Current Journal of Applied Science and Technology

32(1): 1-12, 2019; Article no.CJAST.45326
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Seasonal Variation of Radio Refractivity of Some Selected Stations in Northern Nigeria

M. M. Tanko[1], M. U. Sarki[2*] and M. A. Bilya[2]

[1]Nigerian Meteorological Agency, Nigeria.
[2]Department of Physics, Faculty of Natural and Applied Sciences, Nasarawa State University, Keffi, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2019/45326
Editor(s):
(1) Dr. João Miguel Dias, Assistant Professor, Habilitation in Department of Physics, CESAM, University of Aveiro, Portugal.
Reviewers:
(1) Kingsley Eghonghon, Edo University Iyamho, Nigeria.
(2) J. S. Ojo, Federal University of Technology Akure, Nigeria.
(3) Mihai Todica, "Babes-Bolyai" University, Faculty of Physics, Cluj-Napoca, Romania.
Complete Peer review History: http://www.sciencedomain.org/review-history/28071

Original Research Article

Received 05 September 2018
Accepted 22 November 2018
Published 02 January 2019

ABSTRACT

The seasonal variation of radio refractivity of some selected stations (Abuja, Lafia, Bauchi, Kaduna, Maiduguri, and Sokoto) in Northern Nigeria was analysed using surface meteorological data sourced from the Nigerian Meteorological Agency for five years (2007-2011). From the analysed result, seasonal variation of radio refractivity was observed with higher refractivity during the wet season. The maximum refractivity during the study period was about 385 N-unit recorded in Lafia during the month of August and the minimum was about 282 N-unit recorded in Maiduguri during the month of March. The mean field strength recorded was found to be between 19 dB and 3 dB for the study stations. This implies that the output of the receiving antenna in the region may be subjected to variations of not less than 3 dB on a year and can be as high as 19 dB.

Keywords: Seasonal variation; radio refractivity; mean field strength; dry season; wet season.

**Corresponding author: E-mail: musmansarki@gmail.com;*

1. INTRODUCTION

Radio refractivity is a ratio of the radio wave propagation velocity in free space to its velocity in a specified medium. Changes in the radio refractive index of air in the troposphere determine the propagation of radio wave. The path of propagating radio wave can be curved as a result of changes in the magnitude of radio refractive index of the troposphere [1]. Radio refractive index of the troposphere plays a vital role in the prediction of the terrestrial radio links. Frequencies above 100 MHz at lower atmosphere are significantly affected by the variation of this tropospheric radio refractive index. This effect can also be observed even on lower frequencies above 30 MHz [2].

Variation of radio refractivity is observed to be temporal and spatial. This variation can be hour to hour, day to night, season to season, weather pattern to weather pattern, as well as location to location [3]. Since the radio wave communication links are affected by weather variables, the transmission medium needs to be considered so as to have a better signal from the radio communication network [3,4,5]. Several complex mechanisms which can cause transmission losses to signal and co-channel interference ranging from amplitude and phase scintillations, absorption, a scattering of radio signals, etc. are the products of random spatial variations of radio refractive index in the troposphere. The influence of the interference due to refractivity variation in the troposphere is much more prevalent in the tropical climate than the temperate climate because of the occurrence of high-intensity tropical rainfall [6-5].

Quality determination of Ultra High Frequency (UHF), Very High Frequency (VHF), and Super High Frequency (SHF) signals is a function of radio refractivity. Surface and elevated refractivity data are often required for the characterisation of radio channels. In particular, the surface refractivity is very useful for the prediction of some propagation effects [7,8].

Properties of the earth and the atmosphere greatly influence the propagation of the radio wave in the atmosphere [9]. The multi-directional refraction of the electromagnetic waves is attributed to the “curvature of the earth and the condition of the atmosphere”. Microwave path clearance is a direct function of the refractive index of the medium through which the electromagnetic wave is propagated.

The atmospheric radio refractive index is a function of air temperature, humidity, atmospheric pressure and water vapour pressure. Air temperature, pressure and humidity depending on the height at a point above the ground surface. Even small changes in any of these variables can make a significant influence on radio-wave propagation because radio signals can be refracted over whole signal path. In a well-mixed atmosphere, pressure, temperature and humidity decrease exponentially as a function of height *h*. The value of the radio refractive index is very close to the unit and the changes in this value are very small in time and space. With the aim of making them more visible, the term of refractivity, *N*, is used. The air temperature has more impact compared to the other variables and this is due to the fact the air temperature influences other weather variables [10,11].

The aim of this study is to obtain the seasonal variation of the surface refractivity of some selected stations in Northern Nigeria using surface data.

