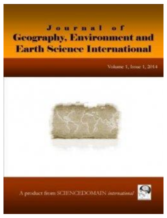

Journal of Geography, Environment and Earth Science International
10(1): 1-12, 2017; Article no.JGEESI.32534
ISSN: 2454-7352

SCIENCEDOMAIN *international*
www.sciencedomain.org

Estimation of Tropospheric Radio Refractivity and Its Variation with Meteorological Parameters over Ikeja, Nigeria

D. O. Akpootu[1*] and M. I. Iliyasu[2]

[1]Department of Physics, Usmanu Danfodiyo University, Sokoto, Nigeria.
[2]Physics Unit, The Polytechnic of Sokoto State, Sokoto, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. The data for the work was sourced and analyzed by author DOA. Author DOA also designed the study, drafted and edited the manuscript. Author MII assisted in literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2017/32534
Editor(s):
(1) Iovine Giulio, CNR-IRPI (National Research Council-Institute of Research for the Geo-hydrologic Protection) of Cosenza, Italy.
(2) Teresa Lopez-Lara,Autonomous University of Queretaro, Qro, Mexico.
Reviewers:
(1) Purushottam Bhawre, Barkatullah University, Bhopal, India.
(2) Oluwaseun Ajileye, Obafemi Awolowo University, Ile-Ife, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/18869

Original Research Article

Received 1st March 2017
Accepted 18th April 2017
Published 1st May 2017

ABSTRACT

Estimation of radio refractivity is critical in the planning and design of radio links/systems for the purpose of achieving optimal performance. This present work investigates the tropospheric radio refractivity over Ikeja, Lagos State, South Western, Nigeria (Latitude 6.58°N, Longitude 3.33°E and altitude 40 m above sea level) and the sensitivity of radio refractivity due to meteorological parameters of monthly average daily atmospheric pressure, relative humidity and temperature for a period of 12-years. The statistical estimation of tropospheric radio refractivity has been evaluated using the method recommended by the International Telecommunication Union (ITU). The result indicated that the radio refractivity during the rainy season is greater than the dry season. It was observed that the maximum average value of radio refractivity of 389.45 N-units and minimum average value of 373.04 N-units occurred during the rainy and dry seasons in the months of April and January respectively. The dry term contributes 67.98% to the total value of the

**Corresponding author: E-mail: profdon03@yahoo.com;*

radio refractivity while the wet term contributes to the major variation. The average refractivity gradient computed for the study area under investigation was -44.32 N-units/km and the average effective earth radius (k – factor) was 1.39 which corresponds to the conditions of super-refraction.

Keywords: Radio refractivity; dry term; wet term; meteorological parameters; refractivity gradient.

1. INTRODUCTION

The part of the atmosphere most closely related to human life is the troposphere. It is the lowest layer of earth's atmosphere and region of all weather on earth. The troposphere extends from the earth's surface to an altitude of about 10 km at the earth's poles and 17 km at the equator [1]. Since temperature decreases with altitude in the troposphere [2], warm air near the surface of the earth can rapidly rise replacing the cold dense air at the upper part of the atmosphere. This will set up convection current in the air molecules of the troposphere. Such vertical movement or convection current creates clouds and ultimately rain from the moisture within the air, and gives rise to the weather condition we experience. At the lower part of the earth called the troposphere, the tropospheric refraction is due to the fluctuations of weather parameters like temperature, pressure and relative humidity [3].

Radio signals can be reflected, refracted, scattered, and absorbed by different atmospheric constituents [4]. However, the degree of atmospheric effects on radio signals depends mainly upon the frequency, power of the signal and on the state of the troposphere through which the radio wave propagates. The characterization of tropospheric variability has great significance to radio communications, aerospace, environmental monitoring, disaster forecasting etc. The quality of propagation of radio waves transmitting to a receiving antenna mostly depends on performance and reliability of the links [5]. Generally for radio link design, the measured data for signal strength at a particular location under study is required by radio-planning-engineers [6]. Consequently, a radio propagation model is required to be used for the evaluation of signal level variations that occur at various locations of interest over different times of the year. An important element of such type of radio propagation model is the variation of radio refractivity in the troposphere [7]. According to [5], radio wave systems could become unavailable due to seasonal variation of refractive index.

The structure of the radio refractive index, n, at the lower part of the atmosphere is a very important parameter in the 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 [8]. Radio–wave propagation is determined by changes in the refractive index of air in the troposphere [9]. Changes in the value of the radio refractive index in the troposphere can curve the path of the propagating radio wave. The atmosphere radio refractive index depends on air temperature, humidity, atmospheric pressure and water vapour pressure. Even small changes in any of these variables can make a significant influence on radio-wave propagation, because radio signals can be refracted over the whole signal path [10]. Refractive index is not constant in the atmosphere and its space-time distribution results in scattering, sub-refraction, super-refraction, ducting and absorption phenomena [11].

The variation of refractive index is due to various phenomena affecting the propagation of radio signal, which for instance include refraction, bending, ducting and scintillation, range and elevation errors in radar acquisition and radio-station interference [8,12–15]. The variation of refractive index as well as specific attenuation of micro/radio wave may be estimated indirectly with the measurement of temperature, pressure and relative humidity. The effect of temperature and relative humidity on specific attenuation of microwave was studied by different researchers [16,17].

