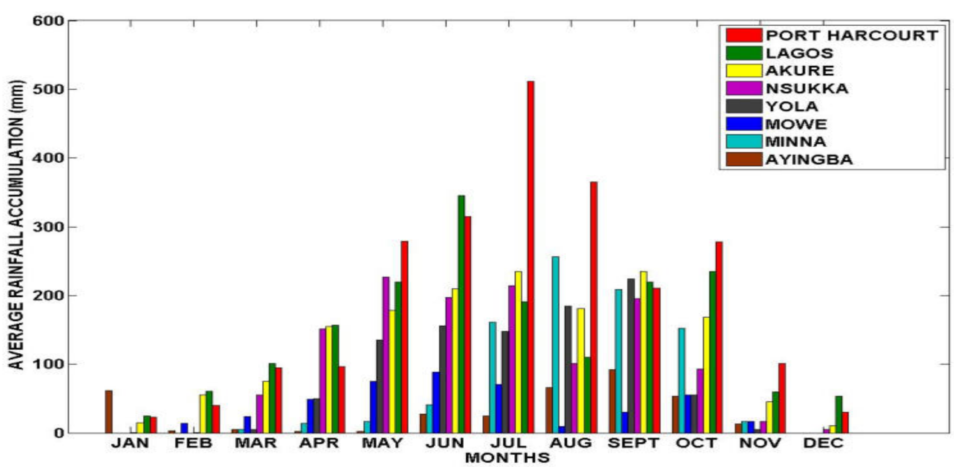


Figure 4: The average monthly rainfall accumulations during the observation period

From the monthly rainfall distribution at the locations shown in Figure 4.1, it is seen that both Port Harcourt and Lagos recorded their peak average monthly rainfall accumulation in the month of July and June with 511 and 345 mm respectively, this is due to the fact that both locations are in the coastal region which leads to leads to increased rainfall, both in amounts and intensity. Rainfall at Redemption Camp (Mowe), Akure and Nssuka attained their peaks in June, September and June with 88, 234 and197mm respectively while the Northern part of the country comprising of Yola and Minna recorded their peak in September and August with 224 and 256mm respectively.

3.4. Rain Rates

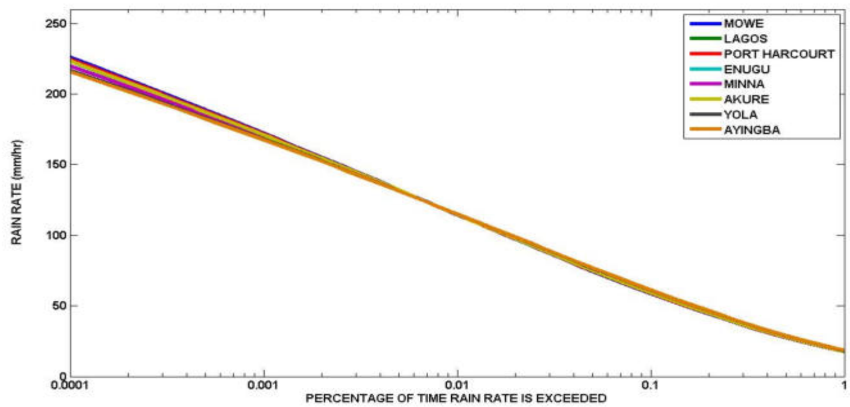
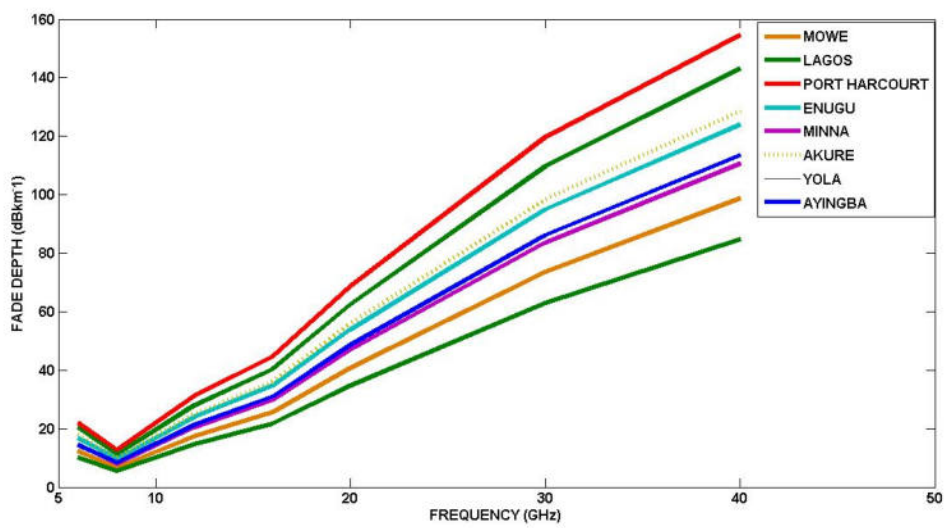


