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On The Assessment of fade Depth and Geoclimatic Factor for Microwave Link Applications in Lagos, Nigeria

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Abstract: *This study examines the impact of geoclimatic parameters on microwave signal fade depth in Lagos State, Nigeria, a tropical megacity with dual rainfall patterns, high humidity, and rapid urbanization. Lagos, Nigeria's commercial hub, experiences two primary seasons: dry (November–March) and wet (April–October), with heavy annual rainfall that affects microwave signal reliability. The study evaluates the effects of urbanization, humidity, and rainfall on microwave communication systems, which are critical for broadcasting, satellite, and telecommunications. Using data from satellites, local weather stations, and microwave networks, statistical models were developed to establish quantitative relationships between fade depth and environmental factors. Results highlight the influence of Lagos' unique geoclimatic and urban characteristics on microwave signal propagation and offer insights for optimizing networks in similar tropical regions. The findings underscore the need for tailored engineering solutions to address the climatic and infrastructural challenges of urbanizing areas in the tropics, providing a foundation for designing robust communication networks capable of withstanding diverse geoclimatic conditions.*

Keywords: *Radio refractivity, refractivity gradient, k-factor, geoclimatic factor and Multipath fading*

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1.0 Introduction

Digital microwave links are vital for communication services such as video, data, and voice transmissions (Adediji *et al*. 2008). . Since the 1950s, terrestrial line-of-sight microwave links have been a cornerstone of long-distance communication systems (Adeyemi & Emmanuel, 2011). However, the increasing demand for high-performance and reliable satellite telecommunications has made the study of atmospheric effects on microwave propagation increasingly critical(Afullo *e al*., 1999). . The lowest part of the atmosphere plays a significant role in influencing microwave propagation between link terminals [4]. Atmospheric refractivity, which determines the bending and behavior of electromagnetic waves, is influenced by parameters such as temperature, pressure, relative humidity, cloud cover, and rainfall [5]. These factors, particularly in the troposphere, can lead to anomalous propagation and signal degradation [6–8]. While extensive research has been conducted in temperate regions [9–11], tropical environments have also gained attention due to their unique climatic conditions [12–15]. For instance, Adediji and Ajewole [1] examined vertical radio refractivity gradients in Akure, Nigeria, revealing significant seasonal variations. This study builds on prior research by focusing on Lagos State, Nigeria, a tropical coastal region. It examines the impact of geoclimatic factors on microwave signal propagation, with an emphasis on radio refractivity, refractivity gradients, and the geoclimatic factor (K).

2.0 Theoretical *Framework*

The radio refractivity (N) is influenced by meteorological parameters such as atmospheric pressure (PPP), temperature (T), and water vapor pressure (e). The relationship is expressed as:

$$N = \frac{77.6P}{T} + \frac{3.73\times10^5 e}{T^2} \quad (1)$$

The water vapor pressure (e) is calculated using the relative humidity (H) and the saturated vapor pressure(es)as:

$$e = \frac{e_s H}{100} \quad (2)$$

The saturated vapor pressure (es) is given by:

$$e_s = 6.1121\exp(\frac{17.62T}{243.21+T}) \quad (3)$$

These equations are valid for radio frequencies up to 100 GHz with an error margin of less than 0.5% (ITU-R 453-12, 2016).

Surface and Upper-Air Refractivity Gradients

$$\frac{dN}{dh} = -7.32exp(0.005577N_s) \quad (4)$$

where Ns is the refractivity at the surface. For the upper air, the refractivity gradient is:

$$G = \frac{N_1 - N_2}{h_1 - h_2} \quad (5)$$

Effective Earth Radius Factor (K)

The effective earth radius factor (K) accounts for the curvature of the earth and is calculated as:

$$K = 1 + \frac{\frac{dN}{dh}}{157} \quad (6)$$

This factor helps to classify signal bending into sub-refractive, super-refractive, or ducting conditions.

Geoclimatic Factor (K)

The geoclimatic factor (K) is crucial for planning terrestrial microwave communication systems and is defined as:

$$K = 10^{-(4.2-0.0029N_s)} \quad (7)$$

Estimation of Fade Depth

Fade depth (A) quantifies signal attenuation due to atmospheric effects. The steps to estimate fade depth are:

Geoclimatic Factor (K)

We first calculatd the geoclimatic factor using equation 8.