The establishment of a radio refractive index database is necessary because the knowledge of radio refractive index is always required when measurements are made in air [18,19]. Several research work on radio refractivity for different regions and climates using measured local meteorological data have been investigated in Nigeria and other parts of the world. This include e.g., [9,20–30] to mention but a few. The results of their works show that the local climate has an appreciable influence on the radio refractivity and hence on the transmitted radio signals.

The purpose of this study is to estimate the tropospheric radio refractivity and its variation with meteorological parameters of atmospheric pressure, relative humidity and temperature for Ikeja, Lagos state, Nigeria during a period of 12-years.

2. STUDY AREA

Fig. 1 shows the study region for Ikeja, a coastal area, and the capital of Lagos State, Nigeria. The state is located in the south-western part of Nigeria. The state has common boundary with Ogun State, Republic of Benin and terminates in Atlantic Ocean in the south [31]. The state has twenty local government areas out of which sixteen are within the metropolitan Lagos; the land coverage is about 3,475 km^2. However, the size of this land coverage is reduced by Lagoons, rivers, creeks and swamps. The Lagos city is the commercial centre of Nigeria where several businesses are found. For example, the Murtala International Airport in Ikeja and head offices of many airlines are within and around the airport, the city and the state also accommodates headquarters of many companies. As a coastal city, rising temperature and increase in sea level could lead to disappearance of the beaches under erosion and flooding, the area might also be damaged by storm [31]. The state is essentially a Yoruba-speaking environment. The seasons in the area is broadly divided into dry and wet under the influence of Intertropical Convergence Zone, ITCZ (where easterly trade winds originating from northern and southern hemispheres converge) that migrates along with the position of strong rainfall [32]. Nigeria being a tropical region has two seasons – the wet and the dry. The wet season is characterized by heavy rainfall. The season falls between the months of April and October. The dry season, on the other hand, is characterized by scanty or no rainfall and dry dust laden atmosphere. The season falls between the month of November and March [3]. It must be noted that some areas in Lagos State, which is very close to the Atlantic Ocean, experience rainfall almost throughout the months of the year [33].

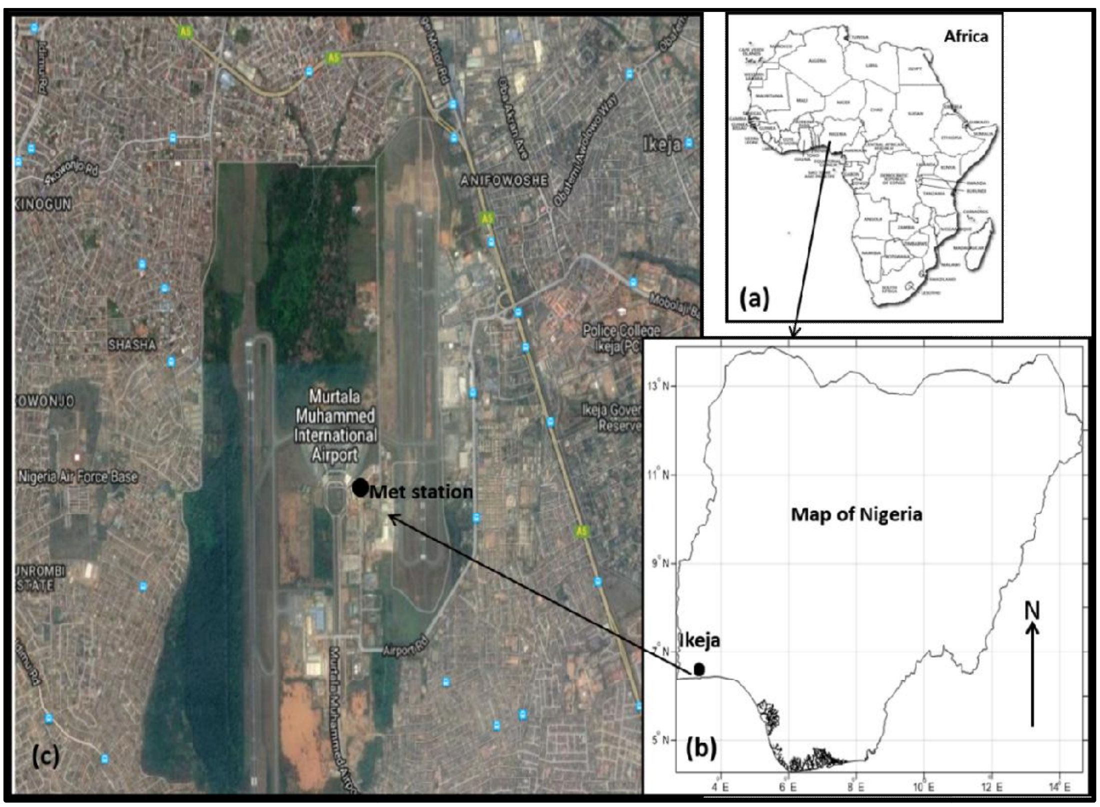

Fig. 1. Map of (a) Africa showing the location of Nigeria (b) Nigeria showing the location of Ikeja in Southwest Nigeria and (c) Ikeja showing the location of the meteorological station in murtala muhammed international airport

3. METHODOLOGY

The measured daily climatic data of atmospheric pressure, relative humidity and temperature utilized in this present work were obtained online from Tutiempo Network, S.L (en.tutiempo.net/climate/ws-652010.html). The daily data were averaged into monthly data. The study area under investigation is Ikeja (Latitude 6.58 °N, Longitude 3.33 °E and altitude 40 m above sea level) with weather station number 652010 (DNMM). To avoid possible misleading indications related to yearly variation in weather condition, the period under focus is twelve years (2001, 2005 – 2007, 2009 – 2016) in order to obtain a good climatological average. The quality assurance of the meteorological measurements was determined by checking the overall consistency of the monthly average of the climatic parameters used in the study area.

