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Study of Rain-Induced Signal Degradation of Terrestrial Radio Links within Minna and Lapai, North-Central, Nigeria

Tyabo A Muhammad[1], Oyedum O David[2], Ayantunji G Benjamin[1], Elemo O Enoch[1], Muhammad B Ladan[3], Jibrin A Yabagi[3] and Ndanusa Babakacha[3]

[1] National Space Research and Development Agency, Abuja, Nigeria
[2] Department of Physics, Federal University of Technology, Minna, Niger State, Nigeria
[3] Department of Physics, Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria

Corresponding E-mail: tyabosadiq@gmail.com

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Abstract

Rain attenuation is a major source of impairment to signal degradation at millimetre wave bands above 10 GHz. This research work determines the extent of signal degradation due to rainfall on terrestrial radio links within Minna and Lapai. The meteorological rainfall data collected from the Automatic Weather Stations installed at the Federal University of Technology, Minna, and at Ibrahim Badamasi Babangida University, Lapai, for a period of 3 years (2011-2013) were used to computate the rainfall attenuation on Microsoft Excel spreadsheets. The Lavergnat-Gole (LG) model was used for the conversion of cumulative distributions of rainfall of 5-min to 1-min integration time in Minna and Lapai respectively. The LG model was used to estimate the rain attenuation in the two stations at a frequency range of 10-18 GHz. The relationship between rain rate and specific attenuation was studied using three years rainfall data. It was observed that a power-law relationship exists between rainfall rates of different integration times. The results for the rain rate exceeded for 0.01% of time, show that the horizontal polarisation experiences more degradation than the vertical polarisation. The results also show that specific and total attenuations increase with increasing operational frequency, and are polarisation-dependent. These results would be useful for planning terrestrial radio networks within the study area.

Keywords: Rain attenuation; Signal Degradation; Rain Rate; Rainfall, Frequency; Lavergnat-Gole; Polarisation

I. Introduction

Rain attenuation is primarily the absorption and scattering of a microwave RF signal by atmospheric snow, ice, rain and losses which are particularly common at frequencies above 10 GHz [1]. The major factor of attenuation of frequencies above 10 GHz is rain, particularly in humid climates countries such as Nigeria which experiences high intensity of rainfall and large presence of very wide rain drops in the wet season; and the intense of rain impairments becomes larger with frequency and display anomalies in various places [2] - [3]. Rain attenuation in the microwave band is presently considered most important factor in designing terrestrial radio wave communication links at frequencies above 10 GHz.

The prediction of rain degradation normally begins from known point rainfall rate statistics, considering the horizontal and vertical configuration of rain cell using climatologically data [4], [5], [6], [7] and [8]. These data can be used to determine the loss of signals by rain with the use of physical and statistical modeling methods. Attenuation forecast methods were centered on locations of elevated latitude such as Europe, East Asia and United States [9]. These models were exploit in tropical (equatorial) regions like, Malaysia [10], Japan [11], Nigeria [12] and [13], however, they do not reveal the precise environment of predicted outcome of the attenuation occurrence.

Consequently, the forecast of rain attenuation within this tropical cities of Minna and Lapai are necessary to analyse signal strength fluctuations at given frequencies above 10 GHz, and the study of the impact of variation on meteorological parameters of the atmosphere has become imperative for improving signal propagation in rain conditions and to support the design of stable free-air communication systems [14].

A. Study Area

Define Minna is capital of Niger State. It lies between latitude 09° 24' N to 09° 44' N and longitude 06° 25' E to 06° 45' E, and Lapai lies between latitude 09° 3' N and longitude 06° 3' E (Fig. 1). The study area is part of the North-Central part of Nigeria. The areas experiences distinct wet and dry seasons with annual rainfall varying from 1,100 mm to 1,600 mm. The wet seasons last for about 180 days in the northern parts to about 120 days in the southern parts of the state [15].

The maximum temperature is recorded usually between March and April which is usually not more than 37 °C, while the minimum is usually between December and January which is usually not more than 19 °C, due to harmattan. The inhabitants in the study area are mainly civil servants and farmers.

