https://dx.doi.org/10.4314/dujopas.v10i4a.3
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 10 No. 4a December 2024*

Assessment of Tropospheric Field Strength Variability and Radio Horizon Distance over the Guinea and Coastal Climatic Zones of Nigeria

Bello, G[1]., Akpootu, D. O[2*]., Zoramawa, A. B[3] and Yusuf, A[4]

[1]Sultan Abdurrahaman College of Health Technology Gwadabawa,
Sokoto State,
Nigeria.

[2]Department of Physics,
Usmanu Danfodiyo University,
Sokoto,
Nigeria.

[3]Department of Statistics,
Usmanu Danfodiyo University,
Sokoto,
Nigeria.

[4]Department of Science Education,
Ibrahim Badamasi Babangida University,
Lapai,
Nigeria.

Email: davidson.odafe@udusok.edu.ng

Abstract

Proper evaluation of the prevalent refractivity circumstances and the appropriate actions to minimise link degradation and maintain signal integrity at the receiver in such a location may increase the reliability of terrestrial satellite communications in any location. In this study, the measured monthly climatic data of atmospheric pressure, relative humidity and temperature covering a period of forty-two (42) years (from 1981 to 2022) for four (4) different locations situated across two (2) climatic zones in Nigeria were acquired from the National Aeronautics and Space Administration (NASA) to investigate the tropospheric field strength variability (TFSV) and to estimate radio horizon distance (d_{RH}) for the chosen sites. The study's findings showed that the maximum values of TFSV obtained are 16.2240 dB, 11.7831 dB, 16.7986 dB and 9.4150 dB for Makurdi, Ibadan, Ogoja and Warri respectively. These field strength variability values imply that, for the selected areas, the output of a receiving antenna may vary by not more than 16.2240 dB, 11.7831 dB, 16.7986 dB, and 9.4150 dB, respectively, and by not less than 3.1411 dB, 3.0076 dB, 2.9347 dB, and 2.9089 dB in a year. The average values of TFSV variability obtained are 8.7021 dB, 5.6036 dB, 7.2246 dB and 5.1234 dB for Makurdi, Ibadan, Ogoja and Warri respectively, indicating that Makurdi has the highest average value of TFSV compared to other investigated locations. The Guinea Savannah and Coastal climatic zones of Nigeria typically have higher TFSV values in the dry season when compared to the rainy season. The expressions $d_{RH} = 132.9607\sqrt{h_T}$, $d_{RH} = 132.5453\sqrt{h_T}$, $d_{RH} = 132.9456\sqrt{h_T}$ *and* $d_{RH} = 133.3587\sqrt{h_T}$ *were established from the calculation of radio horizon distance for Makurdi, Ibadan, Ogoja and Warri respectively if the respective transmitter heights are known.*

Keywords: Coastal zone, Field Strength variability (TFSV), guinea savannah, NASA, Radio Horizon Distance

Author for Correspondence

INTRODUCTION

A channel is used to carry information during a transmission amid a transmitter and a receiver, which is explained by the communication system. The transmission of electromagnetic energy at radio frequencies from a transmitter to a receiver is known as radio wave propagation (Adediji *et al*., 2017). The amount of electromagnetic field that is used to stimulate a reference antenna and subsequently induce a voltage at a specific frequency to provide an input signal to a radio receiver from the transmitting antenna is known as radio field strength in radio frequency telecommunications (Akpootu *et al*., 2019a). Refraction, or the bending of electromagnetic waves as a result of variations in the refractive index of the atmosphere, has an impact on communication systems (Cooray *et al*., 2000). Variations in climatic characteristics, such as temperature, pressure, and relative humidity, have an impact on radio wave signals propagating in the troposphere (Adeyemi and Ogolo, 2014). The quality, amplitude, and phase of radio signals are significantly influenced by the environment, which serves as a route for their propagation (Okpani *et al*., 2015).

According to Adediji *et al*. (2017), field strength in radio frequency telecommunications refers to the strength of the electromagnetic field that is received and can excite a receiving antenna, causing a voltage to be induced at a certain frequency. Following that, a radio receiver receives this voltage as an input signal. Applications for field strength meters include Wi-Fi, cellular, broadcasting, and a host of other radio-related uses. (Freeman, 2007; Adediji *et al*., 2014). The signal antenna's sound level is determined by the variability of the field strength. This will establish the antenna's height and the separation between subsequent antennae.

The area where an antenna's direct rays are tangential to the surface of the Earth is known as the radio horizon. It is the furthest a radio signal can go from its source without encountering obstructions before reaching the surface, hypothetically. A receiver needs to be installed within that range in order to function. The radio horizons of the transmitting and receiving antennas can be combined to increase the effective communication range. The location of points at which a straight line from a particular point becomes tangential to the surface of the earth is known as the optical horizon (Adediji *et al*., 2019).