Figure 5: Combined rain rate for the eight TRODAN stations at percentages of exceedance.

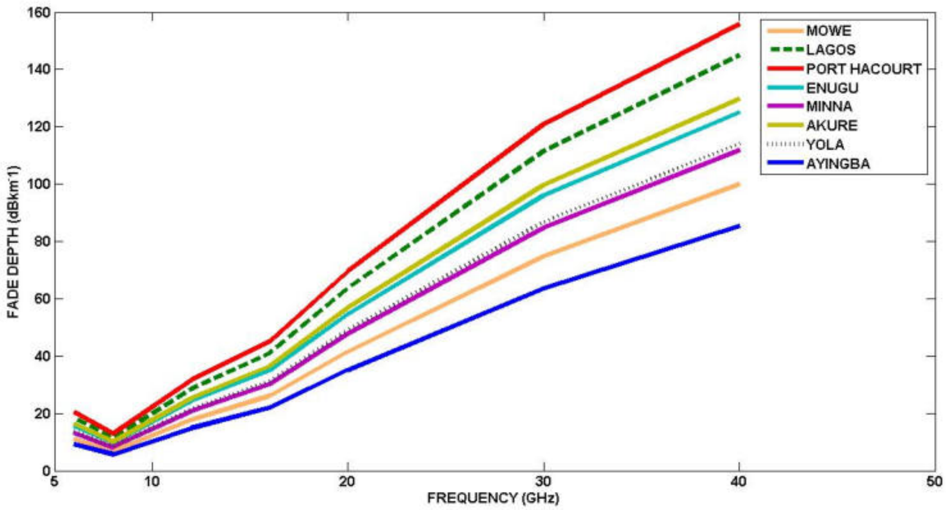
The average cumulative distributions of rain rate over the observation period for the eight locations in Nigeria as derived using Moupfouma model are shown in Figure 5. The rain rates were plotted for other percentage of time 0.001% to 0.01%, 0.1% and 1% of an average year. These results also suggest that there will be total fade out of signals at 0.01% unavailability at Ku and Ka band for all elevation angles in all the 8-stations during rainfall. It means for 99.99% (about 53 minutes outage in a year).

3.5 Rain Fade Depth

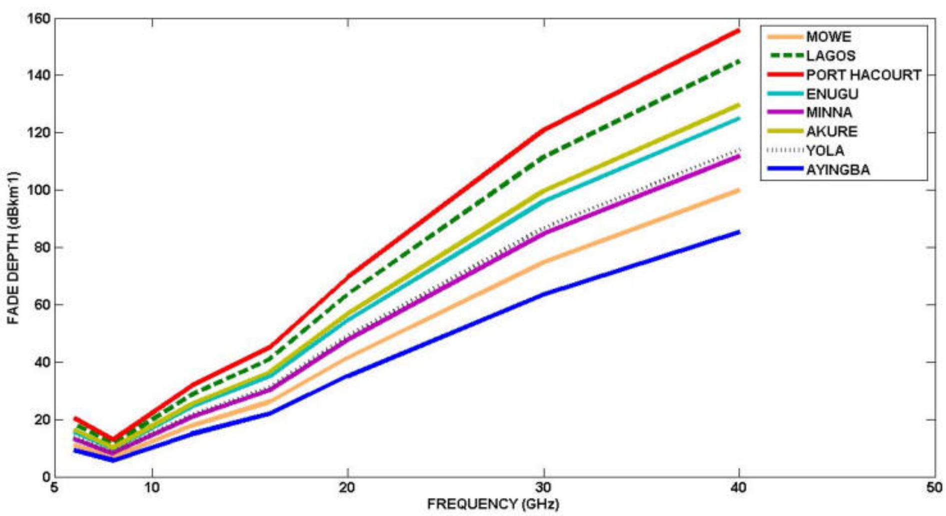
Following the approach presented in the rain fade calculation (op cit), in order to determine the depth of fade (L_{Rain}), the specific attenuation (γ_R) (dB/km) and the path length (D_{Rain}) through the troposphere in km were calculated for C, Ku, and Ka bands in vertical, Horizontal and circular polarization for all location. They are as presented in figure 6.



