Evaluation of Refractivity Gradient and k-factor within the Lower Troposphere of Maiduguri and Enugu under Two Climatic Zones in Nigeria

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Abstract: - Estimation of radio refractivity is important in the planning and design of terrestrial radio communication links for the availability and accessibility of strong networks and signals. This paper investigates the refractivity gradient, effective earth radius factor (k), and the geo-climatic factor K in the first 1km of the troposphere of two selected stations (Maiduguri and Enugu) under different climatic zones in Nigeria. The indirect method of measuring radio refractivity was employed in this study to take measurements over the two selected stations. Vertical profile values of pressure (hPa), Temperature (°C), and Relative humidity (%) within the first 1 km were extracted from MERRA MAIMCPASM V5.20 database profile obtained from a satellite sounding instrument by NASA in the United States. MatLab programming language was used to evaluate the refractivity gradient, k-factor, and geo-climatic factor using the equations recommended by ITU. The results showed that Enugu was predominantly sub-refractive due to the tropical savannah climate while Maiduguri encountered both sub-refractive and normal refractive conditions due to the hot semi-arid climate, and unstable and extreme weather conditions in the region.

Key-Words: - Refractivity, Meteorology, MERRA, MatLab, Troposphere, Geo-climatic and k-factor.

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1 Introduction

The propagation of radio waves through the earth's atmosphere encounters some path bending due to diverse spatial distribution of the refractive index of air, thereby causing severe effects such as multipath fading, interference, and attenuation due to diffraction. These effects significantly damage radio communication, navigation, environmental monitoring, and disaster forecasting systems, [1]. In practice, the change of refractive index n is very low, and can be difficult to have an accurate measure of its variation, [2]. Nevertheless, this variation impedes the transmission of radio wave. For this reason, the refractive index n is increased and denoted with N, [3], [4]. The anomalous propagation that occurs during radio waves propagation is called bending. Bending waves are surface waves that appear in thin media, the width of the media is small compared to the wavelength. The refractive index N helps to characterize the curving of the electromagnetic waves, but not the bending phenomena.

The gradient of the radio refractive index, dN/dH is the index used to characterize the bending of electromagnetic waves, [5]. As electromagnetic waves continually bend as they pass through the atmosphere, the gradient of the radio refractivity index can be categorised as normal, sub-refraction, super-refraction, and trapping/ducting. Figure 1. Illustrates the propagation paths for different refractivity conditions.

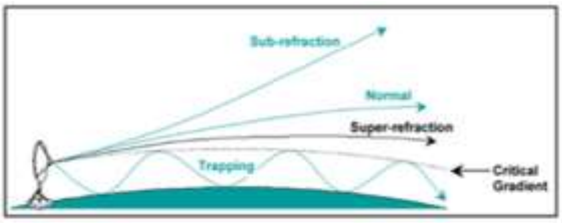

Fig. 1: Propagation paths for different refractivity conditions, [6]

1.1 Effective Earth Radius Factor (k) and Geo-climatic Factor (K)

The effective earth radius factor k is derived using the gradient of the refractive index N as radio waves rise through the altitude of the troposphere. It is also used to characterize refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction, and trapping/ducting. The variability of the k-factor is dependent on the value endorsed by the ITU standard which is 1.33. This value will either underrate or overrate the k-factor value of the study locations, [7]. According to the ITU-R-P-530 recommendation, the geo-climatic factor is used to determine the worst month outage probability. The estimation of this factor is based on the point refractivity gradient(dN_1), which is a function of temperature, pressure, humidity, and vapour pressure which enhances the seasonal variation of radio refractive gradient, [8], [9], [10]. Many research studies had been carried out in this field in West Africa, amongst these studies are found in the journals, [11], [12], [13], [14], [15], [16].

1.2 Study Area

Nigeria is a country in West Africa located between the Equator and the Tropic of Cancer. Nigeria lies amid latitude 4°N and 14°N and longitude 2°E and 15°E respectively with a total area of 923,768 square kilometres. The climatic condition differs in most parts of the country, in the north the climatic condition is arid and to the south, there is an equatorial type of climate or tropical in nature. The weather condition can be generally categorized into two; In the North, from April to October is the wet season, and from November to March is the dry season, while in the South, from March to October is the wet season and from November to February dry season. The two selected areas (Enugu and Maiduguri) for this study are located under two different climatic zones in the country. Table 1 presents the geographical information of the two selected stations in Nigeria.

