Spatial Variation of Radio Refractivity Across Nigeria

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Abstract- The monthly average radio refractivity of Sokoto, Ikeja, Lokoja, have been determined using the data of temperature, pressure and relative humidity between 1971 and 1980 of Nigeria Meteorological Agency (NIMET).

The work employed ITU-R model to determine the various parameters. The result showed that there was variation in the monthly radio refractivity of the study areas but more noticed in Sokoto compared to Ikeja and Lokoja. It was shown that Sokoto with the highest elevation has the lowest average monthly refractivity while Ikeja with the lowest elevation has the highest average monthly refractivity.

The analysis from Refractive Gradient $\left(\frac{dN}{dh}\right)$ and Effective Earth Radius Factor k shows that propagation of radio wave in the three regions (Ikeja, Lokoja and Sokoto) is mostly super-refractive.

Rainfall and Water vapour seem to be the major factors that responsible for difference in their refractivity.

Although, the relationship between the radio refractivity with respect to the latitudes and longitude of the study areas is not very clear, the radio refractivity was then concluded to be inversely proportional to the elevation of a study area.

Index Terms- Atmospheric pressure, Radio refractivity, Spatial variation, Temperature.

I. Introduction

Radio refractivity is defined as the product of the refractive index less than one unit and one million (equation1). The ratio of the velocity of the radio propagation in free space to that in medium is called refractive index.

The radio refractivity is related to refractive index, n, by the equation given as (Manning, 1999):

$$N = (1-n)\,\mathrm{x}\,10^{6} \quad \text{--------------------} \; 1$$

where N = Radio Refractivity and n Refractive Index of air.

According to Priestley and Hill, 1985, the atmosphere radio refractive index depends on air temperature, humidity, atmospheric pressure and water vapour pressure. Also, any little changes in any of these variables can make a significant influence on radio-wave propagation since it can cause radio signals to be refracted over the whole signal path. This can to some extent affects the radio frequency signal to be propagated beyond the designed radio horizon which may in the process interfere with other radio signal transmitted on the same frequency.

According to Okoro and Agbo, 2012, the propagation of radio wave signal in the troposphere is affected by many processes such as the changes of meteorological parameters like temperature, pressure and humidity. In other words, the changes in these parameters or any of these parameters will result in strengthening or weakening of propagated radio signal.

At high altitudes, the value of the refractive index n approximates to 1, and also, in a well–mixed atmosphere, pressure, temperature and humidity behave in a way that they decrease exponentially as a function of height above the Earth's surface (Tamošiūnaitė, *et al.,* 2010).

According to Agbo, et al., 2013, there is need for special consideration of the refractive properties of the lower atmosphere when one is planning or designing terrestrial communication systems. This is because of multi-path fading and interference that can result from trans- horizon propagation.

This work considers mainly how the radio refractivity is influenced by the latitude, longitude and elevation of the study areas by considering the locations of higher latitude, longitude and elevations in the country.

II. Some Related Works

Some of the related works reviewed in this work are as follows.

i. Bawa *et al.,* (2015): "Study of Average Hourly Variations of Radio Refractivity Variations across Some Selected Cities in Nigeria". The work was conducted on the Average Hourly Variations of Radio Refractivity Variations across Some Cities in Nigeria. It made use of three years meteorological data which was measured from January 2010 to December 2013 using Vantage Pro 2 automatic weather station, and it was discovered by them that average hourly variations of refractivity in the dry season was due to the variations of the wet component (humidity).

ii. Ogherohwo, *et al.,* (2014): "Prognostication of Radio Refractivity in Transmission link: Diurnal and Seasonal Variation of Surface Refractivity over Jos-Plateau state". The research was conducted on the diurnal and seasonal variation of surface refractivity over Jos-Plateau state, using the data of ten months (August 2012-May 2013) which was acquired from Nigeria meteorological Agency (NIMET), Jos, Plateau state. From their result, it was showed that surface refractivity has higher values during wet season than dry season.

iii. Okoro and Agbo (2012): "The Effect of Variation of Meteorological Parameters on the Tropospheric Radio Refractivity for Minna". The work investigated the effect of diurnal variations meteorological parameters on the troposheric radio refractivity during dry and rainy seasons for Minna. The calculations of hourly averages of radio refractivity during dry (February) and rainy (August) seasons were done using the data obtained from the Center for Basic Space Science, Nsukka. The results revealed that the hourly averages of radio refractivity during rainy season (August) was higher than the results in dry season (February).