Path Inclination (n)

Compute path inclination as:

$$\eta = \frac{h_t - h_r}{d} \quad (8)$$

Where h_t and h_r are the transmitting and receiving antenna heights above sea level, and d is the path length in kilometers.

Percentage of Time (P) Exceeding a Fade Depth (A)

The percentage of time a fade depth A is exceeded during the average worst month is: $P = P_0 e^{-\frac{A}{A_B}}$ (9)

where A_y is the transition fade depth, and P_o is the percentage of time when A=0

Transition Fade Depth (A_t)

The transition fade depth marks the boundary between shallow and deep fading and is given by:

$$A_t = 10\log(\frac{1+|\eta|}{Kd^{3.0}}) \quad (10)$$

Monotonic Variation of Percentage Time (Pn)

For $P_o < 2.000$ the percentage of time (Pn) that a fade depth A (in dB) is exceeded can be expressed as:

$$P_n = 100[1 - \exp(-\exp(-10^{-7n+20}))] \quad (11)$$

This produces a monotonic relationship between P_n and A, allowing A to be determined for a given P_n through simple iteration.

Transition Fade Depth and Percentage Time Calculations

To calculate the transition fade depth (A_t) and the corresponding percentage time (P_n), the following equation applies:

1. ***Iterative Determination of Fade Depth (A)***
   Fade depth A can be determined iteratively using:
   $$P_n = P_0 e^{-A/A_v} \quad (12)$$
2. ***Final Expression for Percentage Time (Pn):***

The percentage of time a fade depth A is exceeded is given by:

$$P_n = \frac{Kd^{3.0}}{(1+|\eta|)^{1.2}} 10^{-0.0033f-0.001/1} \quad (13)$$

This comprehensive approach enables accurate modeling of fade depth variations for terrestrial microwave communication systems.

3.0 Study Area, Instrumentation and Data Analysis

The area under study is Lagos State, Nigeria, located between latitude 6.5244°N and longitude 3.3792°E. Situated on Nigeria's Atlantic coast in the southwest, Lagos State is characterized by its mangrove swamp and freshwater swamp forests, which result from its dual rainfall pattern, producing a wetland climate. The two main seasons in Lagos are the dry season (November to March) and the wet season (April to October). The dry season is marked by the Harmattan, a dusty wind originating from the Sahara Desert, typically observed between December and February. Despite its relatively small land area of about 3,577 km^2 , Lagos is the most populous and economically active state in Nigeria, with an estimated population exceeding 20 million. The state serves as Nigeria’s commercial hub, hosting major markets, financial institutions, and a variety of industries, including manufacturing, telecommunications, and oil and gas.

Meteorological data for this study were collected at multiple locations across Lagos to ensure comprehensive coverage of the state’s diverse geoclimatic conditions. Data collection points were strategically chosen to account for variations in environmental parameters influenced by urbanization and proximity to water bodies. The equipment used for measurements included portable meteorological devices capable of recording atmospheric parameters such as temperature, pressure, humidity, and wind speed. These devices were deployed at ground level (0 m) and elevated points up to 100 m to analyze variations in height.

