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Original Research Article

Investigation of Field Strength Variability at Ultra-High Frequency and Maximum Angle of Incidence in the Guinea and Coastal Regions of Nigeria

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Abstract

In this study, the field strength variability (FSV) at Ultra High Frequency (UHF) and the maximum angle of incidence was estimated using the measured monthly climatic data obtained from the National Aeronautic and Space Administration (NASA) during the period of forty-two (42) years (1981 to 2022). The two climatic zones considered in this study are the Guinea Savannah and Coastal regions with two locations in each; Makurdi and Ibadan in the Guinea Savannah; Ogoja, and Warri in the coastal region. The findings indicated that for the four locations, the maximum average values of FSV at UHF obtained were 1.2459dB,1.2015dB, 1.2878dB and 1.4249dB, which occurred in the rainy season, the positive values observed indicate a strong signal with good reception quality while the maximum average values of angle of incidence measured were 0.6461º, 0.5334º, 0.6172º, and 0.4824ºfor Makurdi, Ibadan, Ogoja, and Warri respectively. The average maximum angle of incidence were found to be 0.5177º, 0.4126º, 0.4652º and 0.4013º for the locations during the studied period in which Makurdi and Ogoja values fall within the range of values (0.5º - 1º).

Keywords: Coastal zone, FSV, Guinea Savannah, maximum angle of incidence, UHF.

1. INTRODUCTION

Radio frequency or radio wave is a type of electromagnetic radiation of the highest wave length in the electromagnetic spectrum with the frequencies ranging from 300 GHz to as lower as 3 KHz ranges and frequency modulated (F.M) radio in the Mega Hertz (MHz), ranges. The propagation of electromagnetic waves in the atmosphere (mainly the troposphere) is greatly affected by the composition of the atmosphere [1]. This is due to the fluctuation of atmospheric parameters like temperature, pressure and relative humidity primarily at the atmosphere which is normally referred to as "the lower" part of the earth and site of all weather phenomena. Waves in the decimetre band are weakly reflected by ionized layers of the upper atmosphere and as a result, they bend around the earth's curvature and are easily obstructed. They can, however, be concentrated into narrow and highly directional signal beams. These characteristics make UHF suitable for line-of-sight applications that require high accuracy. UHF radio waves are used in many facets of life including ship and aircraft navigation systems, satellite communication, Global Positioning System (GPS), Wi-Fi, bluetooth, walkie-talkies, cordless phones, cell phones and television broadcasting [2, 3]. Ultra-High Frequency (UHF) is the International Telecommunications Union (ITU) designation for radio frequencies between 300 megahertz (MHz) and 3 GigaHertz (GHz), also known as the decimetre band because its wavelength ranges between one decimetre to one metre [4, 6]. They propagate at line-of-sight and are easily blocked by obstacles [2, 3], [7]. Angle of incidence of a ray is the angle between the incoming ray (incident) and a line perpendicular to the surface it strikes, called the normal at the point of incidence. Essentially, it is the angle at which a ray hits a surface measured from the normal line to the ray itself.

Employing measured local meteorological data from Nigeria and other portions of the world, a number of researchers, including [8, 2] to mention but a few have conducted research on Ultra-High Frequency (UHF) for different locations and climates.

The aim of the study is to estimate and investigate the field strength variability at Ultra-High Frequency UHF and maximum angle of incidence for Makurdi, Ibadan, Ogoja, and Warri two in each situated in the Guinea Savannah and Coastal climatic zones of Nigeria.

2.0 METHODOLOGY

2.1 Data Collection

The measured monthly meteorological data of temperature, relative humidity, and atmospheric pressure for four (4) distinct locations over a forty-two (42) year period (from 1981 to 2022) spread across two (2) climatic zones in Nigeria were obtained from the National Aeronautics and Space Administration (NASA). Table 1 presented the state, along with each location's latitude, longitude, and elevation for the locations under investigation.

