International Journal of Engineering Research and General Science Volume 4, Issue 3, May-June, 2016
ISSN 2091-2730

Variation of tropospheric radio wave refractivities across northern Nigeria – the Savannah

Joseph Amajama, Samuel Eyeh Mopta, Faithpraise Fina

Physic Department, University of Calabar-Nigeria, joeamajama2014@yahoo.com, +2437036357493

Abstract— The variations of tropospheric radio wave refractivities in eleven (11) cities across the savannah climatic belts in Nigeria has been examined. Data abstracted from Weather API (Weather2), Yr. no and NIMET (Nigeria meteorological agency) websites has been analyzed. Generally, there was a decrease in the average atmospheric radio wave refractivities as one travels towards the borderline of the Sahara desert. This indicates that to some slight degree step by step, the tropospheric radio wave propagation betters towards the Sahara desert. The correlation between the average tropospheric radio wave refractivities and the perpendicular distances away frosm the Sahara desert was 0.53 with an approximate model of y = 0.1009x + 265.21. The correlation was not unity because of the non-uniformity of the weather patterns across the savannah. Reliefs and rivers account for some of the variations in the non-uniform trends. In addition, isotherms and isohumes in the weather map are non-linear and can cut across the different vegetative climatic zones of the savannah. By and large, results registered that the Sahel savannah will favour radio signal propagation through the troposphere better than the two other savannah belts, and the dry will favour radio signal propagation through the troposphere better than the wet; due to reduction in mean monthly relative humidities which is the most significant component in tropospheric radio wave refractivity.

Keywords— Troposphere, radio-wave, Weather, Savannah, Desert, isohume, isotherm and variations.

INTRODUCTION

The atmosphere is a vital channel for communication. Unlike other channels in the control of the communication scientists, the atmosphere to a vast extent is vulnerable to weather. However for telecommunications and satellite communications, it is almost impossible at one point or the other not to employ the tropospheric channel.

The weather of a place is the state of the atmosphere at a particular time [19], while the climate of a place is the general weather conditions prevailing in that place over a very long period [11]. It has been shown that weather components: atmospheric pressure, atmospheric temperature, atmospheric humidity varies inversely proportional to radio signal strength provided that wind speed and direction remains constant [4] [5] [6] [9]. Also, wind (if direction is contrary to a travelling radio wave) bears negatively on radio waves as it travels through the atmosphere (troposphere) [3].

Mathematically, tropospheric radio wave refractivity is a function of atmospheric pressure, atmospheric temperature and relative humidity [7]. The atmospheric temperature, atmospheric pressure and relative humidity vary inversely as the tropospheric radio wave refractivity. Hence, the tropospheric radio wave refractivity varies inversely as radio signal or wave [8]. However, research has also shown that the wind direction has a slight negative impact on the association between Radio signals and troposheric refractivity [8].

It will be near impossible for radio waves or signals to travel round the globe without the help of the troposphere and its refractivity [10] [15] [17] [18]. The atmosphere as a channel bends the radio wave back to the earth after being transmitted into space from an earth station [10] [15] [17] [18]. The atmosphere is not homogeneous. Every atmospheric channel has a characteristic resistance or impedance on radio wave that depends upon the conditions of the atmosphere of a place and/or climate.

Northern Nigeria is divided into three (3) major climatic belts depending on their vegetations [1]. The vegetation of a place is a reflection of the state of the atmosphere or troposphere of that place and invariably the weather or climate of that place. The different vegetative climatic belts in Northern Nigeria are: Sahel savannah, Sudan savannah, Guinea savannah and Montane [1].

Northern Nigeria falls on the tropical plate of Africa and lies between longitudes $4^0\,00'\,00''$ E and $14^0\,00'\,00''$ E and latitudes $7^0\,00'\,00''$ N and $14^0\,00'\,00''$ N respectively: a location slightly above the equator [1].

The focus of this research narrows on the variance of the tropospheric radio wave refractivities across Northern Nigeria; from the Sahel savannah, through the Sudan savannah to the Guinea savannah belts and the relatively striking montane regions. Also, the relevance of the work is to establish the best belt(s) suitable for tropospheric radio wave propagation and the worse. More so, it intends to probe and draw a verdict on which tropospheric or climatic conditions are favourable for radio wave propagation through the troposphere, since generally Nigeria has predominantly two seasons: the wet and the dry and the both have characteristic different atmospheric conditions or characteristics.