iv. Ayantunji, and Okeke, 2011: "Diurnal and seasonal variation of surface refractivity over Nigeria". They carried out the study of Diurnal and Seasonal Variation of Surface Refractivity over Nigeria, using four years in-situ meteorological data from eight locations over Nigeria- Nsukka, Sokoto, Minna, Akure, Jos, Lagos, PortHarcourt and Makurdi. They observed in their result that the diurnal variation seems to be mainly caused by the dry component in the rainy season and the wet component in the dry season.

v. Valma, *et al*,. 2010: "Determination of Radio Refractive Index using Meteorological Data", The main goals of this paper were to apply the well- known model ITU–R model to determine the radio refractive index – values using local geographical and meteorological data of the study area (Lithuanian) in different seasons of a year and different day times and to be compared with the average value of refractive index at a ground level under standard atmosphere conditions. It was found out by them that the radio refractive index calculated at high altitude was different from that at the ground level.

III. Materials and Method

3.1 Materials

The work made use of secondary data which are the monthly average temperature, atmospheric pressure and relative humidity of ten years (1971 - 1980) for Sokoto, Ikeja and Lokoja obtained from Nigeria meteorological Agency (NIMET). The monthly average of each of the data was taken by dividing the sum by the ten years to get the average value for each month.

3.2 Method

The research will made use mathematical formulas are used for determining the parameters which were used to determine the radio refractivity, N. These parameters are the saturated vapour pressure, e_s and vapour pressure, e. The following are the procedures for determining the radio refractivity:

a. Radio refractivity

i. Calculation of saturated vapour pressure (e_s): The saturated vapour pressure is the pressure of a liquid when it is in equilibrium with the liquid phase. It depends mainly on the temperature of the vapour or air. It is determined using the equation given as (Manning, 1999):

$$e_s = 6.11\exp\left[\frac{17.26(T-273.16)}{T-35.87}\right] \quad \text{---- 2}$$

where *T* is the air temperature in Kelvin (K), e_s is the saturated vapour pressure in hectopascal (*hpa*) and $\exp$ is exponential given by a constant value of 2.718.

ii. Calculation of vapour pressure (e): Vapour pressure is defined as the measurement of the amount of moisture in the air. Vapour pressure is determined using the equation given as (Manning, 1999):

$$e = e_s \text{ x } \frac{H}{100} \quad \text{--------------------- 3}$$

Where H is the relative humidity in percent, e is the vapour pressure in hectopascal (hpa) and e_s is the saturated vapour pressure calculated from (2) above.

iii. Calculation of Radio Refractivity (N): Radio refractivity is the physical property of the medium as determined by its index of refraction. Radio refractivity is also the product of the refractive index less than one unit and one million. Radio refractivity is calculated using the equation given as (Manning, 1999):

$$N = 77.7\frac{P}{T} + 3.73 \text{ x } 10^5 \frac{e}{T^2} \quad \text{----- 4}$$

Where P is the air pressure in (hpa), e is the vapour pressure in hectopascal (hpa) and T is the air temperature in Kelvin (K).

3.3 About the study areas

The study areas- Sokoto, Ikeja and Lokoja are three state capitals in Nigeria. Sokoto is the capital of Sokoto state, Ikeja is the capital of Lagos state and Lokoja is capital of Kogi state. Kogi state is in north-central Nigeria, Sokoto is in North-West Nigeria and Lagos is in South-West Nigeria. The study location for Sokoto is on latitude 13.03^0 N, Longitude 5.2^0E and elevation 270.0 m, Ikeja is on latitude 6.58^0 N, Longitude3.33^0 E and elevation 4.0m, and Lokoja is on latitude 7.8^0 N, Longitude6.73^0E and elevation 128.0m.

IV. Results and Discussions

Table 1.0 shows the calculated radio refractivity of three state capitals in Nigeria- Sokoto, Ikeja and Lokoja which were carefully chosen in terms of magnitude of their latitude, longitude and elevation in the country. From the result, it was observed that there was variation in the monthly radio refractivity of the three study areas. It was also observed that Sokoto, the Sokoto state capital has the average radio refractivity of 301.6216 N-units, Ikeja, the lagos state capital has the average radio refractivity of 375.4484 N-units and Lokoja, the Kogi state capital has the average radio refractivity of 373.1611 N-units.