Table 1: The latitude, longitude and elevation of the studied locations

Climatic Zone	Locations	Latitude	Longitude	State	Elevation (m)
Guinean Savannah	Makurdi	7.73°N	8.53°E	Benue	112.9
	Ibadan	7.43 °N	3.90°E	Oyo	227.2
Coastal Zone	Ogoja	6.67 °N	8.80°E	Cross River	117.0
	Warri	5.52 N°	5.73°E	Delta	6.10

The refractive index (n) of air is typically measured using a quantity known as the radio refractivity (N), which is related to the refractive index (n) by the equation given by Freeman [13]; [14]; ITU-R [15].

$$n = 1 + N \times 10^{-6} \quad (1)$$

The radio refractivity (N) is measured in units called N-units. Equation (1) indicated that N usually falls between 250 and 400 N-units. The radio refractivity, N, was represented as follows in terms of measured meteorological factors, according to the International Telecommunication Union (ITU) ITU-R, [15].

$$N = \frac{77.6}{T}\left(P + 4810\,\frac{e}{T}\right) \quad (2)$$

Where the radio refractivity of the dry term and wet term are given by equation (3) and (4) according to ITU-R [15] through expansion of equation (2) [16 – 18].

$$N_{dry} = 77.6\,\frac{P}{T} \quad (3)$$

$$N_{wet} = 3.73 \times 10^{5}\,\frac{e}{T^{2}} \quad (4)$$

Where e is the water vapour pressure (hPa), T is the temperature (K), and P is the atmospheric pressure (hPa).

According to ITU-R [19] and Freeman [13], equation (2) can be used for all radio frequencies; the inaccuracy is less than 0.5% for frequencies up to 100 GHz, and John [20] discovered that the average value of N = 315 was utilized at sea level.

The relationship between the water vapour pressure, e, and relative humidity is expressed as ITU-R [19]; [21, 27].

$$e = \frac{He_s}{100} \quad (5)$$

where e_s is given by

$$e_s = a \exp\left(\frac{bt}{t+c}\right) \quad (6)$$

Where H is the relative humidity (%), t is the Celsius temperature (°C) and e_s is the saturation vapour pressure (hPa) at temperature (°C). The values of the coefficients a, b and c (water and ice) was presented in ITU-R [19]. The water values and level of accuracy used in this investigation are contained in ITU-R [19].

The field strength variability in decibels at Ultra-High Frequency (UHF) in terms of radio refractivity was obtained using the formula [28]:

$$FSV\ at\ UHF\ (dB) = 20 \times log_{10}\left(\frac{u}{u_o}\right) \quad (7)$$

Where *FSV* is the field strength variability at UHF, is the variability of the field strength in decibels (dB), u is the radio refractivity at the operating frequency in N-units, and u_0 is the reference radio refractivity at the standard frequency of 315.9 MHz.

The radio refractivity at the operating frequency was obtained using [28]:

$$u = \frac{77.6 \times p}{T} + 3.73 \times e \quad (8)$$

Where p is the atmospheric pressure in millibars, T is the atmospheric temperature in Kelvin and e is the vapor pressure in millibars.

A ducting layer is known to trap radio waves if certain geometrical constraints are applied. For coupling of electromagnetic energy into a duct, the angle of incidence of the radio wave at the layer boundary must be very small. According to Barclay [29], using the total-internal-reflection condition of geometrical-optics, the maximum angle of incidence (degrees) is related to the change in refractivity ΔN (N-units) across the layer by

$$\theta_{imax} = 0.081\sqrt{|\Delta N|} \quad (9)$$

As reported by [30] and [31], ΔN rarely exceeds 100N-units, θ_{imax} is limited to 0.5° - 1°. The geometrical consideration of the Earth's curvature shows that the angle of incidence of a wave propagated horizontally intercepting an elevated layer is nonzero. The implication is that terrestrial radio links will not be significantly affected by the occurrence of ducting layers at altitudes higher than about 1 km [30, 31].

