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Assessment of Tropospheric Variation of Radio Refractivity and Field Strength Variability over Some Selected Stations in Northern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author MMT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AA and JSO managed the analyses of the study. Author MSL managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The effects of meteorological parameters on the tropospheric radio refractivity and field strength variability cannot be overemphasised especially at the lower troposphere. The variability of tropospheric radio refractivity and field strength over selected fourteen stations in northern Nigeria has been assessed from daily meteorological data of pressure, temperature and relative humidity for the period of 12years (2003-2014). The data were sourced from the archive of European Re-Analyzed data (ERA Interim). The variables were computed using theoretical formulations and regression analysis was carried out to obtain the degree of influence of the meteorological parameters on surface refractivity. The result revealed a seasonal variation with maximum

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refractivity of about 424 N-unit in the wet months and minimum refractivity of about 248 N-unit in the dry months. Also, the stations in the guinea savannah showed a higher refractivity than the stations in Sudan and the Sahel region. This could be partly attributed to the reduction in humidity enhanced by a distance between the Inter Tropical Discontinuity (ITD) and the stations. Moreso, a higher field strength of about 28 dB during dry months and a lower field strength of about 2 dB during the wet months were observed. The study has revealed a strong correlation between the relative humidity and refractivity in all the three geo-climatic zones of northern Nigeria.

Keywords: Tropospheric refractivity; Inter Tropical Discontinuity (ITD); field strength.

1. INTRODUCTION

In order to propose a reasonable prediction models for radio-climatic study, a reliable radio propagation data is required. This radio propagation data can be either primary or secondary radio propagation data. The secondary data can be estimated from a relevant primary data. Primary radio-climatic data include temperature, pressure and humidity or water vapour pressure, while secondary radio-climatic data includes, refractivity data such as refractivity gradients, ducting data, geo-climatic factor and also data that incorporate the effect of earth curvature on radio wave propagation such as effective earth radius factor (k-factor).

The lower atmosphere is not homogeneous. Therefore, it affects the electromagnetic (EM) wave propagation in the lower atmospheric layers. It was observed by [1] that worse propagation conditions lead to decreased power levels at transmitter/receiver and to increased fading on communication links. Therefore, to achieve optimal performance, the radio link systems must be planned and well designed. One of the basic primary steps in radio link system design is an estimation of the atmospheric refractive index, *n*. It is a ratio of radio wave's propagation velocity in free space and its velocity in a specified medium [2]. Refractive index is always required when measurements are made in air [3]. It was noted in [4] that even small changes of temperature, humidity and partial water vapour pressure lead to changes of the atmospheric refractive index. Therefore, *n* variations are observed in the path of a radio wave. The refractive effect is associated with the bending of EM waves and is related to the vertical pressure, temperature and humidity distributions in the atmosphere [5]. The anomalous electromagnetic wave propagation could cause problems for radars, because the variation of the refractive index can induce loss of radar coverage [6]. In practice, for most cases the actual propagation conditions are more complicated in comparison with the conditions that are predicted in radio system's design. The meteorological conditions have a significant impact on radio wave propagation through the atmosphere [7].

However, the term atmosphere is used for earth's atmosphere. Atmosphere extends from a few meters below the earth's surfaces or water's surface to a height of about 60,000 km. However, about 90% of the atmosphere is within few km from the ground. Most of the mass of the atmosphere is near a planetary surface, as the gravity pulls them towards the earth's center.

Electromagnetic waves would travel in a straight line if the atmosphere is homogenous but since the atmosphere and its permittivity (ϵ) are stratified, electromagnetic waves passing through it are not straight but bend [8]. The structure of the radio refractive index, *n*, at the lower part of the atmosphere is a very important parameter in planning of the communication links. It is defined as a ratio of the radio wave propagation velocity in free space to its velocity in a specified medium. Radio wave propagation is determined by changes in the refractive index of air in the troposphere. Changes in the value of the troposphere radio refractive index can curve the path of the propagating radio wave.

At standard atmosphere conditions near the Earth surface, the radio refractive index is equal to approximately 1.0003 [9]. As the conditions of propagation in the atmosphere vary from the standard ones, the anomalous radio wave propagation is observed. Such anomalies are incident with some meteorological conditions (inversion of temperature, high evaporation and humidity, passing of the cold air over the warm surface and conversely) [10].

The atmosphere radio refractive index depends on air temperature, humidity, atmospheric pressure and water vapor pressure. In a standard atmosphere, the temperature, pressure, and relative humidity decrease with altitude above the ground surface. And the radio refractivity decreases as well [11]. 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 [12].

Horizontal variation of refractive index is generally negligible in the lower troposphere compared to the large-scale vertical variation which has a median gradient of about -40N/km near the surface in the mid-altitude and the most temperate regions. However, significant deviations can arise from local or mesoscale meteorological factors, especially in the tropics. This horizontal variation of refractive index is very significant over Nigeria because of the significant change in climatic condition from the coastal region in the extreme south to the semi-arid region in the extreme North [13].

Surface refractivity is negatively correlated with radio field strength especially at very high frequencies. This is the confirmation of the dominance of the moisture content in the atmosphere. In all the studies reviewed, field strength tends to be high in all the station when the refractivity is low and that corresponds to the time when there is reduced humidity as well as moisture. In the frequency range 30-300 MHz, a factor of 0.2dB change in field strength may be adopted for every unit change in N_s [14]. These works are not enough to generalise the variation of radio refractivity and field strength over Nigeria, due to variation of meteorological parameters in each station and at large in each geographical location. Hence, this work studied the variation of radio refractivity and field strength over fourteen locations in Nigeria covering majorly northern part with different climatic conditions.

2. METHODOLOGY

2.1 Study Area

The stations are located in northern Nigeria between Longitudes 3° and 15° East and Latitudes 9° and 14° north. The climate of this region is characterised by alternate wet and dry seasons in response to the changes in pressure patterns. The rainy season is associated with late onset and earlier cessation, the onset and cessation are also characterized by destructive storms which destroy life and property. The seasonal and latitudinal variations affect diurnal and seasonal temperature ranges, the highest maximum air temperature is recorded in the northern part usually areas north of lat 9° and occur in March/April and minimum temperatures are recorded in December/January North of latitude 9°N.