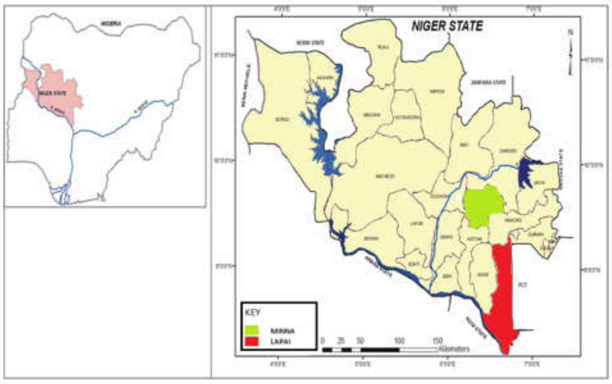

Fig. 1 Map of Nigeria showing Minna (GIS Maps)

II. METHODS

A. Source of Data

Data for this study were collected using the Automatic weather stations installed at Federal University Technology, Minna, and Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria. The meteorological rainfall data span 2011-2013 (3 years) obtained from the stations has an integration time of five minutes interval.

B. Other Recommendations

The model adopted by [16] was used to investigate the rain attenuation of terrestrial microwave signal within Minna and Lapai, Niger State respectively. The steps used in [16], which are valid at least for frequency up to 40 GHz and lengths up to 60 km, were also implemented as discussed in sections i-iv. Therefore, the LG model is suggested as the best model for converting rain rate of 5 $minutes$ integration time to 1 $minute$ integration time in the study areas.

i. Conversion of rain rate

Step 1: According to [16], conversion of rainfall rate from a given integration time to another can be achieved using (1).

$$P_1(R_1) = h^z \times P_T(R_T) \quad (1)$$

$$R_1 = \frac{R_T}{h^Z} \quad (2)$$

$$h = \frac{t_1}{t_T} \quad (3)$$

Where, $z = 0.143$ for tropical region [17], R_1 = rain rate at one minute integration time, R_T = rain rate at T minute integration time, P_1 = percentage probability of time exceedance at 1 minute, P_T = percentage probability of time exceedance at T minute, h = conversion factor, t_1 = integration time at which the rain rate is required and t_T = integration time at which the rain rate is available.

ii. Calculation of attenuation

Step 2: The attenuation per kilometer, called specific attenuation, γ, is calculated using [18]:

$$\gamma_{(0.01)} = kR^{\alpha}_{(0.01)} \ (dB/km) \quad (4)$$

$$r_{0.01} = \frac{1}{1+\frac{L}{L_o}} \quad (5)$$

$$L_o = 35e^{-0.015}R_{(0.01)} \quad (6)$$

Where, $r_{0.01}$ = correction factor, k and α = regression coefficients [18], L_o = rain rate dependent factor, L = path length of the terrestrial microwave link, $R_{0.01}$ = rain rate at 0.01 percentage of time exceedance.

iii. Calculation of effective path length

Step 3: The effective path length, L_{eff} is expressed as:

$$L_{eff} = L \times \frac{1}{1+\frac{L}{L_o}} \quad (7)$$

iv. Calculation of total attenuation

Step 4: An estimate of the total path attenuation exceeded for 0.01% of the time is given by:

$$A_{0.01} = \gamma \times L_{eff} \quad (8)$$

Table I shows a summary of regression coefficients for both horizontal and vertical polarisations used for the conversion process, as available from the literature [18]. The rain attenuation values are measured and recorded in dB/km and the rainfall rate is measured in mm/h.

Table I Values of constants "k" and "α".

Freq. (GHz)	$k_{Horizontal}$	$\alpha_{Horizontal}$	$k_{Vertical}$	$\alpha_{Vertical}$
10	0.0122	1.2571	0.0113	1.2156
11	0.0177	1.2140	0.0173	1.1617
12	0.0239	1.1825	0.0246	1.1216
13	0.0304	1.1586	0.0327	1.0901
14	0.0374	1.1396	0.0413	1.0646
15	0.0448	1.1233	0.0501	1.0440
16	0.0528	1.1086	0.0590	1.0273
17	0.0615	1.0949	0.0680	1.0137
18	0.0708	1.0949	0.0680	1.0025

III. DISCUSSION OF RESULTS

The relationship between rain rate statistics at different integration times has been studied using the data obtained from the Automatic Weather Stations installed at the Federal University of Technology, Minna, and at Ibrahim Badamasi Babangida University, Lapai, for a period of 3 years (2011-2013). Rain-induced attenuation and signal degradation experienced on terrestrial links in Minna and Lapai are presented under the following; Rain-induced Signal Degradation for Minna, Rain-induced Signal Degradation for Lapai and Comparison of Station Attenuation values.