A LITERATURE REVIEW OF THE CLIMATE OF NORTHERN NIGERIA

The Tropical savannah climate or Tropical wet and dry climate is extensive in area and covers most of central Nigeria (Part of Northern Nigeria) beginning from the Tropical rainforest climate boundary in southern Nigeria to the central part of Nigeria, where it exerts enormous influence on the region [13].

The tropical savannah climate exhibits a well marked rainy season and a dry season with a single peak known as the summer maximum due to its distance from the equator. Temperatures are above 18 °C (64 °F) throughout the year. Central Nigeria (Part of Northern Nigeria) has a temperature range of 18.45 °C (65.21 °F) to 36.9 °C (98.4 °F) and an annual rainfall of about 1,500 mm (59.1 in) with a single rainfall maxima in September [13].

The single Dry season experienced in this climate, the tropical savannah climate in central Nigeria (Northern Nigeria) beginning from December to march. It is hot and dry with the Harmattan or North East trade wind, a continental tropical air-mass laden with dust from the Sahara Desert prevailing throughout this period [13].

With the Inter-tropical Convergence Zone swinging northward over West Africa from the Southern Hemisphere in April, heavy showers coming from pre-monsoonal convective clouds mainly in the form of squall lines also known as the north easterlies formed mostly as a result of the interactions of the two dominant air-masses in Nigeria known as the Maritime tropical (south western-lies) and the Continental tropical (north easterlies) begins in central Nigeria (Part of Nothern Nigeria) while the Monsoons from the South Atlantic Ocean arrives in central Nigeria in July bringing with it high humidity, heavy cloud cover and heavy rainfall which can be daily occurrence lasting till September when the monsoons gradually begin retreating southward to the southern part of Nigeria [13]. Rainfall amount in central Nigeria varies from 1,100 mm (43.3 in) in the lowlands of the river Niger Benue trough to over 2,000 mm (78.7 in) along the south western escarpment of the Jos Plateau [13].

The Sahel Climate or Tropical dry climate is the predominant climate type in the northern part of Nigeria. Annual rainfall amount are lower compared to the southern and central part of Nigeria. The Rainy season in the northern region of Nigeria lasts for only three to four months (June - September). The rest of the year is hot and dry with temperatures climbing as high as 40 °C (104.0 °F) [13].

Montane Climate or Alpine climate or highland climate or mountain climate are found on highlands regions in Nigeria generally. Highlands with the montane climate in Nigeria are well over 1,520 metres (4,987 ft) above sea level. Due to their location in the tropics, this elevation is high enough to reach the temperate climate line in the tropics thereby giving the highlands, mountains and the plateau regions standing above this height, a cool mountain climate. One of the Northern Nigeria cities with such a climate as mentioned above is Jos [13].

Northern Nigeria, like the rest of Nigeria and other tropical lands, has only two seasons. These are the Dry season and the Rainy season. The dry season is accompanied by a dust laden air-mass from the Sahara Desert, locally known as Harmattan, or by its main name, the Tropical Continental air-mass or North East trade wind, while the rainy season is heavily influenced by an air-mass originating from the South Atlantic Ocean, locally known as the South West wind, or by its main name, the Tropical Maritime air-mass. These two major wind systems in Nigeria are known as the trade winds [13].