Table 1. The Geographical Information of the Two Selected Stations in Nigeria

STATIONS	GEOPOLITICAL REGION	CLIMATIC ZONE	GEOGRAPHICAL COORDINATES (Lat & Long)	LANDMASS (km²)	AVERAGE TEMPERATURE (°C)
ENUGU	South-East (SE)	Tropical savannah climate	6.46°N & 7.61°E	7,161	26.3
MAIDUGURI	North-East (NE)	Hot semi-arid or local steppe climate	11.83° N & 13.15°E	61,435	25.8

2 Research Methodology

The in-situ method of measuring refractivity was employed in this study to take measurements over two selected stations in Nigeria namely: Enugu and Maiduguri. Vertical profile values of pressure (hPa), Temperature (°C), Geopotential height (m), and Relative humidity (%) were extracted from the measurements obtained from the Satellite Sounding instrument by NASA in the USA via MERRA MAIMCPASM V5.20 database profile.

A programming language was written using MatLab to determine the radio refractivity (N) and refractivity gradient$\left(\frac{dN}{dH}\right)$ applying equations (1) and (2) recommended by [3].

$$N = 77.6\frac{P}{T} - 5.6\frac{e}{T} + 3.35 \times 10^5 \frac{e}{T^3} \tag{1}$$

$$\frac{dN}{dh} = 77.6\frac{1}{T}\frac{dP}{dh}\left(\frac{77.6}{T^2} + \frac{746512e}{T^3}\right)\frac{dT}{dh} + \frac{373256}{T^2}\frac{de}{dh} \tag{2}$$

The effective earth radius factor (k) for each selected state was computed on a Microsoft Excel spreadsheet using the formula in equation (3):

$$k = \left[1 + \frac{\left(\frac{dN}{dH}\right)}{157}\right]^{-1} \tag{3}$$

The geo-climatic factor (K) was determined using the point refractivity gradient (dN_1)in the lowest 100 m of the atmosphere not exceeded for 1% of the average year. The (dN_1) was deduced from the probability distribution frequency curve of an average refractive gradient of each of the two stations over the period of years (2010 - 2014) under consideration. The point refractivity gradient dN_1 values were computed on a Microsoft Excel spreadsheet to estimate the geo-climatic factor (K) using equation (4):

$$K = 10^{-4.6-0.0027dN_1} \tag{4}$$

3 Results and Discussion

This section presents the results and discussion of the estimation and analysis of meteorological parameters (pressure, temperature, relative humidity) at an altitude of 1 km of the troposphere in two selected stations from different climatic zones in Nigeria.

3.1 Monthly Variations of Radio Refractivity Gradient

The refractivity gradient is strongly dependent on the radio refractivity (N) and geopotential height. It was derived from equation (2). The results obtained of the mean values of monthly variations of radio refractivity gradient of the first 1 km for Enugu and Maiduguri are presented in Table 2 and Table 3. The result shows that Enugu had positive values both in the wet season and dry season months and it falls within the range of 1 N-unit/km and above. The bending or refractive gradient that occurs within this range is classified as sub-refractive. On the other hand, Maiduguri had a high positive value of 54 N-units/km observed in July (wet season) and negative values of -3 N-units/km and -4 N-units/km observed from November to February (dry season). The range of these negative values is classified as normal refractive which is within -24 N-units/km to 0 N-unit/km. This implies that Maiduguri is predominantly sub-refractive in the wet season and normal refractive in the dry season. Figure 2 and Figure 3 show the graphical bar chart of the values of the refractivity gradient obtained in Table 2 and Table 3.

Table 2. The mean values of monthly variations of radio refractivity gradient of the first 1 km for Enugu

MONTH/ YEAR	Mean Refractivity Gradient (N-units/km) 2010	Mean Refractivity Gradient (N-units/km) 2011	Mean Refractivity Gradient (N-units/km) 2012	Mean Refractivity Gradient (N-units/km) 2013	Mean Refractivity Gradient (N-units/km) 2014
JAN	53	34	40	34	43
FEB	49	47	51	40	49
MAR	38	51	51	51	52
APR	47	49	45	51	43
MAY	41	42	47	46	41
JUN	34	37	36	39	39
JUL	30	27	29	31	41
AUG	30	34	34	35	31
SEP	37	38	36	36	38
OCT	34	34	34	35	34
NOV	44	38	37	48	44
DEC	44	40	38	44	43

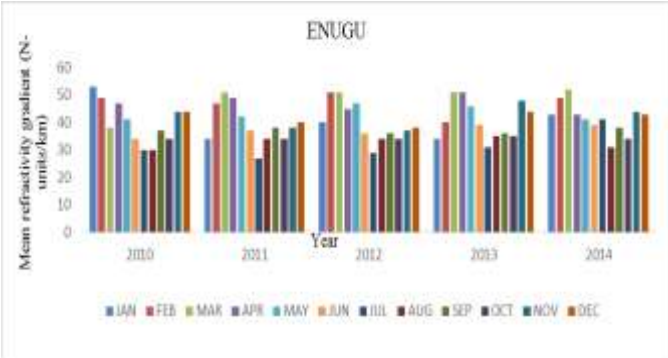

Fig. 2: The mean values of monthly seasonal variations of radio refractivity gradient of the first 1km for Enugu