3.0 RESULTS AND DISCUSSION

3.1 FSV at UHF and Angle of Incidence in the Guinea Savannah Zone

3.1.1 Field Strength Variability at UHF for Makurdi

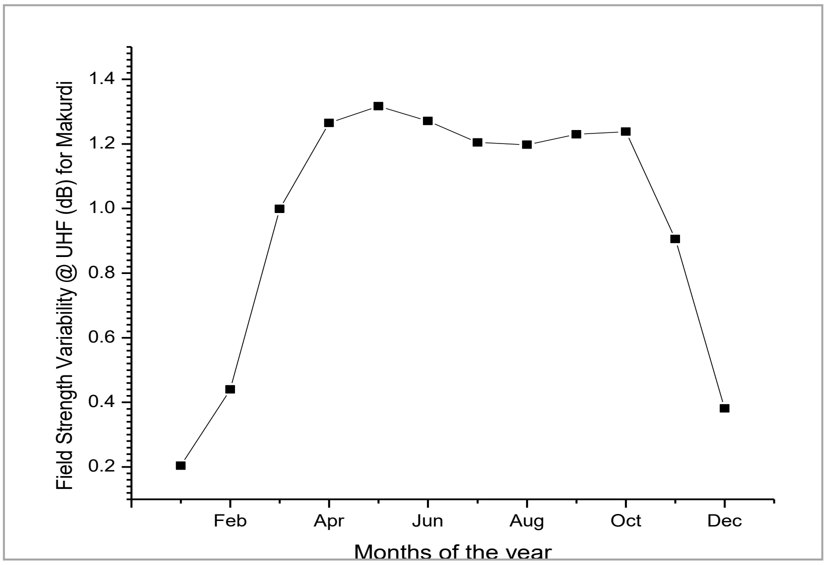

Figure 1: Seasonal Field Strength Variability at UHF Variation for Makurdi

Figure 1 depicts the seasonal variation of field strength variability at UHF for Makurdi during the investigation period. The FSV at ultra high frequency showed gradual increase from a minimum value of 0.2038 dB in the month of January until it gets to it peak value of 1.3169 dB in the month of May and decreases gradually until it get to 1.1973 dB in August which suddenly increases until it reaches another maximum value of 1.2378 dB in the month of October and drops sharply in December. It is worthy of note from the figure that the peak value of FSV at UHF observed in May occurred during the rainy season while the minimum value obtained in January happened in the dry season. The result also revealed that the maximum average value of FSV at UHF for Makurdi was found in the rainy season (April to October) with 1.2459dB while the minimum average value of 0.5857dB was recorded during the dry season (November to March). The positive values obtained indicate that the signal strength is strong in the location.

3.1.2 Maximum Angle of incidence for Makurdi

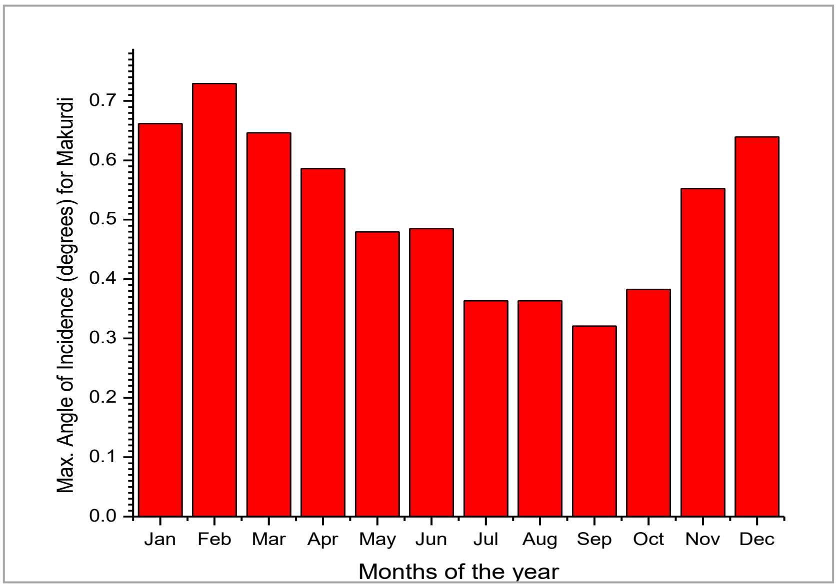

Figure 2: Monthly Variation of Maximum Angle of incidence for Makurdi

The monthly change of angle of incidence for Makurdi during the study period (1981 - 2022) is depicted in the figure 2. As shown clearly from the result, the month of September had the least angle of incidence value, recorded 0.3210º which is less than the reported value (0.5º - 1º) by Dairo and Kolawole [31], this could be as a result of the low value of change in radio refractivity in the month of September obtained to be 15.7060 N-units, while the month of February had the peak value of angle of incidence, and recorded 0.7295º. The result also showed that the maximum angle of incidence value was observed during the dry season, while the minimum angle of incidence happened within the rainy season. However, the value of angle of incidence occur in the rainy season in April, which is when the decline starts until the least value of angle of incidence was obtained in the month of September. The maximum average value of angle of incidence obtained in Makurdi was 0.6461º found in the dry season and the minimum average value obtained was 0.4259º within the rainy season. The average maximum angle of incidence for Makurdi during the studied period is 0.5177º which falls within the range of values reported by Dairo and Kolawole [31].