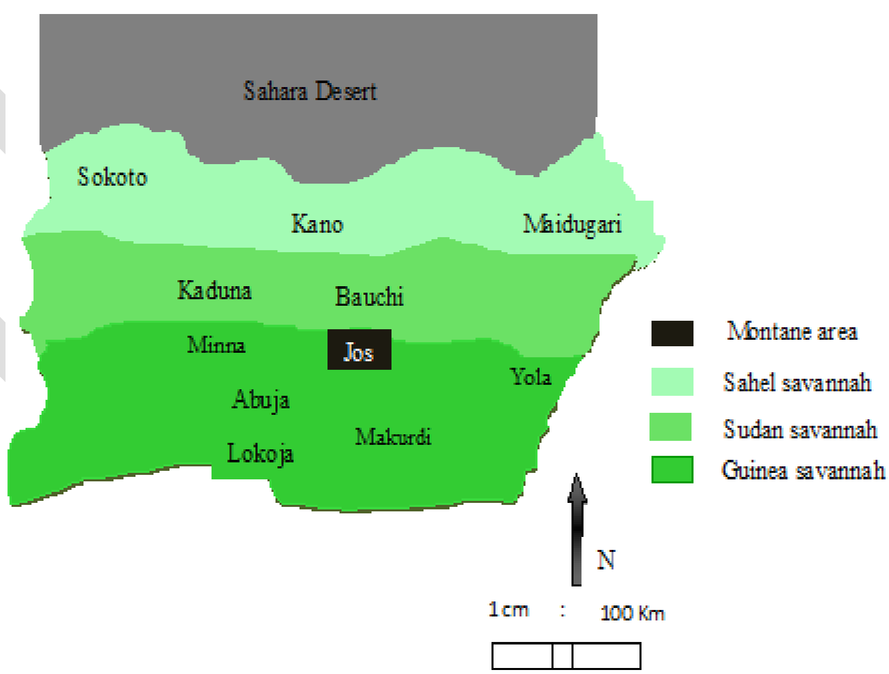

Fig. 1. The map of Northern Nigeria showing the locations of the various cities on the different savannah belts.

METHODOLOGY

Relevant data for mean monthly weather parameters was accessed from Yr. no, Weather2 and NIMET (Nigeria Meteorological Agency) websites. The radio wave refractivity was computed using the Eqn. 1 below [7].

$$N = K \times P^2 \times \sqrt{T} \times \sqrt[3]{H} \qquad (1)$$

Where K = Constant = 0.01064097915

P = Atmospheric pressure in inHg

T = Atmospheric temperature in ^{0}F

H = Relative humidity in %

N = Radio refractivity

The above formulation has an accuracy of $\pm$5 in comparison with the existing International Telecommunication Union (ITU) expression for calculating Radio refractivity. The ITU expression may be used for all radio frequencies: for frequencies up to 100 GHz, the error is less than 0.5 % [16].

RESULTS AND ANALYSIS

The Figs. 2, 3, 4, 5 and 6 show the comparison between the average monthly tropospheric radio wave refractivities of all cities; comparison between average monthly tropospheric radio wave refractivities of the cities in the wet; comparison between the average monthly tropospheric radio wave refractivities of the cities in the dry, relationship between perpendicular distance away from the Sahara Desert and average tropospheric radio wave refractivity and line of best fit between perpendicular distance away from the Sahara Desert and average tropospheric radio wave refractivity respectively. The legend series of the cities in the figures below are in order of increasing magnitude of average tropospheric radio wave refractivity.

