Refractivity gradient of the first 1km of the troposphere for some selected stations in six geo-political zones in Nigeria

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Abstract: This paper presents the evaluation of refractivity gradient and the effective earth radius factor (k) analysed from the climatic profile values of air temperature, relative humidity and atmospheric pressure in the first 1Km of the troposphere over six (6) selected stations from the six geopolitical regions in Nigeria. The study utilized meteorological data from Satellite Sounding instrument by NASA USA. The meteorological parameters measured were extracted from MERRA MAIMCPASM V5.20 database software from January 2010 to December 2014 for each station. The result shows that the average values of the refractivity gradient and k-factor for the 5 years period of consideration are (40.2 N-units/km and 0.797 ≈ 1.0) for Abuja, (40.3 N-units/km and 0.792 ≈ 1.0) for Enugu, (47 N-units/km and 0.773 ≈ 1.0) for Lagos, (43 N-units/km and 0.788 ≈ 1.0) for Port-Harcourt, (26.4 N-units/km and 0.862 ≈ 1.0) for Sokoto, (23.2 N-units/km and 0.876 ≈ 1.0) for Maiduguri respectively. The outcome of the k-factor was dependent on the type of season and the variability of k-factor showed that the value of 1.33 recommended by the ITU will either underrate or overrate k-factor value in each of the station under consideration. In conclusion, the local radio propagation condition in the troposphere for the selected six stations in Nigeria are predominantly sub-refractive based on the k-factor which is \( \frac{2}{3} > k > 0 \).

Keywords: Satellite sounding, Troposphere, Refractive gradient and k-factor.

1. Introduction
The troposphere is the lowermost layer of Earth's atmosphere and it consist of nearly 75-80 percent mass of the atmosphere. Most clouds formation take place in the troposphere, and virtually all weather condition take place within this layer. The troposphere is certainly the moistest layer of the atmosphere; all of the layers above contain very little moisture. The troposphere spreads out upward to about 10 km above the sea level. Air pressure and density decrease with altitude of the troposphere. Air is warmest at the lowest layer of the troposphere and becomes colder as it upsurges through the troposphere [1]. The major tropospheric effects on radio wave transmission are refraction and reflection. Tropospheric refraction transpires if the refractive index of the troposphere decreases as altitude increases, yielding to the bending or curving of waves toward the earth surface [2]. Also, the tropospheric...
refraction is liable to the instabilities of weather variables of temperature, pressure and relative humidity. In the troposphere, there is attenuation of radio signals, caused by absorption by air particles, water molecules, and precipitation (rain). It’s been established that the refraction of electromagnetic waves due to diverse spatial distribution of the refractive index of air causes adverse effects such as multipath fading and interference, attenuation due to diffraction on the terrain obstacles or so called radio holes [3]. These severe effects significantly impair radio communication, navigation and radar locating systems [4]. A lot of research works have been carried out in the area of radio link design and propagation. Many West African researchers have contributed to the development of this field, amongst the researches carried out in this field are; Vertical profile of radio refractivity gradient in Akure South–West Nigeria [5]. Analysis of the EER factor (k-factor) distribution in Nigeria and its impacts on microwave application [6]. The effect of variation of meteorological parameters on the tropospheric radio refractivity for Minna [7]. Likewise, Refractivity Gradient of terrestrial radio link and k-factor in Botswana, Radio Africa [8-10]. All these journals were reviewed to guide the present study.

In so many regions in Nigeria radio wave communication links could become inaccessible due to unpredictable path loss and seasonal fluctuations of refractive index. Therefore, the evaluation of radio refractivity is critical and essential in the development and design of terrestrial radio links for communication network, navigation, surveillance system and other radar systems for the purpose of achieving optimal performance and improving the quality of their services. This study investigates the monthly variation under meteorological conditions and the tropospheric refractive gradient of electromagnetic waves and the effective radius factor (k) above six selected stations in the six geo-political sectors in Nigeria for the period of 60 months between year 2010 and 2014. The selected stations are Abuja (NE), Enugu (SE), Lagos (SW), Port Harcourt (SS), Maiduguri (NE) and Sokoto (NW). The geographical information of these Selected Stations in Nigeria is presented in Table 1.

