Parametric Analysis Of Rain Attenuation For Remote Sensing Sun-Synchronous Satellite Link

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Abstract— **In this paper, parametric analysis of rain attenuation for remote sensing sun-synchronous satellite link is presented. The case study link consist of NigeriaSat-2 satellite with earth station located at University of Uyo, Permanent Site, Uyo, Akwa Ibom State Nigeria. Online satellite tracking tool available at https://www.n2yo.com/satellite/ was used to obtain a ten (10) days prediction of the location of the satellite along with the elevation angles. The analysis utilized the International Telecommunication Union (ITU) global rain rate data specified based on 15 rain zone classifications of rainfall intensities. The earth station location coordinates lies within the ITU rain zone N. The rain attenuation for horizontal polarization, vertical polarisation and circular polarisation are computed for different elevation angles and different rainfall intensity exceeded, R_p, where p is the percentage rain intensity exceeded. The study is conducted for the 10 GHz X-band frequency. The results showed that for any given polarization category (horizontal, vertical and circular) and P, the specific rain attenuation is constant for all the elevation angle but the specific rain attenuation decreases as P increases. Again, the rain attenuation decreases as the elevation angle increases and the rain attenuation decreases as P increases. Also, the rain attenuation are lowest for the vertical polarization and highest for the horizontal polarization. In all, the results showed that the rain attenuation is effected by the elevation angle and the rain rate.**

Keywords— Sun-Synchronous Satellite, Rain Attenuation, Satellite Link, Nigeriasat-2, Satellite Tracking Tool, Horizontal Polarization, Specific Rain Attenuation

1. INTRODUCTION

The NigeriaSat-2 is a sun-synchronous satellite that is meant for earth observation or remote sensing [1,2,3,4,5,6,7,8,9,10,11]. A Sun-synchronous or heliosynchronous orbiting satellite is a special type of polar orbiting satellite which passes over a given location on the earth surface each day at approximately the same local time [12,13,14,15,16,17,18]. This makes such satellite suitable for capturing images from the earth surface with same lighting conditions and hence the images captured in the same season over several years can be compared. Consequently, sun-synchronous satellite like NigeriaSat-2 is used to capture high resolution imagery for applications in mapping, management of water resource, land use management, monitoring of health hazards and environmental disaster mitigation and management [19,20].

Generally, satellites communicate via wireless signal which suffers different forms of signal attenuation due to different equipment, location, climatic and environmental parameters [21,22,23,24,25]. Particularly, in this paper, the impact of attenuation due to rain is considered. The International Telecommunication Union (ITU) rain attenuation model is used to determine the degradation in the satellite signal strength due to rain [26,27,28,29,30]. Also, due to temporal changes in the location parameters of sun-synchronous satellite relative to the earth station, the rain attenuation occasioned by rainfall at the earth station location for the satellite link differs. Specifically, the analysis considered the effect of changes in elevation angle, signal polarisation and different rainfall intensity exceeded percentages on the rain attenuation. Requisite rainfall data and range of elevation angles of the satellite link over its repeat cycle time are obtained and used in the analysis.

2. METHODOLOGY

The International Telecommunication Union (ITU) rain attenuation (A_{rn}) model for satellite communication link with rain rate, R_p (in mm/hr) for p% exceeded time per year is stated as follows [26,27,28,29,30,31];

$$A_{rn} = k(R_p)^{\alpha}(L_e) \quad (1)$$

Where α and k are frequency and polarization dependent constants. The α and k for circular polarization (denoted as α_c and k_c) are computed from the horizontal polarization constants (denoted as α_h and k_h) and vertical polarization constants (denoted as α_v and k_v) provided by ITU as follows;

$$k_c = 0.5\ (k_h + k_v) \quad (2)$$

$$\alpha_c = \frac{(k_h)(\alpha_h) + (k_v)(\alpha_v)}{2(k_c)} \quad (3)$$

Let L_e denote the effective rain path length (expressed in km), Ψ_{est} denote the latitude of the earth station, H_{rn} denote the rain height (expressed in km), θ_{el} denote the elevation angle (expressed in degree) and H_{es} denote the earth station altitude (expressed in km), then;

$$L_e = \frac{L_0}{1+\left(\frac{L_0(R_p-6.2)}{2636}\right)} \quad (4)$$

Where,

$$L_0 = \frac{H_{rn}-H_{es}}{\sin(\theta_{el})} \quad (5)$$

$$H_{rn} = \begin{cases} 4.8 & for\ \Psi_{est} < 30° \\ 7.8 - 0.1(\Psi_{est}) & for\ \Psi_{est} \geq 30° \end{cases} \quad (6)$$