2. MATERIALS AND METHODS

This research was carried out using secondary data, analytical and statistical tools which include Excel Spreadsheets and Instant Plus.

In order to achieve the stated aim and objectives of this study, the following data were collected from six (6) stations for five (5) years:

i. Daily mean of air temperature (°C).
ii. Daily mean of atmospheric pressure (hPa).
iii. Daily mean of relative humidity (%).

The data for this research were obtained from the archive of the Nigerian Meteorological Agency (NiMet), Oshodi Lagos. This data was, however, obtained hourly at main and intermediate synoptic hours for the period. These observations and recordings cover all seasons of the year. The data was compiled and the daily means computed in the stations.

2.1 Study Area

The study area covered six stations of the Northern Nigeria which include: Maiduguri, Sokoto, Bauchi, Kaduna, Abuja, and Lafia. These stations were selected based on the geographical climatic zones and spread in the Northern part of Nigeria. Therefore, this research

Table 1. Characteristic of the study locations

Station	Climatic Zone	Coordinates
Lafia	Guinea Savannah	8.5060°N, 8.5227°E
Abuja	Guinea Savannah	9.0071°N, 7.2634°E
Bauchi	Sudan Savannah	10.2995°N, 9.8176°E
Kaduna	Sudan Savannah	10.6932°N, 7.3127°E
Maiduguri	Sahel	11.8542°N, 13.0839°E
Sokoto	Sahel	12.9177°N, 5.2084°E

looked into the spatial and temporal variations of surface radio refractivity of the study area. The stations of Sokoto and Maiduguri are located in the Sahel while the Bauchi and Kaduna are in Sudan Savannah. The two states of Lafia and Abuja are in the Guinea Savannah of Northern Nigeria. Table Presents the characteristics of the study Stations with their Respective Coordinates.

2.2 Method

The method adopted for the computation of refractivity in this work is an indirect one. This method involves measuring the meteorological parameters involved in the variation of the refractivity. Daily air temperature, pressure, and relative humidity were measured and subsequently, the water vapour pressure is computed from the measured parameters. The indirect method is adopted in this work because of its availability and cost. Measuring radio refractivity directly using Refractometers is the most effective and reliable method.

2.3 Data Analysis

The daily mean of pressure, temperature and relative humidity were obtained by averaging the hourly data, which in turn were averaged to obtain the mean monthly values of the data. This is because the aim of this work is to obtain the seasonal variation of the refractivity and Field Strength Variability. Given by Ukhurebor and Azi [4,12].

$$e_s = H \times \frac{6.1121\exp\left(\frac{17.50t}{t+240.97}\right)}{100} \quad (1)$$

e_s.= saturated vapor pressure

Equation (1) was used in computing the saturated vapor pressure e_s.

$$e = \frac{\rho T}{216.7} \quad (2)$$

e= vapor pressure (hPa)

However, the water vapour pressure was obtained from equation (''2'') using the values obtained from equation (“1”). Given by Ukhurebor and Azi [4,12].

The radio refractivity N

$$N = (n-1)10^6 = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \quad (3)$$

P= Atmospheric pressure (hPa)
T= Absolute temperature in kelvin (K)

The values of e, P and T were then employed into equation (“3”) to obtain the refractivity values for the study stations. Finally, the value of the field strength variability (FSV) was obtained using equation (4)

$$FSV = (N_{s(MAX)} - N_{s(MIN)}) \times 0.2dB \quad (4)$$

The rainfall variation of the study stations was also analysed so as to ascertain the level of influence of precipitation on the refractivity variation. The statistical analysis in this work was carried out using Minitab, MATLAB, and SPSS.

3. RESULTS AND DISCUSSION

The seasonal variation of radio refractivity and field strength variability (FSV) for each station was obtained as outlined in the aim of the study. This is achieved from the monthly mean of all the measured meteorological parameters. MATLAB, Excel and Instant Plus were employed as tools for graph and data analysis. Efforts were made to compare the refractivity variation with rainfall pattern in all the study stations so as to establish a relationship between refractivity and rainfall pattern. To achieve this; rainfall data was incorporated into the research even though it is not part of the variables for obtaining the refractivity. It is an established fact that radio refractivity depends on moisture content in the atmosphere.

To achieve one of the objectives of the study we looked into the behaviour of the refractivity variation in both the rainy and dry season and also the contribution of the wet and dry Terms of the refractivity in these seasons. Having divided our study station into three geo-climatic zones (Guinea Savannah, Sudan Savannah and Sahel) in Northern Nigeria, we equally looked in the behaviour of this variation in these zones.