(a)



(b)



(c)

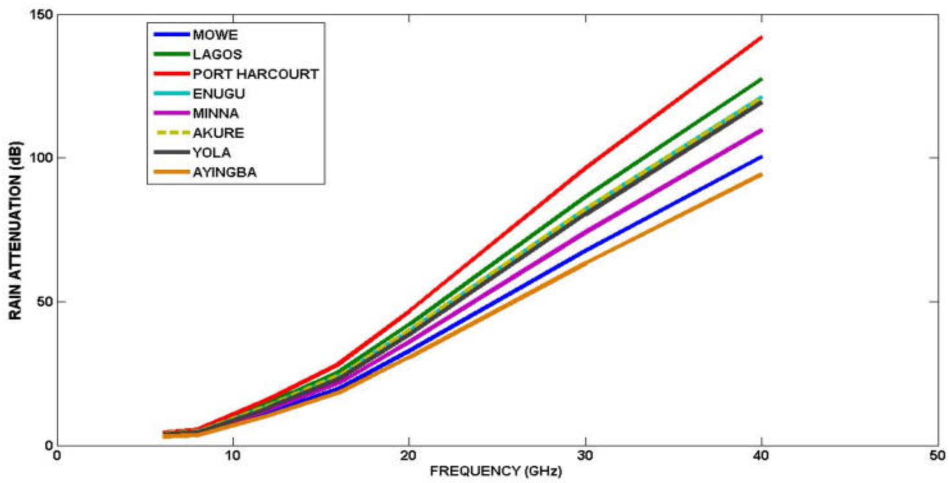
Figure 6: Fade depth of all location for (a) vertical polarization (b) horizontal polarization (c) circular polarization.

Fade depth is the reduction of signal strength from the normal received level, measured in dB. Figure 4 shows the various fade depths of each of the stations from frequencies ranging from the C- band to Ka –band. It indicates the effect of polarization on communication links in Nigeria since this is a consideration for antennal polarity needed by system designers. The results show that the fade depth is most severe in Port Harcourt, followed in descending order, by Lagos, Akure, Yola, Nsukka ,Minna and Ayingba. Port Harcourt has the highest rain rate and was seen to have the highest fade depth. It can be seen from all the polarizations that Ayingba station that has the lowest rain rate will experience least fade for the same frequencies as other stations. It can also be seen graphically that the higher the frequency, the higher the signal fade that will be experienced on communication link.

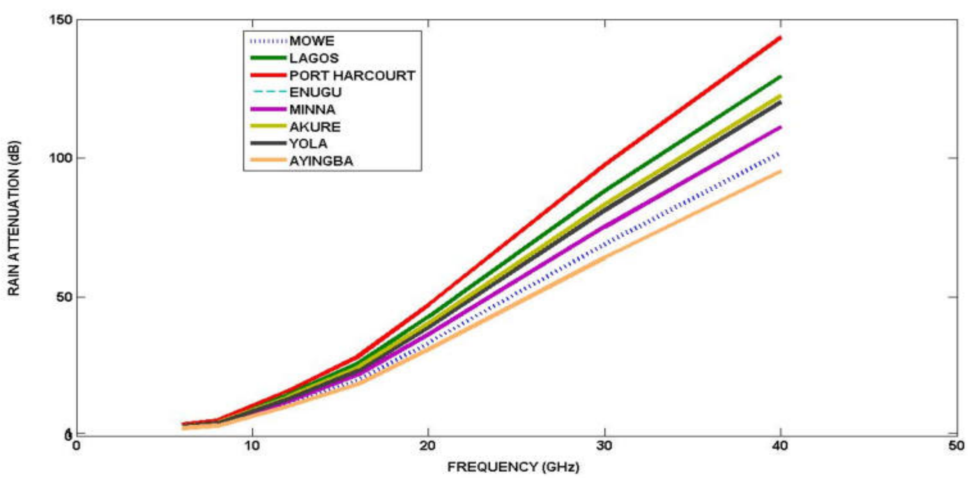
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) DOI: 10.7176/JEES
Vol.9, No.3, 2019