The refractive index, n, of the atmosphere is dependent upon three factors, the atmospheric pressure, temperature and humidity (water vapour content). The value of the refractive index, n, is very close to unity (varying between 1.000250 and 1.000400) at or near the earth's surface and changes in this value is very small in time and in space. With the aim of making them more noticeable, the refractive index, n, of air is measured by a quantity called the radio refractivity, N, which is related to the refractive index, n, as discussed in [8,34]:

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

Although, as the radio refractivity, N, is a dimensionless quantity, it is expressed in N-units. Therefore from equation (1) it is easy to deduce that N typically ranges between 250 and 400 N-units. In terms of meteorological parameters, the International Telecommunication Union (ITU) has recommended the radio refractivity, N, to be expressed as [35]:

$$N = \frac{7\ 76}{T}\left(P + 4810\frac{e}{T}\right) = N_{dry} + N_{wet} \quad (2)$$

with the "dry term" of radio refractivity given by:

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

and the "wet term" of radio refractivity given by:

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

Where, P is the atmospheric pressure (hPa), T is the absolute temperature (K) and e is the water vapour pressure (hPa). The dry term is due to non-polar nitrogen and oxygen molecules. It is proportional to pressure, P, and therefore related to the air density. The wet term is proportional to vapour pressure and dominated by polar water contents in the troposphere.

It was mentioned in [34] and [8] that the expression (2) may be used for all radio frequencies; for frequencies up to $100\ GHz$, the error is less than 0.5%. At sea level, the average value of $N \approx 315$ [34] is used.

The relationship between water vapour pressure, e, and relative humidity is given by the expression as [34]:

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

Where,

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

Where H is the relative humidity $(\%)$, t is the Celsius temperature (℃) and e_s is the saturation vapour pressure (hPa) at temperature (℃). The values of the coefficients a, b and c (for water and ice) are presented in [34]. In this study, that for water were adopted and are given as $a = 6.1121$ $b = 17.502$ and $c = 240.97$ and are valid between $-20°$ to $+50°$ with an accuracy of $\pm 0.20\%$. The radio refractivity, N, also decrease exponentially in the troposphere with height [34].

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

Where N is the refractivity at the height $h(km)$ above the level where the refractivity is N_s while H is the applicable scale height. [34] Suggested that at average mid-latitude, N_s and H are 315 and 7.35 km respectively. Hence, N as a function of height $N(h)$ is given by the equation.

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

However, the results of the work of [36] showed that the model using the scale height of 7.35 km and 7.00 km, as recommended for global environment [34] and tropical environment [2] respectively, gave reasonably accurate results for the refractivity at the altitude of 50 m and 200 m for seven out of the twelve months of the year.

Although the scale height of 7.00 km gave a better result at 50 m altitude while 7.35 km scale height gave a better performance at 200 m.

The refractivity gradient is obtained by differentiating equation (7) with respect to h, thus, we've the refractivity gradient as

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

For a standard atmosphere, the refractivity gradient is -39 N-units/km. According to [2], when *h* < 1 km, refractivity gradient is well approximated by its value in a standard atmosphere. In this work we used the typical values for a standard atmosphere [2], and obtained the refractivity of a standard atmosphere [2] as $N_s = 312\ N - u\ nits$

The vertical gradient of refractivity in the lower layer of the atmosphere is an important parameter in estimating path clearance and propagation effects such as sub-refraction, super refraction, or ducting according to the following criteria [9]:

- Sub-refraction: $\frac{dN}{dh} > -40$

Refractivity *N* increases with height and in this case (sub-refraction), the radio wave moves away from the earth's surface and the line of sight range and the range of propagation decrease accordingly.

- Super-refraction: $\frac{dN}{dh} < -40$

During super-refractive conditions, electromagnetic waves are bent downward towards the earth. The degree of bending depends upon the strength of the super-refractive condition. The radius of curvature of the ray path is smaller than the earth's radius and the rays leaving the transmitting aerial at small angles of elevation will undergo total internal reflection in the troposphere and it will return to the earth at some distance from the transmitter. On reaching the earth's surface and being reflected from it, the waves can skip large distances, thereby giving abnormally large ranges beyond the line of sight due to multiple reflections.

- Ducting: $\frac{dN}{dh} < -157$

During ducting phenomena, the waves bend downwards with a curvature greater than that of the earth. Radio energy bent downwards can become trapped between a boundary or layer in the troposphere and the surface of the earth or sea (surface duct) or between two boundaries in the troposphere (elevated duct). In this wave guide-like propagation, very high signal strengths can be obtained at very long range (far beyond line-of-sight) and the signal strength may exceed its free-space value.

The effective earth radius factor k can be used to characterise refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting respectively. Thus, k may be expressed in terms of refractivity gradient, dN/dh as [8,14] and [37,38].