The satellite-earth link elevation angle (θ_{el}) is computed in terms of the satellite link central angle (γ) as follows;

$$\cos(\gamma) = \cos(\Psi_{sat})\cos(\Psi_{est})\cos(\varphi_{sat} - \varphi_{est}) + \sin(\Psi_{sat})\sin(\Psi_{est}) \quad (7)$$

where φ_{est} and φ_{sat} denote the longitude of the earth station and satellite respectively, Ψ_{sat} is the satellite latitude, h_{sat} is the altitude or heath of the satellite orbit and r_e is the earth radius. Hence,

$$\cos(\theta_{el}) = \frac{\sin(\gamma)}{\sqrt{\left[1+\left(\frac{re}{re+h_{sat}}\right)^2 - 2\left(\frac{re}{re+h_{sat}}\right)\cos(\gamma)\right]}} \quad (8)$$

Therefore,

$$\theta_{el} = \mathrm{acos}\left(\frac{\sin(\gamma)}{\sqrt{\left[1+\left(\frac{re}{re+h_{sat}}\right)^2 - 2\left(\frac{re}{re+h_{sat}}\right)\cos(\gamma)\right]}}\right) \quad (9)$$

The study considered NigeriaSat-2 satellite with the earth station located at University of Uyo, Permanent Site, Nwaniba Road, Uyo, Akwa Ibom State Nigeria with latitude of 5.028933° and longitude of 7.978991°. NigeriaSat-2 is a sun-synchronous satellite with orbit inclination of 97.9°, orbital period of 98.5 minutes , orbital altitude of 7 00 km and orbital longitude that repeats every four (4) days. The elevation angle of the link varies with time over the 4 days period and they repeat every four days. An online tracking tool available at https://www.n2yo.com/satellite/ was used to obtain a ten (10) days prediction of the location of the satellite along with the elevation angles. Within the study period of April 13th to April 21st 20201, the elevation angle has varied within a range of 14° to 87°, as presented in Table 1. Hence, elevation angles ranging from 14° to 87° were used to evaluate the rain attenuation on the NigeriaSat-2 –earth station link for various rain rates. The study was also considered for the same range of elevation angles (14° to 87°) but with different rain rates obtained from different locations across Nigeria.

The map showing the NigeriaSat-2 10-Day tracking predictions data by n2yo.com is presented in Figure 1, where the orbit track is indicated by the yellow line, the satellite footprint is indicated by the transparent pink circle and the earth observation location is indicated by the red dot.

The analysis utilized the ITU global rain rate data specified based on the 15 rain zone classification of rainfall intensities. The earth station location coordinates lies within the ITU rain zone N. Hence, the rainfall intensity exceeded, R_p (mm/h) dataset for ITU rain zone N available at https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.837-1-199408-S!!PDF-E.pdf is extracted and presented in Table 2.

Table 1: NIGERIASAT 2 10-Day Tracking Predictions Data by N2YO.COM

Object Name		NIGERIASAT 2				
Observing Coordinates		Latitude: 5.03°			Longitude: 7.98°	
Local time zone		GMT +1				
Start		Max Altitude			End	
Date, Local Time	Az	Local Time	Az	El	Local Time	Az
3-May 19:23	SE 132°	**19:28**	**E 78°**	**14°**	19:34	NNE 22°
3-May 20:59	S 189°	**21:05**	**W 257°**	**28°**	21:12	NW 329°
4-May 07:38	NE 38°	**07:44**	**E 101°**	**19°**	07:50	SSE 163°
4-May 09:15	N 346°	**09:21**	**W 283°**	**21°**	09:27	SW 220°
4-May 19:59	SSE 156°	**20:06**	**E 78°**	**44°**	20:12	N 0°
5-May 08:15	NNE 17°	**08:22**	**E 103°**	**62°**	08:28	S 185°
5-May 20:37	S 177°	**20:43**	**W 261°**	**55°**	20:50	NNW 341°
6-May 08:53	N 358°	**09:00**	**W 280°**	**39°**	09:06	SSW 207°
6-May 19:38	SE 143°	**19:44**	**E 79°**	**23°**	19:50	N 12°
6-May 21:15	SSW 199°	**21:21**	**W 260°**	**17°**	21:27	NW 319°
7-May 07:53	NNE 29°	**08:00**	**E 100°**	**31°**	08:06	S 173°
7-May 09:32	NNW 336°	**09:37**	**W 283°**	**12°**	09:42	SW 232°
7-May 20:15	SSE 165°	**20:21**	**E 80°**	**74°**	20:28	N 352°
8-May 08:31	N 9°	**08:38**	**W 281°**	**79°**	08:44	S 194°
8-May 19:17	SE 129°	**19:22**	**E 77°**	**12°**	19:27	NNE 26°
8-May 20:53	S 186°	**20:59**	**W 259°**	**33°**	21:05	NNW 332°
9-May 07:32	NE 42°	**07:38**	**E 100°**	**16°**	07:44	SSE 159°
9-May 09:09	N 350°	**09:15**	**W 281°**	**24°**	09:21	SW 216°
9-May 19:53	SSE 153°	**19:59**	**E 80°**	**37°**	20:06	N 3°
9-May 21:32	SW 210°	**21:37**	**W 260°**	**10°**	21:42	NW 308°
10-May 08:09	NNE 20°	**08:16**	**E 99°**	**52°**	08:22	S 182°
10-May 20:30	S 174°	**20:37**	**W 256°**	**66°**	20:44	NNW 344°
11-May 08:47	N 1°	**08:53**	**W 282°**	**47°**	09:00	SSW 203°
11-May 19:32	SE 139°	**19:38**	**E 77°**	**20°**	19:43	NNE 15°
11-May 21:09	SSW 195°	**21:15**	**W 259°**	**21°**	21:21	NW 323°
12-May 07:47	NE 32°	**07:54**	**E 99°**	**26°**	08:00	S 169°
12-May 09:25	NNW 340°	**09:31**	**W 285°**	**15°**	09:36	SW 228°
12-May 20:08	SSE 162°	**20:15**	**ENE 73°**	**62°**	20:22	N 355°

