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Rain Fade on Satellite Transmission in Warri, Benin, and Abuja, Nigeria

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ABSTRACT

Rain-induced attenuation (rain fade) is one of the most significant atmospheric propagation impairments affecting the performance and reliability of satellite communication systems operating at frequencies above 10 GHz, particularly in tropical regions characterized by intense precipitation. This study investigates the impact of rainfall on satellite signal propagation in three representative Nigerian locations, Warri, Benin, and Abuja, to evaluate spatial and temporal rainfall variability and its implications for satellite communication link performance. Rainfall data for the period 2020–2021 were obtained from the Nigerian Meteorological Agency (NiMet) and analyzed using rainfall classification based on rain-rate intensity. Rain events were categorized as drizzle, widespread rain, showers, thunderstorms, and monthly rainfall accumulation; rainfall-type distribution, and frequency of occurrence were statistically analyzed in Microsoft Excel. The study further assessed the suitability of established rain attenuation prediction models, including the ITU-R P.618 model, for tropical propagation environments.

The results reveal pronounced geographical variations in rainfall characteristics, with the coastal cities of Warri and Benin recording significantly higher annual rainfall accumulations (2,670–2,842 mm and 2,018–2,313 mm, respectively) than Abuja (1,326–1,380 mm). Peak rainfall occurred during the wet season, with exceptionally high precipitation recorded in August 2021, contrary to the traditionally expected August break. Stratiform rainfall constituted the dominant rainfall type across all locations, accounting for approximately 65–85% of total rainfall by volume and frequency, thereby producing prolonged periods of background attenuation that reduce satellite link availability and Quality of Service (QoS). Although convective rainfall events (showers and thunderstorms) occurred less frequently, they generated higher rain rates that produced severe, short-duration signal fading capable of exceeding conventional fade margins, particularly in the coastal regions.

The findings demonstrate that rain fade over Nigeria exhibits strong spatial and interannual variability, making generalized global prediction models insufficient without local calibration. The study establishes that coastal satellite earth stations are considerably more vulnerable to rain-induced signal degradation than inland stations due to higher rainfall intensity and more frequent convective events. Consequently, reliable satellite communication system design in tropical environments requires location-specific rainfall statistics, adaptive fade mitigation techniques, increased fade margins for coastal regions, and site diversity strategies. The outcomes of this research provide valuable localized propagation data that can improve rain attenuation prediction, satellite link budgeting, and the overall reliability of high-frequency satellite communication systems operating in Nigeria and similar tropical climates.

Keywords: Fade, Rainfall, Satellite, Communication, and Frequency

INTRODUCTION

Satellite communication has become an indispensable component of modern telecommunication systems, supporting a wide range of services including television broadcasting, broadband internet, navigation, disaster management, and remote sensing [1]. The increasing demand for high-speed data transmission has led to the adoption of higher frequency bands such as Ku-band (12–18 GHz) and Ka-band (26–40 GHz), which offer wider bandwidth and improved data capacity [2]. However, signal propagation between earth stations and satellites is highly susceptible to atmospheric conditions, particularly rainfall [3].

Rainfall attenuates electromagnetic waves through absorption and scattering, leading to signal fading, especially in higher-frequency bands such as Ku-band and Ka-band [4]. When electromagnetic waves pass through rain, they experience attenuation due to absorption and scattering by raindrops [5]. The Southern region of Nigeria experiences heavy and prolonged rainfall due to its tropical climate, making it a critical area for studying rain-induced attenuation [6]. This phenomenon, known as rain attenuation, leads to signal degradation, reduced signal-to-noise ratio (SNR), and in severe cases, complete communication outages.

Nigeria, particularly the southern region, is characterized by a tropical climate with high rainfall intensity and long rainy seasons. The Southern Region, including Warri and Benin, experiences significant rainfall throughout the year, making it highly vulnerable to rain-induced signal attenuation [6]. This presents a major challenge for the design and operation of reliable satellite communication systems in the region [7].

Accurate estimation of rain attenuation is essential for:

- Designing reliable satellite links
- Determining appropriate fade margins
- Optimizing system performance
- Ensuring quality of service (QoS)

To address these challenges, several empirical and theoretical models have been developed, including the widely used ITU-R P.618 model [8]. However, these models provide a global framework for predicting rain attenuation; their accuracy may be limited when applied to specific local climates such as those found in Southern Nigeria [9].

This study aims to estimate the rain fade on satellite transmission in the Southern States of Nigeria using conventional models. The findings will contribute to improved system design and enhanced reliability of satellite communication systems in tropical environments.

Review of the Rain Attenuation Models

The [12] model enjoys widespread global acceptance, and consequently, emerging models are often benchmarked against it to assess their reliability. This is particularly valuable in situations where actual measured data are unavailable, as highlighted by [14].

To calculate slant-path rain attenuation using point rainfall rate, the following parameters are essential:

$R_{0.01}$: point rainfall rate for the location for 0.01% of the average year (mm/h)

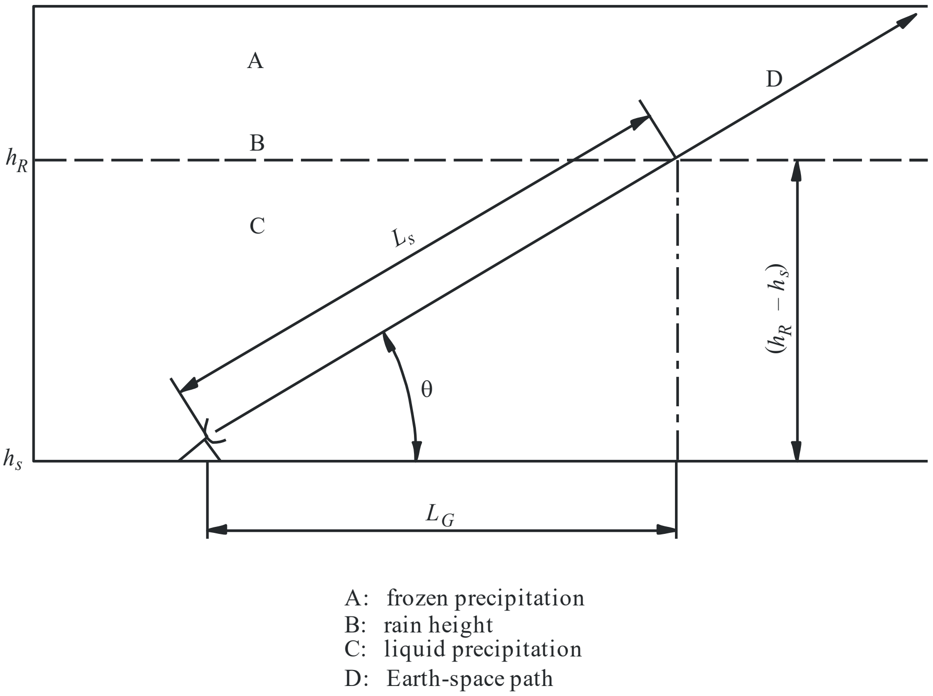
h_s: height above mean sea level of the earth station (km)

θ: elevation angle (degrees)

ϕ: the latitude of the ground station, in degrees N and S, *F*: the frequency of operation in GHz

R_e: effective radius of the earth (8500 km), The procedure for step-by-step calculation of the model is as follows

The step-by-step process for computing the model unfolds as follows:



Source: as depicted in ITU-R P.618-12 (2015).

Figure 1. illustrates the slant path through rain,

Step 1: Determination of the rain height h_R, as given in Recommendation [11].

Step 2: For $\theta \geq 5^{\circ}$ compute the slant-path length, L_s, below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \qquad \text{km} \qquad (1)$$

For $\theta \leq 5^{\circ}$. The following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{\frac{1}{2}} + \sin\theta} \qquad \text{km} \quad (2)$$

Step 3: Calculate the horizontal projection, L_G, of the slant-path length from:

$$L_G = L_s \cos\theta \qquad km \qquad (3)$$

Step 4: Obtain the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min). If this long-term statistic cannot be obtained from local data sources, an estimate can be obtained from the maps of rainfall rate given in Recommendation by [11].

