

Full Length Research

ANALYSIS OF RAINFALL RATES AND ATTENUATIONS FOR LINE – OF –SIGHT EHF / SHF RADIO COMMUNICATION LINKS OVER MAKURDI, NIGERIA

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This work presents the rain rates at 0.01% ($R_{0.01}$) and rain attenuation at 0.01% ($A_{0.01}$) for Makurdi, Nigeria using five-minutes rain fall data measured by the Nigerian Environmental and Climate Observing Program (NECOP) located at the University of Agriculture Makurdi, and the monthly rain fall data measured by the Nigerian Meteorological Agency (NIMET) station located at the Air force Base , Makurdi. Rain rate prediction models such as the Chebil, Moupfouma and Martins; and the International Telecommunication Union (ITU) prediction models were employed. On the other hand, models used to estimate the rain attenuation on radio frequency (RF) signal (13.5GHz) were the Moupfouma and ITU rain attenuation prediction models . The measured rainfall rates of 99.0mm/h, 125.12mm/h and 99.40mm/h were obtained for NECOP - two years data; Air force Base- two years data and Air force Base-ten years data respectively. The weighted average rainfall rates for all the three sets of data obtained from Chebil's model was 103.0mm/h. Similarly, the average rainfall attenuation for the three sets of data was 76.96dB. Among other things, the results also showed that the Chebil rain rate model gave a better rain rate since it uses the measured rain rate at any integration time. Thus, the Moupfouma attenuation model which uses the Chebil rain rate as input also gave more reliable rainfall attenuation in Makurdi, Nigeria for the period under study.

Key words: ITU model; rainfall rates; rainfall attenuation; Makurdi; NECOP; Line-of-sight, EHF / SHF radio communication links

1. INTRODUCTION

Rain in propagation paths causes serious degradation of the performance in millimeter wave telecommunication systems (Kenneth, 1990), particularly to radio signals above 10GHz along both terrestrial and satellite paths (Tattleman and Scharr, 1993; Ajayi *et al.*, 1993; Ojo *et al.*, 2008a). Nigeria is characterized by high frequency of rain occurrence and increased presence of large rain drops in the rainy season; and the severity of rain impairments increases with frequency and varies with regional locations (Choi *et al.*, 1999).

Line-of-sight is the direct free space that exists between two points in a communication link. This involves point-to-point radio systems which are usually set up on a

permanent basis to provide communication links between two or more fixed locations. Radio propagation waves are electromagnetic waves and as the frequency of transmission increases from very low frequency (VHF) to extremely high frequency (EHF), the characteristics of the propagation through the atmosphere change significantly. As the frequency of the system increases the amount of information that can be transmitted over the system increases. The range of frequency used for line-of-sight system is from 1GHz to the current limits of band at about 50GHz (Encyclopedia of line – of – sight propagation, 2011).

In Nigeria, NIGCOM1 satellite, satellite television stations like DStv, Hitv and MyTv Africa all operate under Ku band which is included in super high frequency (SHF) range.

Thus it is important to know the rain induced attenuation in different areas. This knowledge will help satellite engineers and scientists to improve on the quality of communication systems they produce.

This work therefore, examines the analyses of rainfall rates and attenuations for line – of –sight EHF / SHF radio communication links over Makurdi – Nigeria. This work hopes to provide information on the application of rain rate and rain attenuation models especially in contributing some useful ideas in producing better communication systems, which may also help in remote sensing and agricultural research in the area.

In the design of Earth to space link for communication systems, several factors like absorption in atmospheric gases, scattering and depolarization by hydrometers like clouds and precipitation (rain) must be considered because they are the main causes of signal impairment for both terrestrial and Earth to space satellite systems, rainfall being the most crucial especially at frequencies above 10GHz, (Freeman, 2007). The effect of rainfall is observed to be more severe in tropical regions which are characterized by heavy rain intensity and the presence of large rain drops (Ojo *et al.*, 2008a; Moupfouma and Martin, 1995).

Rainfall of high intensity is difficult to be recorded and measured experimentally, as well as being variable from year to year. However, in systems design, it is the highest rainfall rates that are of great interest. In addition, short integration time rainfall is the most essential input parameter in the prediction models for rain attenuation (Salonen and Poiaras-Baptista, 1997). However, hourly rainfall rate data in some countries are easily obtained compared to short integration time data like one-minute, five-minutes and ten-minutes. Therefore, methods for conversion of one-hour, five-minutes and ten-minutes integration rain data to one-minute data were developed by Emiliani *et al.*, (2008) ; Segal (1986) ; Burgueno *et al.*, (1988) and Chebil and Rahman (1999). The conversion technique has been developed based on the ITU-RP 530-2 and ITU-RP 618-9 together with the revised Moupfouma model for satellite and terrestrial rain attenuation predictions respectively.

1.1 RAIN RATE PREDICTION MODELS.

Rain rate models are used to predict the point rainfall-rate cumulative distribution of any location. Several of such models exist. However, some of them have one discrepancy or the other, such as the number of stations and data available and not all the stations satisfy the one-minute integration time requirement (Crane, 1982); some require a relatively high density of short integration time (Stutzmann and Dishman, 1982).

Rice and Holmberg (1973) developed a model for obtaining rain rate values for use in fading calculations. The model requires parameters like highest monthly rainfall accumulation observed in a set of 30-year period, number of thunderstorm days expected in an average year and the average annual accumulation. The thunderstorm ratio is not readily available from local weather agencies; however, this model overestimates rain rates in the high availability range of 0.01% and underestimates rain rates in the low availability range of 0.1% and 1% (Ryde, 1946).