Legend: **Not Visible** **Marginal** **Good** **Excellent** *(Source: available at* n2yo.com*)*

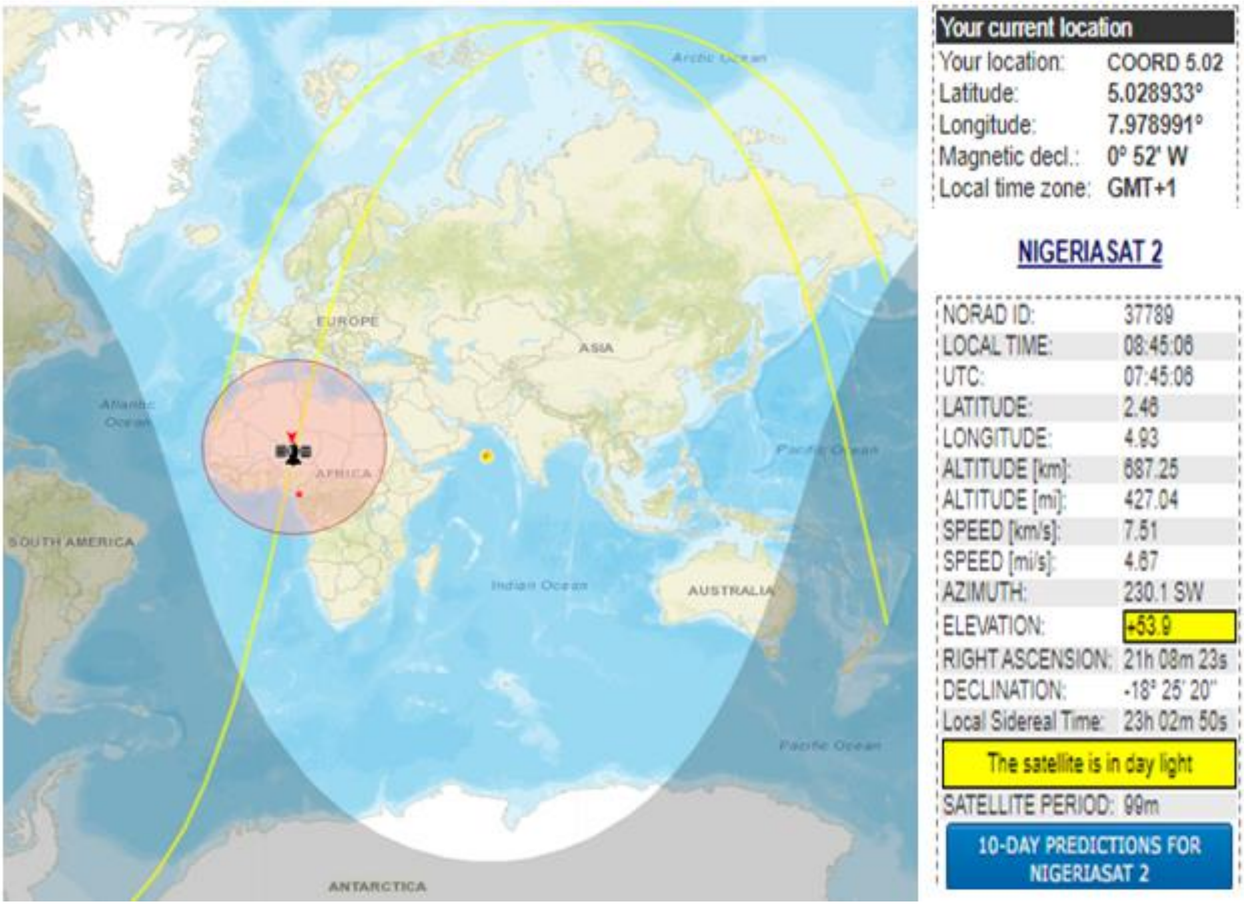

Figure 1 Map showing the NIGERIASAT 2 10-Day Tracking Predictions Data by n2yo.com where the orbit track is indicated by the yellow line, the satellite footprint is indicated by the transparent pink circle and the earth observation location is indicated by the red dot.