Table 1.0: Average monthly Radio Refractivity of Sokoto, Lagos (Ikeja) and Kogi Lokoja

MONTH	N_{Sokoto}	N_{Ikeja}	N_{Lkj}
JAN	285.6039	377.8415	356.3559
FEB	282.3946	382.2086	370.2603
MAR	284.7375	378.681	373.4341
APR	301.4335	376.1984	378.1882
MAY	271.9619	376.0365	380.8090
JUN	281.8731	374.6429	379.7780
JUL	295.4156	371.7249	376.5005
AUG	355.4059	369.2533	378.2139
SEP	348.3326	370.8351	380.3407
OCT	328.5394	373.8039	379.459
NOV	293.4229	378.5692	366.9709
DEC	290.3378	375.5852	357.6222

In other words, Sokoto has the lowest average monthly radio refractivity followed by Lokoja and the Ikeja being the highest, though the difference between the average radio refractivity of Ikeja and Lokoja is just very little (2.28 N-units). But Sokoto has an elevation of 270.0m, Lokoja has an elevation of 128.0m and Ikeja has an elevation of 4.0m above sea level. It can be said that the elevation of the study area is related to the average radio refractivity considering the fact that the location with the highest elevation has the lowest average radio refractivity and the location with the lowest elevation has the highest average radio refractivity. This is in line with the result of the work of Tamošiūnaitė, *et al.*, 2010.

In addition, the result also shows that Sokoto has the maximum and minimum monthly radio refractivity of 355.4059 N-units and 271.9619 N-units respectively, Ikeja has the maximum and minimum monthly radio refractivity of radio refractivity of 382.2086 N-units and 369.25 N-units respectively, while Lokoja has the maximum and minimum monthly radio refractivity of 380.81 N-units and 356.36 N-units in that order (Table 2.0 and Figure 1.0). The maximum and minimum monthly radio refractivity for Sokoto occurred in August and May, the maximum and minimum for Ikeja occurred in February and August, while the maximum and minimum monthly radio refractivity for Lokoja occurred in September and January in that order.

Table 2.0: Maximum and minimum radio refractivity of the study areas

Sokoto		Ikeja		Lokoja	
Maximum	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**
355.4059	271.9619	382.2086	369.2533	380.809	356.3559

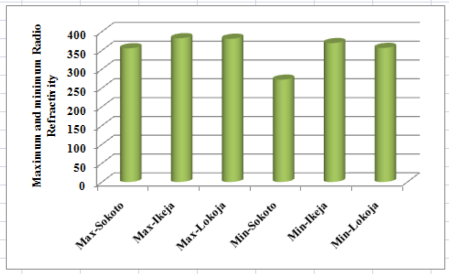

Fig. 1.0: Bar chart of maximum and minimum radio refractivity of the three study areas

Figure 2.0 shows the graphical representation of the average monthly Radio Refractivity of the study areas. It can be seen from the figure that variation occurred in the average monthly radio refractivity of the study areas but is highly noticed in Sokoto compared to Ikeja and Lokoja. There was serious fluctuation of radio refractivity in Sokoto and this will result in fluctuations of radio frequency signals such as television and Radio broadcasting as well as GSM signal transmissions. It will cause transmitted radio signal not to reach the supposed horizon further leading to fading or transmitting beyond the horizon, thereby leading to interference with other radio frequency signal transmitted on the same frequency by another radio or Television stations.

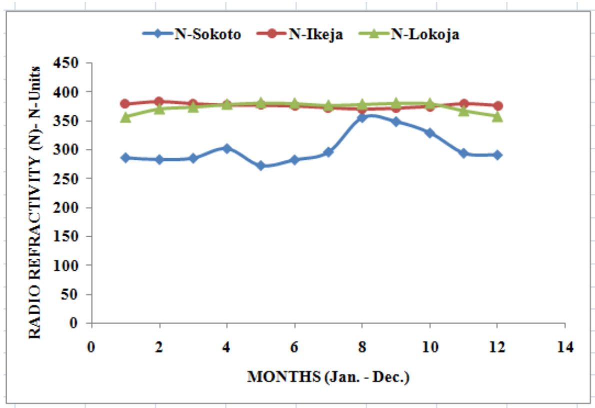

Fig. 2.0: Graphical representation of the radio refractivity of Sokoto, Ikeja and Lokoja

For Ikeja, the radio refractivity increased from January to February from where it started decreasing until it reaches August when it started rising again until it came to November when it then decreased to gently till the month of December. The radio refractivity was low from January to April as it increased from January to May when it started decreasing until it reached July from where it started increasing till the month of September. From September, the radio refractivity started decreasing sharply until December.

