Investigation of Diurnal and Seasonal variation of Radio Refractivity and Field Strength over Ogbomoso, South Western Nigeria

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Abstract.

This study examined diurnal and seasonal variability in secondary weather parameters- refractivity, refractivity gradient, k-factor, and field strength- over Ogbomoso, Nigeria. Results showed significant diurnal variations, with maximum refractivity of 375 N-units and k-factor of 1.48 in the early hours, indicating a superrefractive atmosphere affecting radio signal propagation.

Keywords: Refractivity, Field strength, weather, variability, radio signal.

1 Introduction

When radio waves within the ultra-high and super high frequency ranges travels in the atmosphere, they usually suffer impairments due to refractivity. The behaviour of radio waves as they propagate through the atmosphere is usually influenced by the tropospheric conditions. This is due to the fact that; the troposphere is the layer of the atmosphere where most of the weather-related activities usually take place. It begins from the surface of the earth while extending up to an altitude of 10 km and 17 km at the north poles and equator, respectively [1]. While refraction usually refers to the

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bending of waves as they travel through media of varying refractive index, radio refractivity can simply be referred to as, the deviation in the path of a radio wave as it propagates from air through a medium.

The primary and secondary weather parameters are the major influence on radio signal as it propagates through the troposphere [2]. The primary weather parameters which include; atmospheric pressure, temperature and water vapor are the major influence, as any change in these, will result in associated changes in the secondary parameters (refractivity, refractivity gradient and k-factor). It is the variations in the magnitude of these weather entities that goes on to impact the curvature of the ray path, alter the refractive index of air, thereby leading to fading of radio waves as they travel through the tropospheric environment [3]. As the process of formation and growth of cities increases around the world, so the need for radio refractivity knowledge increases. Radio propagation measurements from tropical and, most importantly, developing countries of the world have been greatly impaired by dearth of information, and any contribution based on actual, long-term measurements and scientific interpretation of climatic and geographic radiosonde station results should be of interests [4], [5]. The knowledge of radio refractivity gradient serves as an important parameter in estimating refractive conditions and propagation effects such as scattering, normal refraction, sub-refraction, super-refraction, ducting and absorption phenomena [6], [7]. Understanding of the weather parameters (primary and secondary) will definitely assist cellular network providers and radio engineers in improving their quality of services [8].

There have been many attempts towards understanding refractivity phenomena throughout the world. For example, [9] investigated variations of radio refractive power due to meteorological variables over major Pakistani cities. The study revealed a higher variation in radio refractive power and pressure in the wet season compared to dry season. The study also showed an inverse relationship between refractivity and temperature and reported that humidity has greater effect on radio refractivity than temperature and pressure. [10] investigated how meteorological parameters contribute to the seasonal, monthly, and annual fluctuations in radio refractivity values. There findings revealed that water vapour has the most influence on radio refractivity variations. Previous studies have also showed that refractivity varies exponentially with height across West Africa, with a dominant sub-refractive and super-refractive atmosphere in major parts of the coastal areas during the dry and wet season seasons, respectively [11]. In Nigeria, there have been continuous efforts by researchers to provide a better understanding of refractivity and refractivity profile. These efforts are either on individual or group of stations. They include studies carried out in Oyo town [3], Ilorin [12], Lagos [13], Akure [14], [15], Kano [16], Auchi [17], North-central [18], among others. Generally, it was revealed that refractivity displays high seasonal and diurnal variability, with the Northern part recording lower refractivity values compared to the southern part. Even though [19] assessed Field Strength Variability(FSV) over some selected northern stations, literature on the FSV in Nigeria is very scanty.

Since studies have revealed that refractivity is greatly dependent on atmospheric weather parameters, which are expected to be greatly impacted by climate change, there is need to continually monitor variations in refractivity pattern for efficient planning of radio links. In this study, buoyed by the expected influence of climate change on the primary weather parameters. we examined data from NIMET to estimate how the refractivity gradient and its constituent factors affect the communication link in Ogbomoso, southwestern Nigeria. The aim of this study is basically to investigate the diurnal and seasonal variability of radio refractivity, its gradient and effective earth radius factor (k-factor), field strength over Ogbomoso.

2 Materials and Methods

2.1 Study Location

The study area is Ogbomoso, a city in Oyo State, South-western Nigeria. Geographically, it is located between Latitude 8.1227 ºN and Longitude 4.2436 ºE, with a population projected to cross 1 Million by 2025 [20]. It falls within the intersection of roads from Oyo, Ilorin, Osogbo and Ikoyi. The city is characterized by two major climatic seasons; the dry (November to March) and wet (April to October) [21]. Figure 1 is the map of Oyo State, showing the study area.