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

Near the earth's surface, $\frac{dN}{dh}$ is about -39 N-units/km which gives an effective earth radius factor $= \frac{4}{3}$. This is referred to as normal refraction or standard atmosphere. Here, radio signals travel on a straight line path along the earth's surface and go out to space unobstructed.

If $\frac{4}{3} > k > 0$ Sub-refraction occurs, meaning that radio waves propagate abnormally away from the earth's surface.

When $\infty > k > \frac{4}{3}$ In this case, Super-refraction occurs and radio waves propagate abnormally towards the earth's surface thus extending the radio horizon.

If $-\infty < k < 0$ ducting occurs and the waves bend downwards with a curvature greater than that of the earth.

4. RESULTS AND DISCUSSION

4.1 Radio Refractivity

Fig. 2 depicts the seasonal variation of radio refractivity for the study area and period under investigation. The radio refractivity at Ikeja showed gradual increase from a minimum value of 373.04 N-units in the month of January until it climaxed at 389.45 N-units in the month of April and decreases gradually until it gets to 380.60 N-units in August which suddenly increases until it reaches another peak value of 387. 41 N-units in the month of November and drops to 380.81 N-units in December. The maximum average value of radio refractivity observed for the study area is 389.45 N-units in the month of April and the minimum value of 373.04 N-units in January. The pattern of variation can be attributed to rain pattern in Ikeja over the period under study. The results showed that high values of refractivity are observed during the rainy season, with an average value of 385.99 N-units, and low values during the dry season, with an average value of 382.94 N-units. The noticeable drop in the value of refractivity in the month of August may be associated to August break, that is, a short period of dryness. The high values observed during the rainy season (April - October) are due to high air humidity (very close to 100%) observed in this part of Nigeria, when the city of Ikeja is under the influence of a large quantity of moisture-laden tropical maritime air resulting from continuous migration of inter-tropical discontinuity (ITD) with the sun. Generally, when the dry and dust –laden north-east winds become dominant in December, the dry harmattan season sets in, resulting in lower values of refractivity. The high values of radio refractivity and its variation is in agreement with the result reported by [23] for Lagos. However, the slight difference may be due to the erratic nature because of the influence of the Atlantic Ocean for the coastal region.

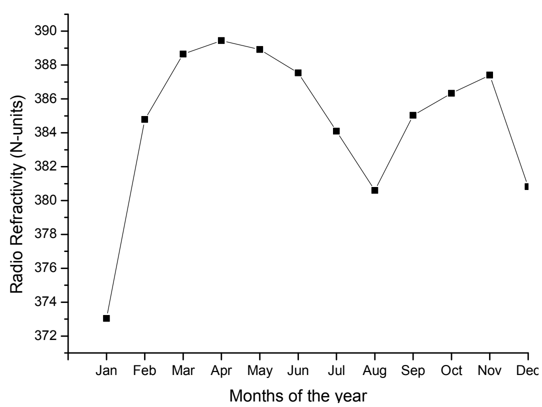

Fig. 2. Monthly radio refractivity variation over Ikeja, Nigeria

Fig. 3 shows the monthly variation of radio refractivity with atmospheric pressure. The atmospheric pressure decreases gradually from January to its minimum value in March and suddenly increases from March and reaches its peak value of 1014.16 hPa in the month of August. It was observed that as the atmospheric pressure increases from April to August the refractivity decreases from April to August. As a dip downward was observed for the refractivity a maximum peak value with dip upward was observed for atmospheric pressure; this implies that during August break the region experiences the highest value of atmospheric pressure. It was observed also that as the atmospheric pressure decreases from August to December, the refractivity increases from August to November and drop to December. High values of atmospheric pressure were observed during the rainy season with an average value of 1012.76 hPa and low values during the dry season with an average value of 1010.94 hPa, similarly, the average values of refractivity are 385.99 N-units and 382.94 N-units during the rainy and dry seasons respectively. It is important to note here that the variation (increase and decrease) of both terms does not occur exactly on same months and considering their values during the rainy and dry season's shows that the dry term of radio refractivity is proportional to atmospheric pressure and therefore related to air density. The maximum average value of radio refractivity observed for the study area is 1014.162 hPa in the month of August and the minimum value of 1010.603 hPa in March.

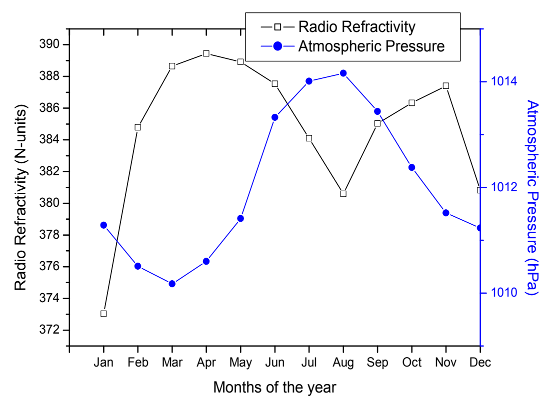

Fig. 3. Monthly variation of radio refractivity with atmospheric pressure over Ikeja, Nigeria