3.1.3 Field Strength Variability at UHF for Ibadan

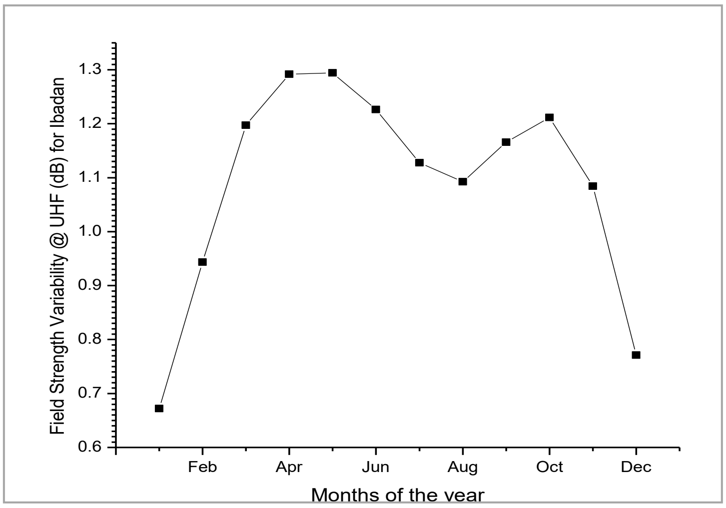

Figure 3: Seasonal Field Strength Variability at UHF Variation for Ibadan

Figure 3 illustrate the seasonal variation of field strength variability at UHF for Ibadan during the investigation period. The FSV at ultra high frequency increases sharply from its lowest value of 0.6721dB in the month of January within the dry season until it reaches April, which then maintained closed value until it gets to the highest value in the month of May with 1.2944 dB during the rainy season. Furthermore, it then decreases to August and also increases until it reaches October and then decreases continuously to December. The figure also revealed that the maximum average value of field strength variability at UHF was observed during the rainy season with 1.2015 dB while the minimum average value of 0.9338 dB was obtained within the dry season. This shows that for Ibadan, the result obtained indicate a strong signal with good reception quality.