Several researchers have studied Electromagnetic wave (EMW) medium interaction processes and the propagation implications over Nigeria, especially the study of variation of radio field strength and radio horizon distance in Nigeria, this include Adediji *et al.* (2014); Adediji *et al.* (2017); Tanko *et al.* (2018); Akpootu *et al.* (2019a); Adediji *et al.* (2019); Tanko *et al.* (2022) to mention but few. No work has investigated a comparative study between the Guinea savannah and coastal region of Nigeria. In view of this, the objectives of the study are to (i) investigate the tropospheric field strength variability for four (4) selected locations situated in the Guinea and Coastal climatic zones of Nigeria (ii) generate a formula to calculate the radio horizon distance for the chosen sites in the two selected climatic zones under study.

METHODOLOGY

NASA makes available 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. Table 1 lists the state, along with each location's latitude and longitude.

Table 1. The latitude and longitude of the studied locations

Climatic Zone	Locations	Latitude	Longitude	State
Guinea Savannah	Makurdi	7.73°N	8.53°E	Benue
	Ibadan	7.43°N	3.90°E	Oyo
Coastal	Ogoja	6.67°N	8.80°E	Cross River
	Warri	5.52°N	5.73°E	Delta

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 (Freeman, 2007; Akpootu and Iliyasu, 2017; ITU-R 2019).

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

Unitless in nature, radio refractivity (N) is measured in units called N-units. Equation (1) thus leads one to conclude that N usually encompasses 250–400 N-units. The radio refractivity, N, should be represented as follows in terms of measured meteorological factors, according to the International Telecommunication Union (ITU) (ITU-R, 2019).

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

where the radio refractivity of the dry term and wet term are given by equations (3) and (4) according to ITU-R (2019) through expansion of equation (2) (Akpootu and Rabiu, 2019; Akpootu *et al.*, 2024a, b).

$$N_{dry} = 77.60\frac{P}{T} \quad (3)$$

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

The variables in this equation are the temperature (K), the atmospheric pressure (hPa), and the water vapour pressure (hPa).

According to ITU-R (2003) and Freeman (2007), equation (2) can be used for all radio frequencies; the inaccuracy is less than 0.5% for frequencies up to 100 GHz, and John (2005) 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, 2003; Akpootu *et al.*, 2019b; Akpootu *et al.*, 2021a,b; Iliyasu *et al.*, 2023; Akpootu *et al.*, 2023; Abdullahi *et al.*, 2024a,b).

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

where e_s is given by

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

The values of the coefficients a, b and c (water and ice) and the definition of equation terms are presented in ITU-R (2003). The water values and level of accuracy used in this investigation are contained in ITU-R (2003).

In the troposphere, the radio refractivity, N, diminishes exponentially with height (ITU-R, 2003).

`

$$N = N_s \exp\left(\frac{-h}{H}\right) \quad (7)$$

N as a function of height N (h) is expressed by

$$N = 315\exp^{-0.136h} \quad (8)$$

Agunlejika and Raji (2010) found that for seven (7) of the twelve (12) months of the year, the model with scale heights of 7.35 km and 7 km is advised for the global environment ITU-R

(2003) and the tropical environment (John, 2005), respectively. The refractivity gradient is obtained by differentiating equation (7) with respect to h, therefore, the refractivity gradient is given by Akpootu *et al.* (2019a) as reported in Bello *et al.* (2024).

$$\frac{dN}{dh} = \frac{-N_s}{H} \exp\left(\frac{-h}{H}\right) \quad (9)$$

A conventional atmosphere has a refractivity gradient of -39 N-units/km. John (2005) states that the refractivity gradient's value in a standard environment is a good approximation for h values less than 1 km. Because John's (2005) typical values for a standard atmosphere were used in this study, the refractivity of a standard atmosphere is N_S = 312 N-units.
Refractive conditions were classified as sub-refraction, super-refraction, ducting, and normal refraction, or standard atmosphere respectively, using the effective earth radius (k). Therefore, as stated by Hall (1989); Afullo *et al.* (1999); Freeman (2007); Maintham and Asrar (2003), k are defined in terms of the refractivity gradient, dN / dh.

$$k = \left[1 + \frac{\left(\frac{dN}{dh}\right)}{157}\right]^{-1} \quad (10)$$

Strong correlations exist between surface refractivity and radio field strength, particularly at very high frequencies (VHF). The monthly range is obtained using Adediji *et al.* (2014). In the frequency range of 30 – 300 MHz, a factor of 0.2 dB change in field strength may be employed for every unit change in N_s values obtained using equation (11). The highest ($N_{s(MAX)}$) and minimum ($N_{s(MIN)}$) values of Ns were determined.

$$\text{Monthly Range} = N_{s(MAX)} - N_{s(MIN)} \quad (11)$$

An assessment of the field strength variability (TFSV) in a given location is investigated using (Adediji *et al.*, 2014).

$$\text{TFSV} = (N_{s(MAX)} - N_{s(MIN)} \times 0.2 \text{ dB} \quad (12)$$

The effective earth's radius model performs well at the surface, where the refractivity gradient is approximately constant, for low-elevation terrestrial radio propagation experiments. In these circumstances, the radio horizon assumes a crucial role in determining the terrestrial radio link's coverage region, contingent upon the transmitter's height (Oyedum, 2009). A receiver must be located inside the radio horizon distance, or d_{RH}, for it to function. This is the furthest that an unimpeded radio signal can possibly travel from its source before coming into contact with the surface. The radio horizon distance can be calculated using Bean and Dutton (1968), as stated in Akpootu *et al.* (2019a), and is dependent on the transmitter height, h_T, and value of Ns in the station.

$$d_{RH} = (2kr h_T)^{1/2} \quad (13)$$

where the earth's radius (6370 km) is represented by r, and k is the effective earth radius factor.