Step 5: Obtain the specific attenuation γ, using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma = cR_{0.01}^{d} \qquad \frac{\text{dB}}{\text{km}} \qquad (5)$$

c and d are regression coefficients that depend on the drop shape of the falling rain, raindrop density, polarization, and frequency. These regression coefficients are computed by using ITU-R P. 838-3 2007 as:

$$c = \frac{[c_H + c_V + (c_H - c_V)\cos^2\theta \cos 2\tau]}{2} \quad (6)$$

$$d = \frac{[c_H d_H + c_V d_V + (c_H d_H - c_V d_V)\cos^2\theta \cos 2\tau]}{2c} \quad (7)$$

García-López Attenuation Model

As described in the study by García-López and colleagues [13], devised a rain attenuation model for satellite links as an expansion of the model initially designed for terrestrial links. The original model was developed based on measurements conducted over satellite links in various regions, including Europe, the United States, Japan, and Australia. Notably, for tropical countries, specific coefficients used in the attenuation calculations are provided separately, as indicated by [16].

Rain attenuation, denoted as A (dB), in a satellite link is determined through the following formula:

$$A = \frac{KR_p^{\alpha} L_s}{\left\{a + \left[\frac{(bR + cL_s + d)}{e}\right]\right\}} \quad (8)$$

Here, L_S signifies the equivalent path length, measured in kilometers, and it is determined as follows:

$$L_s = \frac{H_R - H_s}{Sin\theta} \qquad For\ \theta \geq 5° \quad (9)$$

$$H_R = 4 \text{ km } for\ 0 < |\lambda| < 36° \quad (10)$$

$$H_R = 4 - 0.075(|\lambda| - 36°)\ km \quad for\ |\lambda| < 36° \quad (11)$$

The coefficients *a*, *b*, *c*, and *d* are constants typically determined empirically and can be established using regression techniques. The coefficient e serves as a scaling factor. When e is set to 10^4, the coefficients applicable on a global scale are as follows: *a* = 0.7, *b* = 18.35, *c* = - 16.51, and *d* = 500 [17]. For tropical climates, a = 0.72, b = 7.6, c = -4.75, and d = 2408 [15]. λ represents the latitude of the Earth station in degrees, R denotes the point rainfall intensity in mm/h, *k* and α these coefficients that depend on the frequency, polarization, and elevation angle.

Svjatogor Attenuation Model

Svjatogor [16] derived an attenuation model whose effective rain height, *Hr* depends on the rain intensity. The rain height is given as

$$H_R = \frac{2.7}{\log_{10}(0.3R_p + 1.5)} + 0.0015R_P \quad (km) \quad (12)$$

The factor that represents the reduction in path length is articulated as:

$$k_{rs} = e^{Y}; \quad Y = -0.0045R_p^{0.68}\left[\frac{H_R}{\tan\theta}\right]^{0.6} \quad (13)$$

The rain attenuation is subsequently expressed as:

$$A(\text{dB}) = KR_p^{\alpha} L_s k_{rs} \quad (14)$$

Where:

$$L_s(km) = \frac{H_R - H_S}{Sin\theta} \quad for\ \theta \geq 5° \tag{15}$$

$$L_s = \frac{2(h_R - h_S)}{\left(sin^2\theta + \frac{2(h_R - h_S)}{R_e}\right)^{\frac{1}{2}} + sin\,\theta} \quad for\theta \geq 5° \tag{16}$$

R_e represents the effective radius of the Earth, which is assumed to be 8500 km

METHODOLOGY

The Data Source and Analysis

Nigerian Meteorological Agency (NIMET) provided the rain data utilized in this study, which aims to create a real-time network of meteorological and climatological observation stations spread throughout Nigeria using telemetry technology with five-minute update cycles. The air temperature (°C), atmospheric pressure (mb), relative humidity (%), wind speed (ms^{-1}), wind direction (°*N*), soil moisture (%), soil temperature (°*C*), total precipitation accumulation (mm), and rain rate (mm/h) are some of the characteristics that this apparatus measures. The following stations provided the data on total precipitation accumulation and rain rate. The following locations were carefully chosen: two from the south and one from the north-central part of Nigeria: Warri, Benin, and Auja.

Equipment

A representative piece of NIMET equipment, shown in the figure, is placed at each station to gather the rainfall data needed for the study. Sensors for measuring ambient factors, including temperature and humidity, a solar power system for a continuous power source, a measurement and control system, and a data logging system make up the equipment. Essentially, it is managed by software. This has improved the performance, accuracy, and precision of the linked devices. A tipping bucket rain gauge, measuring 146 mm in height, is used to monitor the intensity of rainfall at each location as part of the NIMET system. The rain gauge measures all of the previously listed characteristics and has a sensitivity of around 0.2 mm. It also includes a data gathering unit and additional sensors in one unit. Rainwater is gathered in a conventional funnel and sized into equal-sized droplets for use in the rain gauge measurement. Every 20 seconds, the quantity of droplets gathered is electronically tallied and averaged over five minutes. Every channel's AGC voltage is continually sampled, digitally recorded, and paired with the time and date of each rain gauge tip. Cleaning the capillary preserves the rain gauge's calibration. The gauge's overall great durability can be attributed to its straightforward drop-forming mechanism. Maintaining cleanliness is necessary to prevent dust particles from obstructing the free flow of water, which in turn ensures reliability [10].

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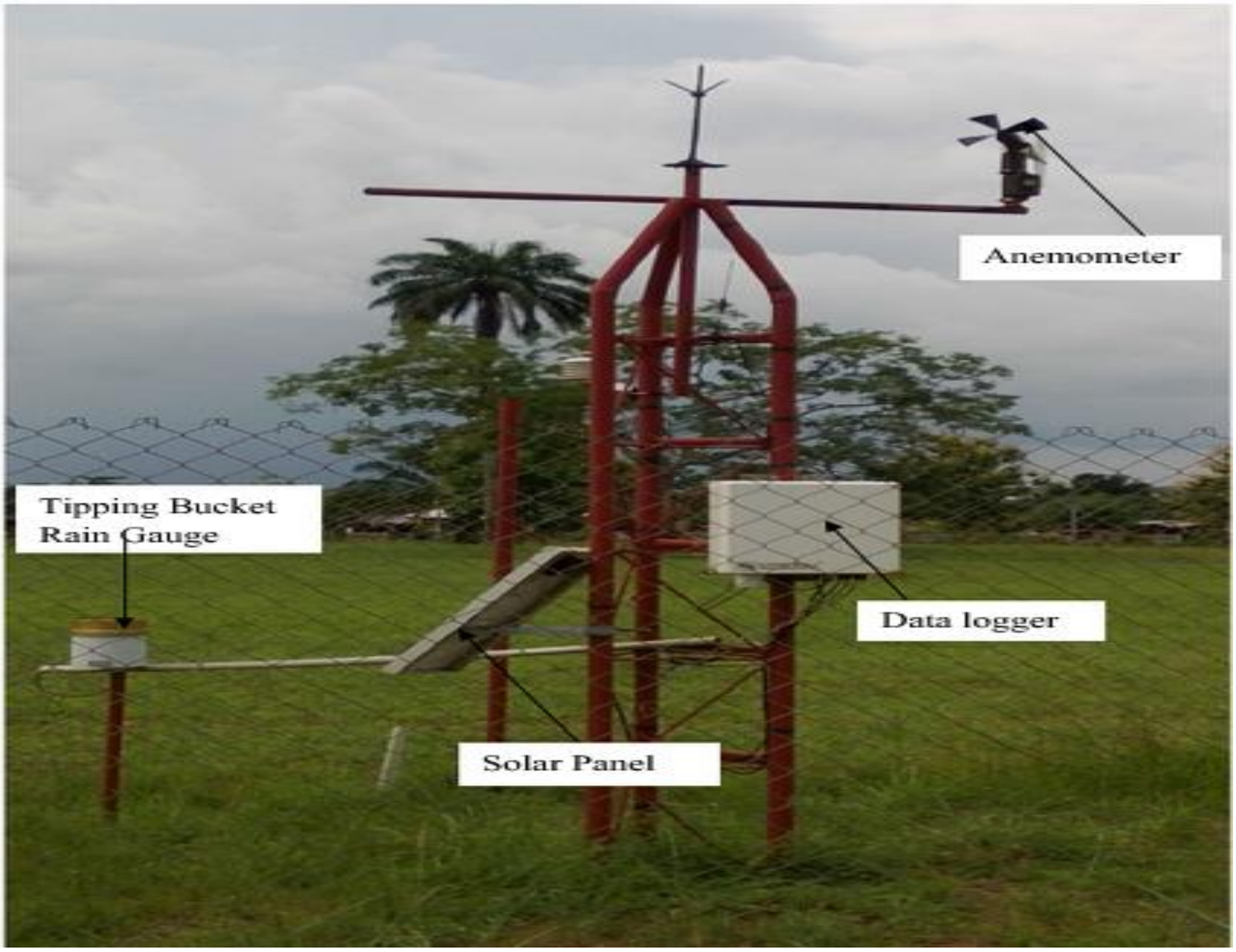

Figure 2. Example of NIMET data collection center Abuja.

