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Rain Attenuation of Radio Waves in South-Eastern Nigeria

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Abstract: Analysis of daily rainfall data collected over a period of years is important, especially in the study of rain attenuation of radio waves. This study investigates rain attenuation of radio waves in South-eastern Nigeria which is a tropical location. The daily rainfall data used for this study on Rain Attenuation of Radio Waves in South-Eastern Nigeria was collected from the Nigeria Meteorological Agency (NiMet), Abuja, Nigeria, for a period of 10 years, 1997-2007. The data which was for Calabar (Lat. 4.58°N, Long. 8.21°E), Ikom (Lat. 6.0°N, Long. 8.87°E), Ogoja (Lat. 6.8°N, Long. 8.71°E), Port Harcourt (Lat. 4.51°N, Long. 7.01°E) and Uyo (Lat. 5.02°N, Long. 7.56°E) was subsequently analysed and reduced to obtain rain parameters such as rain rate, R (mm/h), mean annual rainfall, N_R (mm), raindrop diameters, D_m (mm), total number of raindrops and rain attenuation, A_R (dB). The results of the analysis were compared with those obtained by other researchers and found to be in good agreement. The reduced dip-to-peak values of signal strength observed in our recent studies in South-Eastern Nigeria lend credence to rain attenuation of radio waves in this part of the world. Effects of rain parameters on telecommunication, especially with respect to attenuation, were deduced and they also agreed strongly with literature.

Keywords: Rain Attenuation, Radio Waves, Telecommunication, South-Eastern Nigeria

1. Introduction

Rain is known to cause significant signal impairment at frequencies above 10 GHz [1-4]. Electromagnetic waves can be scattered and absorbed by precipitation particles. Radio path loss through a volume of precipitation or fog depends mainly on the number of particles in the propagation path (Fresnel ellipsoid) and on their size in relation to the wavelength. The rain attenuation can be estimated by means of a calculation method using the principal parameters such as probability distribution, rainfall, frequency and path length [5].

Atmospheric gases such as oxygen and water vapour absorb electromagnetic energy in the region of their spectral lines. In the dense lower troposphere, these lines are broadened to wide absorption bands. In the range from 1 to 100 GHz, water vapour has one spectral line at 22.23 GHz and oxygen several spectral lines between 53 and 66 GHz. Nitrogen and carbon dioxide have no effect below 100 GHz [6].

The attenuation by atmospheric gases is approximately proportional to the density of the gas. The oxygen density can be assumed to be constant with time and within a horizontal direction, but decreases with altitude like the water vapour density which depends not only on temperature (vapour pressure) but also on the relative humidity. Consequently, it is subject to variation with time. According to Hudiara, attenuation of radio-wave by rain depends on the shape, size and distribution of raindrops and rain rate [7]. Therefore, rain rate data and rain attenuation prediction models are being required for establishing any microwave communication system [8, 9].

The dynamics of rain in the equatorial and tropical regions are quite distinct from those of the temperate and high altitude regions. Tropical regions are noted for high rainfall rates [10]. The use of Ku and extra high frequency, EHF, bands will permit telecommunication operators to increase traffic and ultimately reduce telecommunication costs. These frequencies offer the advantage of a bandwidth useful for carrying high data rates for multimedia services [11].

2. Significant of the Study

Throughout the world, considerable effort is devoted to the collection of rainfall data. Many long records exist and most countries now have a reasonable dense network of rainfall stations. The work on data collection is not at present matched by a corresponding effort on analysis [12].

In Nigeria, rainfall data analysis has only been carried out in a few regions. Some of these studies are those carried out by Ajayi in Ile-Ife [13], and Bryant *et al*. and Adimula in Ilorin [14] and Adimula *et al*. [11]. Only very limited rainfall data analysis, especially with respect to attenuation of radio waves, is available for the South-Eastern part of Nigeria. This study is, therefore, undertaken to investigate attenuation of radio waves in South-Eastern Nigeria. Generally, the study appraises the effects of rain parameters on telecommunication in South-Eastern, Nigeria.

3. Theory and Models

3.1. Rain Rate

Rain rate model proposed by Chebil and Rahman [15] is given by:

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

where α = 12.2903 and β = 0.2973 are regression coefficients. Chebil and Rahman [15] showed that their model is the best estimate of the measured data.

3.2. Rain Attenuation

The rainfall rate may be estimated approximately by means of the following equation [5]:

$$R = N_R/20.\ \log 10^{-3}/W \quad (2)$$

(valid for $W < 10^{-4}$, N_R = 500 to 1200 mm) where R is rainfall rate (mm/h), W is probability of exceeding a predetermined time. This refers to the number of minutes in a year in which a pre-determined noise level may be exceeded and N_R is annual rainfall (mm).