However, Chebil and Rahman (1999) proposed a model which is used to convert the rain amount data of any location to its equivalent rain rate data irrespective of the integration time of the available rain data. It uses a long-time mean annual accumulation, M, of rain collected for the location under study and it is expressed by (Chebil and Rahman 1999) as:

$$R_{0.01} = \alpha M^\beta \quad (1)$$

Where α and β are regression coefficients and are defined as;

$$\alpha = 12.2903; \text{ and } \beta = 0.2973,$$

M is the total rain fall measured for a year and rain rate ($R_{0.01}$) is measured in mm/h.

Recent analysis suggests that the rain rate distribution is better described by a model which approximates a log-normal distribution at low rate and a gamma distribution at high rate. The model was developed by Moupfouma and Martin (1995). This model known as the Moupfouma and Martin's rain rate model is good for both tropical and temperate regions. It is expressed by (Moupfouma, 2009) as:

$$P(R \geq r) = 10^4 \left(\frac{R_{0.01}}{r+1} \right)^b \text{EXP}(\mu(R_{0.01}-r)) \quad (2a)$$

where P is the probability of a rain event at 0.01% of the time, r (mm/h) represents the rain rate exceeded for a fraction of the time, $R_{0.01}$ (mm/h) is the rain intensity exceeded during 0.01% of time in an average year and b is approximated by the following expression (Moupfouma, 2009):

$$b = \left(\frac{r-R_{0.01}}{R_{0.01}} \right) \ln \left(1 + \frac{r}{R_{0.01}} \right) \quad (2b)$$

The slope of the rain cumulative distribution is governed by the parameter μ , which depends on the local climate conditions and geographic features. For tropical and subtropical regions,

$$\mu = \frac{4 \ln 10}{R_{0.01}} \exp\left(-\lambda \left[\frac{r}{R_{0.01}}\right]^\gamma\right) \quad (2c)$$

λ and γ are positive constants and are given as $\lambda = 1.066$, $\gamma = 0.214$ and $R_{0.01}$ is the rain rate exceeded for 0.01% of time and is obtained using Chebil and Rahman (1999) model. Thus the refined Moupfouma model can be used to determine the one-minute rain rate cumulative distribution from the long term mean annual rainfall rate.

The third known rain rate prediction model is the ITU recommended model, which depends on the Salonen-Baptista model (Salonen and Poiaras-Baptiste, 1997). It is used to calculate the rain rate of a given location based on its geographic coordinates. ITU Recommendations by P1144-3 and P837-4 are combined to obtain rain rate $R_{0.01}$ (mm/h). The ITU-P 837-4 model requires as input the following parameters:

M_S , defined as the mean annual strait form rainfall amount (mm)

M_C , the mean annual convective rainfall amount (mm) and

P_{r6} , the probability of a given rainy period (%).

ITU has the parameters given above mapped out all over the world using 15 years of re-analysis products of the

European center for medium range weather forecasts (ECMWF ERA 15 data set). To obtain rain rate using ITU model, the following steps are adopted:

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STEP 1

The variables $Pr6$, M_s and M_c are extracted for the four points closest in latitude (Lat.) and longitude (Lon.) to the geographical coordinates of the location under study.

STEP 2

From the values of P_{r6} , M_C and M_S at the four grid points, the values P_{r6} (Lat, Lon), M_C (Lat., Lon) and M_S (Lat., Lon) are obtained by performing bi-linear interpolation

Given values at four surrounding grid point: $I(R, C)$; $I(R, C+1)$; $I(R+1, C)$ and $I(R+1, C+1)$, $I(r, c)$ can be obtained when r is a fractional row number and c is a fractional column number using bi-polar interpolation as ((ITU- R, 2009)):

$$I(r, c) = I(R, C)[(R+1-r)(C+1-c)] + I(R+1, C)[(r-R)(C+1-c)] + I(R, C+1)[(R+1-r)(c-C)] + I(R+1, C+1)[(r-R)(c-C)] \quad (3)$$

Where R, C, r, c are values at four surrounding grid points of the location under study.

STEP 3

The percentages of probability (P_0) of rain in an average year are obtained from (ITU, 2001)

$$P_0(lat, lon) = P_{R6}(lat, lon) \left[1 - \exp^{-0.0117 \left(\frac{M_S(lat, lon)}{P_{R6}(lat, lon)} \right)} \right] \quad (4)$$

STEP 4

The rainfall rate R_p exceeded for P (%) of the average year for $P < P_0$ are then derived as

$$R_p(lat, lon) = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (mm/h) \quad (5a)$$

Where

$$A = ab \quad (5b)$$

$$B = a + c \ln \left[\frac{P(lat, lon)}{P_0(lat, lon)} \right] \quad (5c)$$

$$C = \ln \left[\frac{P(\text{in dB})}{P_0(\text{in dB})} \right] \quad (5d)$$

$$a = 1.11 \quad (5e)$$

$$b = \frac{[M_0(\text{in dB}) + (M_0(\text{in dB})/I)]}{22932 P_0} \quad (5f)$$

$$c = 31.5b \quad (5g)$$

1.2 Rain Attenuation Prediction Models.

Attenuation prediction requires the estimation of surface rain rate distribution. Rain attenuation prediction models are used to determine the attenuation caused by rain for 0.01% of time for point rainfall-rate at 0.01% of time. Several researchers proposed different models for calculation of attenuation along a path. However, in this work the Moupfouma and the International Telecommunication Rain Attenuation models are considered

1.2.1 Moupfouma model for rain Attenuation

To obtain the probability that will be exceeded at 0.01% of the time and the probability that the rain attenuation will be exceeded on the propagation path during a rain event, the specific attenuation is first determined using Moupfouma theoretical relationship.