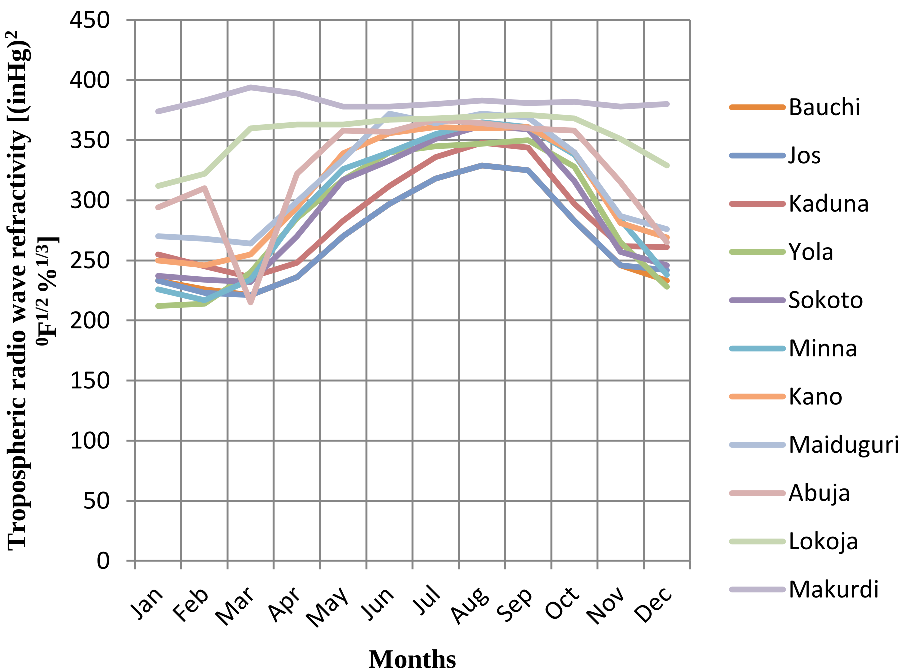

Fig. 2: Tropospheric radio wave refractivities of the cities throughout the year

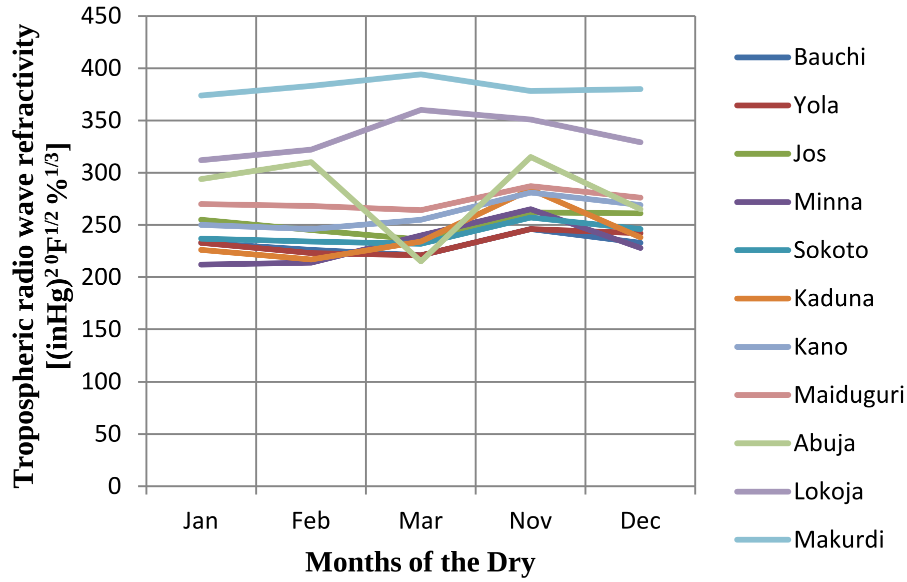

Fig. 3: Tropospheric radio wave refractivities of the cities in the dry

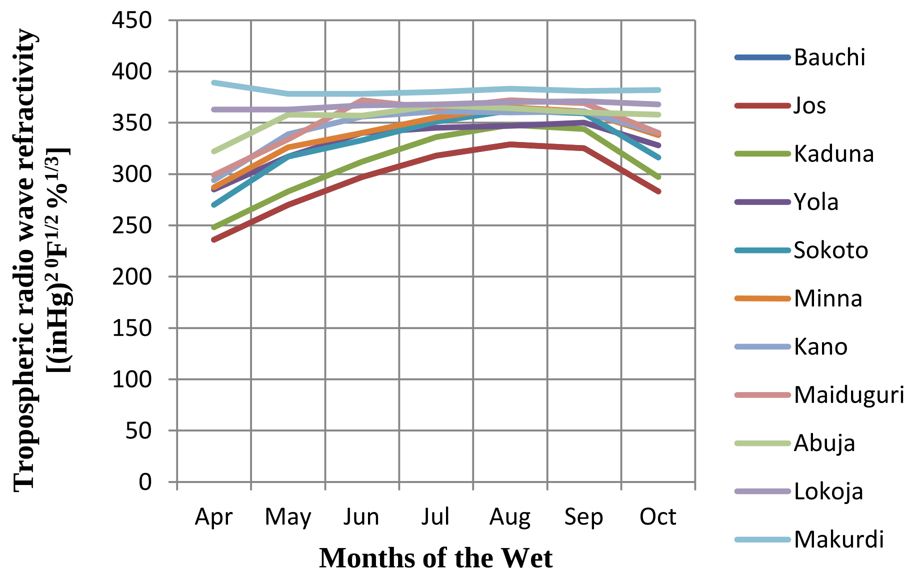

Fig. 4: Tropospheric radio wave refractivities of the cities in the wet

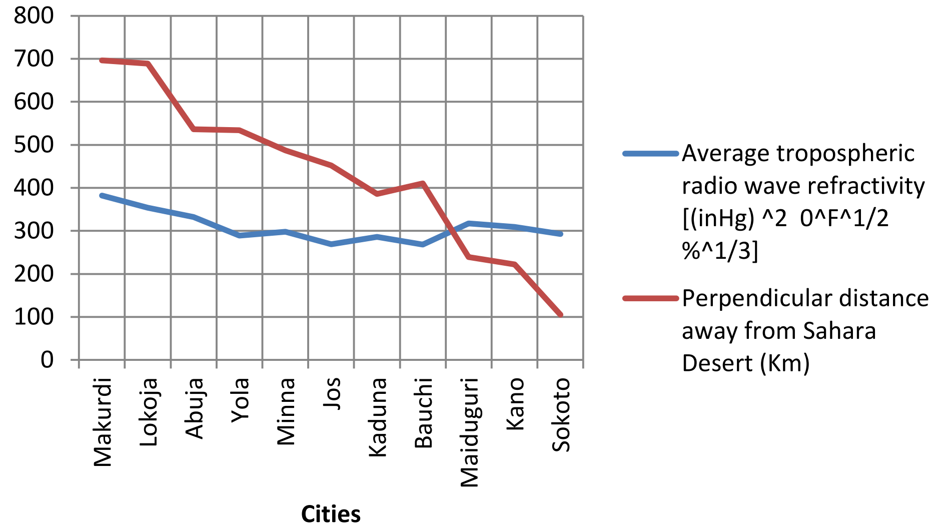

Fig. 5: Average tropopsheric radio wave refractivity and distance away from the coastline of the Atlantic Ocean

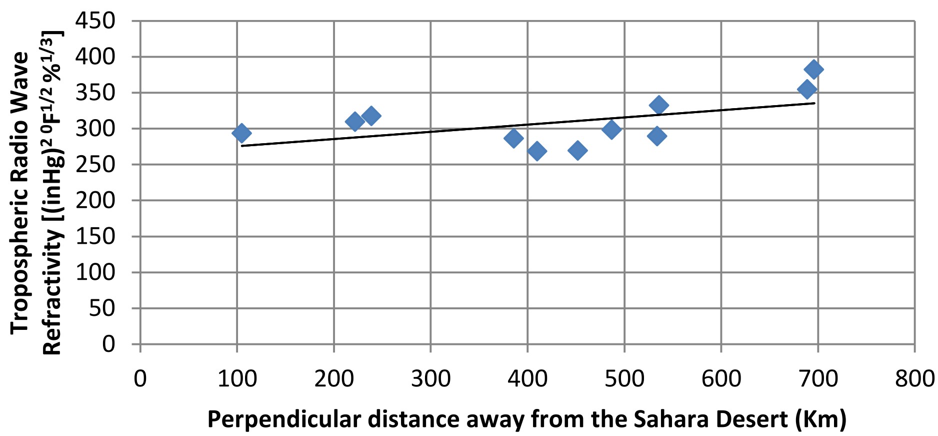

Fig. 6: Line of best fit between Average tropospheric radio wave refractivity and distance away from the coastline of the Atlantic Ocean

In a peck order of increasing magnitude of average tropospheric radio wave refractivities, the cities are arranged thus: Bauchi, Jos, Kaduna, Yola, Sokoto, Minna, Kano, Maiduguri, Abuja, Lokoja and Makurdi.

In Fig. 1 shows the map of Northern Nigeria showing the locations of the various cities on the different savannah belts. Northern Nigeria borders the Sahara desert as captured.