Finally, the degree of significance of the measured parameters on radio refractivity was obtained. This was achieved by correlating each parameter with the refractivity in each of the study stations. In discussing the result, efforts were made to compare our result with results obtained from the previous study. This is deliberately done to check for consistency and agreement. Below is the discussion of the result.

3.1 Seasonal Variation of Refractivity over Lafia and Abuja Stations

The seasonal variation of refractivity over Lafia (Fig. 1) for 2007 to 2011 shows January at 327 N-Units to December at 330 N-Units. The refractivity at Lafia showed a gradual increase from a minimum of about 327 N-units for January to about 385 N-Units for August. This confirms the pattern of rain in the area where August to October records the highest rainfall with the peak at August measuring 232.62 mm as presented in Table 2. The slight drop for the month of July before reaching a peak of about 385 N-units in August can be attributed to August break where there is a cessation of rain. The Lafia station experiences its dry season from November to January.

The variation of refractivity over Abuja as depicted in Fig. 1 also show a seasonal variability with a gradual increase from a minimum of about 316 N-units in January to a maximum of about 378 N-units in August. The refractivity over Abuja showed a continuous pattern from May to October. This can be attributed to the rain pattern of Abuja where consistent heavy rain is experienced within the period as indicated in Fig. 2. The similarities exhibited by the two stations confirmed the fact that they belong to same zone.

3.2 Seasonal Variation of Refractivity over Bauchi and Kaduna Stations

The Seasonal variation of refractivity over Bauchi in Fig. 3 is observed to show the same pattern repeating itself. The minimum value of refractivity recorded was about 289 N-Units in the month of February with the maximum recorded in the month of August at about 361 N-Units. The variation in this station follows the same pattern recording the minimum refractivity between February and March and the maximum refractivity in the month of August. This picture is stressing the fact that Bauchi station experiences its driest moment in the month of February and the highest amount of rainfall in August. This can be confirmed in Fig. 4.

The variation of refractivity over Kaduna is shown in Fig. 3 About 367 N-Units was recorded as a maximum value of refractivity in the station. That was in the month of August like the previous stations. The minimum value of refractivity of about 290 N-Units was recorded in the month of January. Unlike Bauchi station which is in the same climatic zone, Kaduna station shows some similarity with the station in Guinea Savanah. This is because the station is experiencing early rain than other stations in the zone.

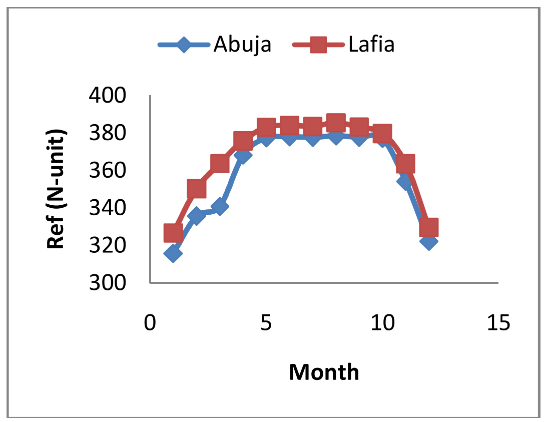

Fig. 1. Seasonal Variation of Surface Refractivity over Lafia and Abuja Station

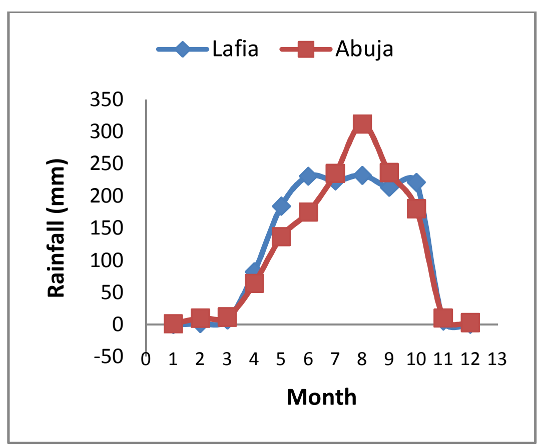

Fig. 2. Seasonal Rainfall Variation over Lafia and Abuja Stations

Table 2. Summary of the mean of the meteorological parameters of all the study stations