Using vertically polarized waves (Moupfouma, 2009),

$$\eta_V = -15.6 + \frac{94.1}{\lambda} \quad (6a)$$

$$\lambda = \frac{3 \times 10^8}{f(\text{GHz}) \times 10^9} \times 100 \quad (6b)$$

The specific attenuation for vertically polarized waves is given as:

$$Y_V = 8.686 \times 10^5 \times \lambda \eta_{VN0} \times \frac{f(Z)}{\Lambda(R_p)^2} \quad (6c)$$

$$N_0 = 0.16 \Lambda(R_p = 82 R_p^{-0.21}) \quad (6d)$$

$$Z = \left(4.88 - \frac{f}{f_0} \right) + 1 \quad (6e)$$

f_0 is a constant frequency given as 20GHz; f is the actual frequency of the link; η_V is the vertically polarized waves; λ is the wavelength; $\Lambda(R_p)$ is the attenuation at p % of time.

During rain events, convective cells often alternate with strait form cells and rain cell height varies. Because of this non uniformity of rain cell structure, the rain intensity cannot be uniformly distributed over a given radio propagation path (Moupfouma, 2009). It is then appropriate for the prediction of rain fades to define and make use of an equivalent propagation path of which the rain structure is assumed to be uniform instead of using the actual relay path length. A terrestrial microwave is characterized by its actual relay path length "L" that corresponds to the space between two ground stations. To determine its equivalent propagation path length " L_{eq} ", an adjustment factor "δ" which makes the rain to be uniform on the whole propagation path is defined as (Moupfouma, 2009):

$$L_{eq} = \delta * L \quad (7a)$$

Provided $R_{0.01}$ (mm/h) is known, then

$$\delta(R_{0.01}, L) = \exp\left(\frac{-R_{0.01}}{1 + \zeta(L) * R_{0.01}}\right) \quad (7b)$$

$\zeta(L)$ is a factor that governs the actual path of the terrestrial link during rain fall. The rain structure is assumed to be uniform.

Then using equation (7a-b), the equivalent propagation path " L_{eq} " for terrestrial microwave radio links becomes:

$$L_{eq}(R_{0.01}, L) = L * \exp\left(\frac{-R_{0.01}}{1 + \zeta(L) * R_{0.01}}\right) \quad (8)$$

The equivalent path behavior is governed by two main parameters; the actual path length of the terrestrial link and the rain rate observed for 0.01% of time of that link. An analysis of equation (8) shows that whenever it stops raining on the terrestrial radio link the equivalent propagation path becomes equal to the actual terrestrial radio link path.

It can be shown that whatever the frequency and rain rate $R_{0.01}$, $\zeta(L)$ can be modeled such that for any line-of-sight path length such as $L=7\text{Km}$, $\zeta(L)$ remains constant and is described as (Moupfouma, 2009):

$$\zeta(L) = -100 \quad (9)$$

But for any terrestrial path length longer than 7Km, $\zeta(L)$ is governed by the actual path length "L" of the link and can be modeled as:

$$\zeta(L) = \left(\frac{44.2}{L}\right)^{0.78} \quad (10)$$

The induced attenuation that will be exceeded at 0.01% of time is thus given as (Moupfouma, 2009):

$$A_{0.01}(dB) = K_v * L_{\text{eq}} \quad (11)$$

$P(A \geq a)$ is the probability that the rain attenuation (dB) will be exceeded on the propagation path during a rain event. Assuming that attenuation A (dB) and a (dB) are

$$P(A \geq a) = \left(\frac{A_p+1}{a+1}\right)^{\phi(a)} \exp[\Lambda(a) * (A_p - a) + \text{Log}(P(A_p))] \quad (13a)$$

Where $P(A \geq a)$ is the probability that the rain attenuation will be exceeded during a rain event, $P(A_p)$ represents the fraction of time of an average year exceeded for rain attenuation value $a = A_p$ and

$$\phi(a) = \left(\frac{a-A_p}{A_p}\right) \ln\left(1 + \frac{a}{A_p}\right) \quad (13b)$$

From 13b,

$$\lim_{a \rightarrow 0} \phi(a) = 0 \quad (13c)$$

Equation (13a) may have probability behavior provided the following boundary conditions are achieved:

$$\lim_{a \rightarrow 0} P(A_p \geq a) = 1 \quad (14a)$$

$$\lim_{a \rightarrow \infty} P(A_p \geq a) = 0 \quad (14b)$$

Assuming at this stage that (14a) and (14b) are fulfilled then from (13a), making use of (13c) and (13a) and (13b),

$$\lim_{a \rightarrow 0} P(A \geq a) = \exp[\Lambda(0) * A_p + \log_e\{P(A_p)\}] = 1 \quad (15)$$

This leads to

$$\Lambda(0) * A_p + \log_e\{P(A_p)\} = 0 \quad (16)$$

This means that

$$\lim_{a \rightarrow 0} \Lambda(a) = \Lambda(0) = \frac{-\log_e\{P(A_p)\}}{A_p} \quad (17)$$

$\Lambda(a)$ describes the rain attenuation slope shape and is governed by rain attenuation (A_p) that is a function of radio link frequency, rain structure and propagation path

induced by rain rates R (mm/h) and r (mm/h) respectively such that $P(R \geq r)$ is the probability that rain rate r (mm/h) will be induced on the propagation path of interest, then

$$P(A \geq a) = P(R \geq r) \quad (12)$$

Then the Moupfouma model for the prediction of attenuation due to rain on a terrestrial line-of-sight SHF/EHF radio link can be written as (Moupfouma, 2009):

length. $\Lambda(a)$ may generally be described as (Moupfouma, 2009):

$$\Lambda(a) = \frac{-\log_e\{P(A_p)\}}{A_p} * \eta(a) \quad (18a)$$

$\eta(a)$ is governed by the climate and depends on the integration time and may be defined as (Moupfouma, 2009):

$$\eta(a) = \frac{1}{1 + \zeta \left(\frac{a}{A_p}\right)^{\nu}} ; \zeta > 0; \nu > 0 \quad (18b)$$

From the use of the boundary conditions of equation (14b) we have that

$$\lim_{a \rightarrow 0} \eta(a) = 1 \quad (19a)$$

and

$$\lim_{a \rightarrow \infty} \eta(a) = 0 \quad (19b)$$

Thus on the basis of equations 13c-17; 18a-b it is obvious that from equation 13a that

$$*A_p + \log_e\{P(A_p)\} = \text{EXP}(0) = 1 \quad (20a)$$

and

$$\lim_{a \rightarrow \infty} P(A_p \geq a) = 0 \quad (20b)$$

It then appears from the equations (19a-b) that Moupfouma model for predicting radio microwave signal attenuation in rainy conditions on terrestrial links (13a) has the behavior required for a probability distribution function.