RESULTS AND DISCUSSION

TFSV and Radio Horizon Distance in the Guinea Savannah Zone

Tropospheric Field Strength Variability (TFSV) and Radio Horizon Distance for Makurdi

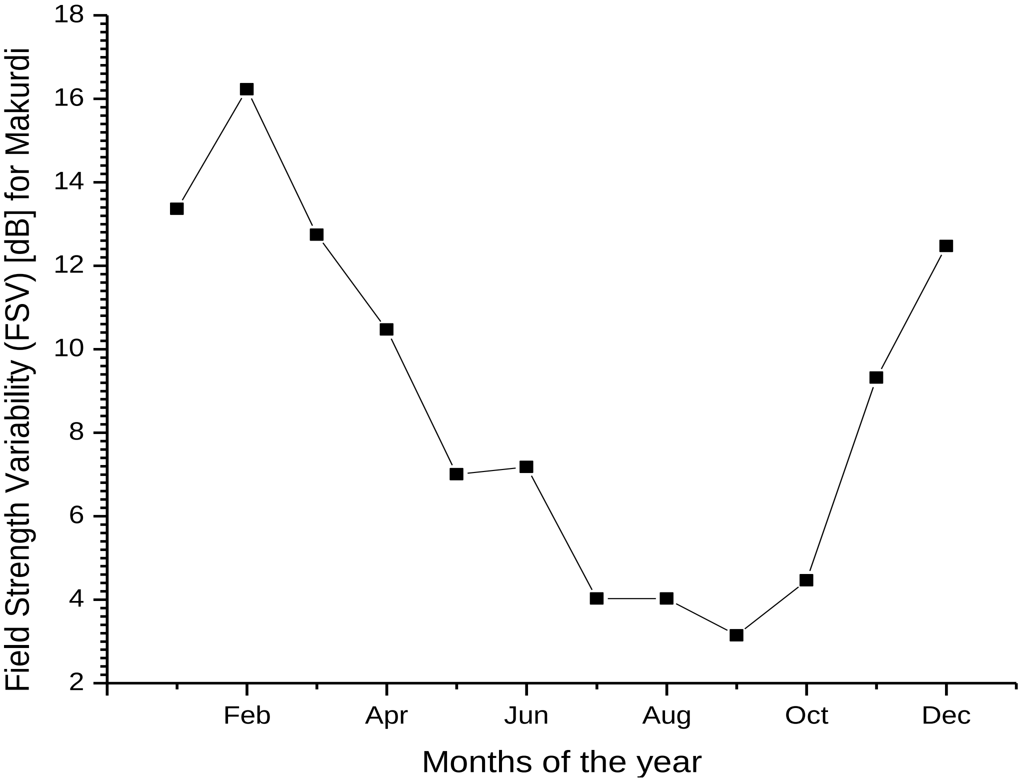

Figure 1. Mean monthly Variation of TFSV over Makurdi

Figure 1 shows the monthly variation of field strength variability over Makurdi during the forty-two (42) years under study. Equations (11) and (12) were used to investigate the field strength variability (TFSV), the highest and lowest TFSV values of 16.2240 dB and 3.1411 dB were found in the months of February and September, which occurred during the period of dry and rainy seasons, respectively. Obviously, the figure shows that the TFSV increases from January and reaches its maximum value of 16.2240 dB in the month of February, then decreases steadily down to May. The TFSV suddenly increases from May to June then decreases to July which maintain almost closed value till August and then decreases down to September where it obtained the lowest value 3.1411 dB in the month of September, and then further increases until it arrived at December. High values of field strength variability are reported during the dry season compared to the wet season, according to the analysis result shown in the figure. An average value of 8.7021 dB was obtained for the period under investigation, also an average value of 12.8226 dB and 5.7589 dB were obtained in the dry and rainy seasons respectively. According to Makurdi's TFSV values, changes in the area's receiving antenna's output should not exceed 16.2240 dB, but they may frequently occur at a rate of no less than 3.1411 dB annually.

Based on the study area, the radio horizon distance was calculated using equation (13) and the estimated equation is written as

$$d_{RH} = 132.9607\sqrt{h_T} \tag{14}$$

Equation (14) can be used to estimate the radio horizon for Makurdi if the transmitter height, $h_{T,}$ is known.