Fig. 4 shows the monthly variation of radio refractivity and relative humidity. The relative humidity increases with increase in radio refractivity from January to April, however, the relative humidity increases continuously until it gets to June and maintain almost a constant value from June to July. A little dip is noticed in August both in relative humidity and radio refractivity, though, that of the radio refractivity is more conspicuous, and this observation is line with the study reported by [25] for coastal regions. The relative humidity increases with the radio refractivity from August to September, however, the radio refractivity increases to November while that of the relative humidity decreases from September to December; the sharp fall in the values of the relative humidity and radio refractivity exhibited similar pattern in December, this could be as a result of high solar insolation observed in the month of December that reduced humid content in the atmosphere, thereby reducing the radio refractivity. The values of relative humidity were high during the rainy season with an average value of 85.12 % and low during the dry season with an average value of 78.25%, likewise the values of the radio refractivity with an average value of 385.99 N-units and 382.94 N-units during the rainy and dry seasons respectively for the study area under investigation. The maximum relative humidity was observed during the rainy season in the month of June with an average value of 87.23 % and the minimum relative humidity during the dry season in the month of January with an average value of 73.15%.

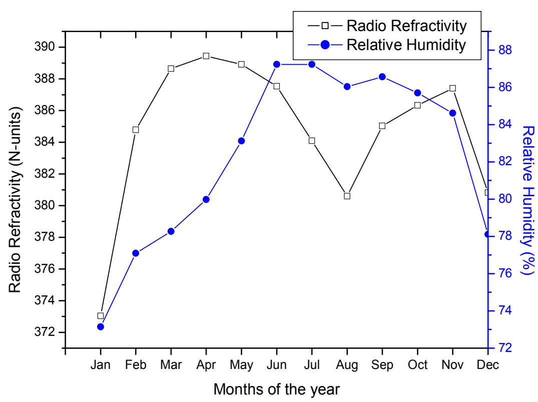

Fig. 4. Monthly variation of radio refractivity with relative humidity over Ikeja, Nigeria

Fig. 5 shows the monthly variation of radio refractivity with temperature (Kelvin) for the study area under investigation. The values of temperature increases with radio refractivity from January to March, the temperature started descending from March to August. A little dip is noticed in August both in temperature and radio refractivity as in the case of the variation between radio refractivity with relative humidity. The values of the temperature gradually increase given almost a straight line pattern from August to December. However, those of the radio refractivity increase from August to November and drop in December. High values of temperature were observed during the dry season with an average value of 301.09 K and low values during the rainy season with an average value of 299.68 K. The high values of refractivity observed during the rainy season are as a result of high moisture or humidity content in the atmosphere and low temperature. The maximum temperature was observed during the dry season in the month of March with an average value of 302.13 K, this is the transition period from dry to rainy season, the minimum temperature was observed in August with an average value of 298.38 K, this clearly indicated that the lowest temperature values are observed when the sky is partly cloudy and partly clear for the study area under investigation.

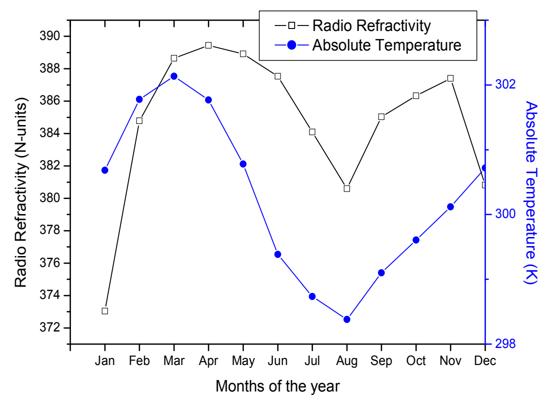

Fig. 5. Monthly variation of radio refractivity with temperature over Ikeja, Nigeria

Fig. 6 shows the variation of radio refractivity with saturation vapour pressure. Observations and trend of the pattern similar to that of variation between radio refractivity and temperature (Fig. 5) was observed. However, the values of temperature are higher than that of saturation vapour pressure, this similarity in pattern shows that the saturation vapour pressure is strongly dependent on the temperature.

Fig. 7 shows the variation of N_{dry} and N_{wet}. Considering the values obtained from this study, it can be seen that the dry term of radio refractivity is a major contributor to the total value of the radio refractivity. The pattern of variation exhibited by the dry term is almost similar to that of atmospheric pressure (Fig. 3), this implies that the dry term of radio refractivity is proportional to the atmospheric pressure and related to air density. On the other hand, we observed the similarity in the trend exhibited by the wet term and radio refractivity (Fig. 2), therefore, we can safely conclude that the wet term of radio refractivity contributes to the major variation of the radio refractivity.

Fig. 8 shows the monthly variation of radio refractivity with refractive index. It was observed that the values of radio refractive index and consequently the radio refractivity showed seasonal variation with high value during the rainy season and low values during the dry season. The average value of radio refractive index during the rainy season is 1.000386 and during the dry season is 1.000383. The value of radio refractivity during the rainy season is 385.99 N-units and during the dry season is 382.94 N-units. The maximum values of radio refractive index and radio refractivity were observed during the rainy season in the month of April as 1.000389 and 389.45 N-units respectively and the minimum values during the dry seasons in the month of January as 1.000373 and 373.04 N-units respectively.