Using reference profile to compute the value of refractivity N_s at the Earth's surface from N_0 as follows:

$$N_s = N_0 \exp\left(-{}^{h_s}/_{h_0}\right)$$

Where

N_s : Refractivity at surface of the Earth

N_0 : Average value of atmospheric refractivity extrapolated to sea level

h_0 : scale height (km)

h_s : height of the Earth's surface above sea level

N_0 and h_0 can be determined statistically for different climates. But for reference purposes, a global mean of the height profile of refractivity may be defined by:

N_0 : 315

h_0: 7.35

Table 3.0: The computed refractivity

City	Height above Sea Level : hs (*10^{-3}) km	Refractivity (Ns)
Ikeja	4.0	314.8266
Lokoja	128	309.5618
Sokoto	270	303.6385

This indicates that the Radio refractivity decrease as the height above sea level increases.

Famoriji J.O (2013) expresses this in this form: "Thus, the range of the radio waves is determined by the height dependence of the refractivity. Thus, the refractivity of the atmosphere will not only vary as the height changes but also affect radio signal".

Bean B.R and Horn J. D (1959) shows this height dependence of the refractivity N variations across the United States and that they felt that the U.S. data better illustrate the height dependence of N_s and the subsequent reduction process employed. It is noted that the coastal areas display high values of N_s while the inland areas have lower values. There are low values of Ns corresponding to the Appalachian and Adirondack Mountains, a decrease with increasing elevation of the Great Plains until the lowest values are observed in the Rocky Mountain region and the high plateau area of Nevada.

Table 4.0: Comparison between Refractivity (Ns) and Average Refractivity (N) of three Cities

City	Height above Sea Level : hs (m)	Refractivity (Ns)	Average Refractivity (N)
Ikeja	4.0	314.8266	375.4484
Lokoja	128	309.5618	373.1611
Sokoto	270	303.6385	301.6216

The different in the value is just that the N_0 and h_0 for N_s are global means values and for reference purposes. The average values N was computer based on the weather parameters (humidity, temperature and pressure) of the years 1971-1980. In case of N_s only height was considered. The different therefore is based on the weather parameters.

Refractivity Gradient

Refractivity Gradient happen any time there is a change in the atmospheric air density and atmospheric air refractive index. The change in atmospheric density and refractive index is due to change in temperature of the air medium. i.e due to Temperature Gradient.

From equation

$$N_s = N_0 \exp\left(-{}^{h_s}/_{h_0}\right)$$

Where N_0 = 315, h_0= 7.35km and h_s= 4m, 128m and 270m for the height of Ikeja, Lokoja and Sokoto respectively above sea level. We used the scale height of 7.35km because it gave a better performance at 200m, but scale height gave a better result at 50m. But for purposes of comparison we used 7.35km.

Differential above equations with respect to h_s

$$\frac{dN_s}{dh_s} = -\frac{N_0}{h_s}\exp\left(-\frac{h_s}{h_0}\right)$$

Table 5.0: Refractivity Gradient

City	Height (*10^{-3}) km	Refractivity Gradient N-unit/km
Ikeja	4	-42.8338
Lokoja	128	-42.1172
Sokoto	270	-41-3113

At standard atmosphere, the refractivity gradient is -39 N- unit/km.

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, supper refraction and ducting (Akpootu D.O et al, 2017)

We can now use the Refractivity Gradient to identify whether the above is sub-refraction or super refraction using (Akpootu et. al. 2017 and Adediji el.al, 2008)

If

$$\frac{dN_s}{dh_s} > -40$$

It is sub-refraction

In this case, the N increase with height and the radio waves moves away from the earth's surface and the line of sight range and range of propagation decrease accordingly.

If

$$\frac{dN_s}{dh_s} < -40$$

It is Supper-refractivity\

In this case the N decreases with height and the electromagnetic/radio waves are bent downward toward the earth. The degree of bending depends upon the strength of the super-refractive condition. If the atmosphere's temperature increases with height (inversion) and/or the water vapor content decreases rapidly with height, the refractivity gradient will decrease and radio waves will bend below the standard or normal path. (i.e. This situation is known as super refraction, and causes the radar beam to deflect earthward below its normal path view. Generally, radar ranges are extended when super refractive conditions exist. However, some targets may appear higher on radar than they would under standard atmospheric conditions. 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 (less than the standard or normal path) 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 distance, thereby giving abnormally ranges beyond the line of sight due to multiple reflections.

$$\frac{dN_s}{dh_s} < -157$$

It is Ducting

In this condition, 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 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.

Abdulhadi AbouAlmal, (2015) summary above as follow, " Anomalous phenomena such as super-reflection and ducting may occur when large negative values of reflectivity gradient $\frac{dN}{dh}$ is obtained.