(Source: available at n2yo.com*)*

Table 2 Rainfall Intensity Exceeded (mm/h) for ITU Rain Zone N

Percentage of time exceeded, P (%)	**1**	**0.1**	**0.01**	**0.001**
Rainfall intensity exceeded, R_p (mm/h) for ITU rain zone N	**5**	**35**	**95**	**180**

(Source: available at https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.837-1-199408-S!!PDF-E.pdf*)*

3. Results and Discussion

The case study satellite, NigeriaSat-2 data transmission link operates in the S-band (2.0 to 4.0 GHz) and X-band (8.0 – 12.0 GHz). The rain attenuation for horizontal polarization, vertical polarization and circular polarization are computed for different elevation angles (based on range of elevation angle presented in Table 1) and for different rainfall intensity exceeded, R_p (based on the rainfall data presented in Table 2). The study is conducted for the 10 GHz X-band frequency. The results of the effective rain path length, Le in km for the selected percentage of time exceeded, P in the range of 1 % to 0.001% are presented in Table 3 and Figure 2 for various elevation angles . The results in Table 3 and Figure 2 show that the effective rain path length is inversely proportional to the elevation angle; which means that the effective rain path length increases as the elevation angle decreases. Also, the results in Table 3 and Figure 2 show that the effective rain path length is directly proportional to the percentage of time exceeded, P; which means that the effective rain path length increases as P increases.

The results of specific rain attenuation in dB/km for p = 0.001% where Rp =180 mm/hr and for p = 0.01% where Rp =95 mm/hr are presented in Table 4 and Figure 3 for various elevation angles.

The results in Table 4 and Figure 3 show that for any given polarization category (horizontal, vertical and circular) and P, the specific rain attenuation is constant for all the elevation angle but the specific rain attenuation decreases as P increases. Also, the specific rain attenuation is lowest for the vertical polarization and highest for the horizontal polarization.

Table 3 The results of effective rain path length, Le in km for the selected percentage of time exceeded, P in the range of 1 % to 0.001%

Elevation Angle (θ°)	Effective rain path length, Le in km for percentage of time exceeded, P = 0.001%	Effective rain path length, Le in km for percentage of time exceeded, P = 0.01%	Effective rain path length, Le in km for percentage of time exceeded, P = 0.1%	Effective rain path length, Le in km for percentage of time exceeded, P = 1%
10	9.72	14.16	20.89	27.40
19	7.40	9.71	12.47	14.53
29	5.91	7.31	8.77	9.74
39	5.00	5.97	6.90	7.49
49	4.41	5.15	5.83	6.25
59	4.03	4.63	5.17	5.50
69	3.78	4.30	4.77	5.05
79	3.64	4.12	4.55	4.80