Data Presentation and Analysis

Table 1: Categorization of Rainfall Pattern

Rain type	Range of rain rate (mm/h)
Drizzle	1 - 5
Widespread	5 - 25
Shower	25 - 50
Thunderstorm	50 above

The tables and figures in this study display the monthly rainfall totals and the prevalence of various rain types for specific periods. Specifically, the data covers two years, from 2020 to 2021, in Warri, Benin, and Abuja. These statistics are presented in Tables 2 to 6

Nigeria sees two principal seasons: the dry season (covering November, December, January, and February) and the wet season (including March, April, May, June, July, August, September, and October). Precipitation mostly occurs in the wet season, during which the Intertropical Convergence Zone (ITCZ) passes the country.

Table 2: Rainfall Type Statistics by Volume in Warri

Table. Monthly Volume of Rainfall by Rain Type in Warri (2020 and 2021)

Month	Warri 2020 Drizzles (mm)	Widespread (mm)	Shower (mm)	Thunderstorm (mm)	Total Volume (mm)	Rainy Days	Warri 2021 Drizzles (mm)	Widespread (mm)	Shower (mm)	Thunderstorm (mm)	Total Volume (mm)	Rainy Days
January	0.44	0.00	0.00	0.00	0.44	5	18.04	73.17	0.00	0.00	84.94	22
February	0.20	0.00	0.00	0.00	0.20	2	22.96	15.00	0.00	0.00	37.69	19
March	63.30	141.34	58.04	0.00	262.71	30	34.03	94.98	0.00	0.00	129.87	23
April	22.79	104.28	69.72	0.00	196.79	23	28.70	151.35	25.25	190.48	395.79	31
May	50.05	89.35	33.47	0.00	172.85	31	45.75	141.82	31.89	0.00	219.46	31
June	16.04	256.95	83.39	59.51	415.89	30	20.83	190.34	97.53	0.00	308.65	31
July	17.90	268.66	84.91	0.00	371.47	31	36.92	103.87	78.24	0.00	219.05	31
August	21.29	56.39	0.00	0.00	77.68	24	24.72	172.82	207.52	70.91	475.97	31
September	18.93	149.32	203.15	115.39	486.79	30	28.98	202.83	0.00	104.70	337.38	29
October	35.90	158.58	38.54	65.85	298.87	31	34.96	173.24	0.00	0.00	208.20	30
November	15.33	177.84	0.00	134.33	327.50	30	42.27	141.09	148.82	0.00	332.18	31
December	14.72	44.70	0.00	0.00	59.42	19	21.73	40.17	30.89	0.00	92.79	24
Total	**276.72**	**1447.41**	**571.22**	**375.08**	**2670.17**	**282**	**359.89**	**1500.68**	**620.14**	**366.09**	**2841.97**	**333**
Percentage (%)	**10.4**	**54.2**	**21.4**	**14.0**	**100**	—	**12.7**	**52.8**	**21.8**	**13.0**	**100**	—

Table 3: Rainfall Type Statistics by Volume in Benin

MONTH	Benin 2020						Benin 2021					
	VOLUME OF RAIN TYPE (mm)						VOLUME OF RAIN TYPE (mm)					
	Drizzles	Wide spread	Shower	Thunder storm	Total Vol. per month	No. of rainy days	Drizzles	Wide spread	Shower	Thunder storm	Total Vol. per day	No of rainy days
January	0.19	0.0	0.0	0.0	0.19	5	14.57	29.68	0.0	0.0	44.27	26
February	0.81	0.0	0.0	0.0	0.81	5	17.82	12.42	0.0	0.0	30.24	19
March	45.6	102	0.0	0.0	148.44	31	24.06	68.36	0.0	0.0	92.42	26
April	25.43	79.47	29.52	0.0	134.42	31	25.89	128.8	112.7	0.0	267.39	29
May	54.35	56.02	0.0	0.0	110.37	31	33.6	125.87	0.0	0.0	159.47	31
June	28.37	212.51	93.75	0.0	334.63	31	23.7	215.75	28.03	0.0	267.48	30
July	11.38	283.68	37.28	75.66	408	31	27.58	172.26	0.0	52.39	252.23	31
August	29.39	70.81	0.0	0.0	100.2	31	7.43	287.11	107.56	50	423.86	31
September	29.09	168.72	131.14	72.36	401.31	31	25.88	198.05	82.08	0.0	306.01	31
October	38.57	148.44	0.0	0.0	187.01	31	39.82	161.64	0.0	0.0	201.46	31
November	27.82	58.56	25	79.18	190.56	30	36.66	145.78	56.91	0.0	239.35	31
December	20.03	0.0	0.0	0.0	2.03	21	22.17	6.48	0.0	0.0	28.65	16
TOTAL	310.84	1180.21	316.69	227.2	2017.97	309	299.18	1552.2	387.28	102.39	2312.83	332
%	15.4	58.5	15.7	11.3	100%		13	67.1	16.7	4.4	100%	

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Table 4: Rain type statistics by volume in Abuja

MONTH	ABUJA 2020						ABUJA 2021					
	VOLUME OF RAIN TYPE (mm)						VOLUME OF RAIN TYPE (mm)					
	Drizzles	Wide spread	Shower	Thunder storm	Total Vol. per month	No. of rainy days	Drizzles	Wide Spread	Shower	Thunder storm	Total Vol. per month	No. of rainy days
January	0.0	0.0	0.0	0.0	0.0	0	0.01	0.0	0.0	0.0	0.01	1
February	0.03	0.0	0.0	0.0	0.0	1	0.41	0.0	0.0	0.0	0.41	4
March	8.08	24.72	0.0	0.0	0.03	21	5.87	21.12	0.0	0.0	26.99	18
April	12.74	78.55	32.77	0.0	32.8	27	9.21	42.52	0.0	0.0	51.7	23
May	39.14	119.86	0.0	0.0	124.04	31	45.42	21.3	0.0	0.0	66.72	31
June	41.74	156.7	0.0	0.0	159	30	29.1	160.36	53.37	0.0	242.83	30
July	20.04	173.38	130.18	0.0	198.44	31	27.67	136.31	27.59	0.0	191.57	31
August	55.05	83.22	0.0	0.0	323.6	31	36	180.09	115.29	0.0	331.38	31
September	67.09	177.57	58.21	0.0	138.28	30	37.51	126.9	58.99	0.0	223.4	31
October	35.65	61.23	0.0	0.0	302.87	26	63.7	42.69	27.83	0.0	149.08	31
November	4.48	0.0	0.0	0.0	96.88	9	22.18	19.33	0.0	0.0	41.51	23
December	0.01	0.0	0.0	0.0	4.48	1	3.92	0.0	0.0	0.0	3.92	6
TOTAL	284.05	875.23	221.16	0.0	0.0	238	277.08	750.62	283.07	0	1325.6	254
%	20.6	63.4	16.02	0.0	1380.42			56.6	23.4	0.0	100%	

Table 5: Frequency of Occurrence of Rain Types in Warri

Month	**Benin 2020 Drizzles**	**Widespread**	**Shower**	**Thunderstorm**	**Total Occurrences**	**Benin 2021 Drizzles**	**Widespread**	**Shower**	**Thunderstorm**	**Total Occurrences**
January	1	0	0	0	1	88	12	0	0	100
February	1	0	0	0	1	90	11	0	0	101
March	68	29	0	0	97	69	23	0	0	92
April	63	33	3	0	99	43	43	10	0	96
May	74	23	0	0	97	45	52	0	0	97
June	30	60	3	0	93	37	57	3	0	97
July	10	84	3	3	100	42	54	0	3	100
August	77	23	0	0	100	7	81	13	0	101
September	37	47	13	7	104	33	57	7	0	97
October	52	45	0	0	97	52	45	0	0	97
November	70	27	0	3	100	57	37	7	0	101
December	90	24	0	0	114	94	3	0	0	97
Total	**573**	**395**	**22**	**13**	**1003**	**657**	**475**	**40**	**3**	**1176**
Percentage (%)	**57.1**	**39.4**	**2.2**	**1.3**	**100**	**56.0**	**40.4**	**3.4**	**0.26**	**100**

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Table 6: Frequency of occurrence of rain types in Benin