Tropospheric Field Strength Variability (TFSV) and Radio Horizon Distance for Ibadan

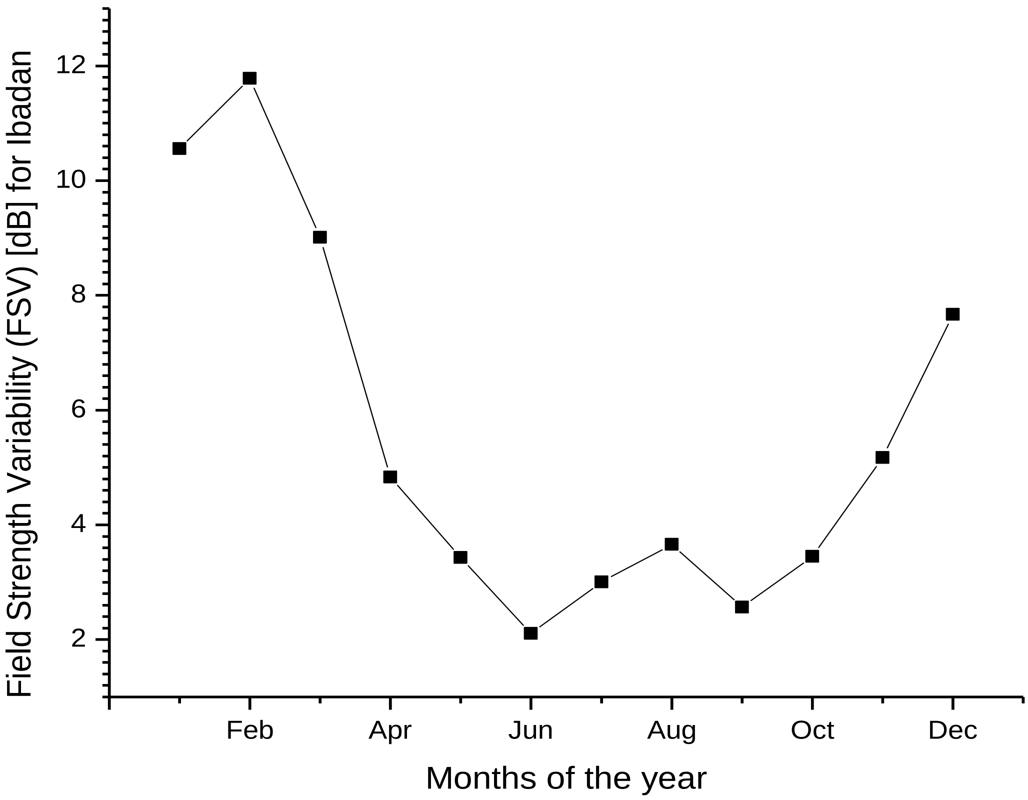

Figure 2. Mean monthly Variation of TFSV over Ibadan

The monthly fluctuations in field strength variations during a 42-year period over Ibadan are depicted in Figure 2. Equations (11) and (12) were used to calculate the field strength variability (TFSV). The largest and lowest TFSV values, respectively, were found in the rainy and dry seasons of February and July, at 11.7831 dB and 3.0076 dB. Apparently, the TFSV increases from January and reaches at the peak point with the value of 11.7831dB in the month of February then decreases steadily until it get to its minimum value of 3.0076 dB in the month of June. Furthermore, the TFSV increases from June and reaches to August then descend to September and then rises until it arrived at December. An average value of 5.6036 dB was obtained for the period under investigation, also an average value of 8.8373 dB and 3.2938 dB were found during the dry and rainy seasons respectively. Figure 2 illustrates the study's findings, which show that field strength values are highest during the dry season and lowest during the rainy season. The study area's field strength variability values indicate that changes in an Ibadan receiving antenna's output may typically occur at a rate of no less than 3.0076 dB annually, but no more than 11.7831 dB.

Using equation (13), the radio horizon distance was calculated. The formula that is obtained is as follows for calculating the radio horizon distance:

$$d_{RH} = 132.5453\sqrt{h_T} \quad (15)$$

If the transmitter height, h_T, is known, the equation in (15) can be used to approximate the radio horizon for Ibadan, Nigeria.

TFSV and Radio Horizon Distance across the Coastal Zone

Tropospheric Field Strength Variability (TFSV) and Radio Horizon Distance for Ogoja