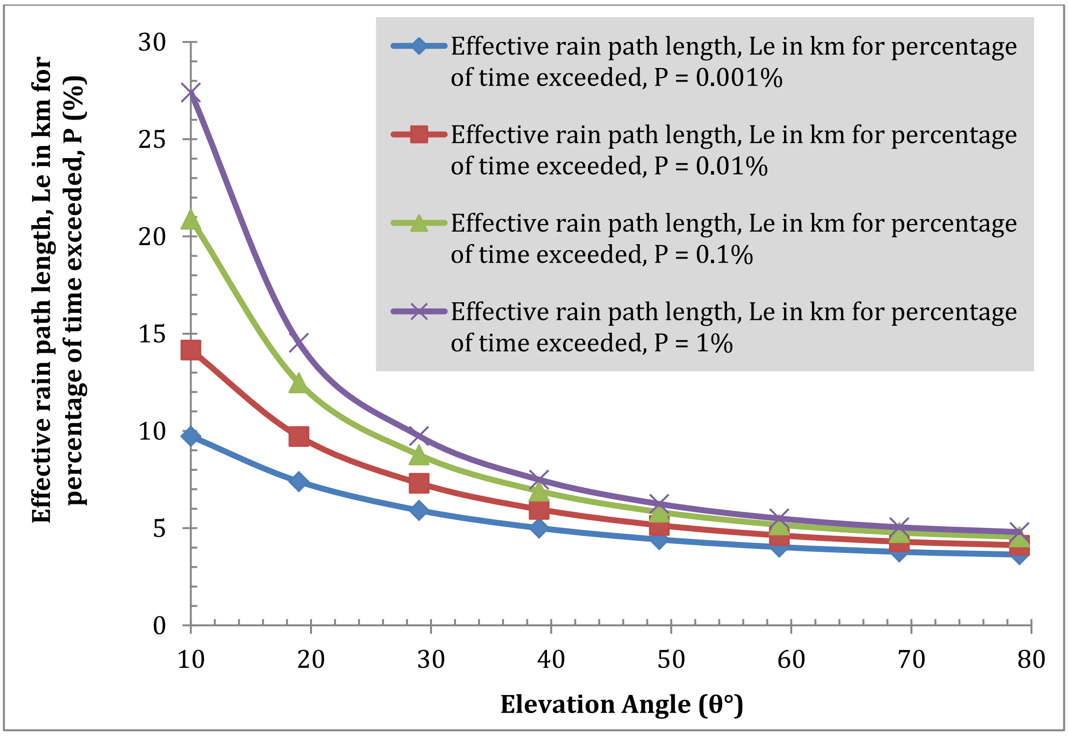

Figure 2 The results of effective rain path length, Le in km for the selected percentage of time exceeded, P in the range of 1 % to 0.001%

Table 4 The results of specific rain attenuation in dB/km for p = 0.001% where Rp =180 mm/hr and for p = 0.01% where Rp =95 mm/hr for the selected elevation angles

S/N	**Elevation Angle (θ°)**	**Specific Rain Attenuation (horizontal) in dB/km for p = 0.001% where Rp =180 mm/hr**	**Specific Rain Attenuation (vertical) in dB/km for p = 0.001% where Rp =180 mm/hr**	**Specific Rain Attenuation (circular) in dB/km for p = 0.001% where Rp =180 mm/hr**	**Specific Rain Attenuation (horizontal) in dB/km for p = 0.01% where Rp =95 mm/hr**	**Specific Rain Attenuation (vertical) in dB/km for p = 0.01% where Rp =95 mm/hr**	**Specific Rain Attenuation (circular) in dB/km for p = 0.01% where Rp =95 mm/hr**
1	10	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092
2	19	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092
3	29	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092
4	39	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092
5	49	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092
6	59	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092
7	69	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092
8	79	8.32518	6.22592	7.23368	3.72809	2.86296	3.28092

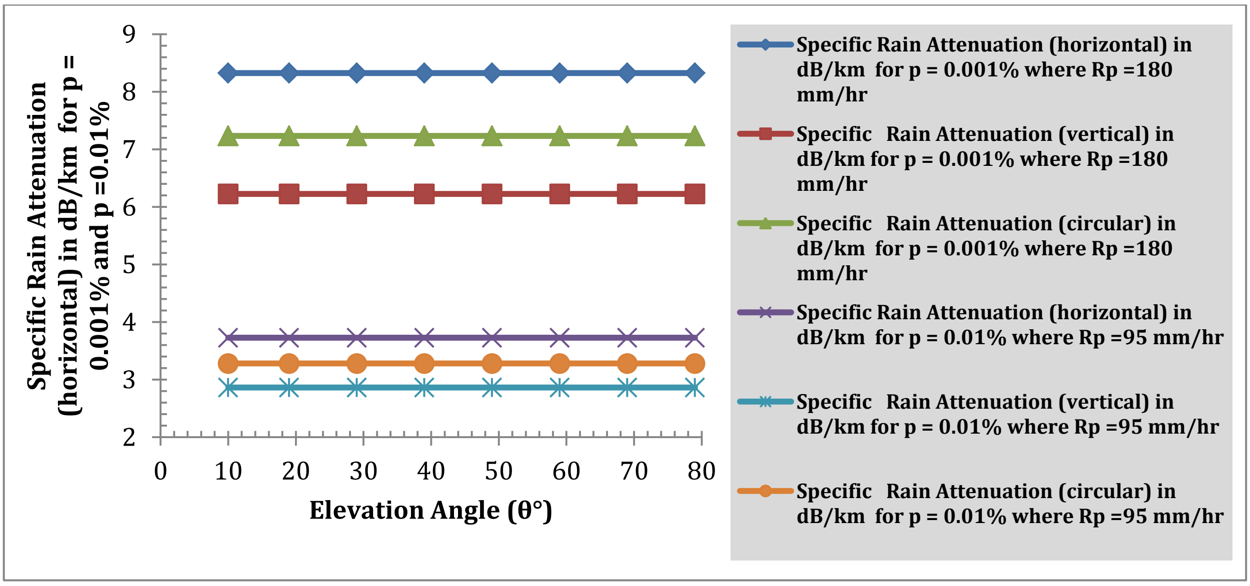

Figure 3 The results of specific rain attenuation in dB/km for p = 0.001% where Rp =180 mm/hr and for p = 0.001% and p = 0.01% for the selected elevation angles

The results of rain attenuation in dB for p = 0.001% where Rp =180 mm/hr are presented in Table 5 and Figure 4 for various elevation angles. The results in Table 4 and Figure 3 show that for any given polarization category (horizontal, vertical and circular), the rain attenuation decreases as the elevation angle increase. Also, the rain attenuation is lowest for the vertical polarization and highest for the horizontal polarization.