	Drizzles	Wide spread	Showe r	Thunder storm	Total of Occurrences	Drizzles	Wide spread	Shower	Thunder storm	Total of Occurrences
January	1.00	0.00	0.0	0.0	1.00	81.00	19.00	0.00	0.00	100.00
February	1.00	0.0	0.0	0.0	1.00	90.00	16.00	0.00	0.00	106.00
March	62.00	32.00	7.00	0.00	101.00	81.00	19.00	0.00	0.00	100.00
April	60.00	33.00	7.00	0.00	100.00	43.00	43.00	3.00	10.00	99.00
May	61.00	36.00	3.00	0.00	100.00	48.00	48.00	3.00	0.00	99.00
June	17.00	70.00	10.00	3.00	100.00	33.00	53.00	10.00	0.00	96.00
July	16.00	74.00	10.00	0.00	100.00	61.00	32.00	7.00	0.00	100.00
August	81.00	16.00	0.00	0.00	97.00	19.00	58.00	19.00	3.00	99.00
Sept.	27.00	50.00	17.00	7.00	101.00	40.00	57.00	0.00	3.00	100.00
October	48.00	45.00	3.00	3.00	99.00	45.00	55.00	0.00	0.00	100.00
Nov.	50.00	43.00	0.00	7.00	100.00	53.00	33.00	17.00	0.00	103.00
Dec	76.00	24.00	0.00	0.00	100.00	79.00	26.00	5.00	0.00	110.00
TOTAL	499	423	57	20	1000	673	459	64	16	1212
%	50	42.3	5.7	2	100%	55.5	38	5.3	1.3	100%

Table 7: Frequency of occurrence of rain types in Abuja

MONTH	ABUJA 2020					ABUJA 2021				
	FREQUENCY OCCURRENCE OF RAIN TYPE (mm)					FREQUENCIES OF OCCURRENCE OF RAIN TYPE (mm)				
	Drizzles	Wide spread	Shower	Thunder storm	Total of occurrences	Drizzles	Wide spread	Shower	Thunder storm	Total of Occurren ces
January	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	1.00	0.00	0.00	0.0	1.00	1.00	0.00	0.00	0.00	1.00
March	86.00	14.00	0.00	0.0	100	79.00	16	0.00	0.00	95.00
April	54.00	43.00	4.00	0.00	101	75.00	17.00	0.00	0.00	97.00
May	68.00	32.00	0.0	0.0	100	87.00	13.00	0.00	0.00	100.00
June	53.00	47.00	0.00	0.00	100	43.00	47.00	7.00	0.00	97.00
July	36.00	52.00	13.00	0.0	101	45.00	48.00	7.00	0.00	100.00
August	71.00	29.00	0.00	0.00	100	39.00	52.00	10.00	0.00	101.00
September	45.00	42.00	7.00	0.00	94	43.00	47.00	7.00	0.00	97.00
October	69	27	0.00	0.00	96	83.00	16	0.00	0.00	99.00
November	1.00	0.00	0.00	0.00	1.00	52.00	13.00	0.00	0.00	65.00
December	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00
TOTAL	484	286	24	0.00	794	548	269	31	0.00	853
%	61	36	3	0.00	100%	64.2	31.5	3.6	0.00	100

RESULTS

The data from Tables 2 to 7, which span two years (2020 to 2021) and come from three distinct locations in Nigeria Warri, Benin, and Abuja were analyzed using a Microsoft Excel program. The results are shown in Figures 2 to 10

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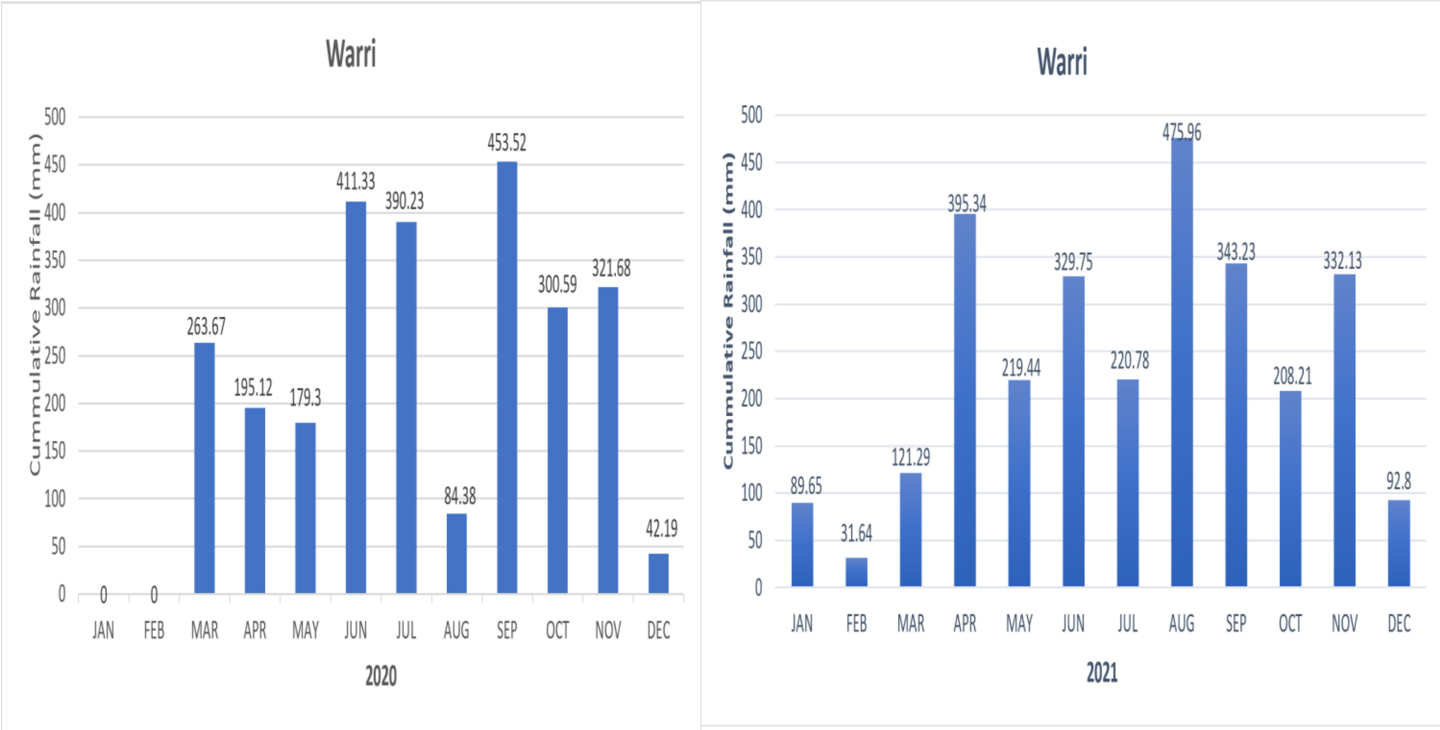

Figure 2: Accumulated monthly rainfall in Warri during the observed period.