3.2 The Result of the Effective Earth Radius (K)

The result of the k-factor was reliant on the type of season. The mean values of the k-factor during dry and wet seasons for the two selected stations in Nigeria from (January 2010 –December 2014) are presented in Table 4. The value of 1.33 recommended by the ITU will either underrate or overrate the variability of k-factor values obtained in the two stations under consideration. The results showed that Enugu had low values of k-factor compared to the Northern station, Maiduguri which had higher values of k-factor due to the extreme climatic conditions that occur in this region. Figure 4 shows the graphical bar chart representation of the results obtained in Table 4.

Table 3. Mean values of monthly seasonal variations of radio refractivity gradient of the first 1 km for Maiduguri.

MONTH/YEAR	Mean Refractivity Gradient (N-units/km) 2010	Mean Refractivity Gradient (N-units/km) 2011	Mean Refractivity Gradient (N-units/km) 2012	Mean Refractivity Gradient (N-units/km) 2013	Mean Refractivity Gradient (N-units/km) 2014
JAN	-3	7	3	-3	4
FEB	4	-4	4	16	17
MAR	9	4	5	21	24
APR	28	9	15	10	33
MAY	44	16	44	34	19
JUN	34	29	31	23	52
JUL	54	30	30	35	38
AUG	40	41	42	44	35
SEP	38	40	40	38	33
OCT	43	32	44	30	31
NOV	15	-4	8	-3	22
DEC	7	-3	10	34	18

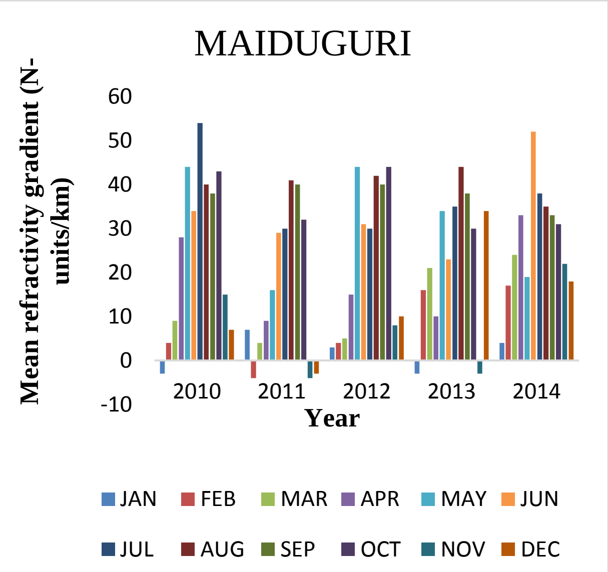

Fig. 3: Mean values of monthly seasonal variations of radio refractivity gradient of the first 1km for Maiduguri

Table 4. Mean effective earth radius factor of monthly variations of radio refractivity gradient of the first 1km for Enugu and Maiduguri from (2010-2014).

Month	Average refractivity gradient (2010 - 2014) Enugu	Effective earth radius factor (k) Enugu	Average refractivity gradient (2010 - 2014) Maiduguri	Effective earth radius factor (k) Maiduguri
JAN	53	0.74762	2	0.98742
FEB	49	0.76214	7	0.95732
MAR	49	0.76214	13	0.92353
APR	47	0.76961	19	0.89205
MAY	43	0.78500	31	0.83511
JUN	37	0.80928	34	0.82199
JUL	32	0.83069	37	0.80928
AUG	33	0.82632	40	0.79695
SEP	37	0.80928	38	0.80513
OCT	34	0.82199	36	0.81347
NOV	42	0.78894	8	0.95152
DEC	42	0.78894	13	0.92353

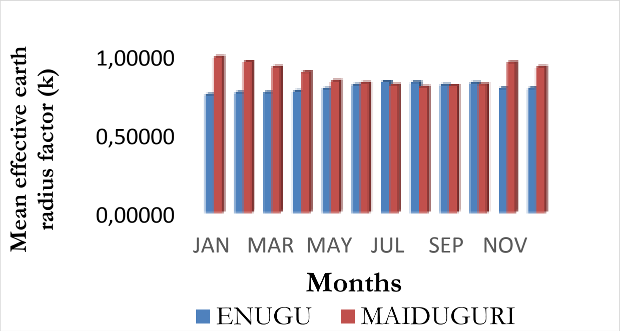

Fig. 4: Mean effective earth radius factor of monthly variations of radio refractivity gradient of the first 1km for Enugu and Maiduguri from (2010-2014).