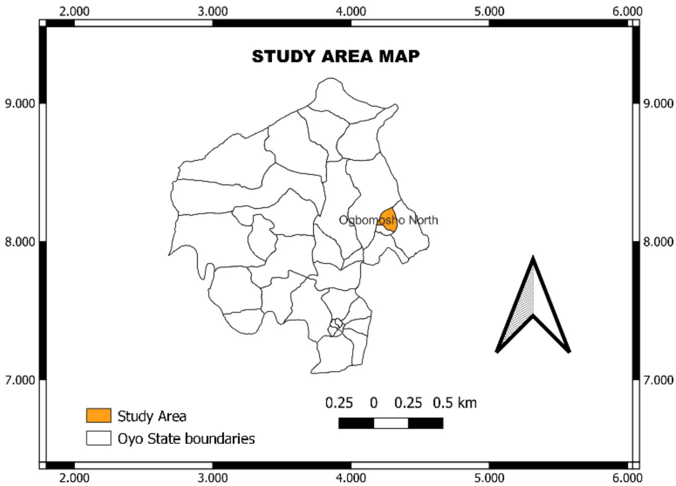

Fig. 1: Typical map of Oyo State, showing the study location

2.2 Data source

A year hourly summary of atmospheric pressure, temperature and relative humidity for Ogbomoso was obtained from the data management unit of NIMET. The data was recorded in a 1-hour interval from January 1, 2021– December 31, 2021. From these, the values of radio refractivity, refractivity gradient and effective earth radius factor

(K-factor) were estimated. Data processing, analyses and graphing were done using Microsoft Excel (2016) and Origin-Pro 8.5 packages.

2.3 Theoretical Background

It has been established that radio refractivity is dependent on primary weather parameters namely; atmospheric pressure, P (hPa), temperature, T (K), and the water vapour pressure, ε (hPa). This dependence is modelled as represented in equation 1

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

Where ε is the water vapour pressure in hPa.

The validity of Equation 1 is only for radio frequencies ranges of up to 100 GHz with an allowed error limit of less than 0.5 % [22], [23]. For easy implementation of this, the values of the relative humidity H (%) and saturated water vapour ε_s (hPa), were first used to estimate the water vapour pressure ε (hPa) using equations 2 and 3

$$\varepsilon = H \times \frac{\varepsilon_s}{100} \tag{2}$$

$$\varepsilon_s = 6.1121\exp\left(\frac{17.502t}{t + 240.97}\right) \tag{3}$$

where t is the temperature in °C

In terms of the profile height, the effective earth radius factor and refractivity gradient were estimated using Equations 4 and 5, respectively; [8], [24].

$$K \approx \left(1 + \left(\frac{\frac{\Delta N}{\Delta h}}{157}\right)\right)^{-1} \tag{4}$$

$$\frac{\Delta N}{\Delta h} = -\frac{N_s}{H}\exp\left(-\frac{h}{H}\right) \tag{5}$$

Refractivity correlates highly with radio field strength especially at Very High Frequencies (VHF). The Field strength variability (FSV) is determined from the monthly ranges of radio refractivity (N). When considering radio waves in the frequency range 30-300 MHz, it is convenient to adopt a 0.2 dB factor change in field strength for every unit change in N_S [14], [25]. To this end, FSV was estimated mathematically using Equation 6;

$$FSV = (N_{\max} - N_{\min}) \times 0.2 \tag{6}$$

3 Results and discussions

3.1 Diurnal variation of refractivity, refractivity gradient, and k-factor for dry and wet seasons

The diurnal variation of radio refractivity, gradient of refractivity, and effective earth radius factor for the dry and wet seasons is shown in Fig. 2 and Fig. 3, respectively. From Fig.2a, refractivity with high values ranging between 365 to 371 N units were recorded during the early hours of the day and at night. A minimum value of about 310 N-units was recorded during peak solar insolation at about 2:00 PM. A similar trend was recorded for the K-factor with high average of 1.48 and a minimum average of 1.37 as depicted in Fig.2b. As for the refractivity gradient shown in Fig.2c, minimum values were observed at the early and late hours of the day, with maximum occurring at 2:00 PM. On the average, the refractivity gradient showed maximum value of -42 N/km and a minimum average of -46 N/km. We attributed the variation to the response of the earth to solar insolation which is often the major force behind the weather condition as detected.