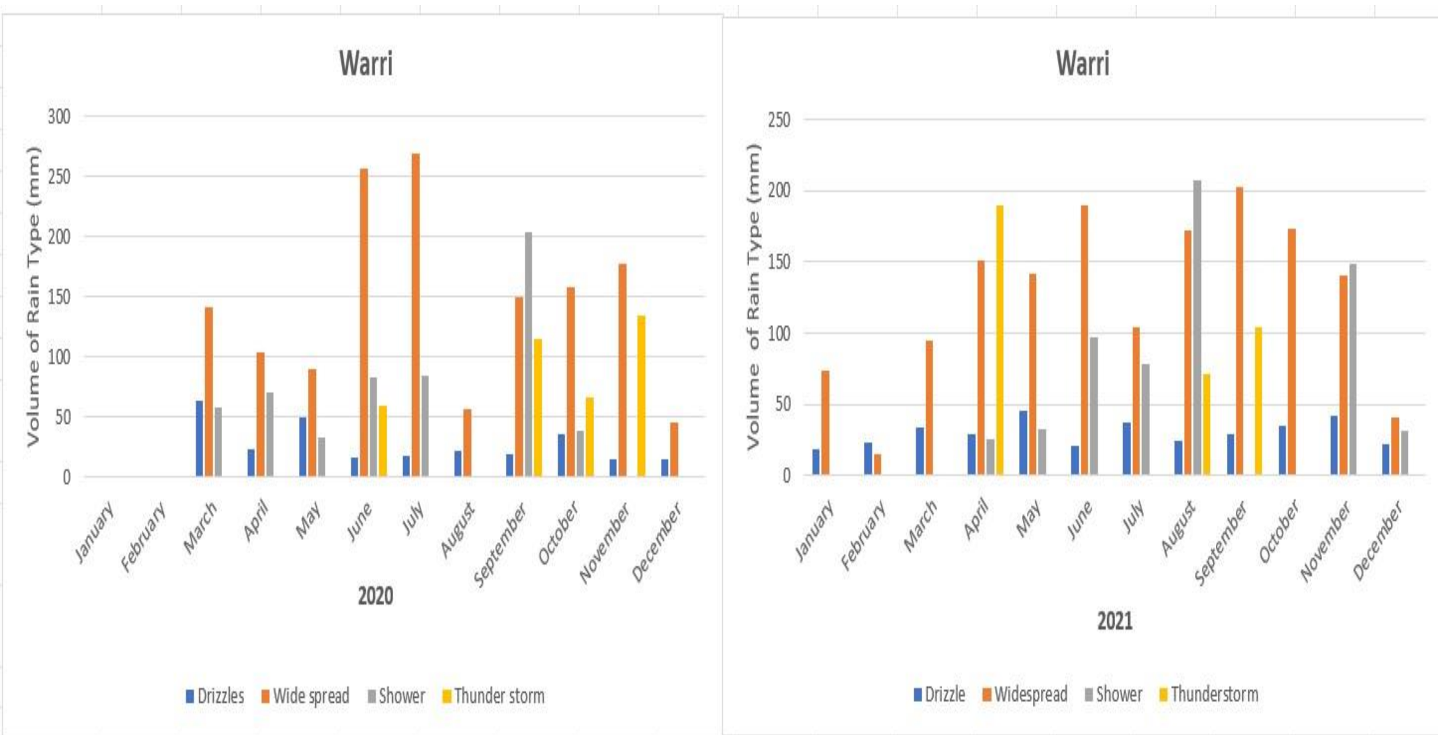

Figure 3: Monthly Rainfall Type Distribution (by volume) Warri during the observed period.

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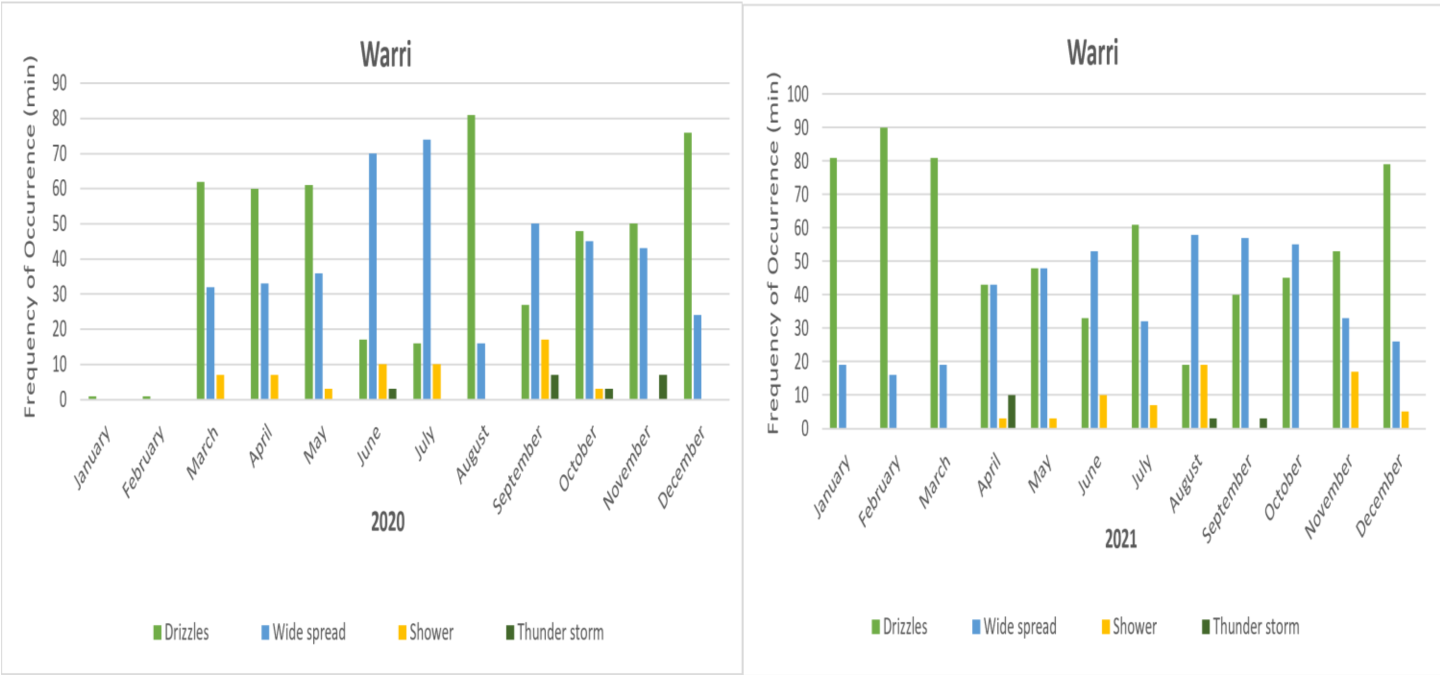

Figure 4: Occurrence Frequency of Rain Types in Warri during the observed period

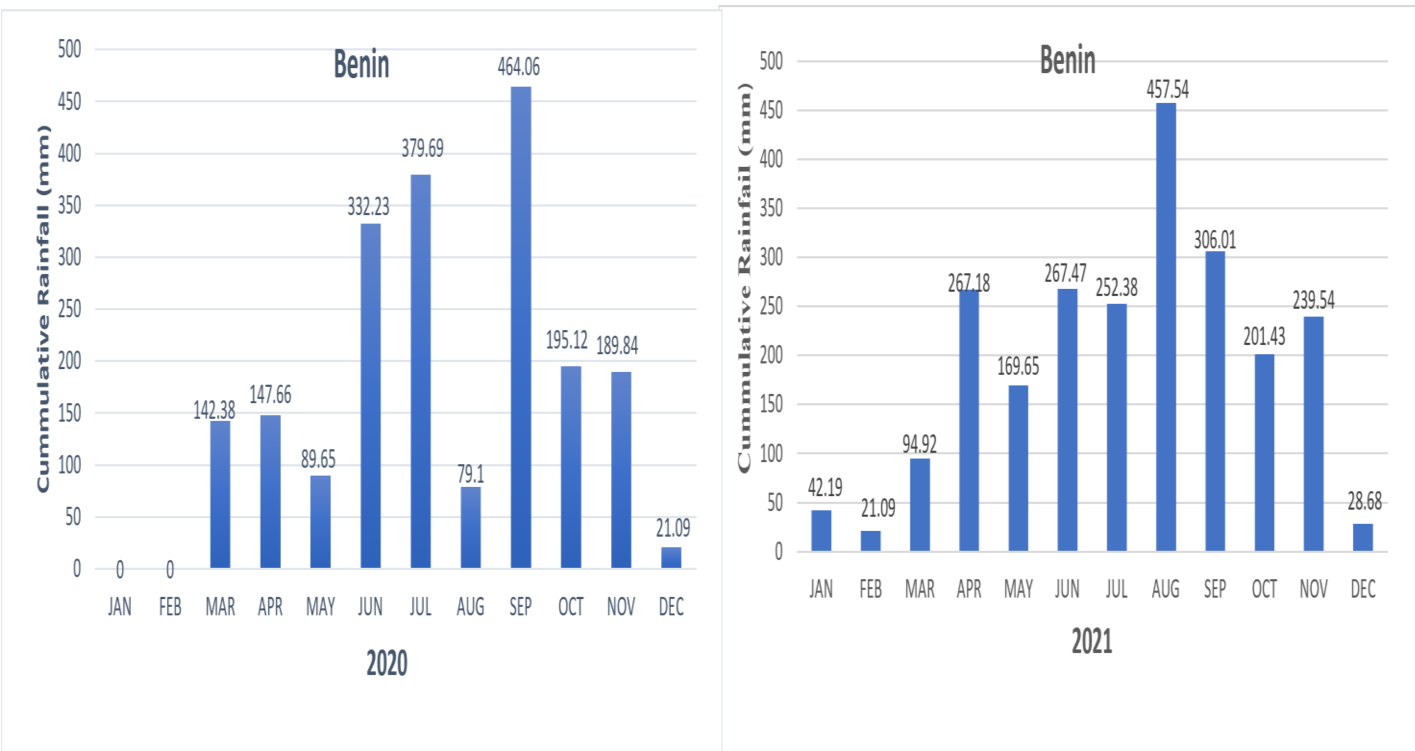

Figure 5: Monthly Rainfall Type Distribution (by volume) Benin during the observed period.

