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ESTIMATION OF REFRACTIVITY GRADIENTS AND EFFECTIVE EARTH RADIUS FACTOR (K-FACTOR) IN THE LOWEST 100 M OF THE ATMOSPHERE OVER OGBOMOSO, SOUTHWESTERN NIGERIA

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ABSTRACT

Upon deviation from standard condition, anomalous propagations are usually experienced in within the atmosphere. As a result, it is very pertinent to considered the value of the tropospheric refractive index while planning, designing and implementing microwave systems. In this study, measurements of meteorological parameters (temperature, relative humidity, and atmospheric pressure) were conducted for a period of 12 months (Jan - Dec, 2021) in Ogbomoso (8.17ºN, 4.24ºE, 372 m above sea level) using a collection of wireless Davis Vantage Pro2 6162 automatic weather stations. The hourly time series of these measured data were extracted and converted to monthly averages and used to compute refractivity, gradient of refractivity, and the k-factor. From the Analyses, results revealed a generally high values of refractivity during the rainy months with a peak value of 359 recorded in May. The values were observed to decrease with increasing height. For the period of this observation, the mean refractivity gradient was found to be 50 N-units/km while the average value of K-factor was 1.49. As a result, it was concluded from these findings that the propagation condition in Ogbomoso is super-refraction.

I. INTRODUCTION

When planning and designing microwave systems, one of the most important parameters to be considered is the value of the tropospheric refractive index. The radio refractive index is often defined as the ratio of the velocity of propagation of radio wave in a free space to the velocity of propagation of radio wave in a specified medium [1–5].

Upon deviation from standard condition, anomalous propagations are usually experienced in within the atmosphere. Changes in meteorological conditions which include temperature inversion and high humidity are believed to be responsible for these aberrations. These meteorological parameters usually exhibit high temporal and spatial variability, with small alterations resulting in significant influence on radio signals [4]. Near the Earth's surface, under standard atmospheric conditions, the radio refractive index is equal to approximately 1.0003 [1], but it is usually not constant under the above mentioned conditions. Changes in the value of the radio refractive index can lead to alterations in the path of the wave.

The term refractivity is mostly used owing to the fact that the value of the refractive index is usually close to unity and exhibits very small temporal and spatial variability [1], [2], [6].

From available literature, several work have been carried out to study the refractivity profiles across different locations in Nigeria [3-5, 7–21]. However, there is dearth of information on the radio refractivity profile in Ogbomoso, as most of the previous works within the southwestern part of Nigeria are restricted to Lagos and Akure. Moreover, climate impacts have identified changes in the meteorological variables with increasing adverse effects on radio link outages over the last few decades. Insight into this trend suggests that the Quality of Service (QoS) provided by the communication links will be even more severely affected over next decades. Hence, there is a need to carry out further studies to understand the radio refractivity profiles with a view to improving quality of service in the area.

As a result, in this study, real time measurements of temperature, relative humidity, and atmospheric pressure were conducted for a period of two years in Ogbomoso (8.17 ºN, 4.24 ºE, 358 m above sea level). The measured data were extracted and used to compute radio refractivity, N, the refractivity gradient, dN/dh and the effective Earth radius factor, K-factor.

II. THEORETICAL BACKGROUND

The troposphere is a region of the atmosphere extending from the surface of the earth up to an altitude of about 9 km and 17 km at the poles and equator, respectively [22], and it is the lowest part of the earth's atmosphere. The upper boundary where the temperature begins to experience an increase with altitude is the tropopause. However, within the troposphere, the temperature has been found to drop with altitude at a rate, which has been reported to be approximately 7 °C per kilometre [22, 23]. Owing to confinement of the earth's weather system to the troposphere, variations in meteorological parameters such as humidity, temperature, and pressure usually results in variation in the refractive index of air in this layer from one point to another.

Generally, it has been established that the tropospheric refractive index, n, decreases with altitude [23,24]. In most discussions relating to this, horizontal homogeneity is usually assumed while neglecting variations in the horizontal path. As mentioned earlier, no noticeable deviation is usually observed since the change in the refractive index is negligibly small. One other important characteristics of the atmosphere is the gradient of refractivity, G, which is responsible for the change in propagation direction of the electromagnetic wave [25]. It is an important parameter when classifying refractive conditions of the troposphere

When taking into account, the correlation between refractivity and the primary weather parameters, it is customary to evaluate refractivity using Equation 1 [3, 22, 24].

$$N = 77.6\frac{P}{T} + 3.73\times 10^{5}\frac{\varepsilon}{T^{2}} \quad (1)$$

Here, P is the pressure measured in hPa, T is temperature in Kelvin and ε is water vapour pressure in hPa. Equation 2 is only valid for radio waves with frequencies not exceeding 100 GHz and have an allowed error limit of less than 0.5 % [6, 26].