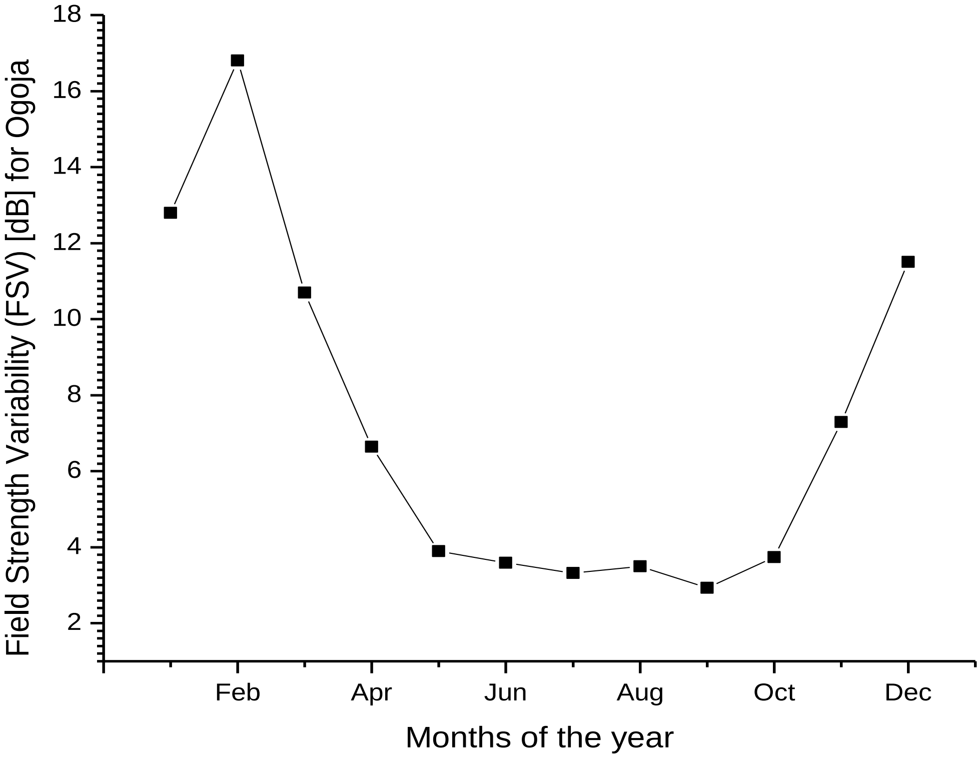

Figure 3. Mean monthly Variation of TFSV over Ogoja

The monthly variations of field strength variability during a 42-year period over Ogoja is shown in Figure 3. The field strength variability (TFSV) was estimated using equations (11) and (12). As seen clearly from the figure, the TFSV increases from January and reaches to its maximum value of 16.7986 dB in the month of February then descend down gradually until it arrived at July. The TFSV further increases suddenly from July to August then decreases to September where it attained it least value of 2.9347 dB and then increases until it get to the month of December. The TFSV values were found to be at their highest and lowest in the months of February and September, respectively, corresponding to the dry and wet seasons, at 16.7986 dB and 2.9347 dB. The analysis's conclusion, as seen in the figure, is that there is more variety in field strength during the dry season than there is during the wet season. An average value of 7.2246 dB was obtained for the period under investigation, also an average value of 11.8177 dB and 3.9438 dB were found in the dry and rainy seasons respectively. The study's TFSV estimates for Ogoja indicate that, on average, the receiving antenna's output in this area may fluctuate by as much as 2.9347 dB annually, but it shouldn't go over 16.7986 dB. The radio horizon distance was calculated using equation (13) and the approximated equation is written as

$$d_{RH} = 132.9456\sqrt{h_T} \qquad (16)$$

If the transmitter height, h_T, is known, equation (16) can be used to get the radio horizon distance for Ogoja, Nigeria.

Tropospheric Field Strength Variability (TFSV) and Radio Horizon Distance for Warri.