### Table 1. Geographical Information of the 6 Selected Stations in Nigeria

| STATIONS | GEOPOLITICAL ZONE | CLIMATIC REGION | GEOGRAPHICAL COORDINATES (Lat & Long) | LANDMASS (km²) | AVERAGE TEMPERATURE (°C) |
|----------|--------------------|----------------|----------------------------------------|----------------|--------------------------|
| ABUJA    | North-East (NE)    | Tropical wet and dry climate | 9.08°N & 7.40°E | 1,769           | 25.7                     |
| ENUGU    | South-East (SE)    | Tropical savannah climate | 6.46°N & 7.61°E | 7,161           | 26.3                     |
| LAGOS    | South-West (SW)    | Partly tropical hot and humid | 6.52°N & 3.38°E | 1,171           | 32                       |
| PORT-HARCOURT | South-South (SS)  | Tropical rain forest climate | 4.82°N & 7.05°E | 369             | 26.4                     |
| SOKOTO   | North-West (NW)    | Sudan savannah | 12.94°N & 5.23°E | 25,973          | 42.5                     |
| MAIDUGURI| North-East (NE)    | Hot semi-arid or local steppe climate | 11.83°N & 13.15°E | 61,435          | 25.8                     |

2. **Methods and Data Analysis**

The indirect method of measuring refractivity was employed in this study to take measurements over some selected stations in Nigeria namely: Abuja, Enugu, Lagos, Sokoto, Port Harcourt and Maiduguri. Vertical profile values of air pressure (hPa), temperature (°C), geopotential height (m) and relative humidity (%) were taken out from the measurements obtained from the Satellite Sounding instrument.
by NASA in USA via MERRA MAIMCPASM V5.20 database software. The monthly variants of meteorological parameters for each year from (2010-2014) were noted down for dry and rainy seasons in Abuja, Enugu, Lagos, Port-Harcourt, Sokoto and Maiduguri. The mean variation of each month was evaluated from the noted data. The partial pressure of water was evaluated from equation (1);

$$e = e_s H$$

(1)

Of which, H denotes the relative humidity, and $e_s$ denotes saturated vapour pressure derived by Clausius-Clapeyron equation given as:

$$e_s = 6.11 \exp \left( \frac{17.26(T-273.16)}{T-35.87} \right)$$

(2)

In relation to the measured weather variables such as the temperature, pressure and relative humidity. Radio refractivity was evaluated using equation (3);

$$N = 77.6 \frac{T}{p} - 5.6 \frac{e}{T} + 3.75 \times 10^5 \frac{e}{T^2} \quad (N \text{ – units})$$

(3)

2.1 Evaluation of Radio link Refractive Gradient and EER Factor (k)

A programing language was written using MatLab to determine the radio refractivity gradient $\frac{dN}{dh}$ applying equation (4) proposed by ITU-R PP.453-13, (2017).

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

(4)

The effective earth radius factor (k) for each selected state was computed on Microsoft excel spreadsheet using equation (5);

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

(5)

The k-factor derived in terms of refractivity gradient $\frac{dN}{dh}$ for each station was used to classify refractive conditions according to (Recommendation ITU-R, pp. 453–459, 2003). If it either sub-refractive, super-refractive, normal refractive or ducting.

3. Result and Discussion

This section presents the results from the estimation and analysis of meteorological variables such as atmospheric pressure, temperature and relative humidity within the altitude of 1km of the troposphere in the six selected stations from the six geopolitical zones of Nigeria.

3.1 The Effect of Refractivity Gradient on the Season of the Year

The values of mean monthly seasonal variations of radio wave refractive gradient for period of 5years (2010-2014) over the study locations is presented in the Figures “1 to 6” below. The values of the mean monthly variations of radio refractivity gradient of the first 1 km for each state was examined, the result shows that in Figures “1 to 4” Abuja, Enugu, Lagos, Port Harcourt had positive values of refractivity gradient in both wet and dry season throughout the period of consideration which implies that these regions were predominantly sub-refractive. However, in Figure 5 Sokoto had the maximum positive value 63 Nunits/km observed in the month of October (wet season) and a least
negative value of -3 Nunits/km in the month of February (dry season). Maiduguri follows the same trend as Sokoto in Figure 6. Maiduguri and Sokoto are predominantly, in the wet season sub-refractive and in the dry season normal refractive.