Prior to implementing equation 1, it's important to first evaluate equations 2 and 3 as given.

$$\varepsilon = H \times \frac{\varepsilon_{s}}{100} \quad (2)$$

$$\varepsilon_{s} = 6.1121\exp\left(\frac{17.502t}{t + 240.97}\right) \quad (3)$$

In this case, t is the temperature in °C.

The k-factor which we will sometimes referred to as the effective earth radius factor is a scaling factor which helps in the quantification of the curvature of an emitted ray path. It is defined as the ratio of the radius, R, of a ray beam curvature to the effective radius of the earth, R_e.

However, radiolink engineer take more direct interest in the refractivity gradient G. To express k -factor as a function of this gradient, it is convenient to assume that the refractive index, n, of air varies linearly with height h within the first few tenths of a kilometre above the earth's surface and invariant in the horizontal direction. It is this argument that led to the mathematical expressions.

$$\frac{R}{R_e} = k \approx \left(1 + \frac{R_e \Delta n}{\Delta h}\right)^{-1} \quad (4)$$

$$\frac{\Delta n}{\Delta h} = \frac{\Delta N}{\Delta h}\times 10^{-6} \qquad N - units/km \quad (5)$$

where R_e is approximately 6370 km and is the height above the earth's surface.

The gradient of refractivity and effective earth radius factor were estimated using Equations 6 and 7, respectively.

$$\frac{\Delta N}{\Delta h} = -\frac{N_s}{H}\exp\left(-\frac{h}{H}\right) \quad (6)$$

$$K \approx \left(1 + \left(\frac{\frac{\Delta N}{\Delta h}}{157}\right)\right)^{-1} \quad (7)$$

Radio refractivity may be classified as: sub-refraction, standard refraction, super-refraction or trapping, depending on the existing tropospheric conditions. When the gradient of refractivity is less than -40 N-units per kilometre, the troposphere is said to be super-refractive and radio signals travelling within it will undergo a downward refraction at a rate less than the curvature of the earth. However, when the refractivity gradient is less than -157 N-units per kilometre will produce a ray that bend downwards the earth's surface with a curvature greater than the curvature of the earth, a condition commonly referred to as trapping. Radio energy can become trapped between a boundary or layer in the troposphere and the surface of the earth or sea (surface duct). Far beyond the line-of-sight, very high signal strengths can be obtained at very long range during ducting [3, 23, 24, 27]. Lastly, for a refractivity gradient that is greater than -40 N-units per kilometre, the troposphere become sub-refractive and radio rays will refract upwards, away from the surface of the earth [23].

III. MATERIALS AND METHODS

The site of the study is the high-rise laboratory complex of the Department of Pure and Applied Physics, Ladoke Akintola University of Technology Ogbomoso, Oyo State Nigeria (8.17 ºN, 4.24 ºE) as indicated on the map in Figure 3. The instrumentation system consists of a Davis 6152 wireless vantage pro2 automatic weather station with an in-built power system provided by a constrained solar-powered unit as shown in Figure 4. The Integrated Sensor Suite (ISS) comprises of several sensors that measures basic weather parameters including rainfall, temperature, relative humidity, UV index among others. The ISS also has a sensor interface module (SIM) which contains electronic circuits that measures and stores values of weather variables for transmission via a wireless console via radio.

The measurement employed the fixed measuring approach, where the ISSs are stationed on the ground and at heights of 50 m and 100 m respectively, for continuous measurement of the atmospheric pressure, air temperature and relative humidity. The time of measurements is from 00 hours local time for 24 hours with an integration time of 60 minutes. Using a wireless terminal, the observation data was transmitted to a data logger attached to the console which was kept on the ground. The logged data are saved temporarily on a laptop for analysis. The allowed error margins for temperature, pressure and relative humidity was set at ± 0.1, ±0.5 hpa and ±2 % respectively.