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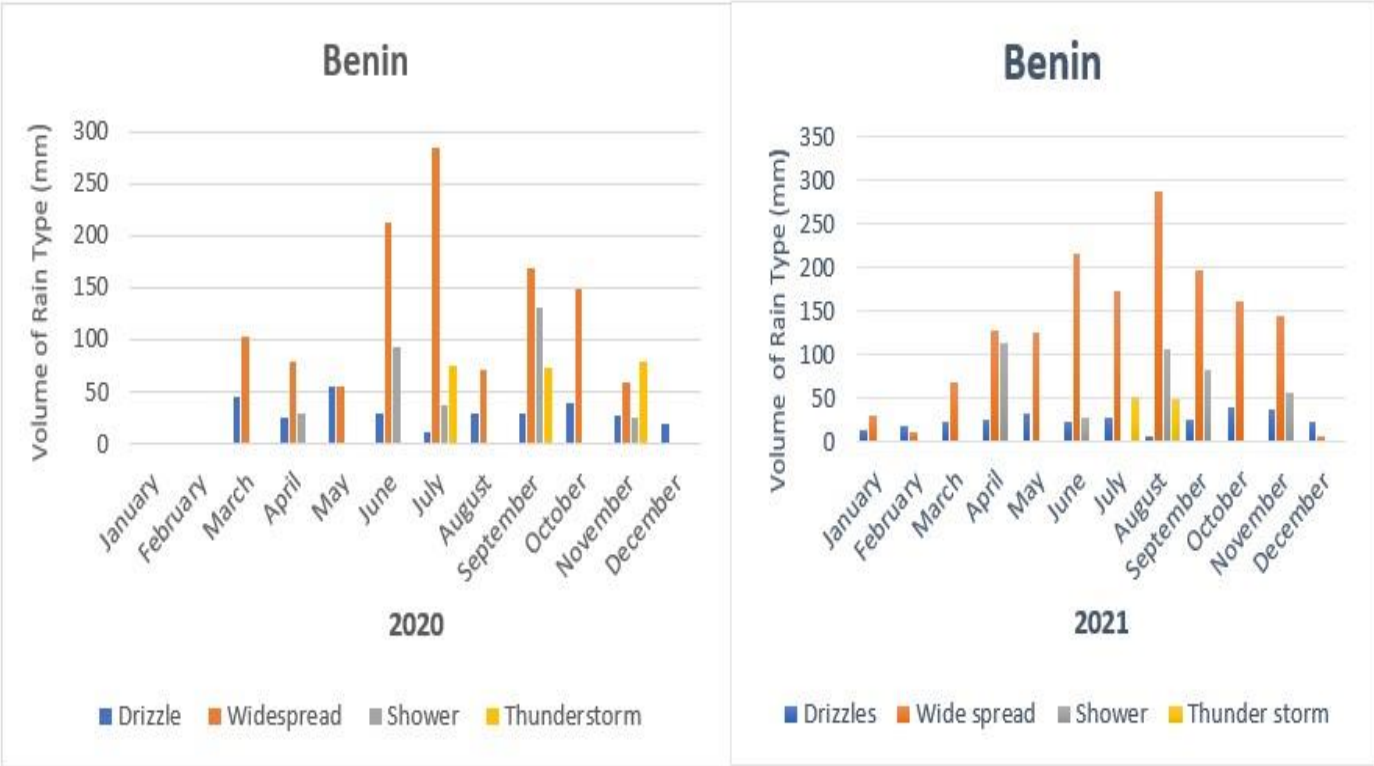

Figure 6: Monthly Rainfall Type Distribution (by volume) Benin during the observed period

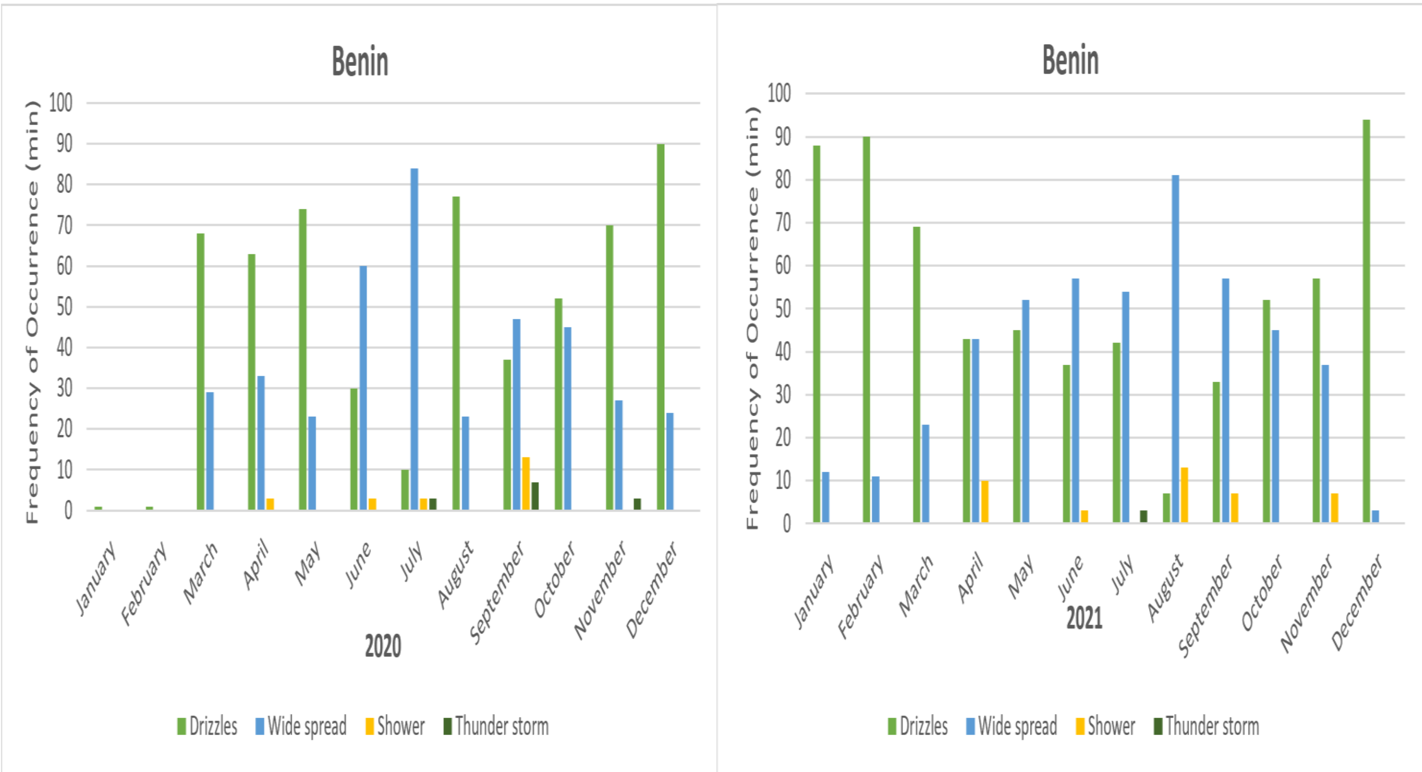

Figure 7: Frequency of Occurrence of Rain Types in Warri during the observed period.