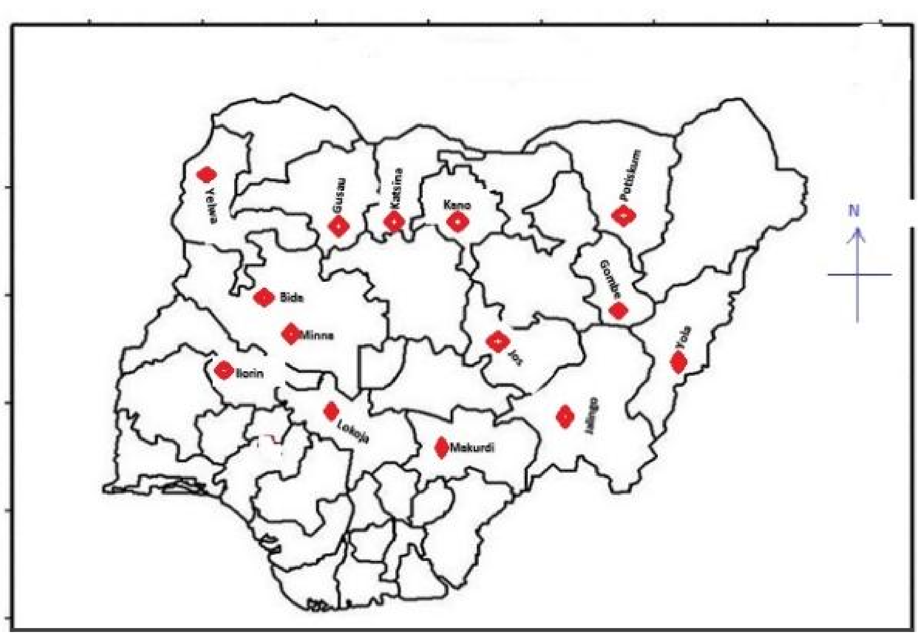

Fig. 1. Map of the study area

The general relief of this belt is between 300 to 900 m, except the Niger-Benue trough, Sokoto and Chad Basins that are below 300m. Northern Nigeria is dominated by savannah vegetation types; Guinea, Sudan and Sahel savannah. The density of trees and grasses decrease northwards responding to climatic conditions. Agriculture is the most dominant economic activity in the region.

2.2 Theoretical Background

All electromagnetic waves obey the inverse-square law in free space. The inverse-square law states that the power density of an electromagnetic wave is proportional to the inverse of the square of the distance from the source. That is, if the distance from a transmitter is doubled, the power density of the radiated wave at the new location is reduced to one-quarter of its previous value [15]. Also, the electromagnetic waves coming from a transmitter may experience three other phenomena: reflection, diffraction, and scattering. All of these factors affect the transmitted signal as it is "carried" through the air medium to the distant receiving antenna.

Radio wave propagation is determined by changes in the refractive index of air in the troposphere [16]. Changes in the value of the troposphere radio refractive index can curve the path of the propagating radio wave. The changing nature of the atmosphere causes the refractive index of the troposphere to vary as the height increases from sea level and this consequently has a significant effect on the radio signal [17]. It is important to find the causative agent of these variations. The procedure recommended by the ITU-R for determining these variations are given in [18]. The atmospheric radio refractive index can be computed from the formula:

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

where N is the radio refractivity expressed as:

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

or

$$N = \frac{77.6}{T}\left(p + 4810\frac{e}{T}\right) \quad (3)$$

The refractive index of air *n* is related to the dielectric constants of the gas constituents of an air mixture. Its numerical value is only slightly larger than one. Therefore, a more convenient atmospheric refractivity *N* (N-units) is usually introduced as (2). The right hand part of (2) can be simply demonstrated, based on the Debye theory of polar molecules, that refractivity can be calculated from pressure *p* (hPa) and temperature *T* (K) [19].

The *e* (hPa) stands for water vapour pressure that is related to the relative humidity *H* (%) by a relation:

$$e = \frac{He_s}{100} \quad (4)$$

It can also be expressed as, [20]:

$$e = H \times \frac{6.1121\exp\left(17.502t/t + 240.97\right)}{100} \quad (5)$$

where H = relative humidity (%) and t = temperature (^{o}C).

Vapour pressure *e* is obtained from the water vapour density r using the equation:

$$e = \frac{\rho T}{216.7} \text{ hPa} \quad (6)$$

The equation (2) may be used for all radio frequencies; for frequencies up to 100GHz, the error is less than 0.5%. The two terms in the refractivity *N* in equation (3) are often separated into dry term D and wet term W:

$$N_{dry} = 77.6\frac{P}{T} \quad (7)$$

$$N_{wet} = 3.73 \times 10^5 \frac{e}{T^2} \quad (8)$$

Both terms decay with height but at different rates leading to the bi-exponential model. The dry term N_{dry} makes a relatively constant contribution to N_s of about 265 whilst the wet term N_{wet} provides most of the variability of *N* [21].

Using N_s values obtained using Eqs (1), maximum ($N_{s\,(MAX)}$) and minimum ($N_{s\,(MIN)}$) values of N_s are determined, from which the monthly range is obtained as:

$$MonthlyRange = N_{s(MAX)} - N_{s(MIN)} \quad (9)$$

Thus, an assessment of field strength variability (FSV) in a given station is explored from monthly ranges of N_s from the relation [22].

where all the parameters maintained their usual meaning as explained earlier. The refractivity of the lower atmosphere; the dry and the wet composition. The dry term contributes a greater percentage, about 70% to the total value of the refractivity in the atmosphere. The dry term is proportional to the density of the gas molecules in the atmosphere and changes with their distribution. The dry term of refractivity which is fairly stable, can be modeled with an accuracy of about 20% using surface measurements of pressure. The field strength variability (FSV) is determined from

$$FSV = (N_{s(MAX)} - N_{s(MIN)}) \times 0.2dB \qquad (10)$$

2.3 Methods

Daily Meteorological parameters which include temperature, relative humidity, pressure and rainfall were obtained from the Era Interim. The water vapor pressure 'e_s' was obtained from equation

$$e = H \times \frac{6.1121\exp\left(\frac{17.50t}{t+240.97}\right)}{100} \qquad (11)$$

Where H is the relative humidity (%) and t is the temperature (^{o}C). The saturated vapor pressure e was subsequently computed from

$$e = \frac{He_s}{100} \qquad (12)$$

The value of the radio refractive index, n, is very close to the unit and changes of this value are very small in time and space. To make those changes more notable, the term of radio refractivity N is used [23] and [24].

$$N = (n-1) \times 10^6 \qquad (13)$$

According to the Recommendation of ITU [25]: The radio refractivity N, as a function of pressure p (hPa), temperature T (K) and water vapor pressure e (hPa) was computed from

$$N = \frac{77.6}{T}\left(p + 4810\frac{e}{T}\right) \qquad (14)$$

where T (K) is the temperature; p (hPa) is the atmospheric pressure; e (hPa) is the partial water vapour pressure. The refractivity is expressed in N-units.