A. Rain-Induced Signal Degradation for Minna

The cumulative distributions of the rain rate for 1-min and 5-min integration times are shown in Fig. 2 and 5, which shows that for the same percentage of time of exceedance, as the integration time increases, the rainfall rate increases.

Fig. 2, 3, 4 and 5 show rain-induced signal degradation experienced in Minna and Lapai respectively. The results show that vertical polarisation is more effective and less attenuated than the horizontal polarisation in signals transfers. The result shows that due to attenuation induced by rain which is experienced at frequencies above 10 GHz, terrestrial radio communication links may perhaps not be achieved at 99% availability, which is equivalent to 0.01 % time exceedance to conform to the strict communication Quality of Service requirement [19].

Fig. 2 shows the cumulative distributions of rainfall rates plotted at 5 and 1 $minute$ integration times. The cumulative distribution of rain rate is converted from 5 $minutes$ to 1 $minute$ integration time using L-G rain rate conversion model. Fig. 2 shows that at about 0.01% of time exceedance, the rain rate is 70 mm/h and 88.12 mm/h for 5 $minutes$ and 1 $minute$ integration times respectively. Also at 0.001% of time exceedance, the rain rates are 125 mm/h and 157.35 mm/h for 5 $minutes$ and 1 $minute$ integration times respectively. This is a clear indication that the conversion of rain rate from higher integration time to lower integration time cannot be achieved ordinarily by considering their ratios. More so, higher rain rates are recorded for lower integration time and lower percentage of time exceedance.

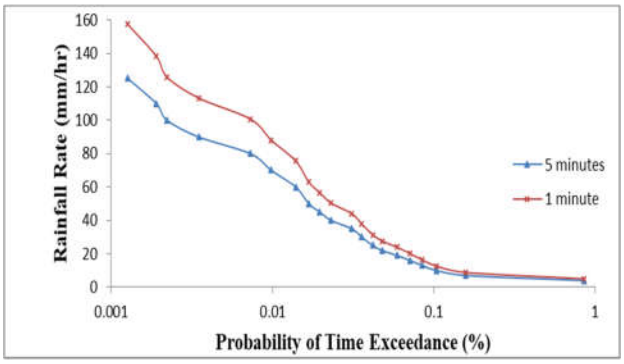

Fig. 2 Rainfall rate for Minna at percentage exceedance $(0.001 - 1\%)$

Fig. 3 shows specific attenuation (dB/km) which is determined at 0.01 % of time exceedance. The specific attenuation values for Minna station present a rapid increase in attenuation of about 3.50 dB/km to 8.99 dB/km between 10 GHz and 18 GHz for horizontal polarisation. On the other hand, the vertical polarisation has less attenuation values of about 2.61 dB/km and 6.87 dB/km between 10 GHz and 18 GHz. This is an indication that the specific attenuation increases with increasing frequency above 10 GHz, and it is higher for horizontal polarisation compared to vertical polarisation. This result is in agreement with the results obtained by [13] and [20].

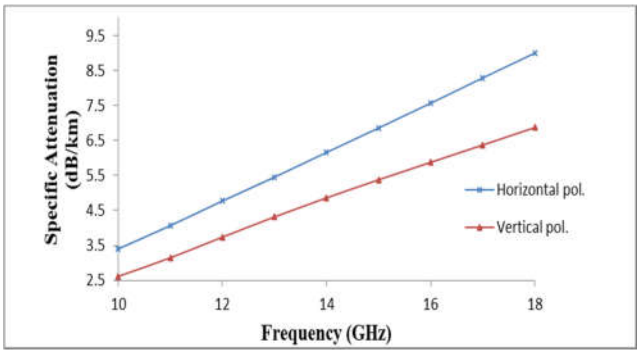

Fig. 3 Specific attenuation in Minna against frequency at 0.01% exceedance

Fig. 4 shows the level of propagation impairment due to signal attenuation that exists over a 10 km supply link distance at 0.01% exceedance in Minna. The result represents large values of attenuation at about 10 GHz frequency up to 18 GHz and a strong indication that fading of the wave is due to rain drops interferences. The total rain-induced attenuation increases with increasing operating frequency with more attenuation expected for horizontal polarisation. These results are in agreement with [20], [21] and [22].