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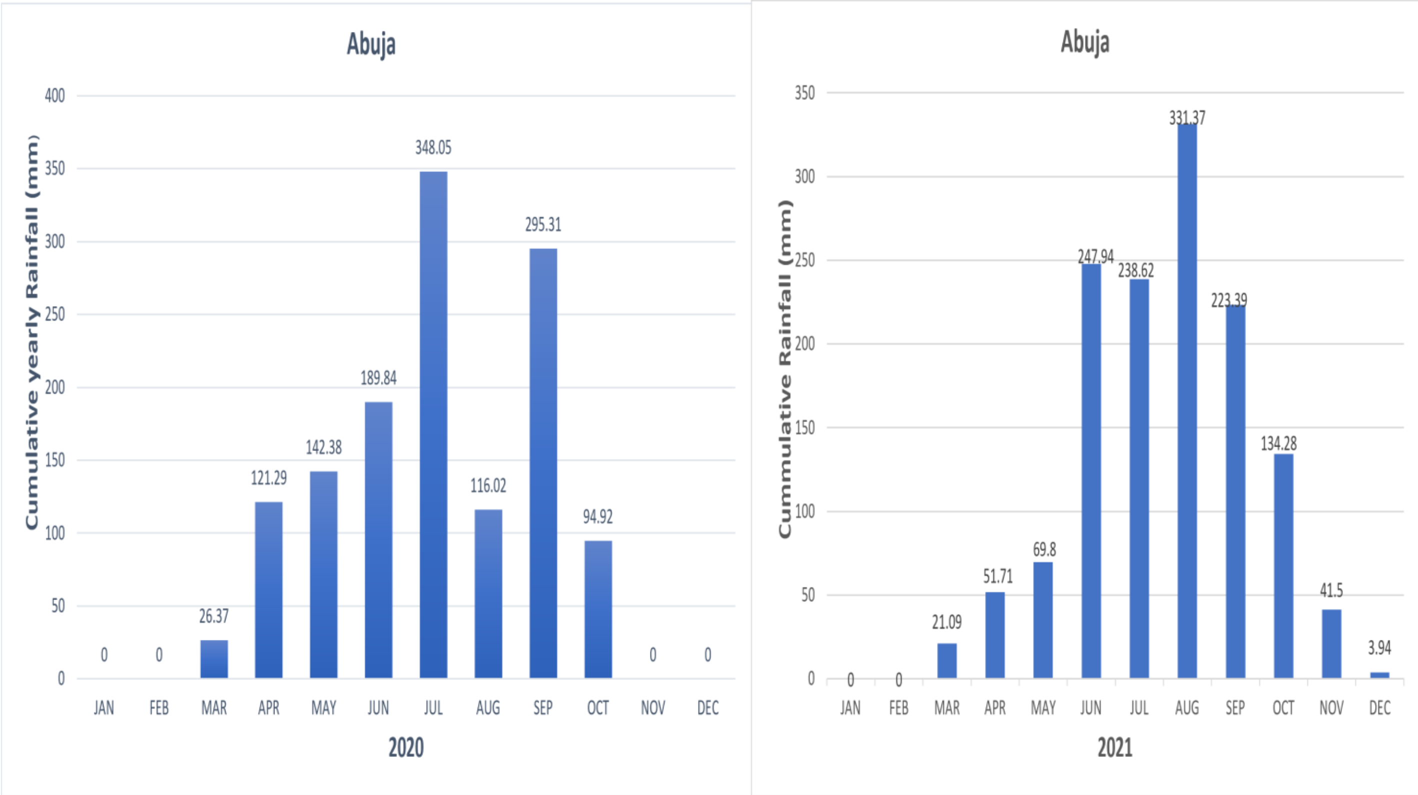

Figure 8: Accumulated monthly rainfall in Abuja during the observed period.

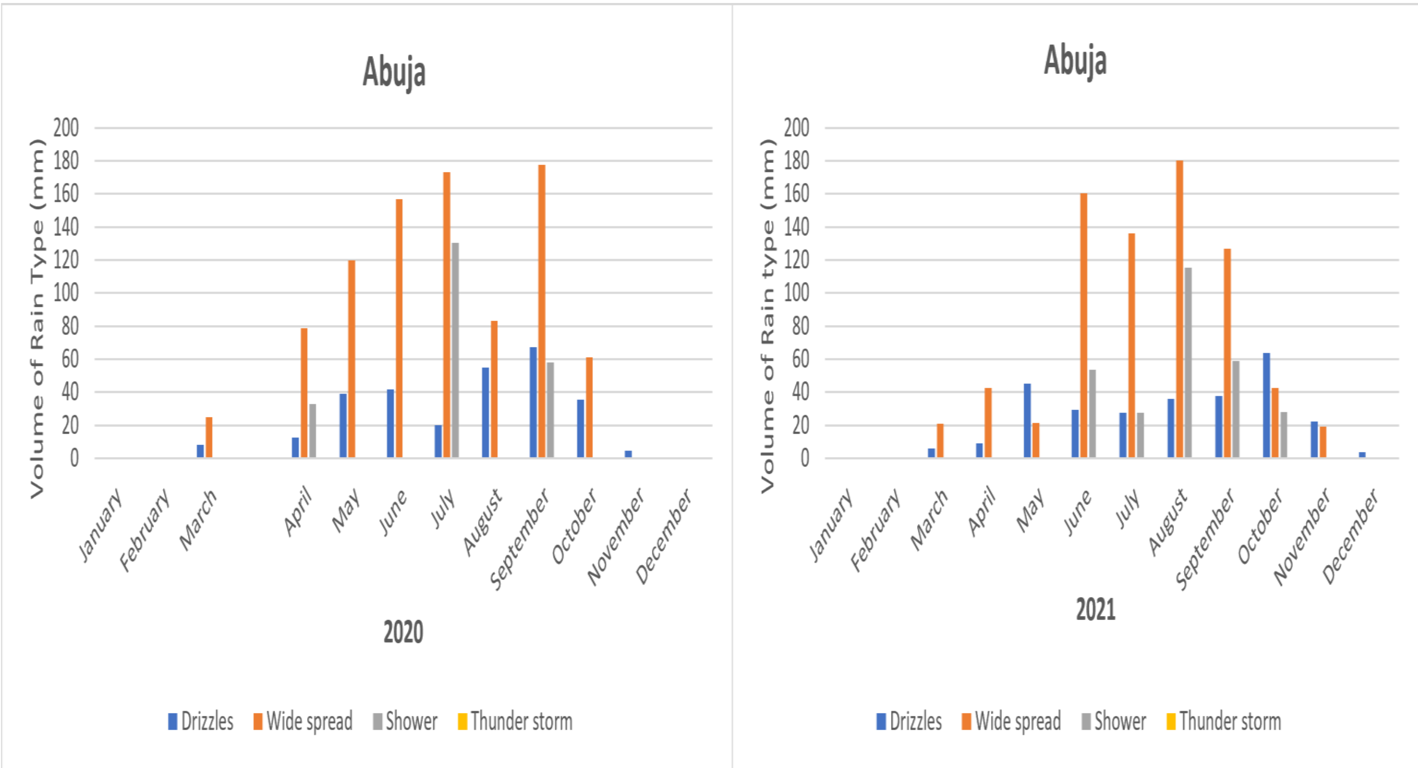

Figure 9: Monthly Rainfall Type Distribution (by volume) Abuja during the observed period.

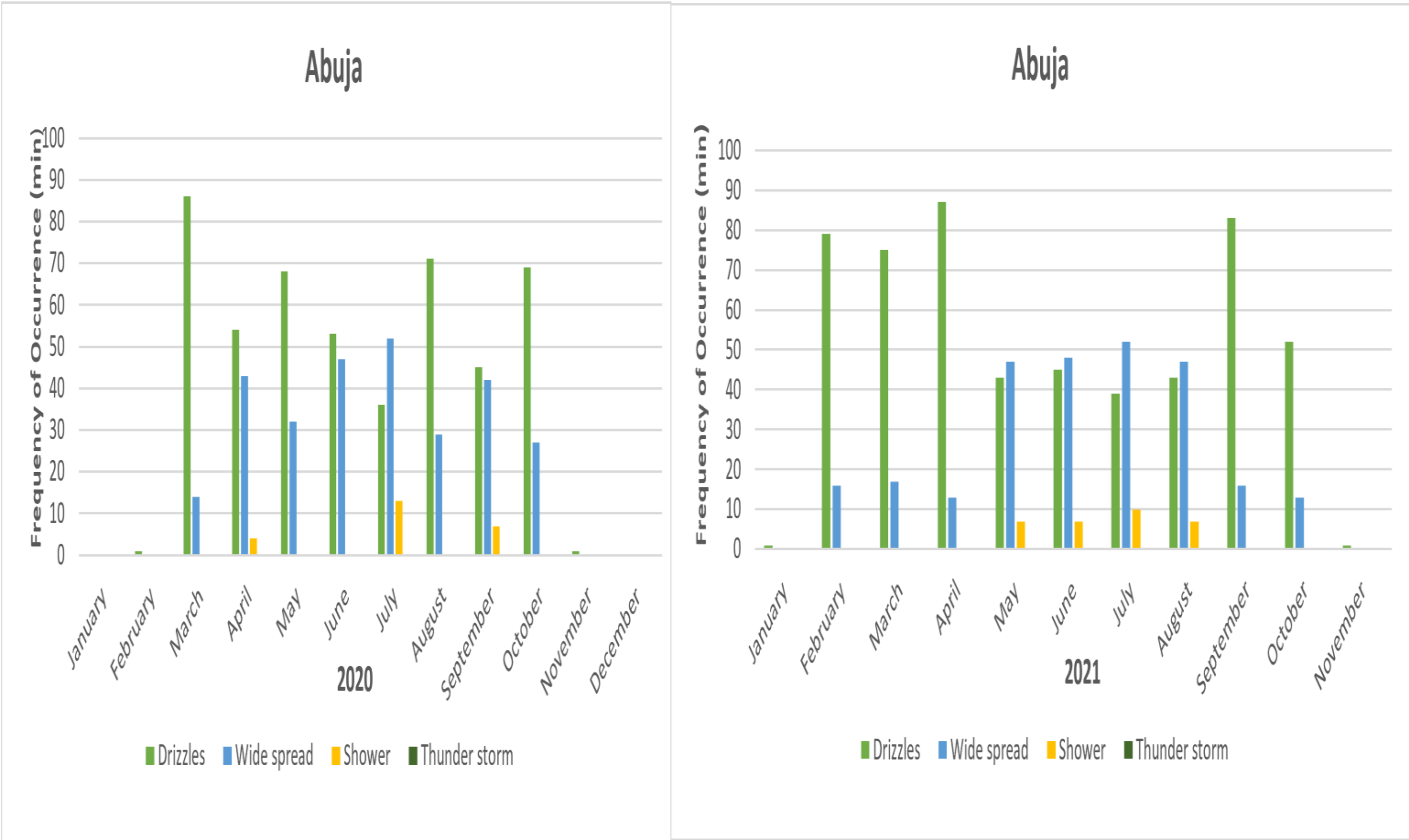

Figure 10: Frequency of Occurrence of Rain Types in Abuja during the observed period.