Station	N_s (N-unit)		Range N_s	RH (%)		Pres (hPa)		Temp (°C)		Rain (mm)	
	Max	Min		Max	Min	Max	Min	Max	Min	Max	Min
Lafia	385.47	326.70	58.77	87.00	41.00	16.00	12.90	32.00	26.10	232.62	0.00
Abuja	378.42	315.84	62.58	87.00	36.00	16.10	12.90	31.20	24.70	311.92	1.34
Bauchi	361.46	289.50	71.96	72.00	17.00	12.20	7.40	32.20	23.80	394.28	0.00
Kaduna	367.41	289.96	77.45	81.00	19.00	14.90	10.60	29.90	23.40	288.48	0.00
Maiduguri	375.22	281.50	93.72	76.00	13.00	15.40	8.90	34.80	23.80	185.48	0.00
Sokoto	376.13	285.71	90.42	79.00	15.00	14.00	8.10	34.00	23.80	215.5	0.00
Study Mean	385.47	281.50	73.00	87.00	13.00	16.10	8.10	34.80	23.40	394.28	0.00

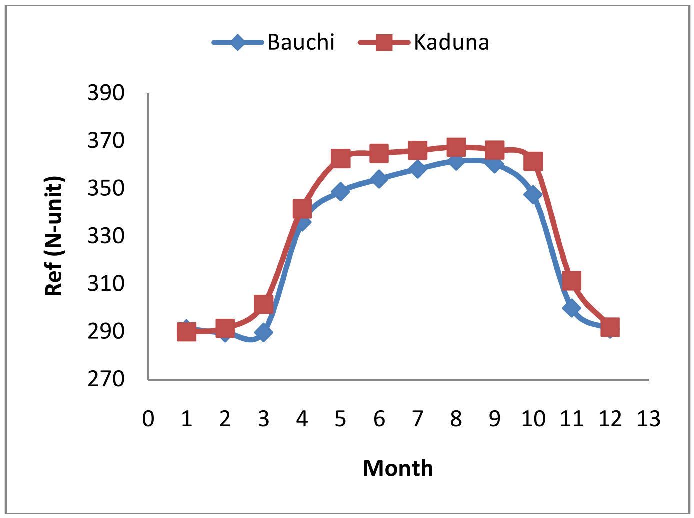

Fig. 3. Seasonal Variation of Refractivity over Bauchi and Kaduna Stations

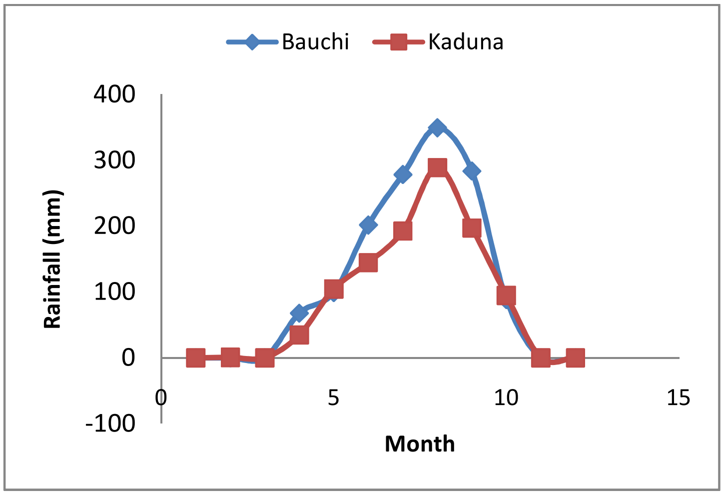

Fig. 4. Seasonal Rainfall Variation over Bauchi and Kaduna Stations

3.3 Seasonal Variation of Refractivity in Maiduguri and Sokoto Stations

In the extreme north in the Sahel, the refractivity variation in Maiduguri and Sokoto stations shows almost similar pattern. The variation of refractivity over Maiduguri as shown in Fig. 5 increased almost steadily from about 281 N-unit in March until it climaxed at 375 N-unit in August. The Sokoto station recorded a maximum value of 376 N-unit in August and a minimum of 261 N-unit in March. Both the minimum and maximum refractivity recorded in Sokoto were a little higher than that of Maiduguri. This is largely due to rainfall record within the study period. In these two stations, higher values of refractivity were recorded between the months of May and October. This is the period of the rainy season in the stations.

However, the sudden drop in refractivity from November to April was attributed to rainfall cessation and the heralding of the dry season. This result agreed with Ayantunji *et al.,* (2011); where a pattern with a very steep rise and fall was reported. That was attributed to the pattern and shorter period of rainfall in Sokoto; a station in the same climatic zone with Maiduguri. The maximum values of refractivity reported in this zone (Maiduguri and Sokoto station) are however found to be higher than that of Bauchi and Kaduna (two stations in the Sudan Savanah) during the peak period because the rainfall at Maiduguri like Sokoto is usually heavy within the short rainy season. Table 2 presents the summary of the mean of the meteorological parameters of the study locations.