Large negative value in sense that

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

From the table above the refractivity gradient at Ikeja, Lokoja and Sokoto are of large negative value than -40.

The refractivity gradient obtained for Ikeja, Lokoja and Sokoto are -42.8338 N-unit/km, -42.1172 N-unit/km and -41.3113 N-unit/km respectively

These indicate that the propagation in this Cities or geographical region is mostly super-refractive. This implies that the Radio waves are bending 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. In the super-refraction, the bending of the trajectory of propagating radio waves towards the ground must have its bend greater than its bending in case of normal positive refraction.

Effective Earth Radius Factor, k

The effective earth radius is the radius of a hypothetical spherical Earth, without atmosphere, for which propagation paths follow straight lines while the heights and ground distance being the same for actual Earth with atmosphere and constant vertical gradient of refractivity (abdulhadi A, 2015).

This k, can be used to characterize refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting.

Thus, can be expressed in terms of refractivity gradient as follows:

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

Table 6: Some basic parameters of the three study areas

City	Height (*10^{-3}) km	Effective Radius Factor k	ITU reference k-factor value is 4/3
Ikeja	**4**	**1.38**	**1.33**
Lokoja	**128**	**1.37**	**1.33**
Sokoto	**270**	**1.36**	**1.33**

The ITU reference k-factor $\frac{4}{3}$ is considered as a normal refraction condition in a standard atmosphere.

If

$$k < \frac{4}{3} = 1.33$$

It is sub-retraction

The positive k-factor values below $\frac{4}{3}$, indicates the occurrence of sub-refraction where signals bend upward. Meaning that, radio waves propagate abnormally away from the earth's surface. Also it can be shown when $(k \times a) < a$ radius of the earth, where a is the actual radius of the earth.

If

$$k > \frac{4}{3} = 1.33$$

It is super-refraction

The positive k-factor values larger than $\frac{4}{3}$, indicates the occurrence of super-refraction where signals bend downward toward the earth surface. Meaning that, radio waves propagate abnormally toward the earth's surface. Also it can be shown when $(k \times a) > a$ radius of the earth, where a is the actual radius of the earth.

If

$$k < 0$$

It is ducting

It is referring to as Negative values of k-factor indicates the occurrence of ducting, where the radio signals or wireless signals gets trapped within two layers and travel for long distance over the horizon. Meaning that, the radio waves bend downwards with curvature greater than that of the earth.

The k-factor for Ikeja, Lokoja and Sokoto are (1.38), (1.37), and (1.36) and their corresponding refractive gradient are (-42.8338), (-42.1172), and (-41.3113) respectively, this is an evidence that Radio waves refractivity over the three city is supper-refraction because

$$\left(k > \frac{4}{3} \text{ positive values}\right)$$

and

$$\left(\frac{dN}{dh} < -40 \textit{ i.e large negative values of refractive index}\right)$$

The k-factor decrease as the height increases. Ikeja been the highest in k-factor, it is an evidence that radio waves refractivity over Ikeja refracted more toward the earth than Lokoja and Sokoto. The signals can be obtained at very long range.

Adediji A.T et al (2008): When super-refraction and ducting are prevalent, very high radio signal strengths can be obtained at very long range (far beyond line-of-sight) and the signal strength may exceed its free-space value.

Moreover, because n (atmospheric refractive index) varies with frequency, so does the effective earth radius (k-factor). The index of refraction of the atmosphere ordinary decrease with altitude so that radar or radio waves that transmitted horizontally are refracted downward.

The atmospheric refractive index over the three cities Ikeja (1.000375), Lokoja (1.000373), and Sokoto (1.000302), their k-factor Ikeja (1.38), Lokoja (1.37) and Sokoto (1.36) and their Average radio refractivity Ikeja (375.4484), Lokoja (373.1611) and Sokoto (301.6216).

Generally, the k-factor, the atmospheric refractive index, radio refractivity decreases as the height increases. That is, they all decrease with altitude. So, Ikeja with lowest Elevation above sea level has the highest values for k-factor, Atmospheric refractive index (n) and Radio refractivity (N). Sokoto has the least values for the three (i.e. k, n and N) because it has highest elevation.