3.1.4 Maximum Angle of incidence for Ibadan

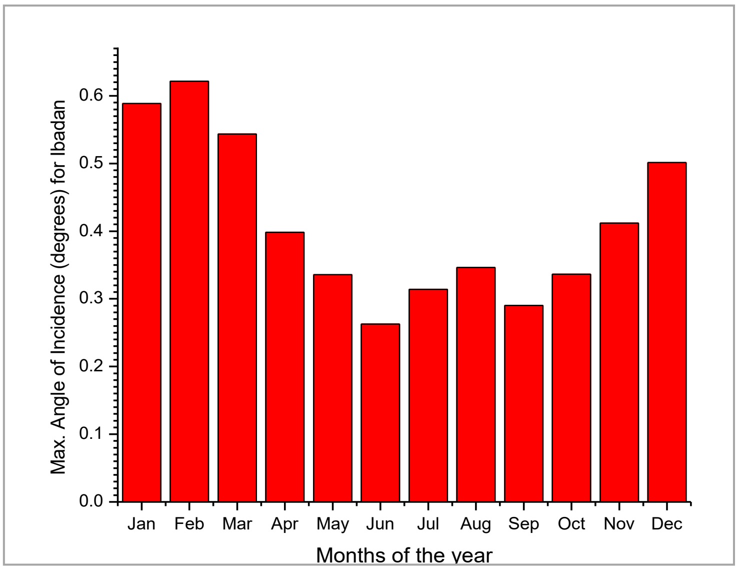

Figure 4: Monthly Variation of Maximum Angle of incidence for Ibadan

The monthly change of angle of incidence for Ibadan during the study period (1981- 2022) is demonstrated in figure 4. The angle of incidence for Ibadan at the peak point occurred in the month of February during the dry season with the value of 0.6217º while the least point measured value occur within the rainy season in the month of June with 0.2628º which is less than the reported value (0.5º - 1º) by Dairo and Kolawole [31], this could be as a result of the low value of change in radio refractivity in the month of June which was obtained to be 10.5235 N-units. However, still in the dry season, the measured value observed in January is 0.5885º which is within the reported range of values. The maximum average value of angle of incidence occurs in the dry season with measured value 0.5334º while the minimum average value was obtained during the rainy season with recorded value of 0.3263º. The average maximum angle of incidence for Ibadan during the studied period is 0.4126º which is slightly less than the range of values reported by Dairo and Kolawole [31].

3.2 FSV at UHF and Angle of Incidence across the Coastal Zone

3.2.1 Field Strength Variability at UHF for Ogoja

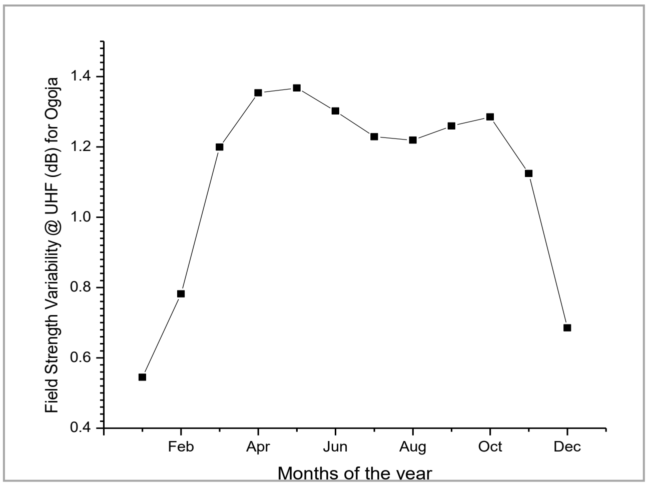

Figure 5: Seasonal Field Strength Variability at UHF Variation for Ogoja

Figure 5 shows the seasonal variation of field strength variability at UHF for Ogoja during the study period. The figure indicate that the FSV at ultra high frequency increases gradually from a minimum value of 0.5445 dB in the month of January until it get to its peak value of 1.3670 dB in the month of May and decreases gradually until it gets to 1.2193 dB in August which suddenly increases until it reached October and dropped to 0.6850 dB in December. However, the peak and the minimum value of FSV at UHF were obtained during the rainy and dry season respectively. The result also indicated that the maximum average value of FSV at UHF for Ogoja occurred in the rainy season with 1.2878 dB while the minimum average value obtained was during the dry season with measured value of 0.8669 dB. This revealed that for Ogoja, the signal signify a good transmission quality throughout the seasons.

3.2.2 Maximum Angle of incidence for Ogoja

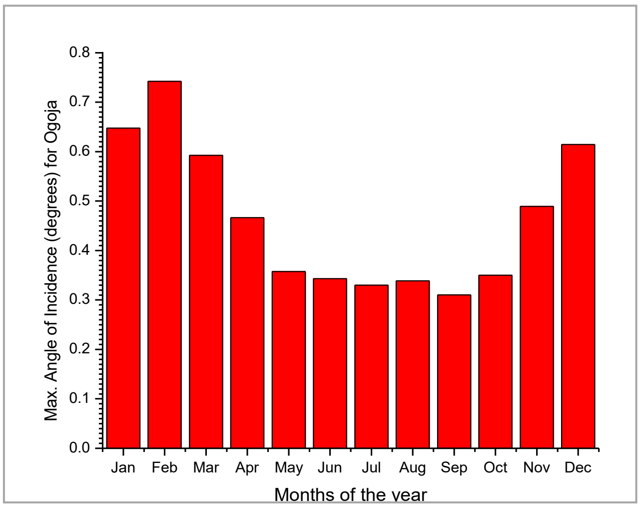

Figure 6: Monthly Variation of Maximum Angle of incidence for Ogoja

The monthly change of angle of incidence for Ogoja over the study period (1981- 2022) is depicted in figure 6. Based on the result obtained, the angle of incidence started decreasing from March until September when the lowest value was recorded during the rainy season with 0.3103º, which is less than the reported value (0.5º - 1º) by Dairo and Kolawole [31], this could be as a result of the low value of change in radio refractivity in the month of September which was obtained to be 14.6740 N-units, while in the month of February within the dry season; the highest angle of incidence value measuring 0.7423º was recorded. However, the maximum average angle of incidence for Ogoja was 0.6172º that occurred during the dry season and the minimum average value of angle of incidence obtained during the rainy season was observed to be 0.3566º. The average maximum angle of incidence for Ogoja during the studied period is 0.4652º which is approximately 0.5 and falls within the reported values by Dairo and Kolawole [31].