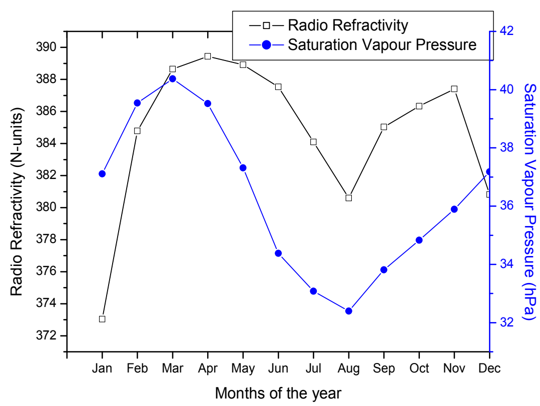

Fig. 6. Monthly variation of radio refractivity with saturation vapour pressure over Ikeja, Nigeria

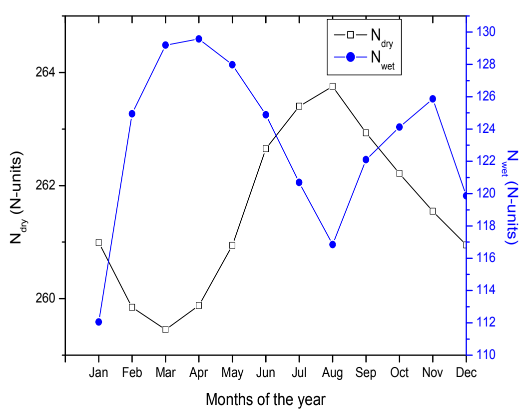

Fig. 7. Monthly variation of dry and wet terms radio refractivity over Ikeja, Nigeria

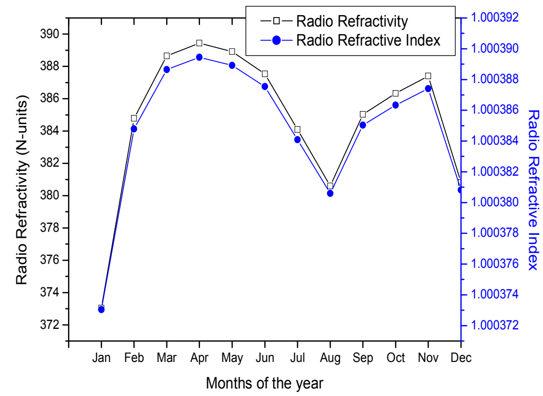

Fig. 8. Monthly variation of radio refractivity with refractive index over Ikeja, Nigeria

Fig. 9 shows the monthly variation of percentage difference between the N_{dry} and N_{wet} (N_{dry}-N_{wet}).The result indicated that the maximum percentage differences occurred in the month of January (about 8.97%) and the minimum in the months of March and April (about 7.85%).

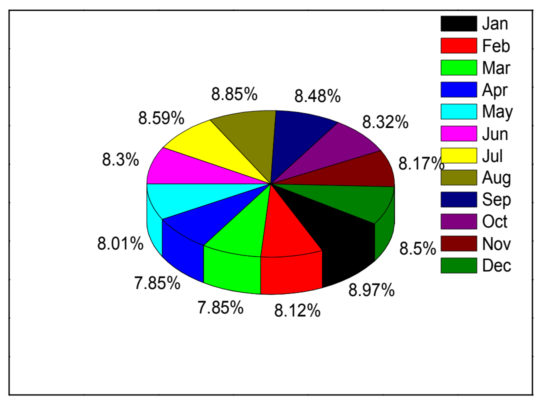

Fig. 9. Monthly variation of percentage difference between the dry and wet term radio refractivity over Ikeja, Nigeria

Table 1 shows the monthly variation of the percentage contribution of both the dry term and wet term radio refractivity to the total radio refractivity. It was observed that the dry term radio refractivity is a major contributor to the total radio refractivity with 67.98% and the wet term radio refractivity with 32.02% for Ikeja, Lagos state, South Western, Nigeria during the period under investigation. It was also observed that the monthly maximum contribution of the dry term is in the months of July and August with 5.71% and minimum in the month of March with 5.62%, similarly, the monthly maximum contribution for the wet term is in the month of April with 2.81%

and minimum in the month of January with 2.43%.

Table 1. Monthly variation of the percentage contribution of N_{dry} and N_{wet}

Month	N_{dry}-N_{wet}	%CN_{dry}	%CN_{wet}
Jan	148.94	5.65	2.43
Feb	134.90	5.63	2.71
Mar	130.26	5.62	2.80
Apr	130.31	5.63	2.81
May	132.97	5.65	2.77
Jun	137.77	5.69	2.71
Jul	142.71	5.71	2.61
Aug	146.91	5.71	2.53
Sep	140.83	5.70	2.64
Oct	138.09	5.68	2.69
Nov	135.68	5.67	2.73
Dec	141.08	5.65	2.60
		Tot=67.98	Tot=32.02

Fig. 10 shows the monthly variation of dry and wet term radio refractivity. It was observed that the dry term radio refractivity are the significant contributors to the total radio refractivity, the highest value of N_{dry} is recorded in the month of August as 263.75 N-units and the lowest in the month of March as 259.45 N-units. On the other hand, the highest value of N_{wet} is recorded in the month of April as 129.57 N-units and the lowest in the month of January as 112.05 N-units.