The reduction coefficient may also be calculated from the following equation [5]:

$$K_R = [61/d^{0.5}R]\ \{1–\exp(d^{0.5}R/61)\} \quad (3)$$

where K_R is the reduction coefficient and d is path length (km). The mean rain attenuation, A_R (dB) on a radio path of length, d, during W percent of the annual minute interval then amounts to [5]:

$$A_R = R.d.\ K_R \quad (4)$$

Rain attenuation, like interference fading, is not distributed evenly over all months of a year.

3.3. Raindrop Diameter

Raindrop diameter has been modelled by Ajayi and Ofoche [13].

$$D_m = -0.19 + 0.19\ln R \quad (5)$$

while Adimula *et al*. (2005) modelled it as

$$D_m = -0.544 + 0.234\ln R \quad (6)$$

3.4. Methodology

The rainfall data obtained from NiMet, Abuja was the main material used in the study. The data was reduced to obtain rain rate and mean annual rainfall. Rain rate was also calculated using the model proposed by Chebil and Rahman [15] in eqn. (1). Data on rain rates was used to calculate rain attenuation using eqns. (3) and (4).

Adimula *et al*. [11] and Ajayi and Ofoche [13] models shown in eqns. (5) and (6), respectively, were used to calculate ranges of raindrop diameter for each of the stations. Rain parameters such as raindrop diameter and rain attenuation were also obtained from measurement in Kolkata (Lat. 22°34′N, Long. 88°29′E), a tropical zone in India [16]. Value of rain rate, rain attenuation and rain raindrop diameter calculated using the various models were compared with their values obtained from experiment.

4. Results

The results were expressed graphically as shown in Figures 1-4. The plots are rain rate versus mean annual rainfall (Figure 1) and raindrop diameter versus rain rate (Figure 2). Others show variations of rain attenuation with rain rates for the experiment (Figure 3) and using Brodhage and Hormuth [5] model for the cities in South-Eastern Nigeria.

Table 1 also shows rain rate and mean annual rainfall. Raindrop diameter values, experimental and theoretical, are shown in Table 2 while Table 3 shows ranges of rain attenuation.

Table 1. *Rain rate and mean annual rainfall.*

Station	Rain rate (mm/h)		Mean annual rainfall (mm)
	Experimental	With Chebil's model [15]	
Port Harcourt	21.4-29.3	55.21-60.6	156.5-214.1
Calabar	26.82-43.1	59.05-67.9	196.3-314.2
Ogoja	11.28-24.76	45.6-57.62	82.3-180.7
Uyo	17.87-30.95	52.29-61.5	130.4-22.6
Ikom	21.52-33.2	55.27-62.87	157.1-242.3