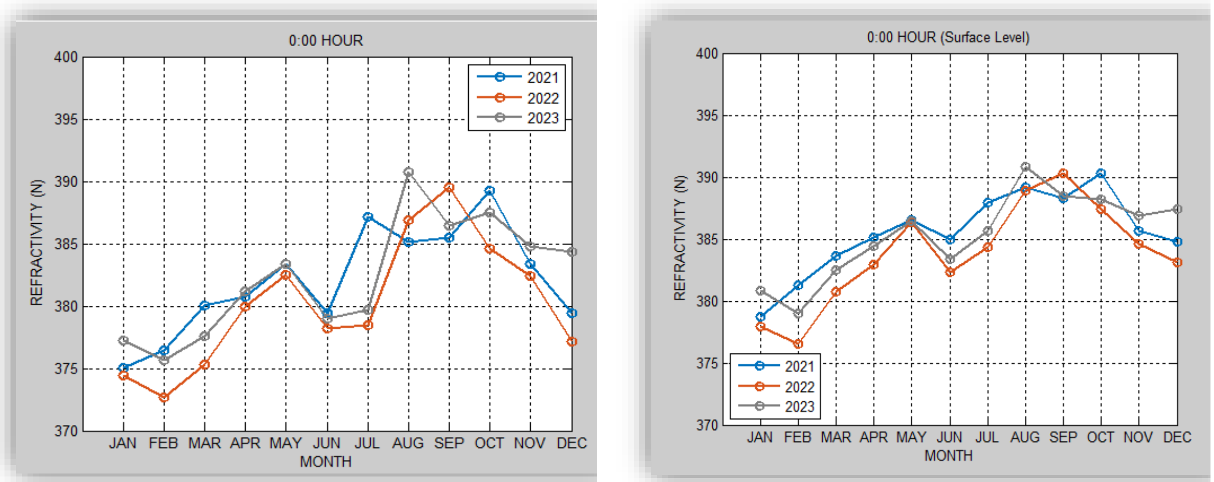
This research utilized three years of meteorological data, spanning January 2021 to December 2023, to examine atmospheric parameters such as air temperature, atmospheric pressure, relative humidity, and water vapour pressure at 00:00 and 12:00 hours daily. Diurnal variations were analyzed by computing hourly averages to provide a 24-hour profile for each month and season.

Data analysis and visualization were conducted using MATLAB software. MATLAB was employed for generating plots, identifying statistical trends, and analyzing variations in k-factor, refractivity, and geoclimatic factors. This enabled the creation of detailed graphs, including monthly averages and diurnal variation profiles, offering deeper insights into the atmospheric conditions and signal propagation phenomena observed across Lagos State.

Fig. 1: Map of Lagos

3.0 Results and Discussion

Fig. 2, shows the monthly average plot of radio refractivity, N, for the year for different time windows. It could be observed that in all the time windows of the day considered, there is a sharp drop in the values of N from November to February but January and February signify the peak of dry months in the area. However, the result truly shows seasonal variation. over the study area as earlier reported by Adediji and Ajewole, [8] and Ojo, O.L *et al*., [18]. The results generally show that N-values for the wet months were higher than the values in the dry months.



(a) **(b)**

Fig. 2a: Refractivity at 0:00 hour 100m for 2021, 2022 and 2023. Fig. 2b: Refractivity at 00:00 hour for 2021, 2022 and 2023