It was mentioned in (Freeman, 2007) and (ITU-R, 2003) that equation (14) may be used for all radio frequencies. For frequencies up to 100GHz, the error is less than 0.5%. There are two terms (the "dry term" and the "wet term") in relationship equation (14). The relationship between the partial water vapour pressure e and the relative humidity H is presented in (12).

Using the refractivity values obtained from equation 13, the Field Strength Variability (FSV) was computed. In the frequency range of 30-300MHz, a factor of 0.2dB change in field strength may be adopted for every change in N_s [26]. The assessment of FSV was explored from the monthly ranges of N_s from the relation (Adediji et al., 2014):

$$FSV = (N_{s(MAX)} - N_{s(MIN)}) \times 0.2dB \qquad (15)$$

The tropospheric radio refractivity variation and field strength variability (FSV) of each of the fourteen stations was obtained. This is achieved from the monthly mean, seasonal mean, station mean, climate zone mean and mean of all the measured meteorological parameters. In an effort to establish a relationship between refractivity and rainfall pattern, rainfall data was incorporated into the research for all the study stations. Even though rainfall is not a parameter in determining the radio refractivity, it is an established fact that radio refractivity depends on moisture content in the atmosphere.

Since the primary meteorological parameters vary both temporal and spatial, we looked into the behaviour of the refractivity as it varies from stations as well as season (wet and dry). Also the contribution of the Wet and Dry Terms of the refractivity in all the stations and seasons was also obtained. Having divided our study station into three geo-climatic zones (Guinea Savannah, Sudan Savannah and Sahel) in Northern Nigeria, we equally assess the behavior 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 study station.

3. RESULTS AND DISCUSSION

3.1 Seasonal Variation of Radio Refractivity

The result shows a seasonal variation of refractivity at all the stations. This result agrees with the previous work of [27,28,29] and [30]. The value of refractivity is observed to be increasing from minimum of about 248 N-Units in March at Katsina station to maximum value of about 424 N-units at Yelwa station (Table 1). This result agrees with the work of [31] which concluded that refractivity increases from the inland toward the coast. This he reported was due to the influence of the Atlantic Ocean responsible for the incursion of the South westerly wind.

3.2 Radio Refractivity in the Guinea Savannah

The seasonal variation of Radio Refractivity in this climatic zone exhibit a similar trend throughout with all the stations with exception of Jalingo; minimum refractivity was recorded in the month of January and maximum in the month of April as depicted in Fig. 2(a). This pattern could be attributed to the pattern of rain in this zone. Fig. 2(a) has shown that a minimum refractivity of about 347 N-units was recorded in the month of January and the maximum of 394 N-units in the month of April with a fall in the month of August at 382 N-units this could be due to august break.

However, for Jos station as displayed in Fig. 2(a) shows an increase from 295 N-units in January to about 367 N-units in April. The high altitude of Jos could be responsible for the low value of refractivity recorded. High altitudes are always characterized with low pressure and since the pressure is positively correlated with the dry component of the refractivity it is obvious for that to manifest in the overall value of refractivity. The values of refractivity for Minna as captured in Fig. 2(a) shows a gradual increase from about 326N-units in the month of January until it peaked at about 393 N-units in the month of April. A gradual drop was recorded from May until a dip of about 385 N-units was recorded in August. Following the same with other stations in the zone minimum refractivity of about 342 N-units and maximum of about 398 N-units was recorded in Makurdi as depicted in Fig. 2(a). A minor peak was recorded at about 393 N-units in the month of October resulting from a rise from the fall recorded in the month of August at about 388 N-units. The higher values of refractivity recorded in this station could probably be attributed to the presence of river Benue in Makurdi. When the Harmattan wind climaxed in February more water vapour is blown from river Benue thereby increasing the humidity over Makurdi and consequently the refractivity. The drop in the month of August is due to the August break as it is with all the stations in the same climatic zone.

However, Jalingo station as depicted in Fig. 2(a) shows a gradual increase from about 303 N-units in the month of January until it climaxed to about 385 N-units in the month of May. Another peak of about 380 N-units was also recorded in the month of September. Further observation of Fig. 2(a) shows that Lokoja station has a lot in common with Makurdi station particularly it higher values of refractivity. In this station like Makurdi about 354 N-unit was recorded in the month of January rising steadily to a peak of 398 N-unit in the month of April. A more pronounced dip was recorded in the month of August at about 386 N-units giving rise to another peak at about 392 N-unit in the month of October. Bida station as depicted in Fig. 2(a) has shown a rise from about 329 N-units in the month of January to a peak of about 395 N-units in the month of April. A fall was recorded in the month of August at about 387 N-units with a second peak at about 393 N-units in the month of October.

3.3 Radio Refractivity of Sudan Savannah

Stations under study in this zone include Yola, Kano, Gombe and Yelwa. The seasonal variation in this zone is depicted in Fig. 3(a) the stations in this zone exhibit a uniform trend of variation with minimum refractivity mostly recorded in the month of January with the exception of Kano. The variation in Yola as shown in Fig. 3(a) displaying a minimum of about 294 N-units in the month of January from where a steady rise was observed to about 384 N-units in the month of May. The manifestation of the August break can be observed with the fall in August where about 380 N-units was recorded. A slightly high value was also recorded in the month of September at about 382 N-units.

The values of refractivity in Gombe station increases near steadily from about 289 N-units in the month of January to about 383 N-unit in the month of September as shown in Fig. 3(a). Kano station recorded about 279 N-units in the month of February as displayed in Fig. 3(a). This confirms the fact that the month of February is the driest month in Kano. The values of refractivity rise through June at about 375 N-units until it climax at 379 N-units in the month of August. Kano has exhibited a deviation from the norm of all the stations in the zone by recording a single peak. This could be attributed to it rainfall pattern where it records most of its rain in the month of August. However, about 315 N-units of refractivity was recorded in the month of January at Yelwa station rising steadily to the peaks of 393 N-units in May and 392 N-units at September. The fall between these two peaks was in the month of August at about 388 N-units.