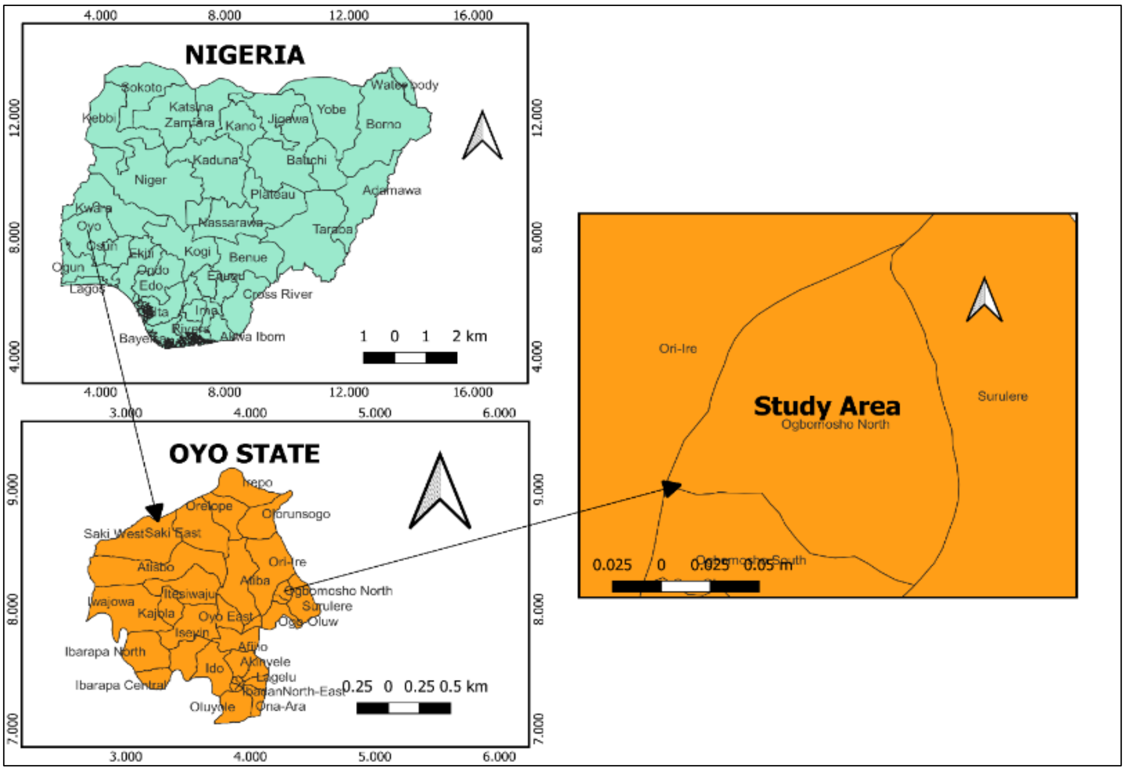

Figure 3: Map of the Study area.
Source: Authors, (2024).

Figure 4: One of the Automatic Weather stations on site in LAUTECH.
Source: Authors, (2024).

The hourly time series of the measured data were used to estimate the values of refractivity, gradient of refractivity and k-factor, respectively. Data analyses and graphing were done using Microsoft excel and OriginPro software.

IV. RESULTS AND DISCUSSIONS

IV.1 MEAN MONTHLY RADIO REFRACTIVITY

Variations in the refractivity over Ogbomoso is presented in Figure 5. During the rainy season which usually occur between March-October, the values of refractivity were observed to be very high, reaching a peak value of 375 N-units in May. This trend, which is in agreement with the result of [3], could be attributed to the high relative humidity (more than 80 %) usually observed in as Ogbomoso is usually subjected to large moisture-filled tropical maritime air arising from continual movement of inter-tropical discontinuities. Between July and August, a slight decrease, attributed to a brief break in rainfall, was observed.

During the dry season however, between November and February, there was a noticeable decline in the refractivity values, having recorded values ranging between 325-354 N-units. We attributed this trend to the presence of dry and dust-laden north-west winds which become dominant in the month of December, that usually setthe path for the dry harmattan season. A slight decrease in refractivity observed in the July–August window is attributed to a brief break in rainfall in the month of August which usually last for about 2-3 weeks.

Generally, the values of refractivity at 2 m (herein referred to as ground level) and other levels differs significantly throughout the entire period of observation, with the refractivity decreasing with height. This is attributed to low ground heat flux and high prevalence of temperature and humidity inversions, leading to low surface temperature and consequently high values of refractivity. The average value of refractivity in Ogbomoso was recorded as 359 N-units.