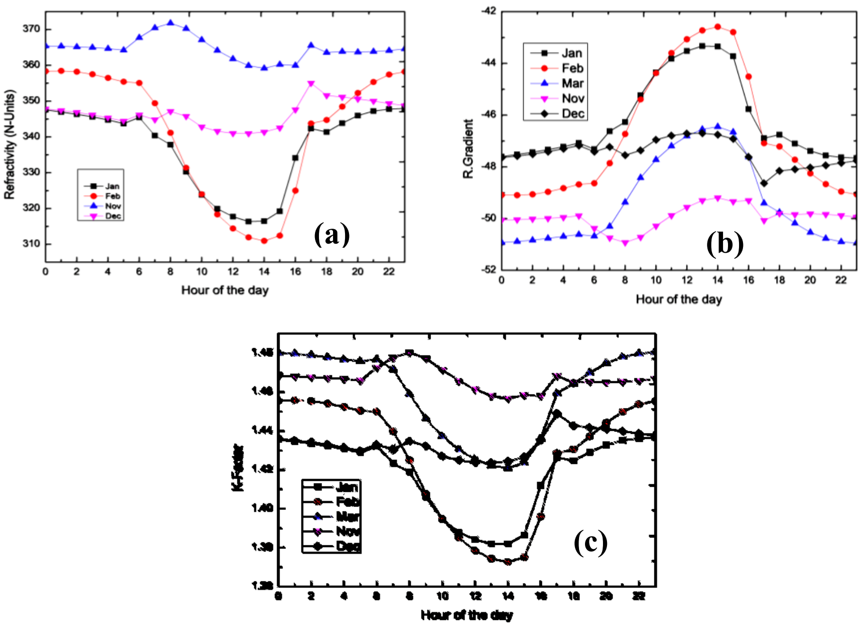

Fig. 2: Diurnal variations (a) radio refractivity, (b) gradient of refractivity, and (c) effective earth radius factor for the dry season

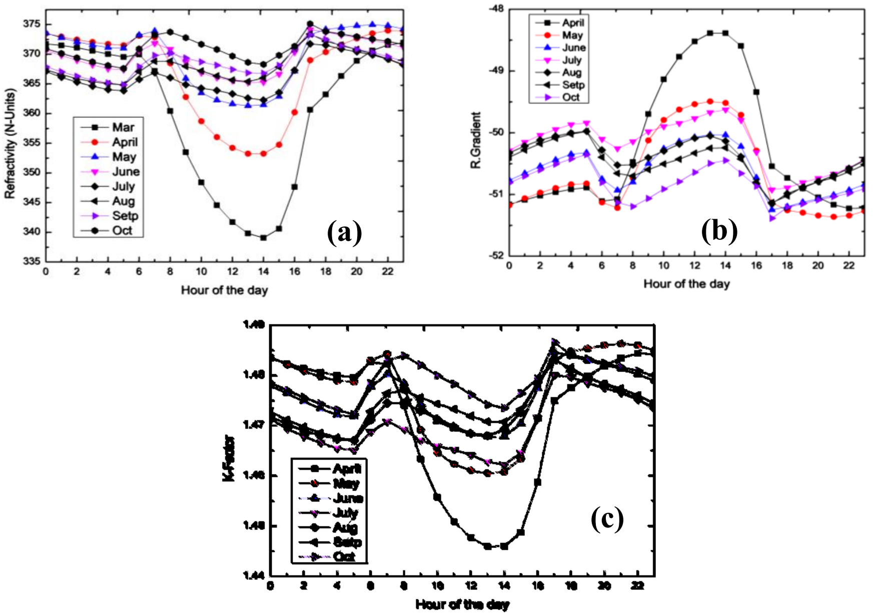

Fig. 3: Diurnal variation of (a) radio refractivity, (b) gradient of refractivity, and (c) effective earth radius factor for the wet season

3.2 Seasonal variation of refractivity, refractivity gradient, and k-factor for dry and wet seasons

The average monthly variation of refractivity, refractivity gradient, and k-factor over Ogbomoso is depicted in Fig. 4. As shown in Fig. 4a, refractivity reached its peak value of 369 N units in May and drops gradually till it reaches a minimum value of about 366 N units in July, an observation that is consistent with those reported by [3], [26]. The refractivity gradient depicted in Fig.4b approached its highest value of -46 N units/km in the month of January, before witnessing a steady decrease until it reached a minimum value of -50 N-units/km in the month of October. This observation agrees closely with work carried out in Oyo town [3] and Akure [15] which share similar climate. We attributed the low values observed in the wet season to the transition mark and break in water vapour content in the atmosphere around the month of October [5].