3.4 Radio Refractivity of Sahel Savannah

Observing the variation of radio refractivity in the sahelian stations under study we will see that lower values are recorded during the intense dry season. This could be attributed to reduced humidity during the period. As depicted in Fig. 4(a), Potiskum recorded a maximum refractivity of about 382 N-units in the month of August and a minimum of about 280 N-units. Rising sharply to April at 342 N-units until a peak is recorded at August suggest the rainfall pattern of this zone where the period for the rain is short but intense. The seasonal variation of radio refractivity of Gusau Station as shown in Fig. 4(a) revealed a minimum of about 283 N-units recorded in the month of January from it rises steadily to about 381 N-units in the month of June. A maximum of about 383 N-units preceding a fall in August at about 379 N-units was recorded in September. A near steady refractivity of about 280 N-units in the month of January to the month of February was observed in the Katsina station as shown in Fig. 4(a). A sharp rise to about 378 N-units in the month of Jun was also observed with a slight fall of about 377 N-units in August. The maximum refractivity recorded in this station is in the month of September at about 378 N-units.

3.5 Field Strength Variability

The analysis of field strength was carried out using the monthly range of daily refractivity. As depicted in the figures, the field strength in all the study stations is found to be higher during the dryer months and lower during the wetter months. This suggests the dependence of the field strength on the moisture content in the atmosphere. The maximum field strength recorded in the study is 28.12dB and a minimum of 1.69dB. This implies that the output of a receiving antenna for terrestrial radio links in this zone should not be less than 2dB in a year but can be as high as 29dB. The higher values of field strength recorded in this study were obtained mostly from Sahelian stations. This could explain the intense dryness of the zone.

The field strength variability of the stations in Guinea savannah as depicted in Fig. 5(a) has displayed higher values in January to March and November to December. While the lower values are observed in the months of April to October with the exception of Lokoja and Makurdi where higher values were recorded in the months of January to February and the month of December. This observation Makurdi and Lokoja in contrast to other stations within the same climatic region can probably be attributed to the presence of river Benue in Makurdi and river Niger in Lokoja. When the Harmattan wind climaxed in February more water vapour is blown from the two rivers thereby increasing the humidity over the two stations which in turn affect the values of Field Strength. The maximum and minimum field strength recorded in this climatic as shown in Fig. 5(a) are 19.12dB in Jalingo and 2.73dB in Jos respectively. For proper planning of terrestrial radio link and the installation of weather RADAR in this zone, the output of the receiving antenna should not be less than 2dB but can be as high as 20dB.

The result of the analysis of field strength in Sudan savannah is displayed in Fig. 5(b). In this zone, the drier months recorded higher values compared to what is reported in the Guinea Savannah. This could be a result of the rainfall period of the zone which mostly las from late April to early October. The maximum field strength recorded as shown in the figures below is 23.96dB in Kano and the minimum recorded is 3.23dB in Yola. The output of a receiving antenna in this zone according to this result can be as high as 24dB but must not be lower than 3dB. The months that recorded higher field strength in this zones are found to be January to April and October to December while those that recorded lower field strength are May to September.

Fig. 5(c) depicts the result of the analysis of field strength in the Sahel. The result has shown higher values in the dry months and lower values in the wet months just like the other two zones. The highest field strength recorded in this study is found from this zone, this could be attributed to the intense dryness of the zone due to its proximity to the source of the dry, hot and dusty north easterly trade wind which usually take over the zone between the month of November until the onset of rainfall in May. The lowest values of field strength recorded in all the stations in the zones were in the month of August for Potiskum and Katsina while Gusau recorded it lowest in

Table 1. Maximum and minimum refractivity and other parameters in the study areas

Climatic zones	Ref		Temp		RH		Pres		Range	Rainfall		FSV	
	Max	Min	Max	Min	Max	Min	Max	Min		Max	Min	Max	Min
Guinea	420.65	254.72	40.07	18.09	100	10.01	995.94	912.95	165.92	74.03	0	24.89	1.71
Sudan	423.79	249.35	45.49	15.62	100	4.59	989.49	949.19	174.44	66.1	0	28.14	1.69
Sahel	408.71	247.74	45.63	16.85	100	3.78	972.24	946.88	160.97	87.19	0	28.02	1.96
Highest	**423.79**	**247.74**	**45.63**	**15.62**	**100**	**3.78**	**995.94**	**912.95**		**87.19**	**0**	**28.14**	**1.69**

Table 2. Maximum and minimum of refractivity and other parameters in Guinea Savannah

Guinea Stations	Ref		Temp		RH		Pres		Range	Rainfall	
	Max	Min	Max	Min	Max	Min	Max	Min		Max	Min
Ilorin	411.64	273.94	38.98	22.35	100	13.26	980.58	968.51	137.69	59.69	0
Jos	394.11	254.72	38.92	18.09	100	10.81	923.12	912.95	139.4	55.23	0
Minna	416.99	271.7	39.82	22.72	100	11.16	986.95	973.98	145.3	62.47	0
Makurdi	420.65	272.71	40.07	21.9	100	10.67	995.25	983.72	147.94	74.03	0
Jalingo	416.14	266.09	39.92	20.33	100	10.01	973.5	960.26	150.05	63.6	0
Lokoja	419.12	272.86	39.42	22.41	100	10.97	992.18	979.61	146.26	67.87	0
Bida	419.23	273.96	39.82	22.72	100	11.16	995.94	982.71	145.27	62.47	0
Study	**420.65**	**254.72**	**40.07**	**18.09**	**100**	**10.01**	**995.94**	**912.95**		**74.03**	**0**

Table 3. Maximum and minimum of refractivity and other parameters in Sudan Savannah

Sudan Stations	Ref		Temp		RH		Pres		Range	Rainfall	
	Max	Min	Max	Min	Max	Min	Max	Min		Max	Min
Yola	413.12	256.13	45.49	15.62	99.41	6.1	975.59	960.14	156.99	55.4	0
Gombe	420.33	253	45.42	19.27	100	4.84	974.19	960.3	167.33	54.35	0
Kano	405.98	249.36	44.12	15.77	100	4.59	963.23	949.19	156.63	62.5	0
Yelwa	423.79	266.89	41.73	21.42	100	8.42	989.49	977.13	156.9	66.1	0
Study	**423.79**	**249.36**	**45.49**	**15.62**	**100**	**4.59**	**989.49**	**977.13**		**66.1**	**0**