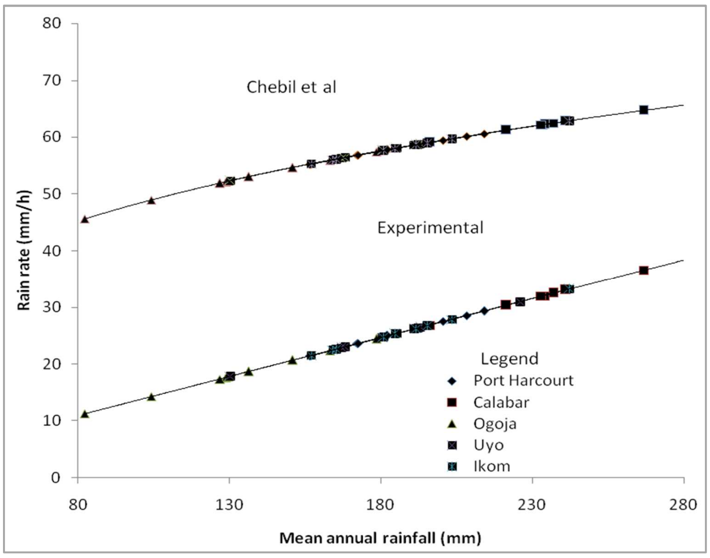

Figure 1. *Variation of rain rate with mean annual rainfall.*

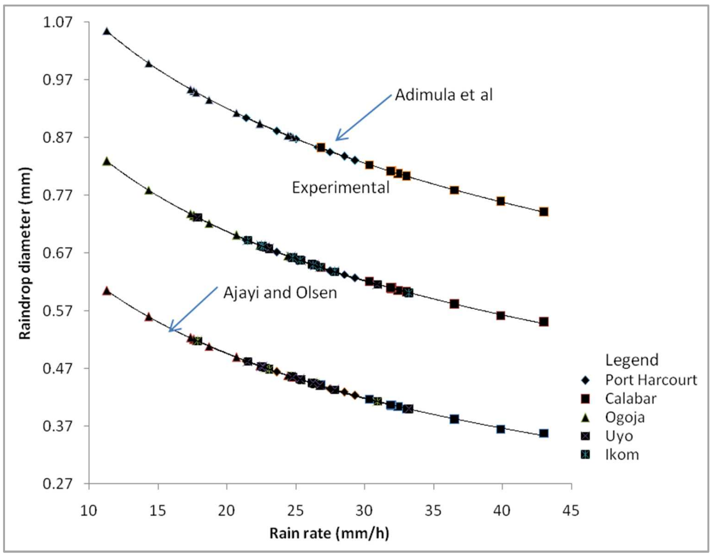

Figure 2. *Variation of raindrop diameter with rain rate.*

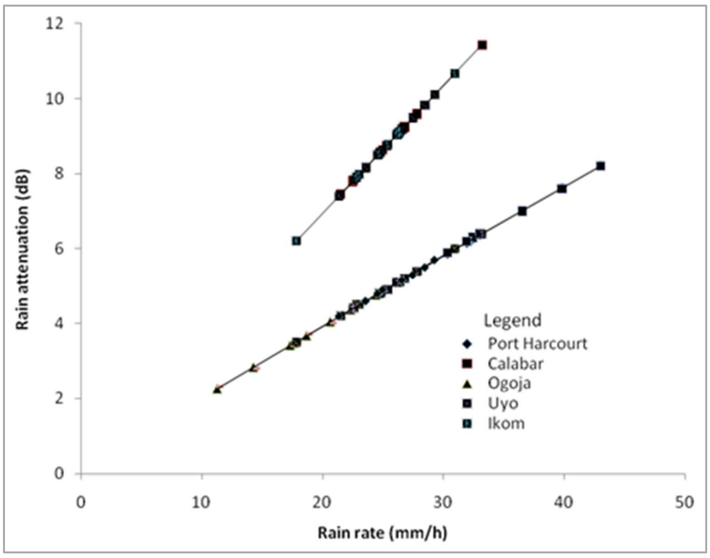

Figure 3. *Variation of rain attenuation with rain rate (Experimental).*

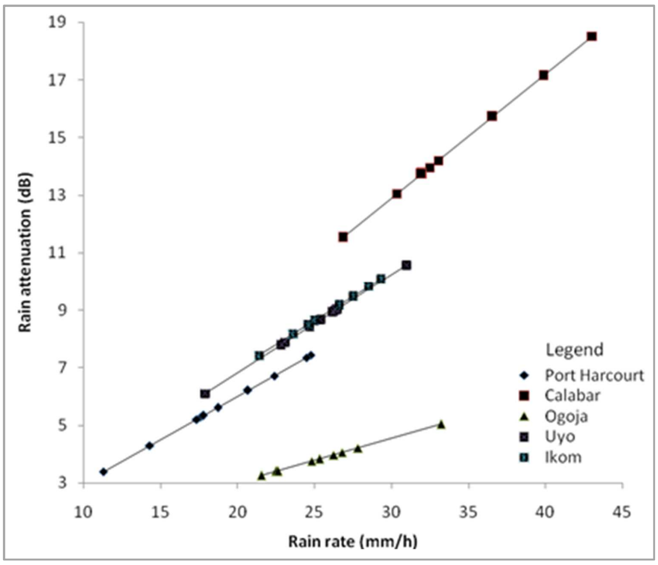

Figure 4. *Variation of rain attenuation with rain rate (using the model of Brodhage and Hormuth [5].*

5. Analysis and Discussion

Several attempts have been made in Nigeria to provide useful information and data on radio wave propagation for both terrestrial and earth space radio links [17]. Correlation of measured values with predicted values often yield better models for characterizing the propagation medium for good quality signal reception. The results obtained in this study have been analyzed and discussed.

5.1. Rain Rate and Mean Annual Rainfall

Table 1 shows that Calabar records the highest rainfall rate followed by Ikom, Uyo, Port Harcourt and Ogoja in that order. The ranges of rainfall obtained by calculation using Chebil and Rahman model [15] are in strong agreement with experimental ranges. It can be observed further that as rain rate increases, the mean annual rainfall also increases. This agrees remarkably with the exponential variation of rain rate with mean annual rainfall proposed by Chebil and Rahman [15].

5.2. Raindrop Diameter and Rain Rate

The experimental results in Table 2 indicates that the largest range of raindrop diameter was recorded in Ogoja, followed by Uyo, Port Harcourt, Ikom and Calabar in decreasing order. The results obtained by calculation using the models of Ajayi and Ofoche [13] and Adimula and others [11] show ranges that strongly agree with the order portrayed by experiment.