3.4 Seasonal Variation of Radio Refractivity over the Study Area during the Study Period

Analysing the mean refractivity in the study area during the study period (Fig. 7), a maximum value of about 374 N-units was recorded in the month of August with a minimum of about 301 N-units recorded in the month of March. The maximum mean refractivity of the study area is lower than what was recorded in Lafia Station and the mean minimum is higher than what was recorded in Bauchi and Kaduna stations. Considering Table 2 the range of 93 N-unit was recorded in Maiduguri Station which higher than 90 N-unit in Sokoto that was reported by Addiji and Ajewole [1]. The rise in refractivity for the study area during the period under study started from March and climaxed at August. In this region, the rainy start mostly between late March and early April. This assertion is confirmed in Fig. 7 where the rise in rainfall curve is seen to be from March and climaxing in the month of August just like refractivity.

3.5 The Degree of Influence of Meteorological Parameters on Refractivity

One of the objectives of this study is to investigate the degree of influence of meteorological parameters on the radio refractivity of the study area. With this, a clear idea of the major driving forces of the refractivity will be obtained. To achieve this, we computed the linear relationship between individual parameter with the radio refractivity.

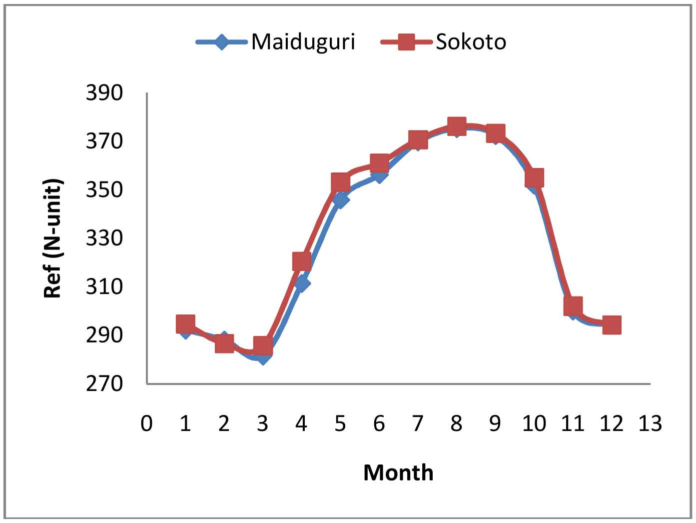

Fig. 5. Seasonal Variation of Refractivity over Maiduguri and Sokoto Stations

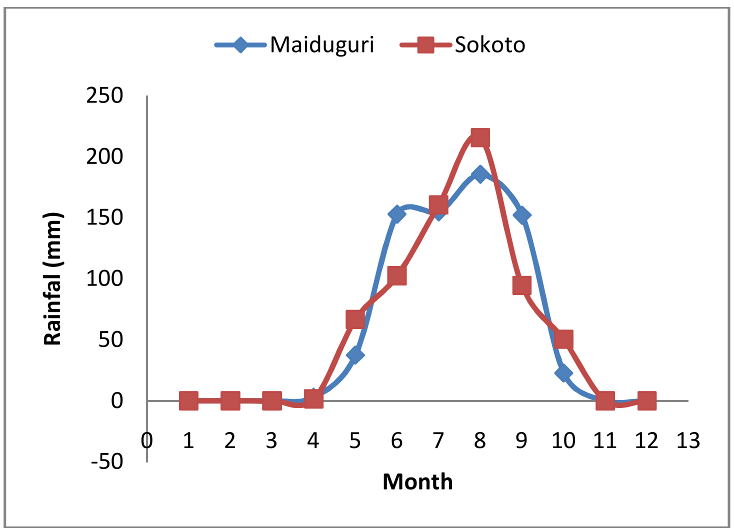

Fig. 6. Seasonal Rainfall Variation over Maiduguri and Sokoto Stations

From Table 3, it is shown that a strong linear relationship exists between rainfall and refractivity with a correlation coefficient of 0.9298 at 5% significant level. This is an indication of near perfect linearity between the two components. Maximum values of refractivity are recorded during the raining season when the precipitation is intense. Hence it can be deduced from this that moisture content in the atmosphere causes the refraction of the electromagnetic wave. With this equation, refractivity can be predicted.

$$N_s = 315.1 + 0.2846 * Rainfall$$

On the other hand, the relationship between pressure and radio refractivity here is very weak. This is confirmed from the correlation coefficient shown in Table 2 which is 0.0710. The contribution of pressure to radio refractivity in this region is just 7.1%. The dry season in the study area starts usually from November to March while it rains for the remaining period of the season with more precipitation between July and September.