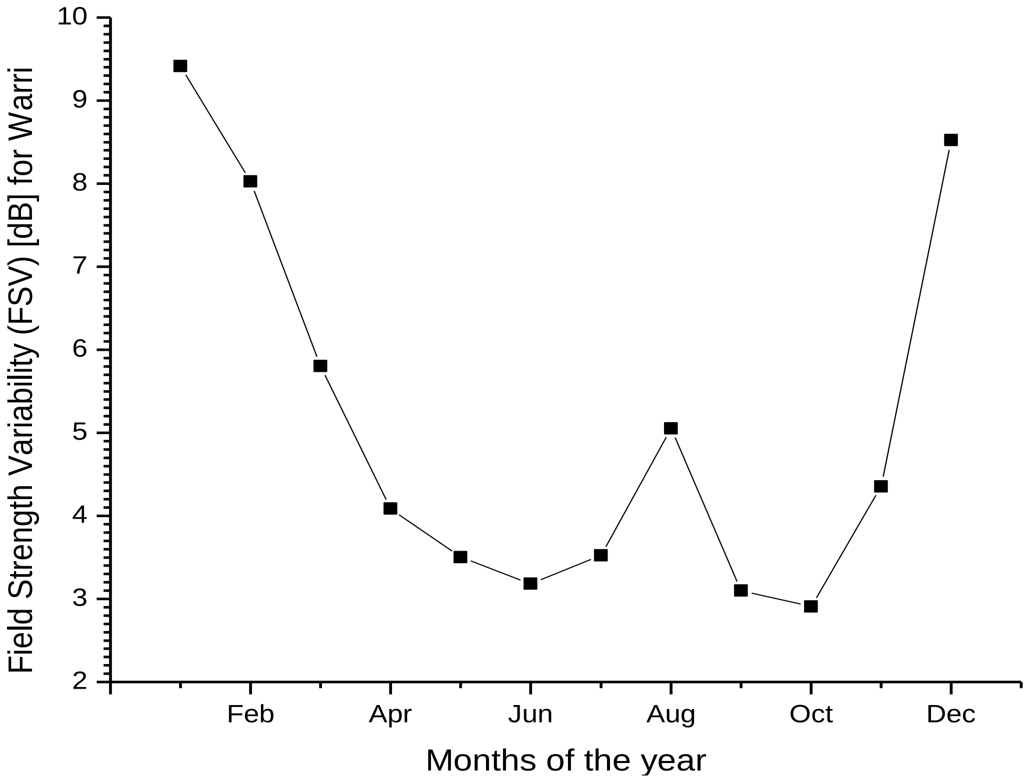

Figure 4. Mean monthly Variation of TFSV over Warri

The monthly fluctuations in field strength variations during a 42-year period over Warri are depicted in Figure 4. Using equations (11) and (12), the field strength variability (TFSV) was determined. The figure clearly depicts that the TFSV gradually started decreasing from it maximum value of 9.4150 dB in the month of January and arrived at June which then increases from June to August and further decreases down to its minimum value of 2.9089 dB in October which also increases from the lowest point and get to December. During the dry and rainy seasons, January and October yielded the largest and lowest values of field strength variability, measuring 9.4150 dB and 2.9089 dB, respectively. According to the figure, field strength levels are highest in the dry season and lowest in the rainy season. An average value of 5.1234 dB was obtained for the period under investigation, also an average value of 7.2243 dB and 3.6228 dB were found during the dry and rainy seasons respectively. Based on the area the inference according to the TFSV values in this study, the output of a receiving antenna at Warri can often fluctuate by at least 2.9089 dB annually, but not by more than 9.4150 dB.
The predicted equation for the radio horizon distance, which was calculated using equation (13) is represented as

$$d_{RH} = 133.3587\sqrt{h_T} \quad (17)$$

In Warri, Nigeria, the radio horizon distance can be calculated using the preceding equation (17) if the transmitter height, h_T, is known.

Table 2. Tropospheric Field Strength Variability (TFSV) Average Values for the Selected Locations

Climatic zone	Selected Locations	Average Values
Guinea Savannah	Makurdi	8.7021 dB
	Ibadan	5.6036 dB
Coastal	Ogoja	7.2246 dB
	Warri	5.1234 dB

Table 2 shows the tropospheric field strength variability (TFSV) Average Values for the Selected Locations. The chosen climatic zones depicts that Makurdi has the highest averaged value of TFSV with 8.7021 dB under Guinea Savannah, and this is followed by Ogoja with 7.2246 dB located in Coastal Region then Ibadan while Warri has the least value of field strength variability as indicated above.

Table 3. Tropospheric Field Strength Variability during the dry and rainy seasons for the selected locations

Climatic zone	Selected Locations	Dry Season	Rainy Season
Guinea Savannah	Makurdi	12.8226 dB	5.7589 dB
	Ibadan	8.8373 dB	3.2938 dB
Coastal	Ogoja	11.8177 dB	3.9438 dB
	Warri	7.2243 dB	3.6228 dB

Table 3 depicts tropospheric field strength variability during the dry and rainy season for the selected locations under Guinea and coastal regions. As seen clearly, the values of TFSV are higher in the dry season than in the rainy season for the two zones, in which among the chosen sites Makurdi has the highest value with 12.8226 dB found in the Guinea savannah climatic zone and this is followed by Ogoja in the Coastal region with 11.8177 dB then Ibadan with the value of 8.8373 dB and lastly Warri under Coastal region with 7.2243 dB.

Table 4. Comparison of Tropospheric Field Strength Variability over Guinea Savannah with that in the Literature

Selected Locations	Average values	In this work	Akpootu *et al*., (2019)
Makurdi	Maximum	16.2240 dB	7.72 dB
	Minimum	3.1411 dB	0.07 dB
Ibadan	Maximum	11.7831 dB	7.72 dB
	Minimum	3.0076 dB	0.07 dB

Based on the table 4 above, the values of TFSV obtained in this work are slightly higher than that of Akpootu *et al.* (2019) for both the maximum and minimum values. The variability in the results obtained this study and that of Akpootu *et al.* (2019) may be due to the fact that this study utilized forty-two (42) years data while that of Akpootu *et al.* (2019) uses twenty-two (22) years data. Also, the study location for Akpootu *et al.* (2019) is Osogbo, Nigeria.

Table 5. Comparison of Tropospheric Field Strength Variability over Coastal Region with that in the Literature

Selected Locations	Average values	In this work	Akpootu *et al.*, (2019)
Makurdi	Maximum	16.2240 dB	7.72 dB
	Minimum	3.1411 dB	0.07 dB
Ibadan	Maximum	11.7831 dB	7.72 dB
	Minimum	3.0076 dB	0.07 dB

As indicated above, the values of TFSV obtained for Ogoja and Warri in this study are in good agreement with those obtained for Adediji *et al.* (2014), where their study area is Akure. The compared locations are all in the Coastal region. Though, there is a significant variation in the maximum values obtained for Warri and that of Adediji *et al.* (2014) this could be due to variation in location and duration under investigation as Adediji *et al.* (2014) utilizes (5) years data.