3.3 The Result of the Geo-climatic Factor (K)

The geo-climatic factor (K) determines the worst month outage probability. The higher the values of the geo-climatic factor, the more the radio wave signals in these regions fade away. Table 5 presents the mean point refractivity gradient (dN_1)and geo-climatic factor (K) for the period of five years (2010 - 2014) in these two selected stations. It was observed that in Enugu and Maiduguri, the worst months outage are found in March and June which had geo-climatic factors K of (4.370E-05 and 3.506E-05) respectively. The geo-climatic factor signifies the path fade depth and this also implies that radio wave propagating signal could encounter ducting condition in these months. The mean monthly variations of geo-climatic factor (K) of the first 1km for Enugu and Maiduguri from (2010-2014) are presented in Figure 5.

Table 5. Mean values of monthly variations of point refractivity gradient and geo-climatic factor (K) of the first 1km for Enugu and Maiduguri from (2010-2014).

Months	Point Refractivity Gradient (dN_1) (2010 - 2014) ENUGU	Geo-climatic factor (K) ENUGU	Point Refractivity Gradient (dN_1) (2010 - 2014) MAIDUGURI	Geo-climatic factor (K) MAIDUGURI
JAN	55	4.370E-05	-28	7.607E-05
FEB	56	4.341E-05	14	5.746E-05
MAR	55	4.370E-05	55	4.370E-05
APR	60	4.227E-05	60	4.227E-05
MAY	53	4.429E-05	54	4.399E-05
JUN	46	4.641E-05	88	3.506E-05
JUL	40	4.831E-05	87	3.529E-05
AUG	26	5.304E-05	50	4.519E-05
SEP	48	4.579E-05	63	4.143E-05
OCT	40	4.831E-05	63	4.143E-05
NOV	50	4.519E-05	15	5.708E-05
DEC	24	5.375E-05	55	4.370E-05

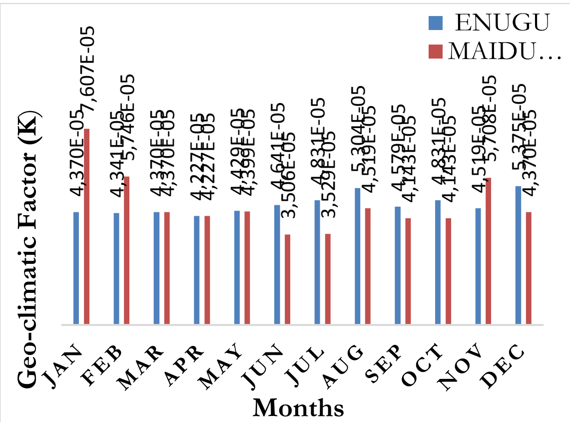

Fig. 5: Mean monthly variations of geo-climatic factor (K) of the first 1km for Enugu and Maiduguri from (2010-2014).

4 Conclusion

In this study, the evaluation of radio propagation parameters in the first 1 km of the troposphere has been examined in two selected stations (Enugu and Maiduguri) under two climatic regions in Nigeria from (January 2010 – December 2014). The method recommended by the International Telecommunication Union (ITU) was adopted in this study. Radio refractivity gradient, effective earth radius (k-factor), point refractivity gradient (dN_1) and Geoclimatic factor (K) was estimated and analysed from the measurements of air temperature, relative humidity, and atmospheric pressure obtained from MERRA MAIMCPASM V5.20 database software using a satellite sounding instrument by NASA, USA. In conclusion, Enugu had positive values of refractivity gradient in both wet and dry season throughout the period of consideration which implies that this region was predominantly sub-refractive, while, Maiduguri had both positive and negative values in wet and dry seasons respectively which indicates that this region was predominantly sub-refractive in the wet season and normal refractive in the dry season. The values obtained from the refractive gradient were used to characterize the bend in the radio wave signals in the region if it's either normal refractive, sub-refractive, super-refractive, or ducting.

The application of the effective earth radius (k-factor) in the radio link design will help to calculate the antenna height required to estimate the diffraction fading or multipath fading, while the geo-climatic factor (K) will be applicable in the calculation of fade depth A (dB). Therefore, it is important to estimate the correct value of the radio refractivity gradient, k-factor, and geo-climatic factor in other to ascertain an adequate fade margin for a reliable radio link performance.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Fashade O. O, carried out the data acquisition, analysis and evaluation.
-Omotosho T. V supervision of research activity and mentorship.
-Ometan O.O, Ayo-Akanbi O. A and Adewusi O. M implemented the Algorithm used in the MatLab programming language.
-Arijaje T. E and Ogundolie O. I was responsible for the Statistics.
-Akinwumi S. A responsible for preparation of the work for publication from the original research group.

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Conflict of Interest

The authors have no conflict of interest to declare that is relevant to the content of this article.