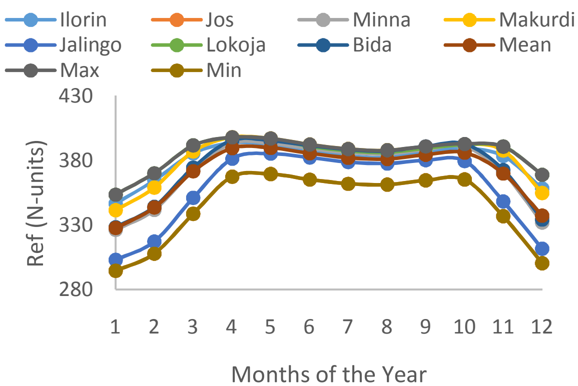

Fig. 2(a). Refractivity of stations in Guinea Savnnah

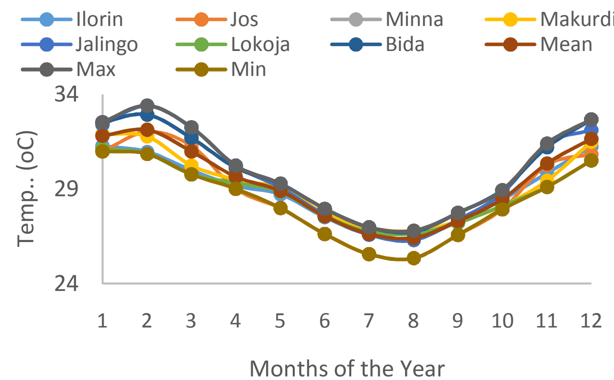

Fig. 2(b). Temperature of stations in Guinea Savannah

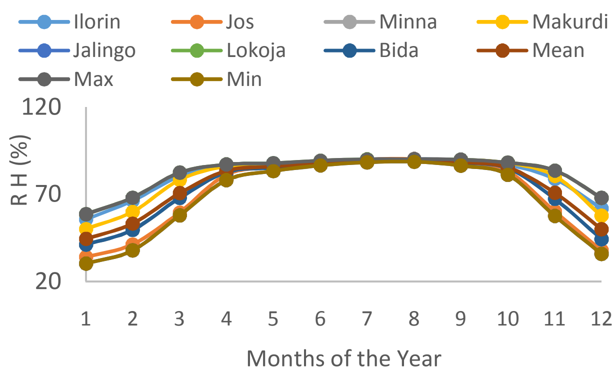

Fig. 2(c). Relative Humidity of stations in Guinea Savannah

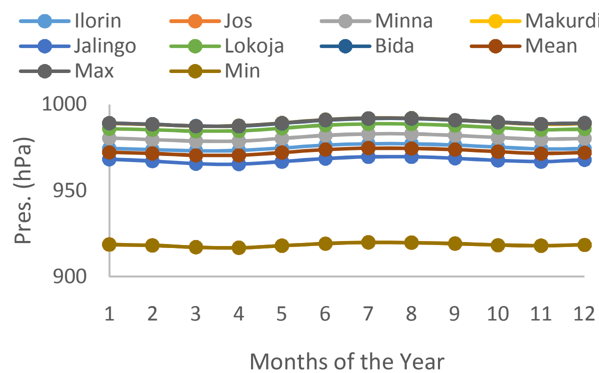

Fig. 2(d). Pressure of stations in Guinea Savannah

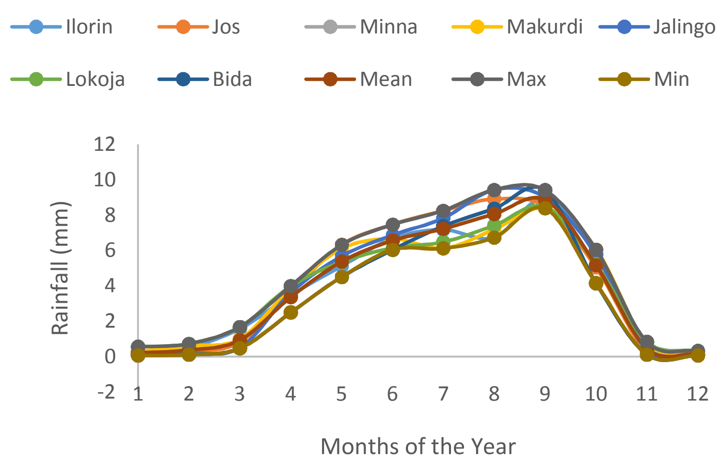

Fig. 2(e). Rainfall of stations in Guinea Savanna

Table 4. Maximum and minimum of refractivity and other parameters in Sahel Savannah

Sahelian Stations	Ref		Temp		RH		Pres		Range	Rainfall	
	Max	Min	Max	Min	Max	Min	Max	Min		Max	Min
Potiskum	406.52	249.91	45.63	18.32	100	3.78	972.24	937.19	156.61	87.19	0
Gusau	408.71	248.62	44.3	17.16	100	4.43	962.9	950.09	160.09	72.61	0
Katsina	406.65	247.74	44.95	16.85	100	4.36	960.09	946.88	158.9	64.95	0
Study	**408.71**	**247.74**	**45.63**	**16.85**	**100**	**3.78**	**972.24**	**937.19**		**64.95**	**0**

the month of September; this is because this zone even though has short period of rainfall but it is intense and frequent especially in the month of August and September. The maximum field strength in the zone as shown in the figures below is 24.18dB in Katsina and the minimum is 3.34dB in Gusau. Terrestrial radio links planning in this zone can be done in such a way that the output of a receiving antenna may generally be subject to variations not less than 1dB in a year but can be as high as 28dB.

3.6 Degree of Influence of Meteorological Parameters on Radio Refractivity

In analyzing radio refractivity, the primary meteorological variables used are temperature, relative humidity and pressure. These variables are singly correlated with refractivity to check how they individually contribute to its variation in the atmosphere. The result as shown in both Fig. 6(b) and Table 5 has indicated a linear correlation with some high degree between refractivity and relative humidity. With the R-squared of 0.9611 this could suggest the fact that relative humidity is a contributory factor to atmospheric refraction in this region. The refractivity can be predicted conveniently in terms of Relative humidity using the fitted equation:

$$\mathrm{Ref} = 263.6 + 1.452 \times \mathrm{RH} \quad (16)$$

Table 5 Showed the regression analysis of Refractivity on temperature. The result indicates an R-square of 0.3953 which suggest the weak contribution of temperature on the refraction in the atmosphere.