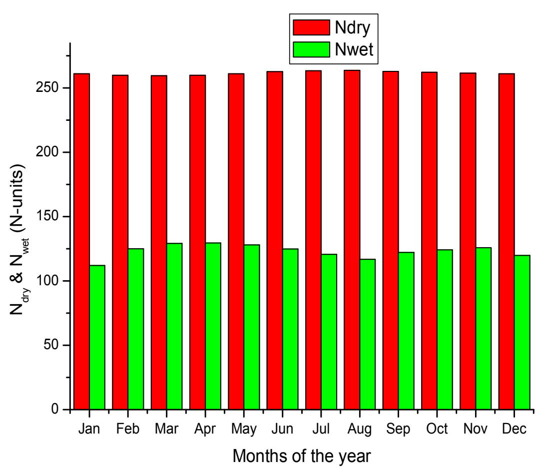

Fig. 10. Monthly variation of dry and wet term radio refractivity over Ikeja, Nigeria

4.2 Refractivity Gradient

The refractivity gradient obtained for the study area under investigation using equations (9) is -44.32 N-units/km. The implication of the result is that propagation in this geographic region is mostly super-refractive, which implies that the electromagnetic waves are bent downward towards the earth. The degree of bending is a function of the strength of the super-refractive condition. As the refractivity gradient continues to decrease, the wave path's curve will approach the radius of curvature of the earth. Super-refraction occurs when the bending of the trajectory of propagating radio wave bends towards the ground surface is greater than its bending in case of normal positive refraction.

4.3 Effective Earth Radius

The effective earth radius, k – factor obtained for the study area under investigation using equation (10) is 1.39. The implication of the result is that propagation in this geographic region is mostly super-refractive. Super refraction results from such meteorological conditions as a rise in temperature with increasing height (temperature inversion), or a marked decrease in total moisture content in the air, either of which will cause a reduction in the dielectric constant gradient with height. Under these situations the K-factor increases resulting in an effective flattening of the equivalent earth's curvature. One of the conditions which may cause this type of abnormal refraction is the passage of warm air over a cool body of water and water evaporation can cause an increase in moisture content and a decrease in temperature near the surface, therefore producing a temperature inversion. However, it is not only the temperature inversion itself which causes the abnormal bending of the microwave beam. The large increase in water vapour content and hence, the dielectric constant near the surface further increases this effect.

5. CONCLUSION

The issue of estimating tropospheric radio refractivity under varying meteorological conditions has been addressed. The method recommended by the International Telecommunication Union (ITU) has been adopted in the evaluation of tropospheric radio refractivity for Ikeja during the period under investigation. The variation of radio refractivity with meteorological parameters of atmospheric pressure, relative humidity and temperature for a period of 12-years has been investigated. The results indicated that an average value of 385.99 N-units and an average value of 382.94 N-units were observed during the rainy and dry seasons respectively. This shows obviously that radio refractivity during the rainy season is greater than the dry season for the study area. The maximum and minimum values of radio refractivity were observed in the months of April and January. The variation of radio refractivity with atmospheric pressure indicates that both radio refractivity and atmospheric pressure are greater during the rainy season than in the dry season. Similar observations were observed for relative humidity. However, the variation of radio refractivity with temperature indicated that high values of radio refractivity and temperature were observed during the rainy and dry seasons respectively and low values of radio refractivity and temperature were observed during the dry and rainy seasons respectively. The dry term contributes 67.98% to the total value of the radio refractivity while the wet term contributes to the major variation. The average refractivity gradient and k – factor obtained from this study area under investigation are -44.32 N-units/km and 1.39 respectively. The implication of the result is that propagation in this geographic region is mostly super-refractive. The results obtained from this study are highly critical for optimal planning and design of radio links/systems for the study area under investigation and regions with similar climatic information.

ACKNOWLEDGEMENTS

The authors are grateful to the Tutiempo Network, S.L for providing all the necessary meteorological data used in this present study. The contribution and suggestions of the anonymous reviewers that led to improving the paper is well appreciated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hall MPM. Effects of the troposphere on radio communication. Institute of Electrical Engineers; 1979.
2. John SS, Introduction to RF propagation, John Wiley and Sons, Inc. Hoboken, New Jersey; 2005.
3. Agunlejika O, Raji TI. Empirical evaluation of wet-term of refractivity in Nigeria. International Journal of Engineering and Applied Sciences (IJEAS). 2010;2(2): 63–68.
4. Chinelo IU, Chukwunike OC. The study of surface refractivity in Awka, South Eastern Nigeria. Journal of Geography, Environment and Earth Science International. 2016;6(2):1-7.
5. Serdege D, Ivanovs G. Refraction seasonal variation and that influence onto GHz range microwaves availability. Electronics and Electrical Engineering. 2007;6(78):39-42.
6. Ali S, Malik SA, Alimgeer KS, Khan SA Ali RL. Statistical estimation of tropospheric radio refractivity derived from 10 years meteorological data. Journal of Atmospheric and Solar-Terrestrial Physics. 2012;77:96–103.
7. Gao JK, Brewster, Xue M. Variation of radio refractivity with respect to moisture and temperature and influence on radar ray path. Advances in Atmospheric Sciences. 2008;25(6)1098-1106.
8. Freeman RL. Radio system design for telecommunications, 3rd ed., Wiley–Interscience, New York; 2007.
9. Adediji AT, Ajewole MO. Vertical profile of radio refractivity gradient in Akure Southwest Nigeria. Progress In Electro-Magnetic Research. 2008;14:157-168.
10. Priestley JT, Hill RJ. Measuring high–frequency refractive index in the surface layer. J. Atmos. Oceanic Technol. 1985;2(2):233-251.
11. Adeyemi B. Surface water vapor density and tropospheric radio refractivity linkage over three stations in Nigeria. Journal of Atmospheric and Solar– Terrestrial Physics. 2006;68:1105–1115.
12. Grabner M, Kvicera V. Refractive index measurement at TV tower Prague. Radioengineering. 2003;12(1):5–7.
13. Jan B, Ewa W. Empirical season's fadings in radio communication at 6 GHz band. Journal of Telecommunications and Information Technology. 2009;2: 48–52.
14. Maitham A, Asrar VHS. Signal strength measurement at VHF in the eastern region of Saudi Arabia. Arabian Journal for Science and Engineering. 2003;28(2C): 3-18.
15. Tom G. Microwave line-of-sight transmission engineering. White Paper No. AMSEL-IE-TS-06015; 2006.