The results of rain attenuation in dB for the vertical polarization computed for various values of P and for the selected elevation angles are presented in Table 6 and Figure 5. The results in Table 6 and Figure 4 show that for the vertical, the rain attenuation decreases as the elevation angle increase. Also, the rain attenuation decreases as P increases.

Table 5 The results of rain attenuation in dB for p = 0.001% where Rp =180 mm/hr for the selected elevation angles

Elevation Angle (θ°)	Rain Attenuation (horizontal) in dB for p = 0.001% where Rp =180 mm/hr	Rain Attenuation (vertical) in dB for p = 0.001% where Rp =180 mm/hr	Rain Attenuation (circular) in dB for p = 0.001% where Rp =180 mm/hr
10	80.92154	60.51649	70.3121
19	61.57539	46.04863	53.50237
29	49.23689	36.82139	42.78155
39	41.66107	31.15587	36.19898
49	36.75418	27.4863	31.93542
59	33.52747	25.07323	29.13176
69	31.46715	23.53244	27.34156
79	30.29651	22.65699	26.3244

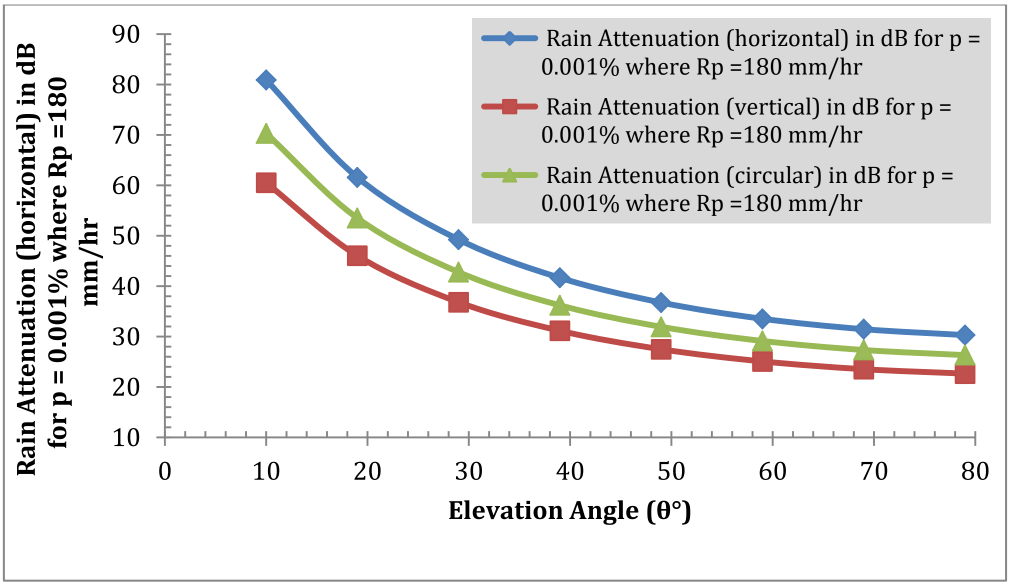

Figure 4 The results of rain attenuation in dB for p = 0.001% where Rp =180 mm/hr for the selected elevation angles

Table 6 The results of rain attenuation in dB for the vertical polarization computed for various values of P and for the selected elevation angles

Elevation Angle (θ°)	Rain Attenuation (vertical) in dB/km for p = 0.001%	Rain Attenuation (vertical) in dB/km for p = 0.01%	Rain Attenuation (vertical) in dB/km for p = 0.1%	Rain Attenuation (vertical) in dB/km for p = 1%
10	60.51649	40.53237	17.76564	2.18864
19	46.04863	27.80724	10.60506	1.16060
29	36.82139	20.92217	7.45532	0.77770
39	31.15587	17.08357	5.87251	0.59850
49	27.48630	14.73746	4.95899	0.49878
59	25.07323	13.25054	4.39974	0.43902
69	23.53244	12.32325	4.05840	0.40300
79	22.65699	11.80385	3.86963	0.38323