Its cumulative distribution function $F(a)$ may be defined as (Moupfouma, 2009):

$$F(\alpha) = 1 - P(A_p \geq \alpha); F(\alpha) = 0 \text{ for } \alpha \leq 0 \quad (21)$$

With boundary conditions such that;

$$\lim_{\alpha \rightarrow +\infty} F(\alpha) = 0 \text{ and } \lim_{\alpha \rightarrow +\infty} F(\alpha) = 1 \quad (22)$$

$$P(A_{0.01} \geq \alpha) = 100 * \left(\frac{A_{0.01} + 1}{\alpha + 1}\right)^{\phi(\alpha)} \exp\left(-\frac{\log_{10}(10^{-4})}{-\log_{10}(10^{-4})} * \eta_{\alpha} * (A_{0.01} - \alpha)\right) \quad (23)$$

$$P(A_{0.01} \geq \alpha) = 0.01 * \left(\frac{A_{0.01} + 1}{\alpha + 1}\right)^{\phi(\alpha)} * \exp\left(9.21 * \eta_{\alpha} * \left(1 - \frac{\alpha}{A_{0.01}}\right)\right) \quad (24)$$

Where

$$\phi(\alpha) = \left(\frac{\alpha}{A_{0.01}} - 1\right) * \ln\left(1 + \frac{\alpha}{A_{0.01}}\right) \quad (25a)$$

and

$$\eta(\alpha) = \frac{1}{1 + 2.27 * \left(\frac{\alpha}{A_{0.01}}\right)^{0.8}} \quad (25b)$$

Equation (24) can be used to determine the variation of probability with attenuation in order to show the attenuation that will occur due to the rain rate $R_{0.01}$ mm/h at 0.01% of time.

1.2.2 International Telecommunication Rain Attenuation Model

ITU recommendation P838-3 is used to obtain the specific attenuation (the attenuation per unit time) while ITU-P 530-9 is used to obtain the rain attenuation (absorption of microwave radio frequency signal by atmospheric rain) for terrestrial line of sight systems. After rain rate has been obtained the as shown above the following steps are taken to obtain the attenuation of rain rate on radio frequency links.

STEP 1

The specific attenuation, γ_R (dB/Km) for the frequency under investigation are obtained from the rain rate using the power law relationship (Moupfouma, 2005):

$$\gamma_R = k(R_{0.01})^{\alpha} \quad (26)$$

The coefficients k and α are frequency and polarization parameters and are determined as functions of frequency, f (GHz) in the range from 1 to 1000GHz. the

Thus if $A_{0.01}$ (dB) is the rain attenuation induced by rain rate $R_{0.01}$ (mm/h) and exceeded for 0.01% of time, then from equation (13a)-(18a) and (18b), the occurrence due to rain on a given microwave link may be consequently determined through (23) and (24):

values of these coefficients can be obtained from ITU-R P 838-3 recommendation

STEP 2

The effective path length, d_{eff} , of the link is then computed as (ITU, 2001):

$$d_{eff} = d * r \quad (27a)$$

where r (an estimate of the distant factor) is given by,

$$r = \frac{1}{1 + \frac{\alpha}{\alpha_0}} \quad (27b)$$

For $R_{0.01} \leq 100$ mm/h,

$$R_{0.01} \leq 100 \quad (27c)$$

For $R_{0.01} \geq 100$ mm/h, the value 100mm/h is used in place of $R_{0.01}$ (ITU- R, 2009)

STEP 3

An estimate of the path attenuation exceeded for 0.01% of the time is given by ITU (2001)

$$A_{0.01}(dB) = \gamma_R d_{eff} \quad (28)$$

$A_{0.01}$ (dB) is the rain attenuation induced by rain rate $R_{0.01}$ (mm/h) and exceeded for 0.01% of time.

γ_R (dB) Is the specific attenuation and d_r or d_{eff} is the effective path length of the link.

Many researchers have employed these models to estimate the rain rate and rain attenuation coefficients in

many parts of the world. Mandeep *et al.*, (2007) presented a paper on the characteristics of rain distribution in Malaysia based on measured one-minute rain rate data. They used International Telecommunication model (ITU) and the Variable Isotherm Height Technique (VITH) model to determine the rain attenuation and to estimate the effect of rain on Ku band signals. They observed that the ITU model gave a good prediction of the measured rainfall rate while the VITH model overestimated the measured rainfall rate and attenuation.

Karasawa and Matsudo (1991) proposed a method of calculating one-minute rain rate data from Automated Meteorology Data Acquisition System (AMeDAS) one-hour rain data. They estimated the accuracy of the model and confirmed that for 0.1% of time, the mean error was about 1% including the error due to measurement and that by processing AMeDAS one-hour data a geographical distribution of 0.01% one-minute data over Japan was obtained. Thus it is possible to predict one-minute rainfall rate from one-hour rainfall rate with fair accuracy.

Fashuyi *et al.*, (2006) carried out a research on rainfall rate modeling for line-of-sight radio systems in South Africa. They used a five-year rainfall data measured by weather services for 12 different locations to study the effect of integration time on the cumulative distribution of rain rate for South Africa. They used rainfall rate data for one-minute and one-hour integration times of 0.1% or less to confirm the power law relationship between the two integration times. A comparison of the 5-years rain intensities for 12 locations showed the variability of rain statistics from one location to another. They discovered that Richard's bay situated in the coastal area of South Africa has the highest rain intensity of $R_{0.01}$ of 182.66mm/h and Brandulei situated in the desert area of the country had the lowest rain intensity of $R_{0.01}$ of 67.01mm/h.