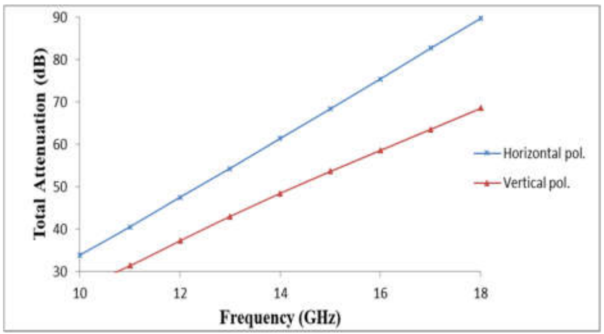

Fig. 4 Total attenuation in Minna against frequency at 0.01% exceedance

B. Rain-Induced Signal Degradation for Lapai

Fig. 5 shows the cumulative rain rate distribution plotted for Lapai. The estimate for the rainfall rate exceeded at 0.01% of the time is 22.66 mm/h, while equivalent estimates for the other time percentage are 56.65 and 47.83 mm/h for 0.0001% and 0.001% respectively. The results reported in this study are in line with works of [12] and [13].

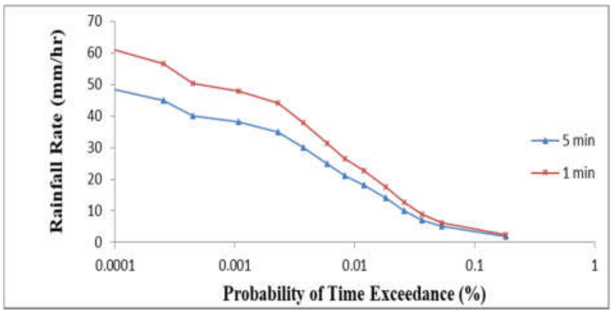

Fig. 5 Rainfall rate for Lapai at percentage exceedance $(0.001 - 1\%)$

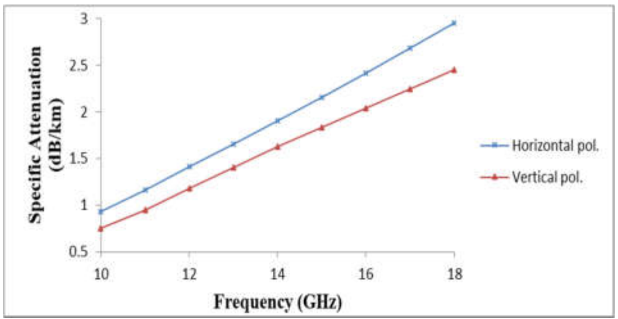

Fig. 6 Specific attenuation in Lapai against frequency at 0.01 % exceedance

Fig. 6 shows specific attenuation (dB/km) determined at 0.01% of time exceedance at Lapai. Attenuation values were observed for Lapai at minimum of about 0.93 dB/km at 10 GHz and increases to a maximum of 2.95 dB/km at 18 GHz for horizontal polarisation. The vertical polarisation has less attenuation values of about 0.75 dB/km at 10 GHz and maximum 2.45 dB/km at 18 GHz. This is an indication that the specific attenuation also increases with increasing frequency above 10 GHz, and it is higher for horizontal polarisation compared to vertical polarisation. These results are in conformity with works of [21] and [22].

Fig. 7 above shows that at 0.01 % exceedance, total attenuation have large values of attenuation from 14 GHz frequency up to 18 GHz indicating fading in the communication links encountered during transmission of signal at high frequencies (above 10 GHz).