CONCLUSION

In this study, the TFSV and radio horizon distance for four selected locations found in the Guinea and Coastal climatic zones of Nigeria was investigated using the measured monthly climatic data of atmospheric pressure, relative humidity and temperature obtained from NASA during the period of forty-two (42) years (from 1981 to 2022). The outcomes showed that the field strength variability's maximum and lowest values are (16.2240 dB and 3.1411 dB); (11.7831 dB and 3.0076 dB); (16.7986 dB and 2.9347 dB) and (9.4150 dB and 2.9087 dB) in the months of (February and September); (February and July); (February and September) and (January and October) for Makurdi, Ibadan, Ogoja and Warri respectively, signifying that In general, variations in the receiving antenna's output in the chosen sites are possible to be as little as 3.1411 dB, 3.0076 dB, 2.9347 dB, and 2.9087 dB each year, and as much as 16.2240 dB, 11.7831 dB, 16.7986 dB, and 9.4150 dB for the study areas, respectively. The field strength variability average values obtained are 8.7021 dB, 5.6036 dB, 7.2246 dB and 5.1234 dB for Makurdi, Ibadan, Ogoja and Warri respectively, indicating that Makurdi and Ogoja has the highest average TFSV with 8.7021 dB and 7.2246 dB in the Guinea and Coastal climatic zones respectively. The highest average TFSV is Makurdi with 8.7021 dB while the least average TFSV observed is Warri with 5.1234 dB in the coastal region. The TFSV are generally high during the dry season as compared to the rainy season in the Guinea Savannah and Coastal climatic zones of Nigeria. The expression given in equations (14), (15), (16) and (17) has been evaluated for radio horizon distance estimation in Makurdi, Ibadan, Ogoja and Warri respectively if the transmitter heights are identified.

ACKNOWLEDGEMENTS

The authors are pleased with the National Aeronautics and Space Administration (NASA) for the provision of all the study's data online.

REFERENCES

Abdullahi, Z., Akpootu, D. O., Momoh, M., Sa'ad, L., Bawa, Y. I., Yabo, A. M., Nouhou, I., Agidi, E. O., Yusuf, A and Yohanna, S. B. (2024a). Investigation and Multivariate Models for Estimation of Surface Water Vapour Density in Ikeja, Nigeria. *Arid Zone Journal of Basic and Applied Research.*, 3(2), 119-133. doi.org/10.55639/607.302928.

Abdullahi, Z., Akpootu, D. O., Momoh, M., Sa'ad, L., Bawa, Y. I., Sununu, T. S., Nouhou, I., Yohanna, S. B., Agidi, E. O and Yusuf, A. (2024b). Estimation of Surface Water Vapour Density and its Fluctuations with Climatic Variables at Owerri, Nigeria. *Arid Zone Journal of Basic and Applied Research.*, 3(2), 134-146. doi.org/10.55639/607.292827

Adediji, A. T., Adebusola, S. O and Ojo, J. S (2019). Estimation of Radio Horizon Distance Using Measured Meteorological Parameters over Some Selected Locations in Nigeria. *Asian Journal of Physical and Chemical Sciences. 7(2): 1-11, 2019;* DOI: 10.9734/AJOPACS/2019/v7i230089

Adediji, A. T., Adebusola, S. O and Ojo, J. S (2017). Variability of Microwave Radio Refractivity and Field Strength over Some Selected Locations in Nigeria. *Physical Science International Journal.*, 14(3): 1-11.

Adediji, A. T., Ismail, M and Mandeep, J. S (2014). Performance analysis of microwave radio refractivity on radio field strength and radio horizon distance over Akure, Nigeria, Wireless Personal Communications., 77:4.

Adeyemi, B and Ogolo, E. O (2014). Diurnal and seasonal variations of surface water vapor density over some meteorological stations in Nigeria. *Ife journal of science*, 127-169

Afullo, T. J., Motsoela, T and Molotsi, D. F (1999). Refractivity Gradient and k-factor in Botswana.Radio Africa.107-110.

Agunlejika, O and Raji, T. I (2010). Validation of ITU-R Model for Atmospheric Refractivity Profile in a Tropical Region. *International Journal of Engineering and Applied Sciences* (IJEAS). 2 (4): 72-82

Akpootu, D. O and Iliyasu, M. I (2017). Estimation of Tropospheric Radio Refractivity and its Variation with Meteorological Parameters over Ikeja, Nigeria. *Journal of Geography, environment and Earth science International.* 10 (1): 1-12. DOI: 10.9734/JGEESI/2017/32534

Akpootu, D. O and Rabiu, A. M (2019). Empirical Models for Estimating Tropospheric Radio Refractivity over Osogbo, Nigeria. *The Open Atmospheric Science Journal.*13:43-55 DOI: 10.2174/1874823019130100043

Akpootu, D. O., Abubakar, M. B.., Nouhou, I., Idris, M., Iliyasu, M. I., Ohaji, D. E., Fagbemi, S. A and Aina, A. O (2021a). Estimation of Terrestrial Solar Radiation and its Variation with other Meteorological Parameters over Lokoja, Nigeria. *International Journal of Current Science Research and Review.*, 4(8): 966-973. DOI: 10.47191/ijcsrr/V4-i8-13

Akpootu, D. O., Aminu, Z., Nouhou, I., Yusuf, A., Idris, M., Aliyu, M. A., Salifu, S. I., Kola, T. A and Agidi, O. E (2024a). Assessment of Tropospheric Radio Refractivity and Its Variation with Climatic Variables Over Zaria, Nigeria. *Dutse Journal of Pure and Applied Sciences (DUJOPAS).,* Vol. 10 No. 1b. 243 – 255. https://dx.doi.org/10.4314/dujopas.v10i1b.25