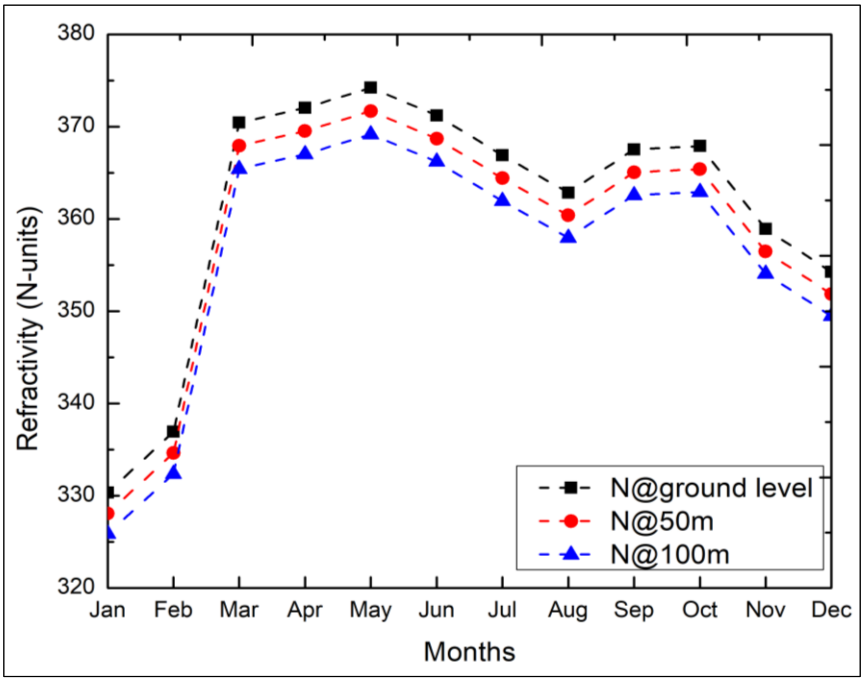

Figure 5: Variations of radio refractivity in Ogbomoso for the year 2021.
Source: Authors, (2024).

IV.2 MEAN MONTHLY REFRACTIVITY GRADIENT

Variations in the vertical refractivity gradient over Ogbomoso is presented in Figure 6. As observed the graph showed irregular pattern that is best described as oscillatory. The refractivity gradient reaches its peak value (-45 N-units per km) in the month of January with the least value recorded in the month of May. The period of peak refractivity gradients coincides with period of intense harmattan in Ogbomoso, which is usually characterised by very cool nights and morning times and very dry day time. The average value of refractivity gradient was found to be -50 N-units/km. From these observation, it was inferred that propagation conditions in Ogbomoso is mostly super-refractive and radio wave transmitted here will have increased range.

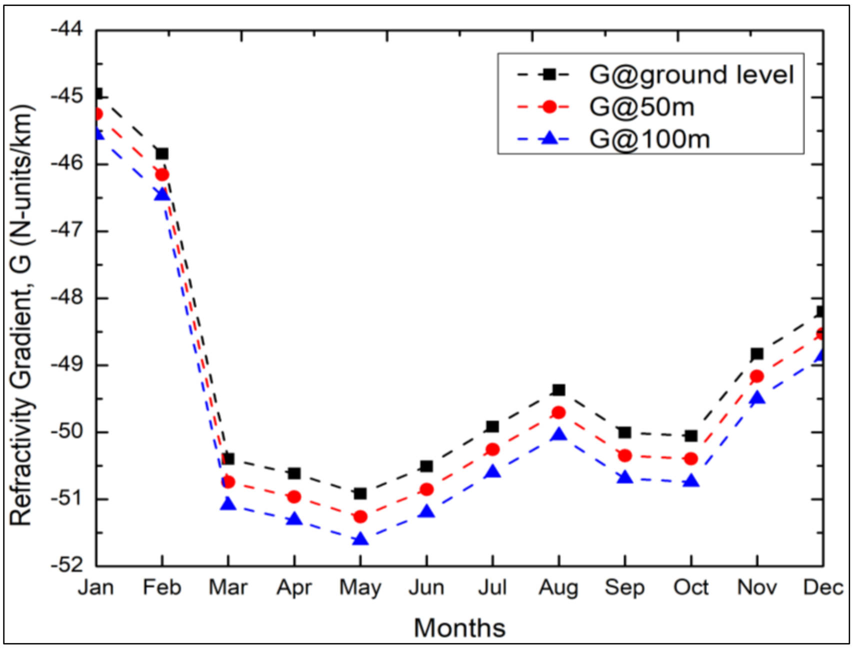

Figure 6: Monthly variations of refractivity gradient in Ogbomoso for the year 2021.
Source: Authors, (2024).