The correlation of temperature and refractivity as shown in Table 7 at -0.67102 is quite strong but negative. This implies that the rise in temperature will likely leads to rise in refractivity.

However, from Table 7 it can be deduce that the relative humidity and refractivity are correlated at 0.980356. This suggest a very strong positive relationship with strong likelihood of increase in relative humidity influencing the corresponding increase in the radio refractivity. The Field strength is found to be quite strong but negatively correlated with refractivity at -0.68461. This implies that as the rise in refractivity might lead to the corresponding rise in field strength. The weak correlation was observed between the pressure and refractivity at 0.10332. This suggest little or no influence on refractivity by the pressure.

Finally, rainfall favorably correlated with refractivity at 0.852985. This implies that a strong relationship exists between the two quantities suggesting a direct proportionality.

Table 5. ANOVA for regression of refractivity on relative humidity

Source	df	SS	MS	F value	Prob>F
Regression	1	11528.8	11529	247.05	0.00
Residual error	10	466.654	46.665		
Total	11	11995.5			

R-squared = 0.9611 (adjusted = 0.9572)

Table 6. ANOVA for regression of ref on temp

Source	df	SS	MS	F value	Prob>F
Regression	1	5401.22	5401.2	8.19	0.0169
Residual	10	6594.24	659.42		
Total	11	11995.5			

R-squared = 0.4503 (adjusted = 0.3953)

Table 7. Correlation coefficient of meteorological parameters and refractivity

Variables	R	Intercept	Slope
Temperature	-0.67102	630.916415	-8.93625
Pressure	0.10332	-2369.9914	2.817173
Rel. Humidity	0.980356	263.644382	1.451942
Rainfall	0.852985	324.352047	9.221702
Field Strength	-0.68461	396.265077	-4.47044