$$N_s = 1.755 * Pressure - 1435.62$$

However, the temperature also just like pressure correlate weakly with radio refractivity in this region. The correlation coefficient from Table 2 is just 1.2%. This is stressing the fact that temperature contributes little to the refraction of radio refractivity in this region.

$$N_s = 341.31 - 1.528 * Temperature$$

The correlation between radio refractivity and relative humidity is found to be 98.8% in this study. Being the product of moisture contents in the atmosphere, the relative humidity is a driving force to the refraction of an electromagnetic wave in the atmosphere. This implies that with relative humidity, refractivity in this region can be predicted to an accuracy of 98.8% with this equation.

$$N_s = 1.387 * RH + 269.355$$

3.6 Wet Term and Dry Term Contribution to Radio Refractivity

From this study, the dry term N_{dry} makes a relatively constant contribution to N_s of about 262 N-unit whilst the wet term N_{wet} provides most of the variability of N. Table 3 displays the summary of the contribution of these terms to the radio refractivity.

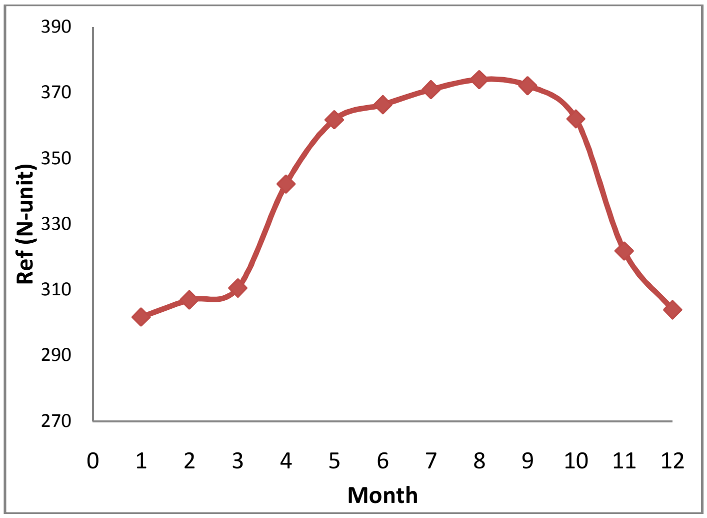

Fig. 7. Mean seasonal variation of refractivity of the study stations over the period of five years

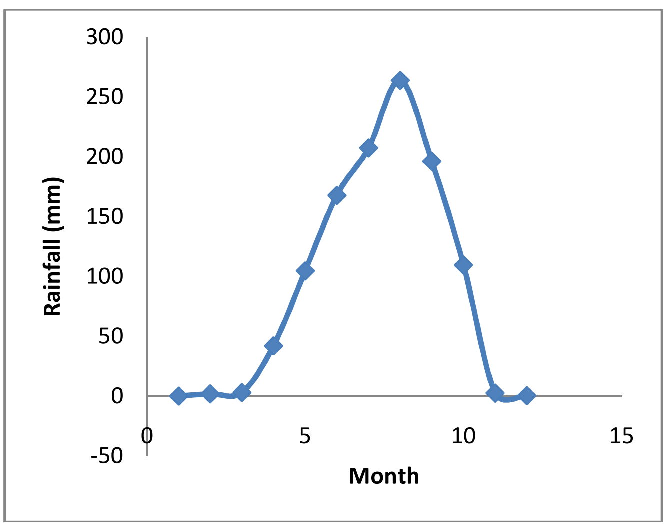

Fig. 8. Mean seasonal rainfall variation of the study stations over a period of five year

The maximum wet Term recorded in Lafia and Abuja stations are 122.14 N-unit and 115.95 N-unit respectively; while the minimum recorded are 65.40 N-unit and 53.56 N-unit respectively. However, the maximum dry Term for the two stations is 263.56 N-unit and 264.73 N-unit respectively while the minimums are 257 N-unit and 258 N-unit respectively. From this, Table 4 displays the summary of the contribution of these terms to radio refractivity. And is caused by the wet term which contributes about 80% of the variation compared to just 20% of the dry term. This trend is the same in all the stations.

Generally, for all the stations studied, the seasonal variation of refractivity showed that the dry term (largely influenced by the pressure) is the primary cause of refractivity variation in rainy season and the wet term (largely influence by Humidity) is the major cause of refractivity variation in the dry season.

3.7 Field Strength Variability (FSV)

The FSV in this work was carried out using Equation (4). As shown in Figs. 9, 10 and 11 the field strength is observed to be higher during the dry season and lower during the rainy season. Recording higher values for field strength during the dry month could be attributed to the prevalence of higher ranges of refractivity in the dry season, which is as a result of higher surface temperature, reduced humidity and nearness to Inter Tropical Discontinuity (ITD). Like refractivity, field strength also depends on the moisture contents in the atmosphere.