Mandeep *et al.*, (2006) worked on rainfall rate conversion in Southeast Asia countries using Segal (1986) model, Burgeuno (1988) model, Joo (2002) model, Chebil (1999) model and Moupfouma (2009) model. They discovered that Segal and Chebil's models of rain rate integration time conversion provided the best estimate for the one-minute rainfall rate distribution in Southeast Asia countries.

Moupfouma (2009) proposed a prediction model for terrestrial line-of-sight super high frequency (SHF) radio communication links. He discovered that the previous rain fade prediction models predicted the attenuation related to a given rain rate or else a given percentage of time and that his own model predicts the percentage of

time for which any given rain attenuation will be exceeded provided the rain rate $R_{0.01}$ (mm/h) which represents the rain rate value exceeded for 0.01% of time in the locality of interest is known.

A prediction model that combines rain attenuation and other propagation impairments along the Earth-satellite paths was proposed by Asoka *et al.*, (2002). Their results showed that the method could be used to predict individual impairments as well as their combined effects at frequencies between 4GHz and 35GHz although the best accuracy was found between 10GHz and 30GHz. The method predicted total path attenuation with an overall error of less than 20%. They discovered that the dominant propagation impairment at frequencies above 10GHz is rain.

Mandeep *et al.*, (2006) also carried out a research on earth to space improved model for rain attenuation prediction at Ku bands and discovered that their proposed model performed better than the ITU-R model. However, in Nigeria, Ojo and Ajewole (2008) carried out a research on rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria and developed contour maps for rain rate and rain attenuation for Nigeria. Their result showed that the rain rate $R_{0.01}$ for Port-Harcourt, Warri and Calabar which are located in the coastal region of Nigeria was approximately 130mm/h while it was approximately 65-80mm/h for Maiduguri and Sokoto which are located in the drier region of the country. However, little has been found in literature of such work being carried out in Benue state, Nigeria, hence, the need for this research in this part of the country.

The rain data used for this work were obtained from the Nigeria Environmental and Climate Observing Program (NECOP) situated in the University of Agriculture Makurdi (8.53°E, 7.32°N), and from Makurdi Airport (8°37' E, 7°42' N) in Nigeria. The NECOP rain rate data span from January 2008 – December 2010 for Makurdi. These rain rate data have five minutes integration time. The Makurdi Airport rain rate data span from January 2000 – December 2010).

2. Analyses

In these analyses, the rain rate computations were carried out using Chebil, Moupfouma and ITU P1144-3 and P837-4 rain rate models because these models have been known to give good results for predicting the rain rate for tropical regions while in the rain attenuation computations, the Moupfouma and ITU P838-3 models were employed because they have been known to give good rain attenuation prediction for tropical regions.

2.1 Rain rate Analysis

In this analysis, two years (2008 – 2009) available rain rate data for NECOP were analyzed and two years (2008 – 2009) available rain rate data for air force base radiator were also analyzed. At the end, comparisons were made for the two data sources so as to validate the NECOP data which is relatively a new source of atmospheric data for Makurdi. Finally, the ten years rain rate data from Makurdi air force base using rain gauge were then analyzed so as to visualize rain attenuation of the terrestrial line of sight radio communication links for Makurdi in the decadal year.

2.1.1 Rain Rate Computation Using Chebil's Model

For NECOP, 2222.7mm of rain was measured for 2 years (2008 – 2009), thus for 1 year 1114.85mm of rain (total rain fall, M) were measured.

Hence, using equation (1), the rain rate at 0.01 integration time was obtained as:

$$R_{0.01} = 12.2903(1114.85)^{0.2973} = 98.97\text{mm/h} \quad (29)$$

Similarly, from the rain gauge data for the air force base data (2008 – 2009), 4906mm of rain was measured. Thus, for one year 2453mm of rain (total rain fall, M) was

obtained. And using this value of M in equation (1), the rain rate was computed to be 125.12mm/h.

Finally, for the rain gauge data from air force base, 11311.8mm of rain was measured for ten years (2000 – 2010). Therefore, using the one year (total rain fall, M) of 1131.18mm in equation (1), the rain rate of 99.398mm/h was computed.

2.1.2 Moupfouma and Martins Rain Rate Model

Equations (2a-b and 25) were employed to obtain the rain rate distribution values using NECOP rain data (2008-2009), air force base two years rain data(2008-2009) and air force base ten years data (2000-2010) . The computed rain rate, values were respectively 103, 122 and 100mm/mm. Arbitrary rain rate depicted by "r" were chosen above and below the computed in order to obtain the rain rate coefficients, b and μ according to equation 2a-b.

The results are as shown in Tables 1- 3 respectively, which show the variations of rain rate with the probability of occurrence for Makurdi using Moupfouma rain rate model.

Table 1: Rain Rate Distribution Coefficients with Probability of Occurrence for Makurdi Using Moupfouma Rain Rate Model on NECOP Data.