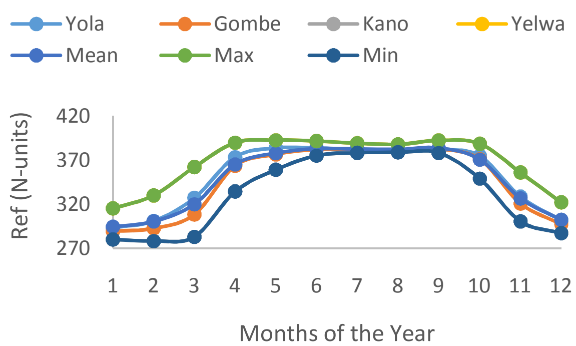

Fig. 3(a). Refractivity of stations in Sudan Savannah

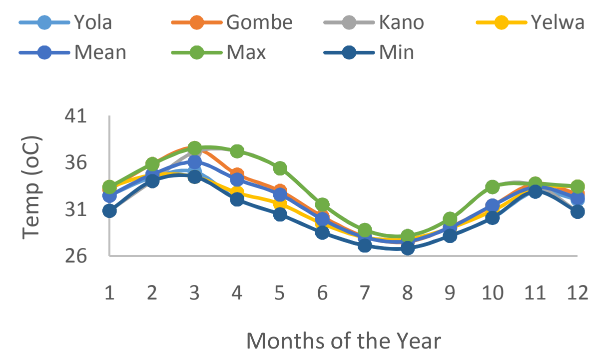

Fig. 3(b). Temperature of stations in Sudan Savannah

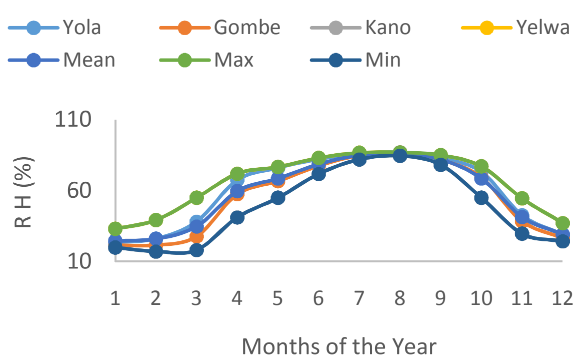

Fig. 3(c). Relative Humidity of stations in Sudan Savannah

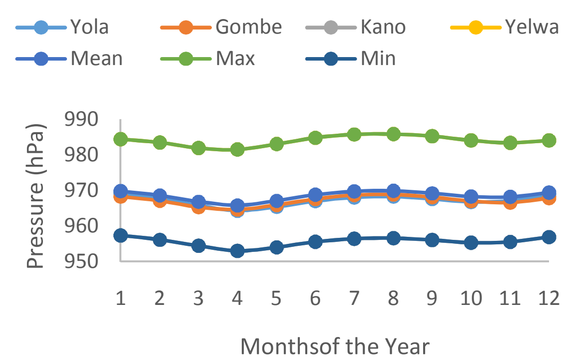

Fig. 3(d). Pressure of stations in Sudan Savannah

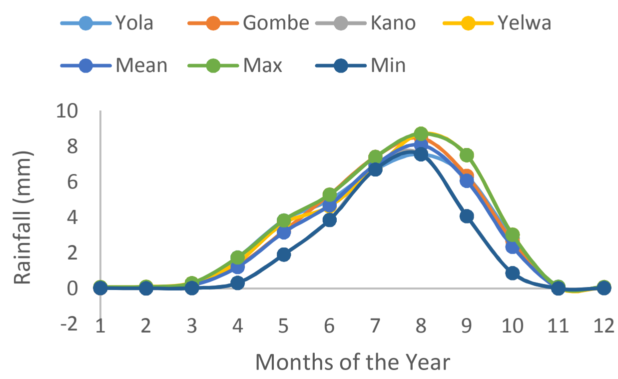

Fig. 3(e). Rainfall of stations in Sudan Savannah

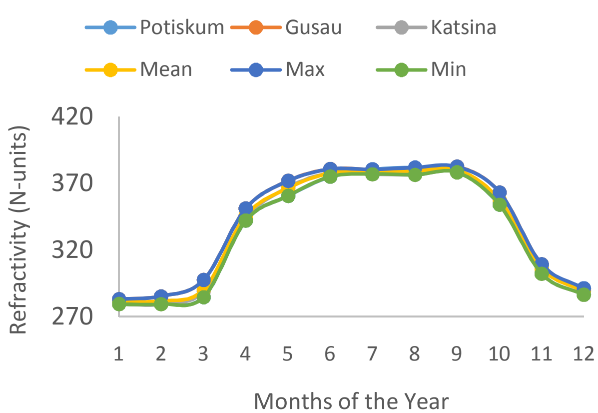

Fig. 4(a). Refractivity of stations in the Sahel

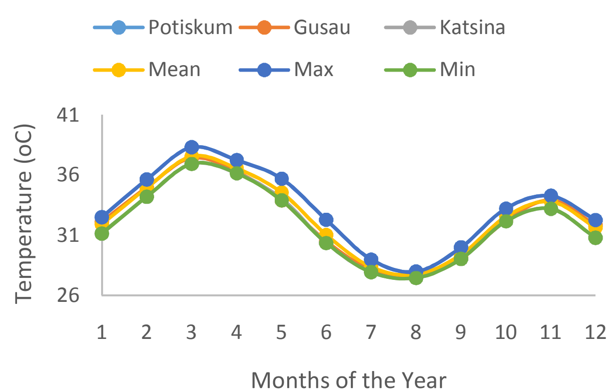

Fig. 4(b). Temperature of stations in Sahel

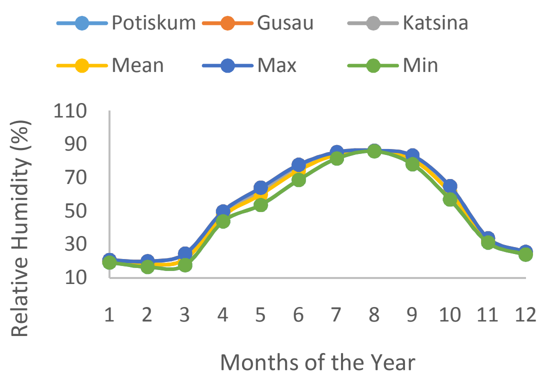

Fig. 4(c). Relative Humidity of stations in Sahel

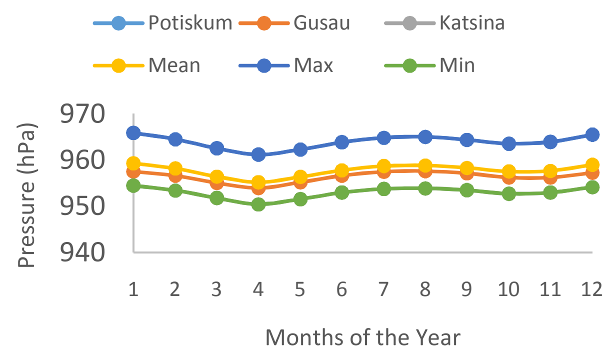

Fig. 4(d). Pressure of stations in the Sahel

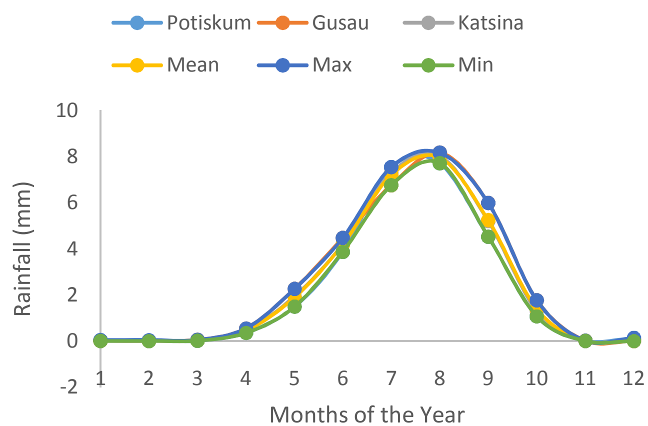

Fig. 4(e). Rainfall of stations in the Sahel

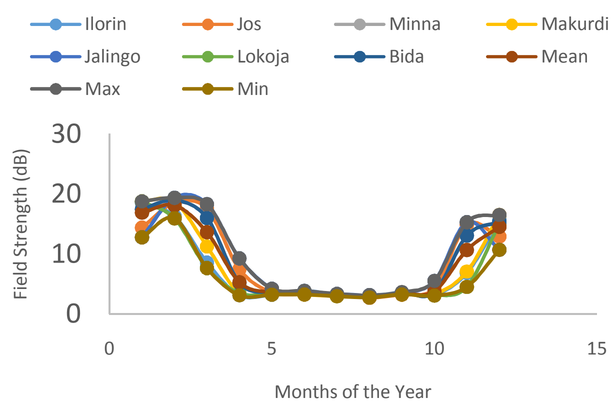

Fig. 5(a). Field Strength of stations in Guinea

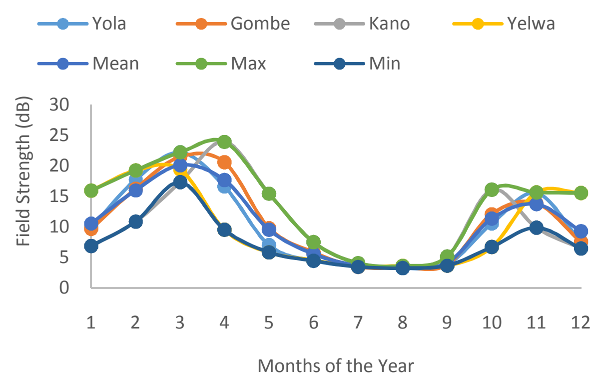

Fig. 5(b). Field Strength of stations in Sudan

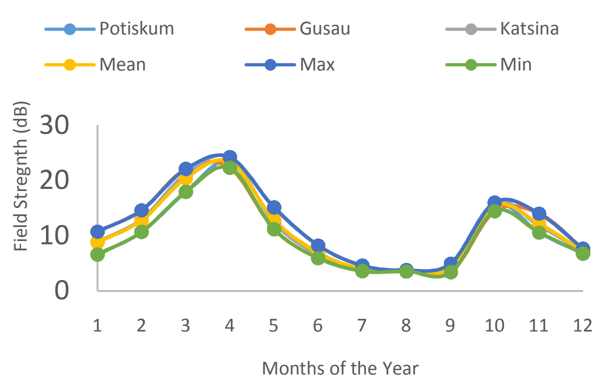

Fig. 5(c). Field Strength of Sahel

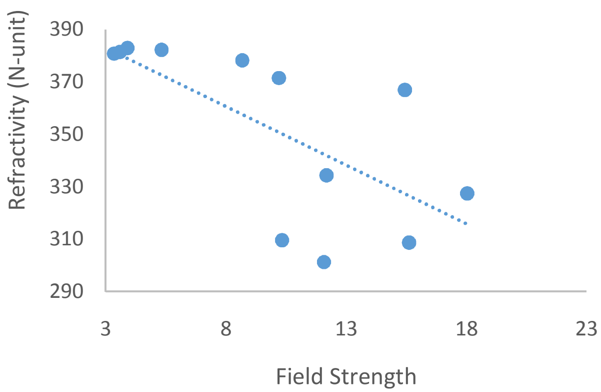

Fig. 6(a). Mean Refractivity and Field Strength Variability of Northern Nigeria

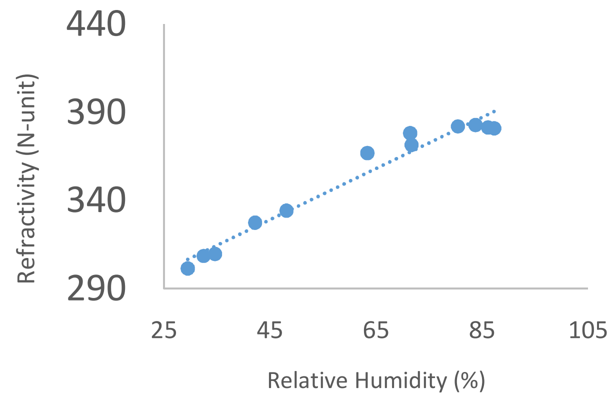

Fig. 6(b). Mean Refractivity and Relative Humidity of Northern Nigeria

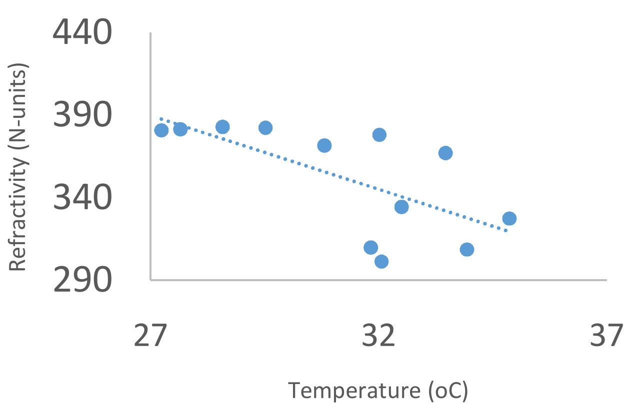

Fig. 6(c). Mean Refractivity and Temperature of Northern Nigeria

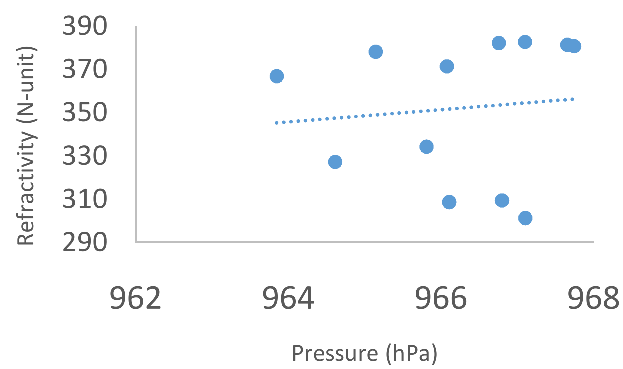

Fig. 6(d). Mean Refractivity and Pressure of Northern Nigeria

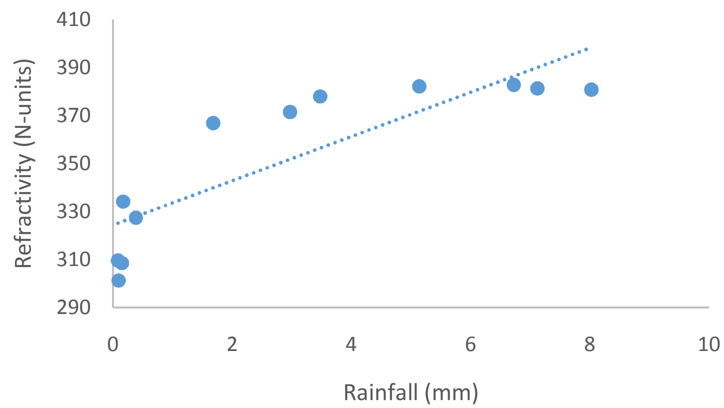

Fig. 6(e). Mean Refractivity and Rainfall of Northern Nigeria

4. CONCLUSIONS

This study presented the analysis of the radio refractivity and field strength of fourteen meteorological stations in Northern Nigeria for twelve years (2003-2014). From this study therefore, the surafce radio refractivity varies both daily, seasonally as well as geoclimatic zone of the region. Elevated values of radio refractivity were recorded in wet days and months of the season while low values of radio refractivity were recorded in the dry days and months of the