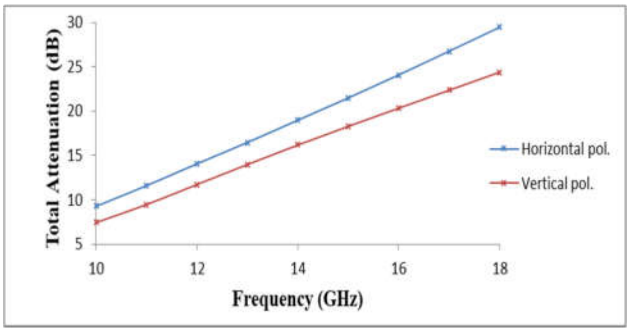

Fig. 7 Total attenuation in Lapai against frequency at 0.01 % exceedance

C. Comparison of Station Attenuation Values

Fig. 2, 3, 5 and 6 indicates some noticeable peculiarities with the two stations studied. Fig. 2 and 5 show that at 0.01% of time exceedance, specific attenuations are high in Minna accounting for 8.99 dB/km in value over Lapai with 2.95 dB/km respectively for horizontal polarisation, with Minna at 6.87 dB/km and Lapai at 2.45 dB/km for vertical polarisation respectively at 18 GHz operational frequency. Fig. 4 and 6 represent total attenuations at 0.01 % of time exceedance, with Minna accounting for higher value of about 89.70 dB/km and Lapai at lower value of about 29.45 dB/km respectively for horizontal polarisation, while for vertical polarisation, Minna account for 68.48 dB/km and Lapai at 24.39 dB/km respectively at 18 GHz operational frequency. The results indicate that Minna station accounts for the largest and about three times higher attenuation values than Lapai due to intense rainfall and therefore experience higher attenuations resulting to loss of signals.

IV. CONCLUSION

The rain rate and rain attenuation measurements over Minna and Lapai, Niger State, Nigeria has been investigated and the results revealed that Minna station experiences higher attenuation than Lapai station (with 0.01% time exceedance) which are characterised by availability of 99.999 to 99.9 % for attenuation induced by rain which is experienced at frequencies above 10 GHz, terrestrial radio communication links, which is equivalent to 0.01 % time exceedance to conform to the strict communication quality of service requirement. Also the LG model was used of for the estimation of rain rate and attenuation for both stations from 2011-2013 at a frequency range of 10-18 GHz. Results obtained for rainfall rate for Minna and Lapai at percentage exceedance (0.001-1%), revealed that at 0.01 % of time exceedance, specific attenuations are high in Minna accounting for 8.99 dB/km in value over Lapai with 2.95 dB/km for a horizontal polarisation, and Minna at 6.87 dB/km and Lapai at 2.45 dB/km for vertical polarisation respectively at 18 GHz operational frequency. Similarly the results presented for total attenuation in Minna and specific attenuation in Lapai at 0.01 % of time exceedance, with increase in frequency, shows that Minna accounts for a higher value of attenuation, about 89.70 dB/km and Lapai at lower value of about 29.45 dB/km for horizontal polarisation, while for vertical polarisation, Minna account for 68.48 dB/km and Lapai at 24.39 dB/km respectively at 18 GHz operational frequency. In summary, the results indicate that Minna station accounts for the largest and a three times higher attenuation values than Lapai, due to intense rainfall and thus experience higher attenuations resulting to loss of signals. These results has significant implications on radio propagation, because the terrestrial relay links at VHF are at higher frequency bands, which is much abundant in Nigeria and may be particularly affected if these variations are not considered during the design of radio link within Minna and Lapai. This study further highlights the relationship between rain rate and specific attenuation within this period. Using the rainfall data from these weather stations, it was observed that a power-law relationship exists between rainfall rates of different integration times, while the peak activities of rain rate are hidden at higher integration times. Equally, the specific and total degradation increases with increasing operating frequency and also depends on polarisation. This result indicates that there is high rain rate and rain attenuation in the tropical climate areas of Minna and Lapai, which is as expected, when compared with other studies [23]. These results will be of useful for both earth-satellite and terrestrial links, because the degradation is influenced by the frequency, polarisation type and rain rate.

References

[1] O. D. Oyedum, “Effects of Topographic conditions on microwave propagation in Nigeria”. *Nigerian Journal of Space Research.* vol. 3, pp. 92 – 97. 2007.

[2] S. K. Sarkar, J. S. Ojo, and M. O. Ajewole, “Rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria”. *Progress in Electromagnetics Research B*, vol. 5, pp. 207-223. 2008.

[3] Y. S. Choi, J. H. Lee, and J. M. Kim, “Rain attenuation measurements of the Koreasat beacon signal on 12 GHz, CLIMPARA’98. vol. 208, No. 211. 1997.

[4] ITU-Radiocommunications Sector, “Study Group 3 Databanks-DBSG3”. *http://www.itu.int/ITU-R/study-groups/soft-ware/dbsg3/index.html.* ITU-R, P Series, Geneva, Switzerland, 2009.

[5] F. Moupfouma, “Electromagnetic waves Attenuation due to Rain: A Prediction Model for Terrestrial or LOS SHF and EHF Radio Communication Links”. *Journal of Infrared Milli-Terahz Waves*, vol. 30, 2009.