Fig. 2 shows the tropospheric radio wave refractivities of the cities throughout the year. Bauchi has the least average tropospheric radio wave refractivity seconded by Jos since it a continuation of the Jos plateau and resides in the Sudan savannah. Hence, it shares the same average monthly relative humidities with Jos (Isohume) but has a slightly higher average monthly temperature by virtue of its location in the Sudan Savannah. Average temperature tends to increase as one confronts the Sahara desert except with the presence of reliefs and rivers. Temperatures around mountain or alpine or montane climate are usually low. Kaduna trails these two cities with low average tropospheric radio wave refractivity since it is also located on the high plains of Northern Nigeria and made up undulating plateau and hills [12]. It shares similar average monthly relative humidities with Bauchi and Jos, but has the highest average monthly temperatures. It rests on the Sudan Savannah, but is closer to the Sahara Desert than Bauchi. With the exception of Yola and Minna, there is a gradual increase in average tropospheric radio wave refractivity as one move away from the Sahara desert or southwards. Yola lies close to one of the highest plateaus and escarpments in Nigeria with it having some of the highest mountain ranges in Nigeria. There are the Mandara Mountains which lie to the north of the city, the Shebshi Mountains which lie to the south and hold the title of the second highest point in Nigeria. Yola lies on the banks of the Yola River which is the main tributary to the Benue River. Despite its location down south of Northern Nigeria, its relief and rivers are responsible for its abnormal fall in average tropospheric radio wave refractivity. Minna is situated on the Guinea Savannah belt and lies on the escarpment of the Northern highlands with higher atmospheric temperature. This is responsible for its slight difference in refractivity from the trend.

Fig. 3 shows the tropospheric radio wave refractivities of the cities in the dry. Makurdi and Lokoja have very distinct high tropospheric radio wave refractivity by virtue of their close proximity to the rainforest and presence of huge rivers. Generally, there is a marked drop of tropospheric radio wave refractivity in all the cities of the savannah, most especially those of the Sahel close to the Sahara desert. Hence, better signal strength will be recorded, because of low relative humidity and clearer sky, even with a huge range of temperature: very low night temperature and very high daylight temperature.

Fig. 4 shows average tropospheric radio wave refractivities of the cities in the wet. Here, there is a noticeable rise in temperature in average tropospheric radio wave refractivity generally. To a very large degree, the refractivities are near steady in June, July, August and September when the humidities of the cities are at their peak except Jos and Bauchi which are a mountain climate and quasi-mountain climate respectively. Tropospheric signal propagation will be poor in the wet because of very high relative humidity. Relative humidity is a huge weight against radio signal propagation in the troposphere in comparison with other tropospheric radio wave refractivity parameters [7]. However, with the exception of other weather parameters like rain and wind, there is generally a stable signal due to steady temperatures (night and daylight) and relative humidity.

Fig. 5 shows average tropospheric radio wave refractivity and distance away from the coastline of the Atlantic Ocean. To a slight extent there is a gradual decrease in tropospheric rafractivitiy towards the Sahara Desert. Relief and rivers played a significant effect in the change in weather pattern across the same belt [2].

Fig. 6 shows line of best fit between average tropospheric radio wave refractivity and distance away from the borderine of the Atlantic Sahara Desert. The correlation between the average tropospheric radio wave refractivities and the perpendicular distances away from the Sahara desert was 0.53 with an approximate model of y = 0.1009x + 265.21. The correlation was not unity because of the non-uniformity of the weather patterns across the country. Reliefs and rivers account for some of the variations in the non-uniform trends [2].

CONCLUSION

Generally, there was a decrease in the average tropospheric radio wave refractivities as one heads towards the borderline of the Sahara desert. Hence the atmospheric radio wave propagation via the troposphere step by step, betters towards the Sahara desert.

The correlation between the perpendicular distances away from the borderline of the Sahara desert and the average atmospheric radio wave refractivities is 0.53. Also, the approximate model of average atmospheric radio wave refractivity away from the Sahara desert borderline is y = 0.1009x + 265.21: where y is the average atmospheric radio wave refractivity and x is the perpendicular distance away from the Sahara desert borderline. The above correlation was not unity because of the irregularities of the weather or climate nature across the country. The reliefs and rivers account for some of the anomalies in the irregular trend towards the desert borderline. In addition, isotherm and isohumes but not isobars were brought into account because these lines are non-linear and can cut across the vegetative climatic zones, for example is Kaduna, which shares similar mean monthly temperatures with cities in the Sudan savannah but has common mean monthly humidities as Jos in the Guinea savannah and a montane climate.

By and large in Northern Nigeria, the most favourable belt for radio signal propagation through the troposphere is the Sahel savannah belt with low mean monthly relative humidities, while the least favourable is the Sudan belt with comparable higher mean monthly relative humidities, in view of the fact that, the variation in mean monthly temperatures between the two belts is not comparable to their relative humidities and the variance in the mean monthly atmospheric pressure is near uniform. A point of fact as afore-stated is that: relative humidity bears more weight in the expression for calculating radio wave refractivity, seconded by atmospheric temperature and the least is the atmospheric pressure [1]. This is to some extent due to their ranges of variations.