season. This clearly suggest the dependence of the values of radio refractivity on the moisture content of the atmosphere. The study also revealed the refractivity as a function of temperature. From the correlation of temperature and refractivity as clearly shown in Fig. 6(c) it revealed a partially strong negative correlation. This suggest that an increasing temperature result to a decreasing refractivity. This is true in all the three regions of study. Observing the behaviour of radio refractivity in the three geoclimatic zones of the study area; we can conclude that higher values of radio refractivity ranging from about 421 N-uint to about 254 N-uint are recorded in the Guinea savannah than the two zones (Sudan and Sahel). This could also be attributed to the fact that the Guinea Savannah is characterized by high humidity and prolong rainfall compaired to the two zones. However, the lower values of radio refractivity recorded in Sahel particularly could be attributed to the reduced humidity and elevated temperature where some stations within the zones records near zero humidity within the season and also the proximity of the region to Inter Tropical Discontinuity (ITD) which is an imaginary boundary that separate the moist south westerly that incur inland and a dry and dusty north easterly trade wind.

Also from this study, the Field Stregnth variability has been oberved to be higher in the dry months than in the wet months in all the studied stations. Unlike the refractivity which correlate directly with rainfall; the field strength is always low during the rainy months. The strength of the radio field as recorded in the climatic zones is found to be stronger in Sudan and Sahel than in Guinea Savannah. Just like refractivity, this could be atrributed to intense dryness of the two zones compaired to the Guinea Savannah. The field strength recorded within this region is between 28.14dB to 1.69dB. This implies that for proper planning of terrestrial radio link in the region the output of a receiving antenna may generally be subject to variations not less than 1dB in a year but can be as high as 28dB.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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