Rain rate (mm/h)	b	μ	Probability (%)
55.0	-0.19883263	0.0354408	0.047197210
60.0	-0.19067530	0.0348242	0.039344299
75.0	-0.14634945	0.0332411	0.023618401
85.5	-0.09915331	0.0323112	0.016849082
95.0	-0.04606295	0.0315639	0.012498695
110.0	0.05610764	0.0305255	0.007834331
120.0	0.13569069	0.0299104	0.005731191
125.5	0.18310472	0.0295941	0.004819328
130.0	0.22373800	0.0293457	0.004178168
140.0	0.31971733	0.0288238	0.003030647

Table 2: Rain Rate Distribution Coefficients with Probability of Occurrence for Makurdi Using Moupfouma Rain Rate Model on Air Port Base Two Years Data

Rainrate, r (mm/h)	b	μ	Percentage of time (%)
75.0	-0.188127819	0.029879386	0.040704990
85.5	-0.164908841	0.029123022	0.029831551
95.0	-0.135987654	0.02851368	0.022768787
110.0	-0.076231137	0.02766470	0.015055558
120.0	-0.027518143	0.02716050	0.011481367
125.5	0.0021097550	0.02690080	0.009898069
130.0	0.0277877910	0.02669665	0.008767304
140.0	0.0893025100	0.02626728	0.006692968

Table 3: Rain Rate Distribution Coefficients with Probability of Occurrence for Makurdi Using Moupfouma Rain Rate Model on Air Port Base Ten Years Data

Rainrate (mm/h)	b	μ	Percentage of time (%)
60.0	-0.1871927	0.0375607	0.040085074
75.0	-0.1379983	0.0359379	0.023158443
85.5	-0.0867835	0.0349829	0.016066158
95.0	-0.0296794	0.0342144	0.011611866
110.0	0.0794744	0.0331450	0.006975525
120.0	0.1641054	0.0325108	0.004955638
125.5	0.2144175	0.0321843	0.004099286
130.0	0.2574827	0.0319278	0.003505909
140.0	0.3590512	0.0313886	0.002466037

2.1.3 Rain Rate Computation Using ITU 1144-3 and 837-4 models for Makurdi

Makurdi is in latitude 7.32°N and longitude 8.53°E , so that the four closest points extracted from ITU

ESARAIN-xxx-v5TXT data files are as shown in Figure 1.

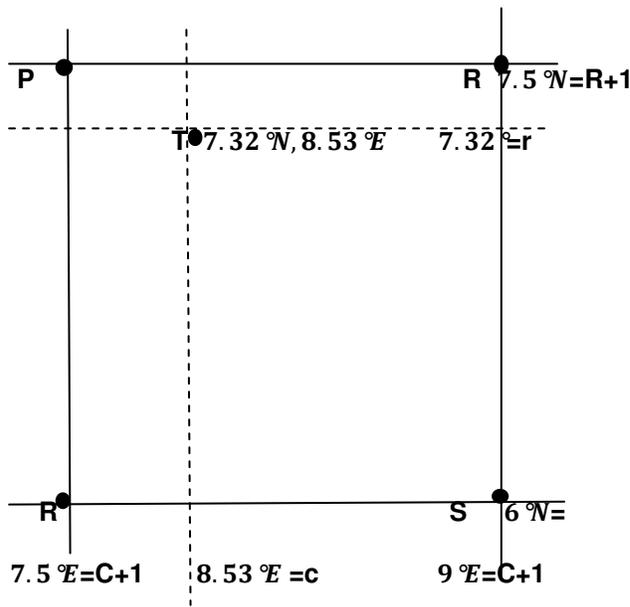


Fig. 1: The position of Makurdi and the four grid points closest to it.

The numerical variables (M_s, M_c and $P_{R\epsilon}$) at the four grid points closest to Makurdi's location as shown in Figure 1 were obtained from ESARAIN- M_s -v5-TXT, ESARAIN- M_c -v5-TXT and ESARAIN- $P_{R\epsilon}$ -v5-TXT respectively as

$$P (M_s, M_c, P_{R\epsilon}) = P(1002.42, 662.97, 42.647); Q(M_s, M_c, P_{R\epsilon}) = Q(1380.09, 1351.04, 62.994)$$

$$R (M_s, M_c, P_{R\epsilon}) = R(1277.10, 1320.66, 54.722); S(M_s, M_c, P_{R\epsilon}) = S(1824.51, 2002.25, 71.303)$$

M_s, M_c and $P_{R\epsilon}$ were obtained using equation (3) as:

$$M_s = 2745.16, M_c = 2692.02 \text{ and } P_{R\epsilon} = 78.96$$

respectively.

From equation (4);

$$P_0 = 26.14\%$$

From equation (5b-f)

$$a = 1.11, b = 8.978 \times 10^{-3}$$

$$c = 0.2972, A = 9.97 \times 10^{-3},$$

$$B = -1.045, \text{ and } C = -7.869$$

The rain rate of Makurdi was thus obtained from equation (5a) as:

$$R_{0.01} = 112.19 \text{ mm/h} \quad (30)$$

2.2 Rain Attenuation Analysis for Makurdi

2.2.1 Rain attenuation using Moupfouma model on NECOP rain rate data for Makurdi

Line-of-sight radio frequencies operate at frequency range from 150MHz – 40GHz within a distance of approximately 200km. Considering a radio link with frequency f 13.5GHz (assumed frequency of a radio wave) and distance $L=70\text{Km}$, the frequency scale when using vertically polarized wave Z and the wavelength, λ were obtained from equation (6e) and (6b) respectively as:

$$Z = 5.205, \lambda = 2.22 \text{ mm} \quad (31)$$

From equation (6a),

$$\eta_v = 26.7874 \text{ dB} \quad (32)$$

On substituting the value of Z into the special function calculator; Γ (gamma approximation) was obtained as:

$$\Gamma = 32.8316 \quad (33)$$

From (6d) the attenuation at 98.97mm/h rainfall rate was obtained as:

$$\Lambda(98.97) = 31.24\text{dB} \quad (34)$$

Equation (6c) was used to obtain the specific attenuation Υ_v as:

$$\Upsilon_v = 4.504\text{dB/km} \quad (35)$$

Also, from (10);

$$\zeta(L) = 0.699 \quad (36)$$

The equivalent path length L_{eq} was obtained from equation (8) as:

$$L_{eq} = 17.09\text{Km} \quad (37)$$

Thus the rain attenuation at 0.01% of time was obtained from equation (11) as:

$$A_{0.01} = 76.97\text{dB} \quad (38)$$

2.2.2. Rain attenuation using Moupfouma model on Air force Base two year rain rate data for Makurdi

Using the same information as in section 1 such as $L=70\text{Km}$ and $f = 13.5\text{GHz}$, which is the frequency scale when using vertical polarized wave Z ; the wavelength, λ and Γ were obtained from equations (31 -33) respectively as:

$$Z = 5.205, \lambda = 2.22\text{Km}, \eta_v = 26.7874, \Gamma = 32.8316$$

On substituting the value of $R_{0.01}$ as earlier computed into equation (6d), the attenuation at 125.12mm/h was obtained as:

$$\Lambda(125.12) = 29.74 \quad (39)$$

Substituting the values of Z, λ, Λ and Γ into equation (6c) the specific attenuation Υ_v is obtained as:

$$\Upsilon_v = 5.818\text{dB/Km} \quad (40)$$

Using the values obtained for $R_{0.01}$, equations (8) and (10) were used to obtain the equivalent path length as:

$$L_{eq} = 17.005\text{Km} \quad (41)$$

Employing equations (40) and (41) in equation (11), the rain attenuation exceeded at 0.01% of time was obtained from equation as:

$$A_{0.01} = 98.94\text{dB/Km}. \quad (42)$$

2.2.3. Rain attenuation using Moupfouma model on Air force Base ten year rain rate data for Makurdi

Using the information as contained in section 2 (i.e, $L=70\text{Km}$ and $f = 13.5\text{GHz}$), the frequency scale when using vertical polarized wave Z , the wavelength, λ and Γ were obtained from equations (6b-e) as:

$$Z = 5.205, \lambda = 2.22\text{mm}, \eta_v = 26.7874, \Gamma = 32.8316$$

On substituting the value of $R_{0.01} = 99.398$ into equation (6d), the attenuation at 99.398mm/h was obtained as:

$$\Lambda(99.398) = 32.215\text{dB} \quad (43)$$

Substituting the values of Z, λ, Λ and Γ into equation (6c) the specific attenuation Υ_v is obtained as:

$$\Upsilon_v = 4.522\text{dB/km} \quad (44)$$

Using the values obtained for $R_{0.01}$, equations (8) and (10) were used to obtain the equivalent path length as:

$$L_{eq} = 16.047\text{Km} \quad (45)$$

Employing equations (44) and (45) in equation (11), the rain attenuation exceeded at 0.01% of time was obtained from equation as:

$$A_{0.01} = 72.563\text{dB/Km}. \quad (46)$$

Equations (24), (25a-b) were run in Microsoft excel to obtain the attenuation distribution for Makurdi (NECOP two years (2008-2009) data), Air force Base (two years data) and air force base (ten years data) for the same time as shown in Tables 4-6 respectively. These values show the relationships between the attenuation of radio frequency signals due to rain and probability of time for Makurdi .

Table 4: Distribution of rain attenuation coefficients with probability of occurrence for Makurdi using Moupfouma model (NECOP data).

Attenuation(dB)	η	ϕ	Percentage of time (%)
40.0	-0.201013511	0.380371456	0.047277756
45.0	-0.191213321	0.358426918	0.035617029
55.0	-0.153895294	0.322406392	0.022180482
60.0	-0.127070220	0.307391234	0.018093957
75.0	-0.017411027	0.270742479	0.010654263
85.5	0.082792935	0.250549940	0.007677236
95.0	0.188312260	0.235057620	0.005790940
110.0	0.380865227	0.214627760	0.003742651
120.0	0.525302378	0.203127356	0.002789499
125.5	0.609809678	0.197385963	0.002366177
130.0	0.681500001	0.192959134	0.002063839
140.0	0.848651708	0.183894373	0.001511172

Table 5: Distribution Of Rain Attenuation Coefficients With Probability of Occurrence for Makurdi Using Moupfouma Model (Air Force Two Year Data).

Attenuation(dB)	η	ϕ	Percentage of time (%)
55.0	-0.1963174	0.3678122	0.040177658
60.0	-0.1865582	0.3517802	0.032642460
75.0	-0.1365158	0.3122249	0.019317165
85.5	-0.0846025	0.2901696	0.014202149
95.0	-0.0268017	0.2731202	0.011041679
110.0	0.08356298	0.2504654	0.007659528
120.0	0.16906836	0.2376257	0.006076402
125.5	0.21988233	0.2311921	0.005361101
130.0	0.26336844	0.2262208	0.004841595
140.0	0.36590414	0.2160117	0.003861352

Table 6: Distribution of rain attenuation coefficients with probability of occurrence for Makurdi using Moupfouma model (air force base ten years data).

Attenuation(dB)	η	ϕ	Percentage of time (%)
40.0	-0.19702938	0.369318782	0.041009924
45.0	-0.18328455	0.347654132	0.030962291
55.0	-0.13654697	0.312189425	0.019322294
60.0	-0.10433002	0.297441221	0.015757743
75.0	0.023838357	0.261530810	0.009215741
85.5	0.138802876	0.241797502	0.006573608
95.0	0.258776796	0.226682682	0.004894689
110.0	0.476012293	0.206783953	0.003077729
120.0	0.638024952	0.195599168	0.002242047
125.5	0.732544554	0.190019820	0.001875232
130.0	0.812598472	0.185719966	0.001615663
140.0	0.998858358	0.176920731	0.001148409

2.2.4. Rain Attenuation Computation Using ITU P838-3 Model for Makurdi

Using the values of $R_{0.01}$ obtained in equation (30), $R_{0.01} = 112.19\text{mm/h}$,

The specific attenuation is obtained from (26) as:

$$Y_{R0.01} = 5.606\text{dB} \quad (47)$$

Using $R_{0.01}$ in (27c), which is then used in (27b) to obtain:

$d_0 = 7.8096$, $r = 1.004 * 10^{-1}$. Hence the effective path length, d_{eff} of the link was computed using (27) as :

$$d_{\text{eff}} = d_r = 7.0258\text{Km} \quad (48)$$

Thus the attenuation induced by rain and exceeded at 0.01% of time was computed using the values obtained in equations (47) and (48) in (28) to obtain:

$$A_{0.01} = 5.606 * 7.0258 = 39.39\text{dB} \quad (49)$$

3 .0 DISCUSSIONS

3.1 Rain Rate for Makurdi.

Observations from the analyses show that the rain amounts measured was 2229.7mm for Makurdi NECOP two years data (2008-2009), 4906.0mm for Makurdi air force base two years data (2008-2009) and 11311.8mm for Makurdi air force ten years data. Their respective rain rates obtained using Chebil rain rate model were 99.0mm/h, 100.0mm/h and 125.1mm/h. The discrepancy observed in the rain amounts and hence in the rain rate of (2008-2009) data from both NECOP and Air force base stations could be attributed to the fact that the position of the rain gauge for NECOP is very close to the ground and the holes are often blocked by dead grasses during the rainy season, thus blocking free seepage of rain through the rain gauge. This could lead to wrong results or missing data in the rain amounts.

Table 1 which presents rain rate distribution coefficients with probability of occurrence for Makurdi using Moupfouma rain rate Model on NECOP (2008-2009) data shows that the rain rates having 0.01% probability of time lie between 95 – 125.5mm/h with the highest probability falling on a value between 95 and 110 mm/h. Table 1

also shows that at probabilities of 0.05%, the obtained rain rate was 55.0mm/h

Again, considering the rain rate distribution coefficients with probability of occurrence for Makurdi using Moupfouma rain rate model on Air port base (2008-2009) data (Table 2), it could be observed that the rain rates having 0.01% probability of time lie between 120 – 140mm/h with the highest probability falling on a value between 120 and 125.5 mm/h. Similarly, at probability of 0.04%, the rain rate was 75.0mm/h. But at probability of 0.04% the rain rate was 75.0mm/h.

On the other hand, considering the ten years data from the Air port base Makurdi, the rain rate distribution coefficients with probability of occurrence using Moupfouma rain rate model (Table 3) shows that the rain rates having 0.01% probability of time lie between 95 – 120mm/h. In addition, at probabilities of \approx 0.05%, the rain rate obtained was 55.0mm/h. Consequently, the results from Tables 1 – 3 indicate that at 0.01% probability of time, the rain rates obtained over Makurdi using Moupfouma rain rate model lie in the range between 100 – 140 mm/h, and at a high probability of 0.04 the lowest rain rate that will be obtained is \approx 55.0mm/h.

3.2 Rain Attenuation for Makurdi

Observations of the rain attenuation for Makurdi show that the rain attenuations obtained using Moupfouma model for NECOP two years data (2008-2010), Air force base two years data (2008-2010) and Air force base ten years data were 76.97dB, 98.94dB and 72.56dB respectively. Using ITU model the obtained attenuation was 39.39dB.

Observation in Table 4 (NECOP data) shows that at probabilities of 0.05%, the rain attenuation obtained was 40.0dB, while at 0.01%, the attenuation lies between 75.0 and 95.0dB. Hence, at probabilities of time greater than 0.01%, lower attenuation was obtained and vice versa.

Table 5 (Air force two year data) shows that at probabilities of 0.04% and 0.01% the observed attenuation is 40.0dB and \approx 85.0-130.0dB respectively.

This implies that the attenuation that will occur in a line of sight radio frequency path propagating at a frequency of 13.5GHz is \approx 85.5dB-130.0dB and at a high probability of 0.04% a low attenuation of 40.0dB is obtained in Makurdi.

Table 6 (Air force base ten years data) shows that at probabilities of 0.05% and 0.01% the rain attenuations observed were 40.0dB and \approx 75.0-95.0dB respectively ,

thus exhibiting the same character as that of NECOP (2009 – 2010) data (Table 4). Generally, it can be observed that the higher the percentage of probability, the lower the attenuation and vice versa.

4.0 CONCLUSIONS.

- The annual rain accumulation for Air force and its corresponding rain rate for Makurdi (2008-2009) were higher than the rain accumulation for NECOP (2008-2009). Thus the position or elevation of rain-gauge contributes to the accuracy of the measurements of rain amounts in any location.
- The rain rate at 0.01% of time for Makurdi is 99.398mm/h (Chebil and Moupfouma, Air force base ten year data) causing attenuation on the radio signal (frequency of 13.5GHz) of about 72.6dB. On using ITU model, the rain rate was 112.2mm/h and the attenuation on the signal strength (frequency of 13.5GHz) was 39.4dB.
- This research work shows that the Chebil rain rate model is a better model because it computes the rain rate of any location to its equivalent one-minute rain rate value irrespective of the integration time the data was measured. Consequently the Moupfouma's attenuation model which uses the Chebil's rain rate as input also provides a good estimation for rain attenuation for any location

4.1 Recommendations

- When communication satellites are being produced for areas with high rain fall rate, it is recommended that satellite engineers should put into consideration the differences in degree of attenuation from one location to another because these attenuations represent an uncertainty in the design of communication link and this affects service availability and can lead to interruption of communication link performance. It is thus necessary to compensate for this difference via radio frequency (RF) modification, that is, larger antenna and larger amplifier for the satellites systems.
- It is also recommended that the height of NECOP rain gauge satellite should be increased from a few centimeters to a minimum of 100 meters in altitude from the ground so as to avoid the

- blockage of the gauge filter caused by dead grass and debris.
- A more comprehensive work can be carried out, with the analyzed data covering a period of time of at least fifteen years for each location to be studied.
- Scattering of radio waves is another major cause of concern in communication. Thus a thorough study of radio scatter in the micro and millimeter wave will be vital for planning and designing radio systems.
- A thorough study of radio refractivity in Nigeria can be undertaken for various frequencies in different seasons. Such a study can be of immense help for prediction of radar and other communication systems performances.

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