Since the signals propagation in the three cities are mostly super-refraction, it is necessary to be considered in planning and design of radio communication system in those region

Akpootu D.O (2017): The implication of the result is that propagation in this geographical 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 climate information

Let bring in two parameters (Rainfall and Temperature)

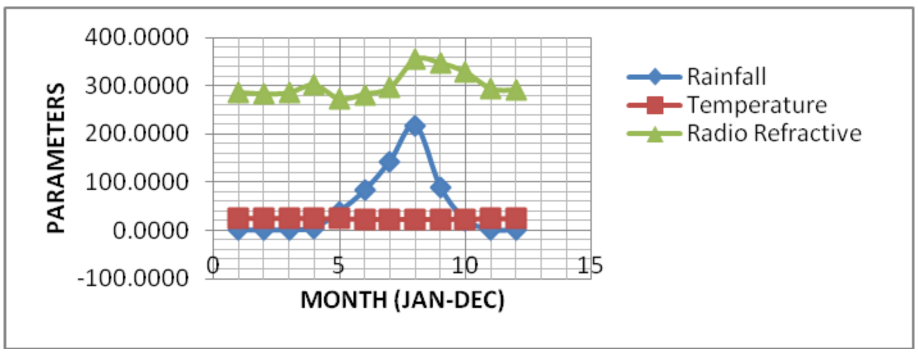

Fig. 3.0: Temperature, Rainfall and Refractive Index of Sokoto

The maximum value 355.4059 N-unit at Sokoto was as a result of heavy rainfall (218.0200), because maximum value 355.4059 N-unit corresponds to maximum rainfall (218.0200) both maximum value occurred in August.

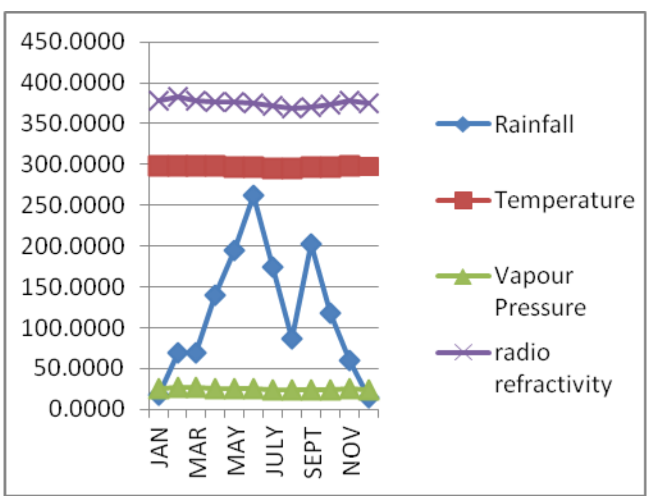

Fig. 4.0 Temperature, Rainfall and Refractive Index of Ikeja

The maximum refractivity 382.2086 N-unit occurred in February at the beginning of rainfall.
The maximum of refractivity in the month of February value might be due to:

- Cloudiness at the earlier portion of the year or due to harmattan (a dusty wind from the Sahara that blows toward the western coat of African during the winter) period,
- Sudden increase the temperature in the month of February
- Commencement of rainfall in the this month
- Sudden increase Vapour Pressure of January (25.92438) to February (27.09256)

The major factors that contributed to high refractivity are mainly:
The commencements of rainfall and increase in the humidity or vapour pressure in the month of February. This high refractivity during the month of February are as a result of high moisture or humidity content in the atmosphere. The high temperature may causing temperature inversion that cause air humid or colder air to descended down making the air thicker. This will suddenly increase the density and refractive index of the air creating what we can call density gradient and refractive index gradient. Since the lower part of the earth is high in density and refractive index, the radio refractivity will be expected to high at this period of the year.

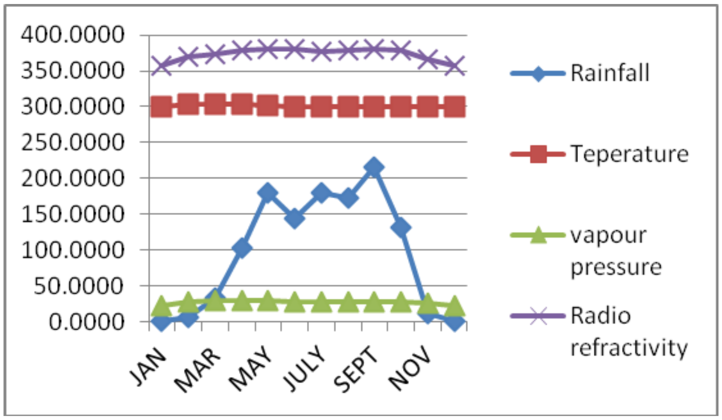

Fig 5.0: Temperature, Rainfall and Refractive Index of Lokoja.