**Figure 1.** The mean values of monthly variants of radio refractivity gradient of the first 1 km for Abuja

**Figure 2.** The mean values of monthly variants of radio refractivity gradient of the first 1 km for Enugu

**Figure 3.** The mean values of monthly variants of radio refractivity gradient of the first 1 km for Lagos
**Figure 4.** The mean values of monthly variants of radio refractivity gradient of the first 1 km for Port-Harcourt

**Figure 5.** The mean values of monthly variants of radio refractivity gradient of the first 1 km for Sokoto

**Figure 6.** The Mean Values of Monthly variants of Radio Refractivity Gradient of the First 1km for Maiduguri
3.2 The Effect of EER Factor \((k)\) on the Season of the Year

The mean values of k-factor for seasonal fluctuations of radio refractivity gradient for the period of 5 years over the study locations in the course of the dry season months and the wet season months are presented in Table 2 and also in Figure 7 and Figure 8 respectively. The outcome of the k-factor was dependent on the type of season. The variability of k-factor demonstrate that the estimation of 1.33 suggested by the ITU will either underrated or overrate k-factor value in each of the station under consideration. In all the states, the mean k-factor fall under the sub-refractive domain \(\frac{4}{3} > k > 0\). It can be deduced that these regions encountered sub-refractive conditions all through the wet season and dry season due to interference, attenuation by heavy rain, moderate to strong winds and atmospheric absorption which contributes largely to radio waves to propagate anomaly away from the straight line path.

Table 2. The mean values of k-factor during the dry and wet Season in the six selected stations in Nigeria

| Month of the year | ABUJA (k-factor) | ENUGU (k-factor) | LAGOS (k-factor) | SOKOTO (k-factor) | P/HARCOURT (k-factor) | MAIDUGURI (k-factor) |
|-------------------|------------------|-----------------|-----------------|------------------|----------------------|---------------------|
| JAN               | 0.84             | 0.75            | 0.77            | 0.96             | 0.77                 | 0.99                |
| FEB               | 0.79             | 0.76            | 0.75            | 0.98             | 0.76                 | 0.96                |
| MAR               | 0.76             | 0.76            | 0.73            | 0.89             | 0.76                 | 0.92                |
| APR               | 0.76             | 0.77            | 0.73            | 0.87             | 0.76                 | 0.89                |
| MAY               | 0.77             | 0.79            | 0.76            | 0.83             | 0.77                 | 0.84                |
| JUN               | 0.77             | 0.81            | 0.79            | 0.80             | 0.81                 | 0.82                |
| JUL               | 0.80             | 0.83            | 0.81            | 0.79             | 0.82                 | 0.81                |
| AUG               | 0.82             | 0.83            | 0.81            | 0.80             | 0.83                 | 0.80                |
| SEP               | 0.80             | 0.81            | 0.81            | 0.78             | 0.81                 | 0.81                |
| OCT               | 0.79             | 0.82            | 0.77            | 0.77             | 0.80                 | 0.81                |
| NOV               | 0.80             | 0.79            | 0.76            | 0.92             | 0.79                 | 0.95                |
| DEC               | 0.87             | 0.79            | 0.78            | 0.96             | 0.77                 | 0.92                |

Figure 7. The Mean Values of k-Factor during Dry Season for the Six Selected Stations in Nigeria
4. Conclusion

For this article, the influence of geographical and climatic conditions on radio wave signal propagation has been addressed in some selected states in the six geopolitical region of Nigeria namely; Abuja, Enugu, Lagos, Sokoto, Port Harcourt and Maiduguri under 5 years period of consideration (January 2010 – December 2014). The method prescribed by the International Telecommunication Union (ITU) has been embraced in the evaluation. The result showed that Abuja, Enugu, Lagos, Port Harcourt had positive values of refractivity gradient in both wet and dry season throughout the period of consideration which implies that these regions were predominantly sub-refractive. Sokoto had the maximum positive value 63 N.units/km observed in the month of October (wet season) and the least negative value of -3 N.units/km at the month of February (dry season). Maiduguri follows the same trend as Sokoto. Maiduguri and Sokoto are predominantly sub refractive during wet season and normal refractive during dry season. The result of the k-factor was dependent on the type of season and the variability of k-factor demonstrated that the estimation of 1.33 prescribed by ITU-R will either underrate or overrate k-factor value in each of the station under consideration. In conclusion, the confined radio signal propagation condition at the lower troposphere for each of the six selected stations in Nigeria are predominantly sub-refractive based on the k-factor which is $\frac{4}{3} > k > 0$.

Acknowledgement

The Authors express their appreciation to the University’s Research Centre (CUCRID) and Board of Covenant University, Ota, Nigeria for supporting and sponsoring the publication of this research.

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