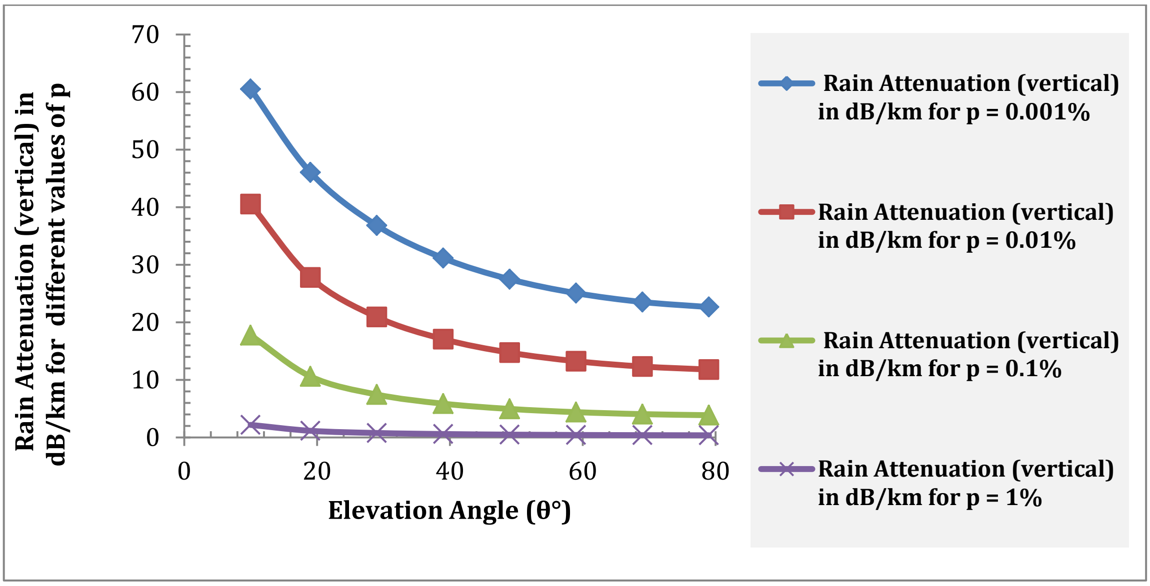

Figure 5 The results of rain attenuation in dB for the vertical polarization computed for various values of P and for the selected elevation angles

4. Conclusion

Analysis of rain attenuation for a sun-synchronous satellite link and the impact of different parameters on the rain attenuation are presented. The case study satellite is NigeriaSat-2. An online satellite tracking tool was used to obtain the elevation angle of the satellite at different times in its orbital repeat period. The results for the case study satellite showed that the vertical polarization has the lowest attenuation and that both elevation angle and rain rate affect the rain attenuation.

References

1. Pelton, J. N. (2019). Key trends in remote-sensing satellite systems and services. In *Space 2.0* (pp. 31-45). Springer, Cham.
2. Sokol, G., Kotlov, V., Khorischenko, O., Davydova, A., & Heti, K. (2017, April). Using Spacecraft in Climate and Natural Disasters Registration. In *EGU General Assembly Conference Abstracts* (p. 8691).
3. Chizea, F. D. (2017). *Construction of X/S Band for Nigeriasat-2 Mission Control Centre and Validation of Data From the Satellite* (Doctoral dissertation).
4. Maguire, D. (2021). A Comprehensive Roadmap to 50 Years of (Satellite) Earth Observation Resources for the Island of Ireland (1972–2023). *Irish Geography*, *52*(1), 49.
5. Froehlich, A., & Siebrits, A. (2019). African Union Member States: National Space Infrastructure, Activities, and Capabilities. In *Space supporting Africa* (pp. 191-272). Springer, Cham.
6. Chizea, F. D. (2017). *Construction of X/S Band for Nigeriasat-2 Mission Control Centre and Validation of Data From the Satellite* (Doctoral dissertation).
7. Schklar, D. (2017). Master thesis: OUFTI-Next Nanosatellite: Feasibility Study and Mission Assessment.
8. Ikpaya, I. O., Onuh, S. O., Achem, C. U., Okehie, B. M., & Madalla, F. Y. (2017). Pursuit of Nigeria into Space for Sustainable Development. In *Space Operations: Contributions from the Global Community* (pp. 233-251). Springer, Cham.
9. UJA, E., EQUERE, U., & POPOOLA, J. (2019). REMOTE SENSING, A TOOL FOR EROSION STUDY: A CASE STUDY OF NEKEDE AND ITS ENVIRONS. *REMOTE SENSING*, *5*(12).
10. Chizea, F. D., Umunna, R. J., & Ovie, E. O. (2019). NASRDA's Experience in Human Capacity Development and Capability Accumulation in Satellite Technology. *Advances in Sciences and Humanities*, *5*(3), 70.
11. Rabiu, B. (2018). Space unites the world. *World Space Week. National Space Research and Development Agency, Obasanjo Space Centre, Abuja, Nigeria*, *10*.
12. Paek, S. W., Kronig, L. G., Ivanov, A. B., & de Weck, O. L. (2018). Satellite constellation

design algorithm for remote sensing of diurnal cycles phenomena. *Advances in Space Research*, *62*(9), 2529-2550.