IV.3 MEAN MONTHLY EFFECTIVE EARTH-RADIUS FACTOR

The monthly mean variations of the effective earth radius factor (K-factor) is displayed in Figure 7. Here, it was observed that the K-factor is low in the dry period. For the dry and wet seasons, the values range from 1.40 to 1.45 and 1.45 to 1.49, respectively. These results agree favourably with that of Kolawole (1981), who reported that the effective earth's radius factor, K, is usually lowest over Nigeria in the month January with values in the range 1.12 – 1.38 and highest values varying from about 1.30 to 1.50. In the present study, the average value of K-factor is about 1.49. While the work of Kolawole (1981) suggested that the value of the K-factor usually reaches its peak in the month of August, the present study however found this to not be so, as the highest value of K-factor was recorded in the month of May. This variation could be attributed to the influence of climate change over the years.

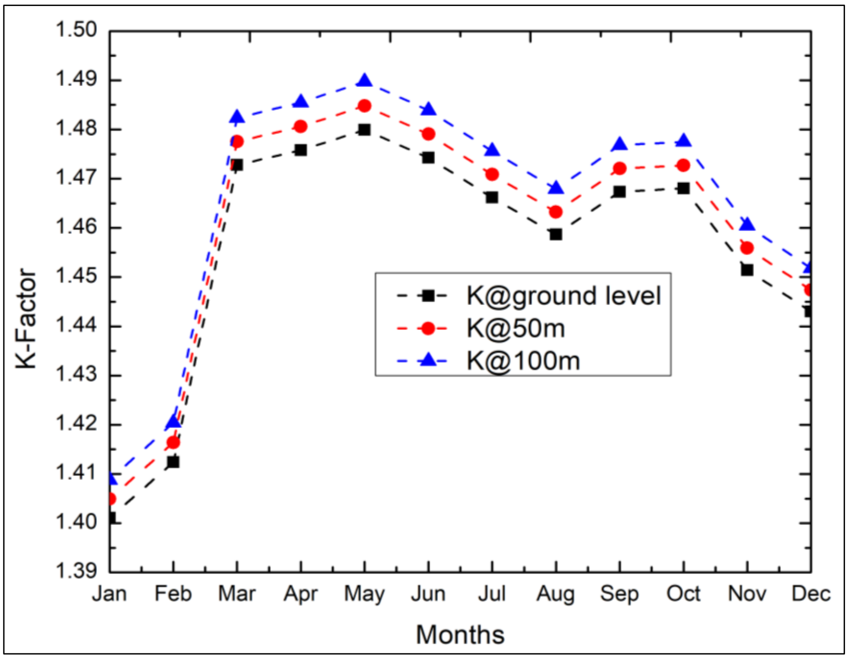

Figure 7: Monthly variations of effective earth radius factor in Ogbomoso for the year 2021.
Source: Authors, (2024).

V. CONCLUSIONS

In this work, the vertical refractivity profile, refractivity gradient, and effective earth radius factor in the first 100 m of the troposphere over Ogbomoso was investigated based on experimental measurements with a view to characterizing the propagation conditions of the atmosphere. Analysis revealed that the surface refractivity is generally high during the rainy reason for all levels considered, with a marked decrease in the dry months of December and January, when the dry harmattan is usually intense. The average value of surface refractivity recorded in this study is 359 N-units with a corresponding average value of refractivity gradient and k-factor of -50 N-units/km and 1.49, respectively. Based on these results, the study therefore concluded that, the atmospheric propagation condition in Ogbomoso is mostly super-refractive.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Suleman Kamaldeen and Sheu Akeem Lawal.
Methodology: Suleman Kamaldeen and Sheu Akeem Lawal.
Investigation: Suleman Kamaldeen and Suleiman Saheed.
Discussion of results: Suleman Kamaldeen and Sheu Akeem Lawal.
Writing – Original Draft: Suleman Kamaldeen. and Suleiman Saheed.
Writing – Review and Editing: Suleman Kamaldeen and Sunmonu Lukman.
Resources: Suleiman Saheed.
Supervision: Sunmonu Lukman.
Approval of the final text: All Authors.

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