16. Ihara T. Applicability of specific rain attenuation models at millimeter wavelengths. IEICE Transactions on Communications E 77-B. 1994;10:1275–1278.
17. Tamosiunaite M, Tamosiunas S, Dauksas V, Tamosiuniene M, Zilinskas M. Prediction of electromagnetic waves attenuation due to rain in the localities of Lithuania. Electronics and Electrical Engineering. 2010;9(105): 9–12.
18. Guanjun G, Shukai Li. Study on the vertical profile of refractive index in the troposphere. International Journal of Infrared Millimeter Waves. 2000;21(7): 1103–1111.
19. Nel JW, Erasmus SJ, Mare S. The establishment of a radio refractivity database for Southern Africa. In: Communications and signal processing proceedings, COMSIG 88, Southern African Conference on 24; 1988.
20. Agbo GA. Tropospheric refractivity dependence on atmospheric weather conditions in Jos – Nigeria. Journal of Basic Physical Research. 2011;2(2):2-6.
21. Ajileye OO. Long-term average of effective earth radius factor over West Africa using satellite meteorological dataset. International Journal of Electronics Communication and Computer Engineering. 2015;6(2):175–179.
22. Ajileye OO, Jegede OO, Ayoola MA, Eguaroje OE, Mohammed SO. Variations of surface refractivity for different climatic zones across West Africa. International Journal of Scientific and Engineering Research. 2014;5(3):521–530.
23. Ayantunji BG, Okeke PN, Urama JO. Diurnal and seasonal variation of surface refractivity over Nigeria. Progress in Electromagnetics Research. 2011;30:201-222.
24. Ekpe OE, Agbo GA, Ayantunji BG, Yusuf N, Onugwu AC Variation of tropospheric surface refractivity at Nsukka in South – Eastern Nigeria. Nigerian Journal of Space Research. 2010;7:42–48.
25. Emmanuel I, Adeyemi B, Adedayo KD. Regional variation of columnar refractivity with meteorological variables from climate monitoring satellite application facility (CM SAF) data over Nigeria. International Journal of Physical Sciences. 2013;8(17):825–834.
26. Grabner M, Kvicera V. Statistics of lower atmosphere refractivity in Czechia, In: Asia-pacific microwave conference proceedings, APMC. 2005;4:4-7.
27. Isikwue BC, Kwen YA, Chamegh TM. Variation in the tropospheric surface refractivity over Makurdi, Nigeria. Research Journal of Earth and Planetary Sciences. 2013;3(2):50–59.
28. Luhunga PM, Mutayoba E, Masoud H, Chang'a L, Prodanov AD. Analysis of tropospheric radio refractivity over Julius Nyerere International Airport, Dar es Salaam. 2014;1(2):21–31.
29. Usman AU, Okereke OU, Omizegba EE. Instantaneous GSM signal strength variation with weather and environmental factors. American Journal of Engineering Research (AJER). 2015;4(3):104–115.
30. Žilinskas M, Tamošiunas S, Tamošiūnaitė M, Tamošiūnienė M. Yearly. Seasonal and daily variations of radio refractivity. Physical Aspects of Microwave and Radar Applications. 2011;119:533–536.
31. Salau OR. The changes in temperature and relative humidity in Lagos State, Nigeria. World Scientific News. 2016;49(2):295–306.
32. Salau OR, Ayodele F, Kelvin AA, Gbenga EA, Adetona TF. Effects of changes in enso on temperature and rainfall distribution in Nigeria. Multidisciplinary Digital Publishing Institute, MDPI, J. of climate, Switzerland, Climate. 2016;4:5.
33. Aribisala JO, Ogundipe OM, Akinkurolere OO. The study of climate change. British Journal of Applied Science and Technology. 2016;13(6):1–7.
34. International Telecommunication Union-recommendation, ITU-R. The radio refractive index: Its formula and refractivity data. 2003;453–459.
35. International Telecommunication Union, 1970–1986–1990–1992–1994–1995–1997–1999–2001–2003. The radio refractive index: its formula and refractivity data. Recommendation ITU-R, pp. 453–459.
36. Agunlejika O, Raji TI. Validation of ITU-R model for atmospheric refractivity profile in a tropical region. International Journal of

Engineering and Applied Sciences (IJEAS). 2010;2(4):72-82.

37. Afullo TJ, Motsoela T, Molotsi DF. Refractivity gradient and k-factor in botswana. Radio Africa. 1999;107-110.

38. Hall MPM. Effect of the troposphere on radio communication, IEEE electromagnetic wave series, Peter Peregrinus Ltd, United Kingdom. 1989; 105-116.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/18869