[6] L. Da Silva Mello, M. S. Pontes, R. M. De Souza, and N. A. Pérez Garcia, “Prediction of rain attenuation in terrestrial links using the full rainfall rate distribution”. *Electronic Letters*, vol. 43, pp. 1442-1443. 2007.

[7] P. K. Karmakar, R. Bera, G. Tarafdar, A. Mitra, and A. K. Sen, “Millimeter wave attenuation in relation to rain rate distribution over a tropical location”. *International Journal of Infrared & Millimeterwaves*, vol. 12, pp. 1333. 1991.

[8] S. H. Lin, “National Long Term Rain Statistics and Empirical Calculation of 11 GHz Microwave Rain Attenuation”. *The Bell System Technical Journal*, pp. 56. 1977.

[9] Z. X. Zhou, L. W. Li, T. S. Yeo, and M. S. Leong, “Cumulative distribution of rainfall rate”. *In Proceeding in 2nd Euro conference on next generation internet design and engineering*, vol. 2, pp. 287-396. 2000.

[10] A. C. M. Nurrodin, A. F. Ismail, A. K. Abdullah, K. Bedron, M. Ismail and W. Hashim, “Rain Fades Estimation for the X-Band Satellite Communication Link in the Tropics”. *International Journal of Computer and Communication Engineering*, 2, July, 2013.

[11] R. Nakajo, and M. Yasuyuki, “Characteristics of rain attenuation time variation in Ka-Band satellite communications for the kind of rain types in each season”. *Proceedings of ISAP2012*, Nagoya, Japan. 2012.

[12] I. O. Y. Abayomi, and M. Kabir, “Performance evaluation of some rain attenuation prediction models at coastal locations at 12 and 40 GHz”. Global Journal of Earth and environmental Science, vol. 6, No. 2, pp. 27-37. 2021.

[13] E. C. Ibekwe, K. C. Igwe, and J. O. Eichie, “Rain attenuation prediction for 5G communication links in Minna, Nigeria”. International Union of Radio Science, Conference Series, 2034. 2021.

[14] G. A. Agbo, “Tropospheric refractivity dependence on atmospheric weather conditions in Jos, Nigeria. *Journal of Basic Physics Research (Nigeria)*, vol. 2, no. 2, pp. 1-6. 2011.

[15] R. M. Cope, and J. E. Truswell, “The geology of parts of Niger and Zaria province, Northern Nigeria”. Bulletin No. 29. *Published by the Geological Survey of Nigeria*, pp. 29. 1963.

[16] J. Lavergnat, and P. Golé, “A stochastic raindrop time distribution model, *Journal of Applied Meteorology*, vol. 37, pp. 805–818. 1998.
[17] [17] L. D. Emiliani, L. Luini, and C. Capsoni, “Extension of ITU-R Method for Conversion of Rain Rate Statistics from Various Integration times to One minute. *Electronics Letters*, vol. 44, no. 8, pp. 557-558. 2008.
[18] ITU-R Recommendation, “Characteristic of Precipitation for Propagation Modelling”. *International Telecommunication Union Proceedings,* ITU-R P Series, Geneva, Switzerland, pp. 837-5. 2007.
[19] ITU-R Recommendation “*The Radio Refractive Index, its Formular and Refractivity data”*. Published by John Wiley & Sons Inc. New York, pp. 530-543. 2001.
[20] K. C. Igwe, O. D. Oyedum, M. O. Ajewole, A. M. Aibinu, and J. A. Ezenwora, “Performance evaluation of some rain rate conversion models for microwave propagation studies”. *Advances in Space Research*, 2021.
[21] B. C. Sikwue, A. H. Ikoyo, and E. U. Utah, “Analysis of rainfall rates and attenuations for line – of –sight EHF/SHF radio communication links over Makurdi, Nigeria”. *Research Journal of Earth and Planetary Sciences*, vol. 3, no. 2, pp. 60 – 74. 2013.
[22] C. D. Umeh, “Determination of rain attenuation signals in Akure, Ondo State using the International Telecommunication Union of Radio Communication (ITU-R) Model”. Department of Physics and Astronomy University of Nigeria, Nsukka, 2010.
[23] I. T. Union, “Propagation data and prediction methods required for the design of Earth-space telecommunication systems”, in Recommendation ITU-R Sector, p. 618-11. 2013.