Table 3. Correlation of Metrological parameters with Refractivity

Parameters	Correlation	Slope	Y-Intercept
Rainfall	0.9298	0.2846	315.11
Pressure	0.0710	1.7551	-1435.62
Temperature	0.012	-1.5282	384.314
Humidity	0.9881	1.3868	269.355

Table 4. Wet Term and Dry Term Contribution to Radio Refractivity

Station	N_{wet}		N_{dry}		N_{wet}%		N_{dry} %	
	Max	Min	Max	Min	Max	Min	Max	Min
Lafia	122.14	65.41	263.56	257.69	32.36	20.71	82.73	69.12
Abuja	115.95	53.56	264.73	258.42	30.27	16.39	80.28	68.27
Bauchi	98.98	26.50	264.66	256.23	27.41	9.10	90.90	72.59
Kad	102.91	24.18	265.78	259.07	28.38	8.39	91.66	72.06
Maiduguri	113.58	24.16	265.57	254.41	30.27	8.58	91.42	69.73
Sokoto	114.19	25.79	265.17	254.79	30.36	9.00	91.00	69.64
Study	122.14	24.16	263.56	254.41	32.36	8.34	91.66	68.27

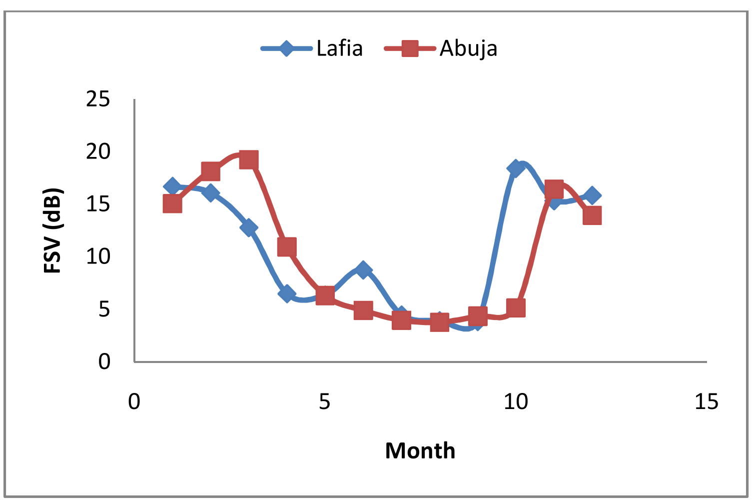

Fig. 9. Field Strength Variability of Lafia and Abuja Stations

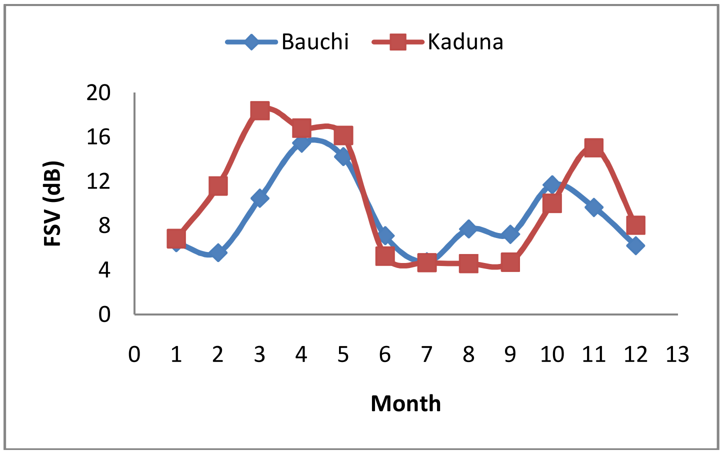

Fig. 10. Field Strength Variability of Bauchi and Kaduna Stations

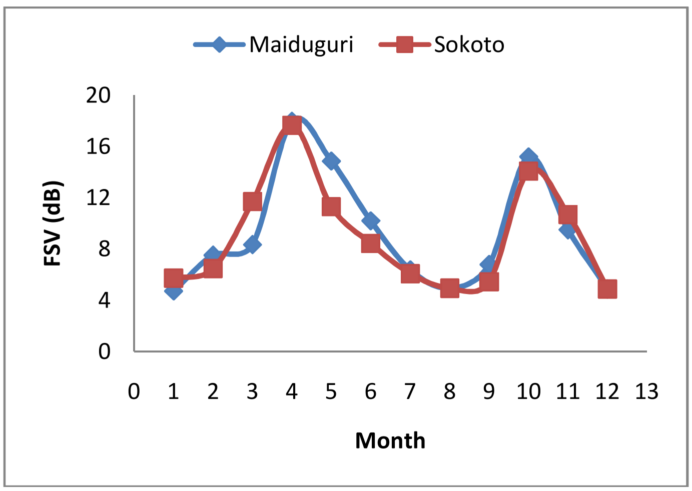

Fig. 11. Field Strength Variability of Maiduguri and Sokoto Stations

The field strength of Lafia and Abuja stations is found to follow the trend as shown in (Fig. 9) Higher values were recorded during the dry season and lower values during the rainy season. For the zone, the maximum FSV as shown in Table 4 is 18.40 dB and 19.23 dB for Lafia and Abuja stations respectively while the minimum is 3.85dB and 3.76 dB respectively. This suggests that the output of a receiving antenna in this zone should not be less than 3 dB in a year, but can be as high as 19 dB.

Furthermore, the field strength recorded in Bauchi and Kaduna station is displayed in Fig. 10 From the Table 5, it can be deduced that the maximum field strength recorded for Bauchi and Kaduna are 15.46 dB and 18.38 dB respectively; while the minimum are 4.75 dB and 4.59 dB respectively. A close look at Fig. 10 reveals an inconsistent pattern where lower values of field strength are recorded in December and January. This could be attributed to intense dryness experience in this zone in the two months resulting in almost equal values of refractivity. For the purpose of management of terrestrial radio link in this zone, the output of a receiving antenna may generally be subjected to variations to as high as 18 dB in year and should not be less than 4 dB.

However, the result recorded in Maiduguri and Sokoto stations (Sahel) shows a pattern almost similar to that of the Bauchi and Kaduna stations. Table 5 shows a maximum of 17.98 dB and 17.66 dB for Maiduguri and Sokoto stations respectively and a minimum of 4.73 dB and 4.89 dB respectively. This implies that the output of a receiving antenna in this zone may generally be subjected to variations not less than 4 dB in a year, but can be as high as 18 dB.

Table 5. Field Strength mean of the study area

Station	Field Strength (dB)	
	Max	Min
Lafia	18.40	3.85
Abuja	19.23	3.76
Bauchi	15.46	4.75