In Lokoja experienced two similar maximum of radio refractivity 380.809 N-unit in May and 380.3407 in September and these are corresponds to rainfall value (179.3909) in May and (216.3182) in September respectively. The rainfall can be seen to be major factors contributed to the rising of Radio refractivity index.

Table 7: Average Radio Refractivity, Rainfall and Humidity

City	*Average Rainfall (1971-1980)*	*Average Radio refractivity (1971-1980)*	*Average Humidity)1971-1980)*
Ikeja	***117.3553***	***375.4484***	***84.475***
Lokoja	***98.0825***	***373.1611***	***73.2667***
Sokoto	***49.8167***	***301.6216***	***41.225***

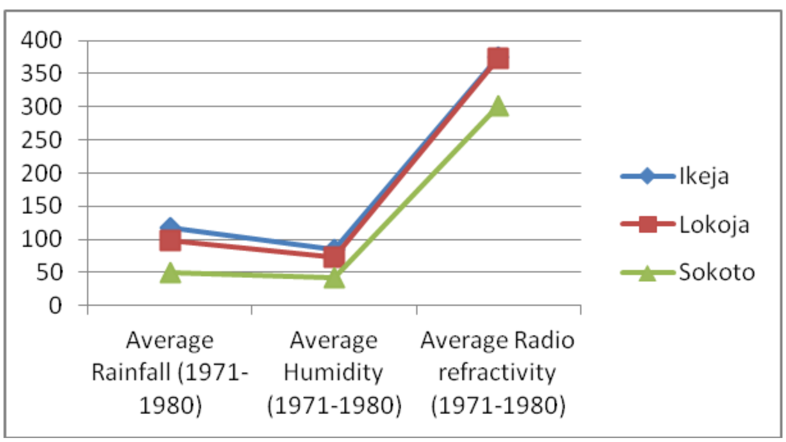

Fig.5.0: Average rainfall, Humidity and Radio refractivity.

It evidence the amount rainfall is another factor (apart from the height from the sea level) that can enhance the refractivity of radio waves above sea level. The Ikeja city has the highest average radio refractivity (375.4484) in year 1971-1980 with average rainfall of (117.3553) and average humidity (84.475) followed by Lokoja with average rainfall (98.0825) and average humidity (73.2667) and then the least is Sokoto.

Valma E et al (2011) stated that, air temperature, Pressure and humidity depend on the height at a point above the ground surface. Even small changes in any of these variables can make a significant influence on radio-wave propagation, because radio signals can be refracted over whole signal path. In a well-mixed atmosphere, pressure, temperature and humidity decrease exponentially as a function of height.

From the above the radio refractivity in the seasons considered is of influence by the changes in the air humidity with height of the city above sea level also with amount rainfall. The radio refractivity and vertical gradient could change when the weather suddenly becomes colder. Significant increase in rainfall and humidity will make air more humid and weather colder. Sudden increase in the rainfall and humidity will cause change in the density and refractive index of the atmosphere resulting into density and atmospheric refractivity vertical gradient. The Ikeja has more rainfall and highest humidity will makes atmosphere more denser and of high atmospheric refractive index than the other two cities, thereby give higher radio refractivity. Since humidity decrease exponentially with the height, we will expect also that Ikeja should have more humidity values that other because of it low elevation.

Surface refractivity is high with respect to topographic altitude because the surface will more saturated with moisture in the rainy season thereby making water vapour in the air to be relatively high and stable.

The high average value of radio refractivity over Ikeja (375.444) can be attributed to high average rainfall (117.3553) over the year 1971-1980. The result shows that high average radio refractivity is normally observed during the rainy season. City with much average rainfall is characterized by heavy rainfall e.g Ikeja. This in line with Akpootu D.O (2017) who stated in his research report on radio refractivity over Ikeja that; some areas in Lagos State, which very closed to the Atlantic Ocean, experience rainfall almost throughout the months of the year.

Apart from the different in the height above sea level of the three cities, water vapour also gives evidence of the differences in their refractivity.

Ikeja maximum refractivity (382.2086) (February) corresponds to maximum vapour pressure or humidity (27.09256) (February), Lokoja maximum refractivity (380.809) (May) corresponding to vapour pressure (29.14457) or humidity in month of May but the vapour pressure (29.35261) or humidity from the April might make contribution to month of May refractivity, and in Sokoto maximum refractivity (355.4059) (August) corresponds to maximum Vapour pressure (20.89127).

V. Conclusion

The monthly average radio refractivity of Sokoto, latitude 13.03^0 N, Longitude 5.2^0 E and elevation 270.0 m, Ikeja, latitude 6.58^0 N, Longitude3.33^0E and elevation 4.0 m, and Lokoja, latitude 7.8^0 N, Longitude 6.73^0E and elevation 128.0m have been determined using the data of temperature, pressure and relative humidity for ten years (1971 to 1980) of NIMET.