Akpootu, D. O., Aminu, Z., Yusuf, A., Nouhou, I., Kola, T. A., Agidi, O. E., Salifu, S. I., Idris, M., Aliyu, M. A and Aruna, S. (2024b). Investigation of Tropospheric Radio Refractivity and other Relevant Parameters Using Meteorological Variables Over Bauchi, Nigeria. *FUDMA Journal of Sciences (FJS)* Vol. 8 No. 2, April, 2024, pp 306 – 31. DOI: https://doi.org/10.33003/f js-2024 -0802 -2366

Akpootu, D. O., Iliyasu, M. I., Nouhou, I., Abubakar, M. B., Ohaji, D. E., Aina, A. O., Haliru, A. S and Sani, M. Y (2021b). Estimation and Investigation of Geopotential and Scale heights over Iseyin, Nigeria. *International Journal of Current Science Research and Review.*, 4(9), 1070-1078. DOI: 10.47191/ijcsrr/V4-i9-01

Akpootu, D. O., Momoh M.., Abdullahi Z and Umar M. (2023). Estimation of Surface Water Vapour Density and its Variation with other Meteorological Parameters over Akure, Nigeria. *Saudi Journal of Engineering and Technology.*, 8(8): 189-199. DOI: 10.36348/sjet.2023.v08i08.001

Akpootu, D. O., Mustapha, W., Rabiu, A. M., Iliyasu, M. I., Abubakar., Yusuf, S. O and Salifu, S. I (2019b). Estimation of Surface Water Vapour Density and Its Variation with Other Meteorological Parameters Over Owerri, South Eastern, Nigeria. *Hydrology*., Vol. 7, No 3, 46 – 55. Doi: 10.11648/j.hyd.20190703.12.

Akpootu, D. O., Said, R. S., Mustapha, W., Arewa, S. P., Sulu, H. T., Iliyasu, M.I. and Salifu, S.I. (2019a). Performance Analysis of Tropospheric Radio Refractivity on Radio Field Strength and Radio Horizon Distance and its Variation with Meteorological Parameters over Osogbo, Nigeria. *International Journal of Advances in Scientific Research and Engineering (IJASRE)*, *5*(10), 81–97. http://doi.org/10.31695/IJASRE.2019.33545.

Bean, B. R and Dutton, E. J (1968). *Radio meteorology.* New York: Dover Publication Co.

Bello, G., Akpootu., D. O and Sharafa, S. B. (2024). Assessment of Tropospheric Radio Refractivity and its Variation with Climatic Variables in the Guinea Savannah Region of Nigeria. *European Journal of Theoretical and Applied Sciences,* 2(3), 88-104. DOI: 10.59324/ejtas.2024.2(3).10

Cooray, F.V., Sörensen, M., Götschl, T and Pedersen, T (2000). Propagation of lightning generated transient electromagnetic fields over finitely conducting ground. *Journal of Atmospheric and Solar- Terrestrial Physics* 62, pp. 583–600

Freeman, R. L (2007). Radio system design for telecommunications (3rd Ed.).New York: Wiley-Inter Science.

Hall, M. P. M (1989). Effects of the Troposphere on Radio Communication. Institute of Electrical Engineers.

Iliyasu, M. I., Akpootu, D. O., Momoh, M., Abdullahi, Z., Yusuf, A., Muhammad, N., Sidi, S. A., Aruna, S., Umar, M and Sani, M. Y (2023). Estimation and Correlation of Surface Water Vapour Density in Benin, Nigeria. *Asian Journal of Research and Reviews in Physics.,* 7(4), 43-56. DOI: 10.9734/AJR2P/2023/v7i4148

International Telecommunication Union recommendation, ITU-R (2003). The radio Refractive Index: Its Formular and Refractivity data. 453 – 459

International Telecommunications Union, Radio Study Group (ITU-R), *Recommendation on Radio refractivity,* ITU-Rec. P. 453(2003-2019). https://www.itu.org/rec.p.453

John, S. S (2005). Introduction to RF Propagation. John Willey and sons, Inc. Hoboken; New Jersey.

Maithan, A and Asrar, V. H.S (2003). Signal strength measurement at VHF in the eastern region of Saudi Arabia. Arabian Journal for Science and Engineering 28 (2C): 3-8.

Okpani, P.E., Nwofe, P.A and Chukwu, N.O (2015). Effect of secondary radioclimatic variables on signal propagation in Nsuka, Nigeria, *European Centre for Research Training and Development, UK.*

Oyedum, O. D (2009). Seasonal variability of radio field strength and horizon over Northern and Southern Nigeria. Nigeria Journal of Pure and Applied Physics, 5, 97–104.

Tanko, M. M., Akinbobola, A., Liman, M. S and Ojo, J. S (2018). Assessment of Tropospheric Variation of Radio Refractivity and Field Strength Variability over Some Selected Stations in Northern Nigeria. *Physical Science International Journal.,* 18(1): 1-19, DOI: 10.9734/PSIJ/2018/41320

Tanko, M. M., Liman, M. S., Lumbi, W. L., Aliyu, U. S and Sarki, M. U (2022). Field Strength Variability Mapping of Nigeria. *Journal of the Nigerian Society of Physical Sciences.* DOI:10.46481/jnsps.2022.746