With the exception of winds and may be rainfall that affect communications [66] [67], radio signal propagation through the troposphere in the Sahel Savanna will be less stable than the Guinea Savannah owing to the fact that there is less variation in the atmospheric parameters: atmospheric temperature, pressure and humidity in the former belt than the latter belt.

Finally, radio signal propagation will generally propagate better throughout Northern Nigeria in the troposphere during the dry than the wet. This is on the account that the mean monthly relative humidities generally falls during the dry, but rises in the wet.

REFERENCES:

[1] About Nigeria (n.d.). Retrieved January 10, 2016 from http://www.nigeriahc.org.uk./about Nigeria.

[2] Amajama, J., & Etim, I. P (2016). Variance of atmospheric radio wave refractivities across Nigeria–from the Savannah to the mangrove. *International Journal of Engineering Research and General Science*, 4(2), 221-235.

[3] Amajama, J., & Oku, D. E. Wind versus UHF Radio signal (2016). *International Journal of Science, Engineering and Technology Research (IJSETR)*, 5(2), 583-585.

[4] Amajama, J (2016). Impact of Atmospheric Temperature on (UHF) Radio Signal. *International Journal of Engineering Research and General Science*, 4(2), 619-622.

[5] Amajama, J (2016). Atmospheric Pressure Bearing on (UHF) Radio Signal. *International Journal of Scientific Engineering and Technology*, 5(3), 131-133.

[6] Amajama, J (2016). Force of Atmospheric Humidity on (UHF) Radio Signal. *International Journal of Scientific Research Engineering & Technology (IJSRET)*, 5(2), 56-59.

[7] Amajama, J (2015). Mathematical Relationships between Radio Refractivity and Its Meteorological Components with A New Linear Mathematical Equation to Determine Radio Refractivity. *International Journal of Innovative Science, Engineering & Technology*, 2 (12), 953-957.

[8] Amajama, J (2015). Association between atmospheric radio wave refractivity and UHF radio signal strength. *American International Journal of Research in Formal, Applied & Natural Sciences,* 13(1), 61-65.
[9] Amajama, J (2016). Impact of weather components on (UHF) radio signal. *International Journal of Engineering Research and General Science (IJERGS)*, 4(3), 474-480
[10] Atmospheric refraction (2015). In Wikipedia. Retrieved November 10, 2015, from http://en.wikipedia.org/wiki/Atmospheric_refraction.
[11] Climate. (n.d.). Concise English Oxford Dictionary (11th ed.). (2004). Oxford: Oxford University Press.
[12] Kaduna (n.d.). Wikipedia: the free encyclopaedia. Retrieved 10 January, 2016 from https://en.m.wikipedia.org/wiki/Kaduna
[13] Geography of Nigeria (2016). Wikipedia: the free encyclopaedia. Retrieved 10 January, 2016 from https://en.wikipedia.org/wiki/Geography_of_Nigeria
[14] Meng, Y. S., Lee, Y. H. & Ng, B. C. (2013). The effects of tropical weather on radio wave propagation over foliage channel. IEEE transaction on vehicular technology, 58(8), 4023 – 4030.
[15] Mike W. (2015). Refraction. Retrieved November 10, 2015, from http://www.mike- wills.com/Tutorial/refraction.htm.
[16] Recommendation ITU-R (2003). The radio refractive index: its formula and refractivity data. Retrieved November 10, 2015, from http://www.itu.int/rec/R-REC-P.453-9-200304.
[17] Tropospheric propagation (2015). In Wikipedia. Retrieved April 5, 2015, from http://en.wikipedia.org/wiki/tropospheric_propagation.
[18] The effects of the earth's atmosphere on radio waves (2015). Introduction to wave propagation, Transmission lines and Antennas. Hwy - Port Richey: Integrated Publishing, Inc. Retrieved April 5, 2015, from www.tpub.com/neets/book10/40c.htm.
[19] Weather. (n.d.). Concise English Oxford Dictionary (11th ed.). (2004). Oxford: Oxford University Press