The result showed that there was variation in the radio refractivity of the study areas but more noticed in Sokoto compared to Ikeja and Lokoja. It was also shown that Sokoko with the highest elevation has the lowest average monthly refractivity while Ikeja with the lowest elevation has the highest average monthly refractivity.

The analysis from Refractive Gradient $\left(\frac{dN}{dh}\right)$ and Effective Earth Radius Factor k shows that propagation of radio wave in the three regions (Ikeja, Lokoja and Sokoto) is mostly super-refractive.

Rainfall and Water vapour seem to be the major factors that responsible for difference in their refractivity.

Although, the relationship between the radio refractivity with respect to the latitudes and longitude of the study areas is not very clear, the radio refractivity can be concluded to inversely proportional to the elevation of a study area.

VI. Recommendation

As a result of not been able to relate the latitudes and longitudes of the study areas with the radio refractivity, there is need to carry out this work using at least ten study areas or states to be spread across the six geopolitical zones of the country in future works.

References

[1] Ayatunji, B. G. and Okeke, P. N., (2011): "Diurnal and seasonal variation of surface refractivity over Nigeria", Progress in electromagnetic Research B, vol. 30, pp 201-222nd Earth Science International 10(1): 1-12, 2017; Article no. JGEESI.32534 ISSN:2454-7352

[2] Abdulhadi AbouAlmal et al, (2015): "New Methodology for predicting Vertical Atmospheric Profile and Propagation Parameters in Sub-tropical Arabian Gulf Region", Author Draft, IEEE Trans on Antennas and Propagation, Vol. 63, No.9, SEPTEMBER 2015, pp 4057-4068, DOI: 10.1109/TAP.2015.2452937.

[3] Adediji A. T and Ajewole M.O: "Vertical Profile of Radio Refractivity gradient in Akure South-West Nigeria" Progress In Electromagnetic Research C, Vol. 4, 157-168,2008.

[4] Akpootu D.O and IIiyasu M. I (2017): "Estimation of Troposheric Radio Refractivity and Its Variation with Meteorological Parameters over Ikeja, Nigeria", Journal of Geograpghy, Environment and Earth Science International 10(1): 1-12, 2017; Article no. JGEESI.32534 ISSN:2454-7352 PP 1-12

[5] E. Valma , M. Tamošiūnaitė, S. Tamošiūnas , M. Tamošiūnienė , M. Žilinskas , Determination of Radio Refractive Index using Meteorological Data , Electronics And Electrical Engineering, Vol 10(106), PP 125-128

[6] G. A. Agbo, and O. N. Okoro, A.O. Amechi (2013): Atmospheric Refractivity Over Abuja, Nigeria, International Research Journal of Pure and Applied Physics, Vol.1, No. 1, pp.37-45

[7] Manning, T. (1999). "Microwave Radio Transmission Guide" British library cataloguing in the publication data. pp 89-115

[8] Ogherohwo, E. P, Eggah, M. Y., Patience, R. P. (2014): Prognostication of Radio Refractivity in Transmission link: Diurnal and Seasonal Variation of Surface Refractivity over Jos-Plateau state, International Journal of Advanced research in physical science, Vol. 1(8), Pp 76-92.

[9] O. N. Okoro and G. A. Agbo (2012): "The Effect of Variation of Meteorological Parameters on the Tropospheric Radio Refractivity for Minna". Global Journal of Science Frontier Research Physics & Space Science, Vol. 12(2), Pp 36-42

[10] Priestley JT, Hill RJ (1985): "Measuring high–frequency refractive index in the surface layer", J. Atmos. Oceanic Technol, Vol. 2, Pp 233-251.

[11] S. A. Ayegba, Ale Felix, Mba W. Tochukwu, and Agunanna Henry I (2016): "Variation of Radio Refractivity with season: a case study of Ikeja, Lagos state, Nigeria", International Journal of Scientific & Engineering Research, Vol 7(12), Pp 984-993.

[12] Reference Standart Atmospheres. Draft Revision to Recommendation ITU–R P. 835–3. Document 3/33(Rev.1). E–2004.

[13] Tamošiūnaitė M., Tamošiūnas S., Daukšas V., Tamošiūnienė M., Žilinskas M. Prediction of Electromagnetic Waves Attenuation due to Rain in the Localities of Lithuania // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 9(105). – P. 9–12.

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