Kaduna	18.38	4.59
Maiduguri	17.98	4.73
Sokoto	17.66	4.89

4. CONCLUSIONS

This study achieved all the stated objectives of the research through the designed methods. The results have shown a clear variation in the values of radio refractivity with most of the refractivity in the Guinea Savannah and less in the Sahel. This clearly has confirmed the fact that there is less humidity in the Sahel than the Guinea Savannah due to the proximity of the zone to the ITD (Inter Tropical Discontinuity), a meteorological boundary between the moist southwesterly monsoon and warm, and dry and dusty northeasterly trade wind.

4.1 Seasonal Variation of Radio Refractivity

The result from this work shows a seasonal variation of refractivity at all the stations. This result agrees with the previous work of [1,2,13,14].

The value of refractivity is observed to be increasing from a minimum of about 282 N-Units in March at Maiduguri station to maximum value of about 385 N-units at Lafia station (Table 1).

In conclusion, the analysis of the radio refractivity in some selected stations in Northern Nigeria confirmed a seasonal variation. The variation recorded in the rainy season was found to be higher than what was recorded in the dry season; this is attributed to the amount of moisture in the atmosphere during the rainy season. The value of refractivity during the study period increases from about 281 N-unit in Maiduguri (a station in Sahel) to about 385 N-unit in Lafia (a station in Guinea Savannah). This trend asserts the fact that Sahelian stations are drier than stations in the Guinea savannah; this could be attributed to their proximity to the ITD; an imaginary boundary between the moist South-westerly monsoon flow and the hot, dry North-easterly wind from the Sahara which gives them a higher surface temperature and reduced humidity. This conclusion agrees with the previous work. Much consideration must be given to this variation when planning terrestrial radio links in the region.

However, in analysing the Field Strength variability (FSV); maximum value was observed to dominate months in the dry season while the minimum value was observed in the rainy season. The high values recorded in the dry season could be attributed to reduced humidity characterised by the season. After computing the FSV for five years in six stations, maximum field strength recorded was 18.40 dB in Lafia station and the minimum was recorded in Abuja station at 3.76 dB. This implies that the output of a receiving antenna in this region may generally be subjected to variations not less than 3 dB in a year and can be as high as 18 dB. Good assessment of field performance to ensure more reliability of existing intended terrestrial radio links can be enhanced in line this with the knowledge of these FSV trends.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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http://www.sciencedomain.org/review-history/28071