3.6 Attenuation

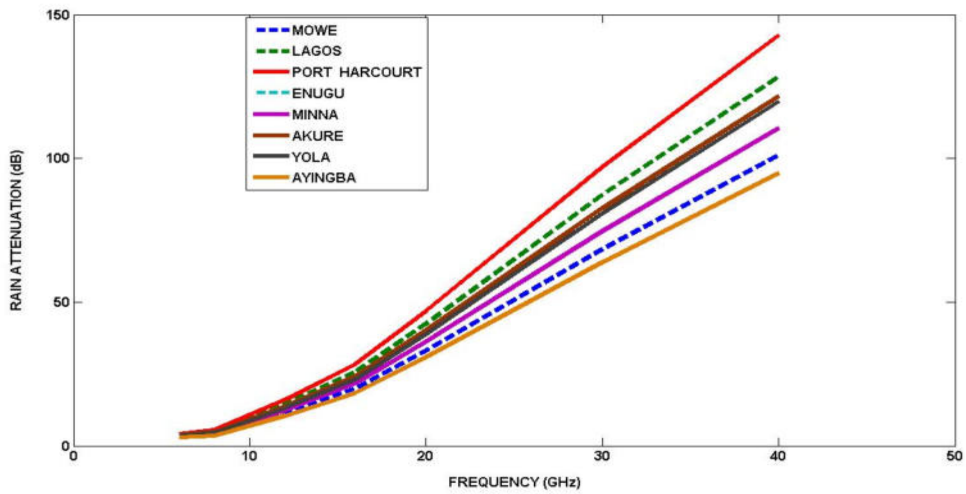
The ITU's long-term rain attenuation statistics have been analyzed to determine the amount of rain fading for 0.01% unavailability at different frequencies ranging from C-band up to Ka-band for circular, horizontal, and vertical polarizations.



(a)



(b)



(c)

Figure 7: Attenuation at 0.01% exceedance for all regions for (a) vertical polarization, (b) horizontal polarization, and (c) circular polarization.

Rain attenuation on earth-space path and the effective path length have been calculated for frequencies 6 -40 GHz for rain rates exceeded for 0.01% of time as shown Table 4.3 and the graphs are plotted in Figure 4.7. The result of this study shows that the rain attenuations for vertically and circularly polarized signal are less than that of the horizontal polarization at all the frequencies and elevation angles investigated. It is also observed that rain attenuation is less severe in the Northern part but is more severe in the southern part of Nigeria, with Port Hacourt, Lagos and Nssuka having the highest rain impairment. The results also suggest that there will be total fade out of signals at 0.01% unavailability at Ku and Ka band for all elevation angles in all the 8-stations during rainfall.

5. Conclusion

This work has provided information on features of rain fades in Nigeria. It is found that June, July, August, September and October are months of heavy and intense rain in Nigeria. The probabilities of the fade occurrence for these months are high.

It can be concluded that as frequency increase from C band to Ka-band, the attenuation increases, and so also the depth of signal fade.

Considering all the locations under study, Ayingba and Yola require lower fade margin for satellite link design purposes at all frequencies and percentage availabilities. On the other hand, Port Harcourt and Lagos requires the highest fade margin at all frequencies and percentage availabilities.

It is recommended that when communication satellites are being produced for areas with high rain fall rate, the satellite engineers should put into consideration the differences in degree of attenuation values from one location to another because these values represent an uncertainty in the design of communication link and this affects service availability and can lead to interruption of communication link performance.

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