3.2.3 Field Strength Variability at UHF for Warri

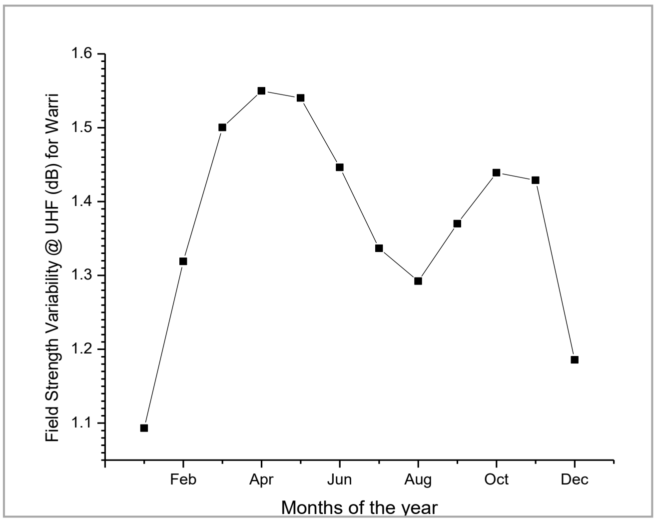

Figure 7: Seasonal Field Strength Variability at UHF Variation for Warri

Figure 7 depicts the seasonal variation of field strength variability at UHF for Warri during the study period.The FSV at ultra high frequency showed gradual increase from it least value in the month of January within the dry season with 1.0931dB until it gets to the maximum value in the month of April when the rainy season begins with 1.5498 dB which suddenly decreases and get to the month of August still in the rainy season with 1.2923 dB, it then further increases until it reaches October then decreases gradually to the month of December. However, the result also show that the maximum average value of field strength variability at UHF for Warri was 1.4249 dB observed in the rainy season while the minimum average value of 1.3054 dB was obtained in the dry season, in which the positive result revealed a strong signal with good reception quality in Warri for all the seasons.

3.2.4 Maximum Angle of incidence for Warri

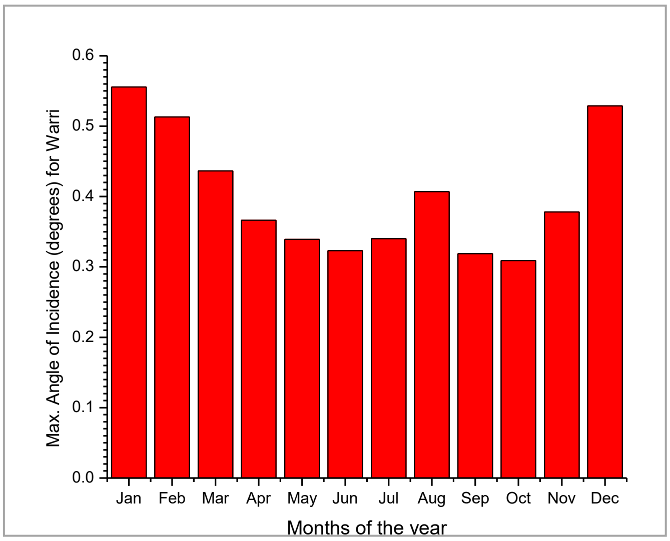

Figure 8: Monthly Variation of Maximum Angle of incidence for Warri

Figure 8 portrays monthly change of angle of incidence for Warri over the study period (1981- 2022). The result show that the peak angle of incidence value was obtained in January with 0.5558° during the dry season, while the least angle of incidence measuring 0.3089° in the month of October occur during the rainy season, which is less than the reported value (0.5° - 1°) by Dairo and Kolawole [31], this could be as a result of the low value of change in radio refractivity in the month of October obtained to be 14.5445 N-units. Nevertheless, February and December have values of 0.5131° and 0.5288° within the dry season respectively, which are importantly closed to the peak recorded value. Furthermore, the maximum average value of angle of incidence obtained was 0.4824° during the dry season and the minimum average value of 0.3433° was observed within the rainy season. The average maximum angle of incidence for Warri during the studied period is 0.4013° which is less than the range of values reported by Dairo and Kolawole [31].