The effective earth radius factor depicted in Fig.4b recorded its lowest value of about 1.41 in the month of January before increasing gradually to the peak value of about 1.47 in the month of May. There is a steady increase in the values between the month of May and October which happens to be the peak of the rainy period for Ogbomoso.

Generally, from the comparison made with other work in literature, our results showed that the influence of climate change on refractivity is almost insignificant.

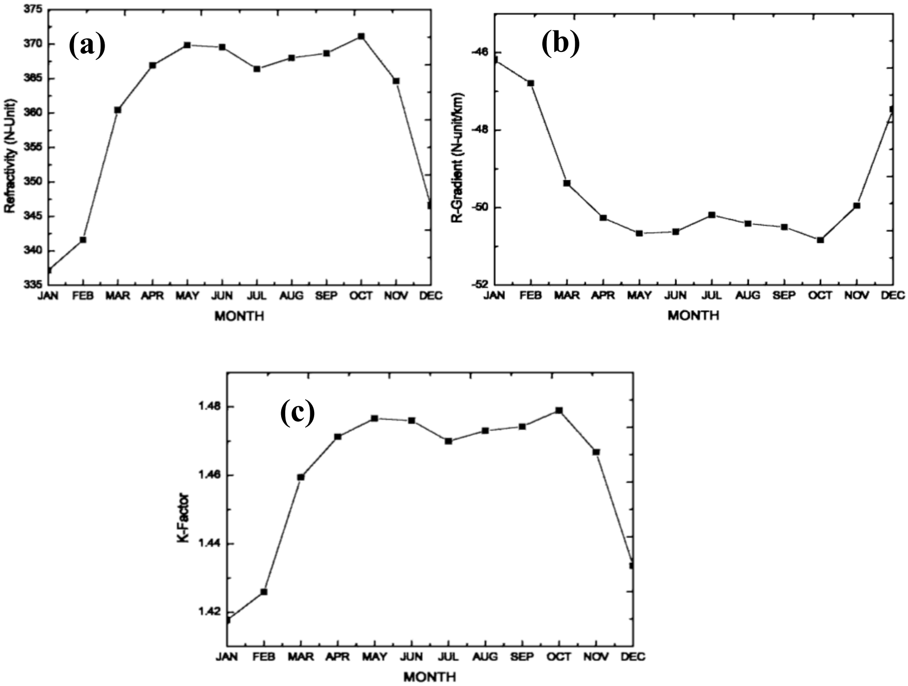

Fig. 4: Seasonal variation of (a) radio refractivity, (b) gradient of refractivity, and (c) effective earth radius factor.

3.3 Seasonal variation of Field strength in Ogbomoso

The field strength variability (FSV) is shown in Figure 5. The maximum variability in field strength was observed in February with value of about 1.362583 dB and minimum values were recorded in April, August, and September, respectively, as they all witnessed average FSV of 0.071622 dB. This variability in strength is one important factor in determining the output of an antenna in a given climatic zone. The higher field strength variability recorded in the dry season was attributed to elevated surface temperature, low humidity and almost constant pressure [28]. For the planning of the radio links in Ogbomoso, the study recommended a fade margin of between 0.076 dB and 1.36 dB.

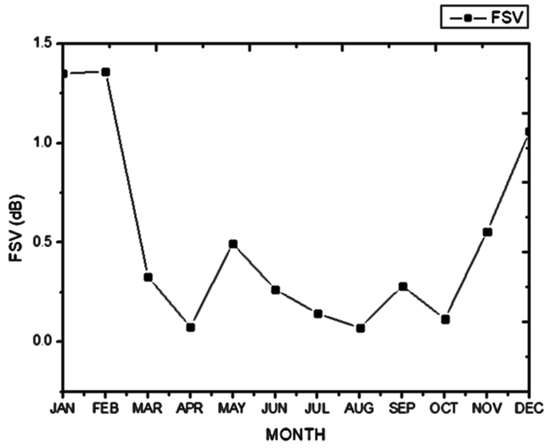

Fig. 5: Monthly variation of field strength variability

4 Conclusions

This study has successfully investigated variability in refractivity in Ogbomoso. Results show high diurnal variability during the dry and wet seasons, with relatively higher values in the wet season as compared to dry season. The refractivity gradient shows seasonal variation with a high value in the dry season and a low value in the wet season. K-factor exhibit similar seasonal variability as compared to refractivity. The lowest and highest values were recorded in the months of January and October, respectively. Radio refractivity, refractivity gradient and k-factor show significant diurnal and seasonal variation. Within the study area, receiving antenna output with a value of between 0.07 dB and 1.36 dB is recommended. Based on the analyses, propagation condition in the atmosphere in Ogbomoso was classified as super-refractive.

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