Comparing Tables 1 and 2, it can be observed that as the range of raindrop diameter increases, the range of rain rate decreases. Ogoja records the largest range of drop diameter but the shortest range of rain rate. This result agrees with Cerro's conclusion that "one common feature of drop size diameters is their strong sensitivity to rain rate. Thus, raindrop size diameter fittings improve when the range of rain rate considered is narrow" [18]. This observation may result from the fact that during high rainfall, large raindrops tend to break up when colliding with other large raindrops [19] resulting in raindrops with lower diameters.

Again the fall velocity of a raindrop particle is directly proportional to its diameter [20], the larger the particle, the faster it falls. In regions where there is high rainfall rate, falling droplets encounter air resistance or frictional force, the magnitude of this force depending on the size of the drops bottom or the surface area resisting the fall [20]. The air resistance or frictional force is directly proportional to the size of the raindrop which in turn is proportional to the fall velocity. Hence, large drops falling at high terminal velocity experience large frictional force which causes them to split into small raindrops.

Table 2. *Raindrop diameter, experimental and theoretical.*

Station	Ranges of raindrop diameter (mm)		
	Experimental	With Ajayi's model [11]	With Adimula's model [6]
Port Harcourt	0.63-0.69	0.42-0.48	0.83-0.91
Calabar	0.55-0.65	0.36-0.44	0.74-0.85
Ogoja	0.66-0.78	0.46-0.60	0.87-1.06
Uyo	0.62-0.73	0.41-0.52	0.82-0.95
Ikom	0.60-0.69	0.40-0.48	0.80-0.90

5.3. Rain Attenuation and Rain Rate

Results in Table 3 show that Calabar, which records the highest rain rate (Table 2) also records the highest signal attenuation due to rain. Ogoja which records the lowest rain rate (Table 1) also records the least signal attenuation due to rain. Other stations follow suit. This result is in perfect agreement with Omotosho's observation that Douala (in Cameroun) recorded a high attenuation due to rain as a result of the fact that it had a high rainfall rate [21]. This suggests that rain attenuation increases with increasing rainfall rate. Table 3 shows good agreement between the results obtained by calculation using the model of Brodhage and Hormuth [5], and experiments.

Table 3. *Ranges of Rain Attenuation.*

Station	Ranges of rain attenuation (dB)	
	Experimental	Using Brodhage & Hormuth model [5]
Port Harcourt	5.2-8.2	3.39-7.44
Calabar	7.45-11.4	11.53-18.51
Ogoja	2.26-4.8	3.25-5.03
Uyo	7.41-10.1	6.09-10.57
Ikom	6.2-10.7	10.7-14.65

5.4. Rain Attenuation of Radio Waves

Rain rate and rain attenuation prediction is one of the vital steps to be considered when analysing a microwave satellite communication link at the *Ku* and *Kạ* bands [22]. Onuu [2] and Choi *et al*. [23] reported that raindrops absorb and scatter radio waves leading to signal attenuation and reduction of the system availability and reliability. Attenuation by barriers and solid structures is significant at all frequencies while at frequencies above 10 GHz rain strongly attenuates and depolarizes radio waves [2, 5, 24]. Depending on the types of obstacles, in the environment, the basic laws of physics cause a transmitted signal to make a multitude of paths via reflection, refraction and diffraction towards the receiving station. Some of the signals will be received with sufficient signal strength to be detected and demodulated into a meaningful data stream. Some signal may be so greatly attenuated that the receiver does not detect them while others are scattered when they encounter obstacles [25].

From the foregoing, it is evident that rain causes serious signal impairment. The results of this study show that signal attenuation increases with increasing rain rate. Thus, if two people in each of Port Harcourt, Calabar, Ogoja, Uyo and Ikom make phone calls at the same time, the poorest signal transmission and reception will be recorded in Calabar which shows the highest rain rate and the next poorer reception in Ikom, Uyo and Port Harcourt in that order. The best signal transmission and reception will be recorded in Ogoja which has the least value of rain rate. Recent wide range measurements and signal strength analysis, which were characterized by large dips and peaks lend credence to the great effects of raindrop size and rain rate on radio wave attenuation in South-Eastern Nigeria [26, 27]. Again, experiment shows that Calabar records the lowest range of raindrop diameters but highest signal impairment while Ogoja showed the highest range of raindrop diameters and least signal attenuation. It follows therefore that regions that record high rain rate are generally characterized by small drop diameters and high signal impairment.

6. Conclusion

This study was aimed at analyzing experimental rainfall data in some cities in South-Eastern Nigeria and proposing the effects of the parameters obtained from these data on telecommunication, especially with respect to signal attenuation. The analysis carried out has shown remarkable agreement with similar analysis carried out within the tropics. It is believed that the effects of rain on telecommunication could be the reason for the reduced dip-to-peak values of signal strength observed in our recent studies during the rainy season in South-Eastern Nigeria. Also, the effects of rain on telecommunication are in agreement with available literature.

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