Table 2: FSV at UHF Average Values for the Selected Locations

Climatic zones	Selected Locations	Average values
Guinea Savannah	Makurdi Ibadan	0.9708 dB 1.0899 dB
Coastal Region	Ogoja Warri	1.1124 dB 1.3751 dB

Table 2 shows the field strength variability (FSV) at UHF average values for the selected locations. Based on the chosen sites, the results shows that the locations experience a strong signal with good reception quality. However, among the entire chosen site, Warri has the highest averaged value with 1.3751dB located in the coastal region.

Table 3: FSV at UHF during the dry and rainy seasons for the Selected Locations

Climatic zones	Selected Locations	Dry Season	Rainy Season
Guinea Savannah	Makurdi Ibadan	0.5857 dB 0.9338 dB	1.2459 dB 1.2015 dB
Coastal Region	Ogoja Warri	0.8669 dB 1.3054 dB	1.2878dB 1.4249dB

Table 3 shows field strength variability at UHF during the dry and rainy seasons across the climatic zones. It shows that in the dry and rainy season, the whole chosen site gain positive values signifying good transmission quality. However, it was observed that Warri has the highest averaged value with 1.4249 dB in the rainy season found in coastal region.

Table 4: Maximum Angle of incidence Average Values for the Selected Locations

Climatic zones	Selected Locations	Average values (degrees)
GuineaSavannah	Makurdi Ibadan	0.5177° 0.4126°
Coastal Region	Ogoja	0.4652°

	Warri	0.4013°

Table 4 depicts the maximum angle of incidence average values across the studied locations. Based on the chosen sites, Makurdi has the highest averaged value of angle of incidence with 0.5177° situated in the Guinea Savannah, and this is followed by Ogoja with 0.4652° located in Coastal Region.

Table 5: Maximum Angle of incidence Average values during the dry and rainy seasons for the Selected Locations

Climatic zones	Selected Locations	Dry Season	Rainy Season
Guinea Savannah	Makurdi Ibadan	0.6461° 0.5334°	0.4259° 0.3263°
Coastal Region	Ogoja Warri	0.6172° 0.4824°	0.3566° 0.3433°

Table 5 depicts the maximum angle of incidence average values during the dry and rainy seasons across the selected climatic zones. The table shows that in both dry and rainy seasons, Makurdi has the highest average value with 0.6461° and 0.4259° respectively which is situated in the Guinea Savannah.

4. CONCLUSION

In this study, the field strength variability (FSV) at UHF and maximum angle of incidence for four selected locations situated across the Guinea Savannah and Coastal climatic zones of Nigeria was investigated using the measured monthly climatic data obtained from the National Aeronautics and Space Administration during the period of forty-two (42) years (from 1981 to 2022). The maximum and minimum average values of FSV at ultra high frequency were observed to be (1.2459 dB and 0.5857 dB); (1.2015 dB and 0.9338 dB); (1.2878 dB and 0.8669 dB) and (1.4249 dB and 1.3054 dB). The result shows that in the dry and rainy season, the entire chosen site gain positive values signifying good transmission quality. The maximum and minimum average values of angle of incidence obtained were (0.4259° and 0.6461°); (0.3263° and 0.5334°); (0.3566° and 0.6172°) and (0.3433° and 0.4824°); for Makurdi, Ibadan, Ogoja, and Warri respectively. The average maximum angle of incidence for Makurdi, Ibadan, Ogoja, and Warri during the studied period are respectively 0.5177°, 0.4126°, 0.4652° and 0.4013° which indicate that only Makurdi and Ogoja falls within the range of values (0.5° - 1°) as reported in the literature. The results of this study are essential for improving network design, maximising communication system performance, comprehending environmental interactions, guaranteeing regulatory compliance, and developing telecommunications technology in the rapidly changing wireless communication environment.

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