13. Gupta, R. P. (2018). Important Spaceborne Missions and Multispectral Sensors. In *Remote Sensing Geology* (pp. 61-86). Springer, Berlin, Heidelberg.
14. Szantai, A., Audouard, J., Forget, F., Olsen, K. S., Gondet, B., Millour, E., ... & Bibring, J. P. (2021). Martian cloud climatology and life cycle extracted from Mars Express OMEGA spectral images. *Icarus*, *353*, 114101.
15. Darack, E. (2019). Spying From Above: How the Atmosphere Helped Shape Our Modern Surveillance Systems. *Weatherwise*, *72*(6), 14-25.
16. Lozhkin, D. (2020). Analysis of Spatiotemporal Variability of Surface Temperature of Okhotsk Sea and Adjacent Waters Using Satellite Data. In *Satellite Systems-Design, Modeling, Simulation and Analysis*. IntechOpen.
17. Nwosu, C. B. (2018). SATELLITE GAME SERVER: OVERVIEW AND ANALYSIS.
18. Zahid, E. (2019). *Building a Low-Cost Ground Station for Weather Satellite Image Reception* (Master's thesis, UiT Norges arktiske universitet).
19. Okon, E. O. (2018). Space-Base Disaster Management and Poverty Reduction in Nigeria. *American International Journal of Social Science Research*, *2*(1), 39-51.
20. Chizea, F. D. (2017). *Construction of X/S Band for Nigeriasat-2 Mission Control Centre and Validation of Data From the Satellite* (Doctoral dissertation).
21. Fadil, S., & Abuhamoud, N. (2020, September). Link Analysis Model for Direct Broadcast Satellites Case of study: Benghazi and Sebha. In *Proceedings of the 6th International Conference on Engineering & MIS 2020* (pp. 1-7).
22. Uijlenhoet, R., Overeem, A., & Leijnse, H. (2018). Opportunistic remote sensing of rainfall using microwave links from cellular communication networks. *Wiley Interdisciplinary Reviews: Water*, *5*(4), e1289.
23. Alfattani, S., Jaafar, W., Hmamouche, Y., Yanikomeroglu, H., & Yongaçoglu, A. (2020). Link budget analysis for reconfigurable smart surfaces in aerial platforms. *arXiv preprint arXiv:2008.12334*.
24. Debnath, A. (2021). Ka-Band signal propagation experiment at NESAC Umiam. *Indian Journal of Radio & Space Physics (IJRSP)*, *49*(1-2), 42-47.
25. Maitra, A., De, A., & Adhikari, A. (2019). Rain and rain-induced degradations of satellite links over a tropical location. *IEEE Transactions on Antennas and Propagation*, *67*(8), 5507-5518.
26. Pinto-Mangones, A. D., Pérez-García, N. A., Torres-Tovio, J. M., Ramírez, E. J., Castaño-Rivera, S. O., Velez-Zapata, J., ... & Rujano-Molina, L. M. (2019). Rainfall rate and rain attenuation contour maps for preliminary “Simon Bolivar” satellite links planning in Venezuela. *Dyna*, *86*(209), 30-39.
27. Islam, M. R., Budalal, A. A. H., Habaebi, M. H., Badron, K., & Ismail, A. F. (2017, November). Performance analysis of rain attenuation on earth-to-satellite microwave links design in Libya. In *IOP Conference Series: Materials Science and Engineering* (Vol. 260, No. 1, p. 012041). IOP Publishing.
28. Yuan, F., Lee, Y. H., Meng, Y. S., Manandhar, S., & Ong, J. T. (2019). High-Resolution ITU-R Cloud Attenuation Model for Satellite Communications in Tropical Region. *IEEE Transactions on Antennas and Propagation*, *67*(9), 6115-6122.
29. Kalaivaanan, P. M., Sali, A., Abdullah, R. S. A. R., Yaakob, S., Singh, M. J., & Al-Saegh, A. M. (2020). Evaluation of ka-band rain attenuation for satellite communication in tropical regions through a measurement of multiple antenna sizes. *IEEE Access*, *8*, 18007-18018.
30. Hossain, M. S., & Islam, M. A. (2017, February). Estimation of rain attenuation at EHF bands for earth-to-satellite links in Bangladesh. In *2017 International Conference on Electrical, Computer and Communication Engineering (ECCE)* (pp. 589-593). IEEE.
31. Usha, A., & Karunakar, G. (2021). Preliminary analysis of rain attenuation and frequency scaling method for satellite communication. *Indian Journal of Physics*, *95*, 1033-1040.