DISCUSSION

The dry season (spanning November, December, January, and February) and the wet season (encompassing March, April, May, June, July, August, September, and October). Precipitation predominantly occurs in the wet season, during which the Intertropical Convergence Zone (ITCZ) traverses the country. The data from Table 2 to Table 7 indicates that in Warri, the month of September recorded the greatest accumulation of approximately 454 mm in 2020, closely trailed by June with an accumulation of around 411 mm. Conversely, in 2021 at the same location, the peak monthly accumulation of roughly 476 mm was observed in August. The month in which a pause in rainfall is anticipated registered the highest monthly accumulation value in Warri in 2021. Nonetheless, in the year 2020, it was quite evident that there was a distinct August break. Figure 2 also illustrates that there was a higher amount of rainfall in 2021 compared to 2020, with approximately a 29% increase in Warri. This highlights the variability in rainfall rates that can occur at the same locations in different years.

In Benin during 2020, the months of September and July stood out with the highest values of approximately 464 mm and around 380 mm, respectively. These two months could be regarded as the most challenging for the region. Notably, there was a noticeable August break in Benin during 2020, with a monthly accumulation of merely about 79 mm.

Similarly, in Abuja, the greatest monthly accumulation, approximately 348 mm, was observed in July 2020. This was closely trailed by September, with a recorded accumulation of around 295 mm. Notably, in 2020, there was also a distinct August break in this region.

In the subsequent year, 2021, the scenario shifted. August recorded the highest accumulation, totaling 331 mm, when the break was traditionally expected to take place. This was followed by June with 248 mm, marking an altered pattern compared to the previous year.

The observation that both Warri and Benin experienced their highest average monthly rainfall during the wet season lends support to their classification as part of the same coastal region. This is because, due to the movement of the Intertropical Convergence Zone (ITCZ), rain persists even during the dry season in rainforest and coastal areas.

In 2020, out of the total recorded rainfall of 2670.17 mm in Warri, 64.6% was categorized as stratiform rainfall, and the remaining 35.4% was classified as convective. Similarly, in 2021, 65.5% of the rainfall was identified as stratiform, while the remaining 34.8% was characterized as convective. This pattern underscores the dynamic nature of rainfall in the same location across different years. During 2020, Benin witnessed a cumulative rainfall of 2017.97 mm, with 74% characterized as stratiform precipitation, while the remaining 27% was categorized as convective rain. Likewise, in 2021, a substantial part of the rainfall, amounting to 80%, was classified as stratiform.

In Abuja, during the year 2020, out of the overall recorded rainfall of approximately 1380.42 mm, a significant 84% was characterized as stratiform rainfall, leaving the remaining 16% classified as convective. Similarly, in 2021, a majority of the rainfall, specifically 77.6%, exhibited stratiform characteristics, with the remaining 23.4% falling into the convective category.

One can conclude that in the three locations, namely Warri, Benin, and Abuja, the predominant rainfall type is stratiform rather than convective. It is also evident from both Figures 3 and 6 that convective rainfall is more prevalent in Warri and Benin compared to Abuja, where there was no occurrence of convective rainfall during the observed period.

Additionally, it becomes evident from Figures 2 and 5 that convective rainfall can occur in any month of the year. It can be noted that convective rain types, including thunderstorms and showers, are relatively infrequent in their occurrence. Conversely, stratiform rain types, such as drizzle and widespread rain, account for at least 85% of the total rainfall in all months, with many months experiencing up to 95% of their rainfall as stratiform.

The dominance of the stratiform rain type can be attributed to two primary factors. Firstly, stratiform rain types persist for longer durations compared to convective rain types. Secondly, stratiform rain types are characterized by the fragmentation of larger raindrops into smaller sizes, whereas the reverse process, where stratiform raindrops combine to form larger sizes, does not occur [18].

The study shows that Warri and Benin (coastal areas) have significantly higher rainfall accumulations. Warri had 2670–2842 mm/year, with Benin, 2018–2313 mm/year, compared to Abuja, which had 1326–1380 mm/year. Higher rainfall volume and intensity directly translate to higher specific attenuation (dB/km), as per the ITU-R models. This means satellite signals passing through these intense rain cells experience greater energy loss through absorption and scattering, leading to lower signal-to-noise ratio (SNR) and potential outages.

Although stratiform rain dominates total volume (65–80%), convective events are more intense (rain rates >25–50 mm/h). The study notes that while less frequent, convective rainfall contributes significantly to signal attenuation severity. In Warri and Benin, convective rain was more prevalent, 35% of volume, than in Abuja, 16–23%. These events cause deep, rapid signal fades that can exceed standard fade margins, making communication links unreliable during peak rain events.

The wet season (March–October) is long, but the study highlights an important anomaly: the August break (a period of reduced rainfall). In 2020, a clear break occurred in Warri: 78 mm; Benin: 100 mm; Abuja: 138 mm. However, in 2021, August recorded the highest monthly rainfall, Warri: 476 mm; Abuja: 331 mm. This inter-annual variability means that simply designing for a typical wet season or break is insufficient. Engineers must account for severe rainfall potentially occurring in any month, requiring adaptive or highly robust fade margins.

However, less intense, stratiform rain (drizzle, widespread rain) accounts for over 65% of rainfall events by volume and occurs on most rainy days. In 2020, in Benin, the frequency of occurrence of drizzle was 57%, and widespread 39%. This means that for extended periods (hours to days), there is a continuous background attenuation. This reduces effective link availability and forces systems to operate with tighter margins for extended periods, affecting Quality of Service (QoS).

The Key Findings are:

1. Coastal locations (Warri, Benin) face a more severe degradation risk than the north-central location (Abuja) due to significantly higher annual rainfall accumulations and a higher proportion of intense convective rain events (showers/thunderstorms), which cause deep, rapid signal fades.

2. Stratiform rain is the dominant type by volume and occurrence, leading to prolonged periods of background attenuation that degrade overall link availability and QoS, especially during the extended wet season.

3. High inter-annual variability, including the unpredictable occurrence of the August break, challenges the use of static, model-based fade margins. For example, the month traditionally expected to have a rain pause (August) recorded the highest rainfall in 2021, showing that severe degradation can occur at any time during the wet season.

4. Global prediction models, ITU-R P.618, require local calibration for these tropical locations. The study's detailed categorization of rain types (drizzle, widespread, shower, thunderstorm) and their frequency/volume provides essential local data for refining attenuation predictions.

CONCLUSION

From the Analysis of rainfall in the three locations, namely Warri, Benin, and Abuja, the predominant rainfall type is stratiform rather than convective. Convective rainfall is more frequent in Warri and Benin compared to Abuja. Stratiform rainfall accounts for at least 85% of total rainfall in all the months. In terms of volume, convective rain is more common at each site than stratiform rain; yet, stratiform rain lasts longer than convective rain. The highest monthly precipitation was recorded in August 2021 in Warri, Benin, and Abuja. August is a month when rain is usually predicted to break.
However, this study concludes that rainfall in Southern Nigeria causes significant, location-specific, and temporally variable signal degradation on satellite links, necessitating localized fade mitigation strategies.

RECOMMENDATION:

Satellite communication system designers and operators must:

1. Adopt higher fade margins for coastal stations (Warri, Benin) than for Abuja.
2. Implement adaptive power control or hybrid Fade Mitigation Techniques (FMTs) to handle both prolonged stratiform attenuation and sudden convective fading.
3. Use multi-year, local rainfall statistics (including type and event frequency, not just annual totals) to predict realistic link performance.
4. Consider site diversity for critical links, linking a coastal station with an inland station, as the rainfall spatial distribution differs significantly between the south and north-central zones.

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