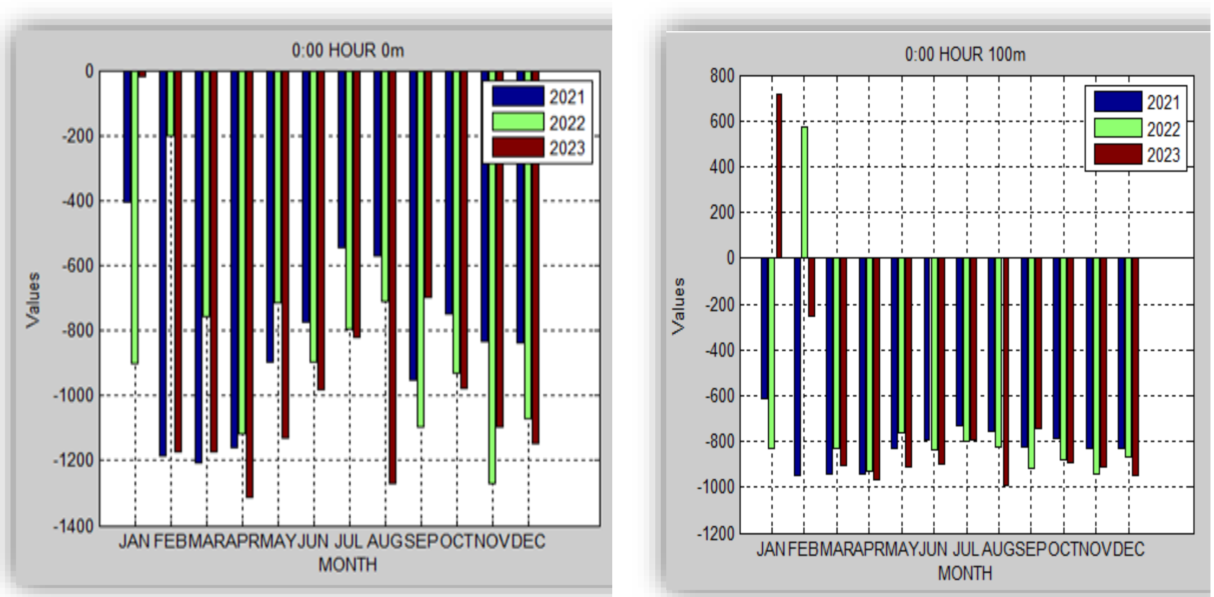
3.1 Refractivity Gradient

The refractive gradient is the rate at which the refractivity of the atmosphere varies with altitude. The atmosphere's refractivity gradient influences how electromagnetic waves bend or refract. Waves in a typical atmosphere bend somewhat downward because of the height dependent decrease in refractivity. When assessing whether waves undergo conventional propagation, sub-refraction, ducting, or super refraction, the refractivity gradient is essential. Reliability Gradient focuses on the way that atmospheric conditions change with height due to a vertical shift in refractivity. This affects the atmosphere's wave bending.

In this research, firstly I compare the refractivity gradient of the three years at each height and time. At 0:00 hour (0m) refractivity gradient has it highest at -1300N/km and there was a positive refractivity gradient the 0:00 (100m) in feburary 2022 and january 2021

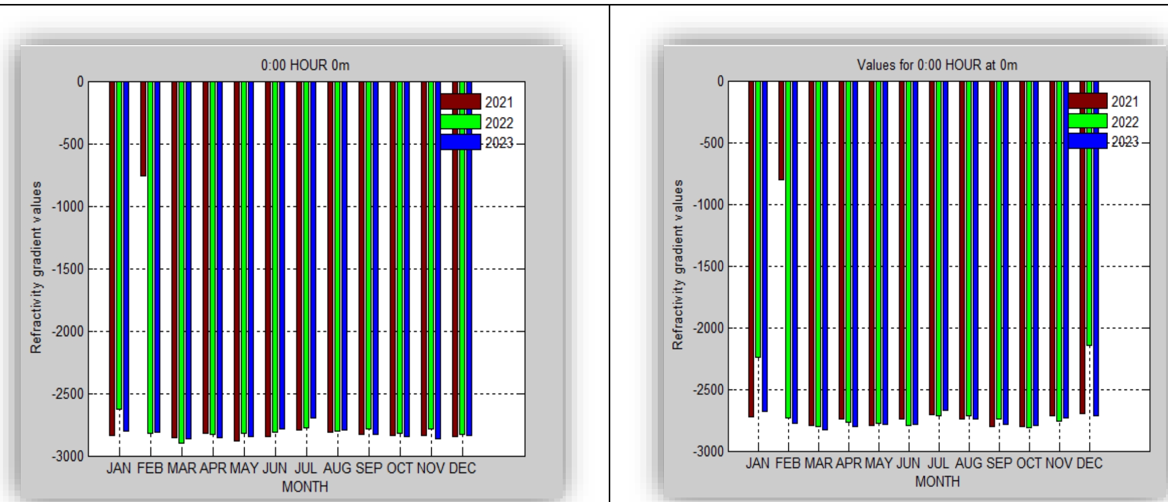
At the 100m height for 0:00 hour, there was a positive refractivity gradient in january 2023 and febuary 2022, which a signify of subrefraction. And negative values which signify atmospheric ducting

During the day, surface heating causes the air to warm and ascend, which lowers the humidity close to the surface, particularly during the dry season. Refractive index falls more slowly with height due to this, resulting in a less negative refractivity gradient. According to research conducted in tropical areas, under typical atmospheric conditions, the refractivity gradient varies during the day with a very high value of close to -3000N/km for both height (Hall, 1979; Ojo, 2013). However, because of the frequent rains and cloud cover during the rainy season.



(a) (b)

Fig. 3a: Refractivity gradient at 0:00 hour 0m for 2021, 2022 and 2023 and Fig. 3b: Refractivity gradient at 0:00 hour 100m for 2021, 2022 and 2023.



(a) (b)

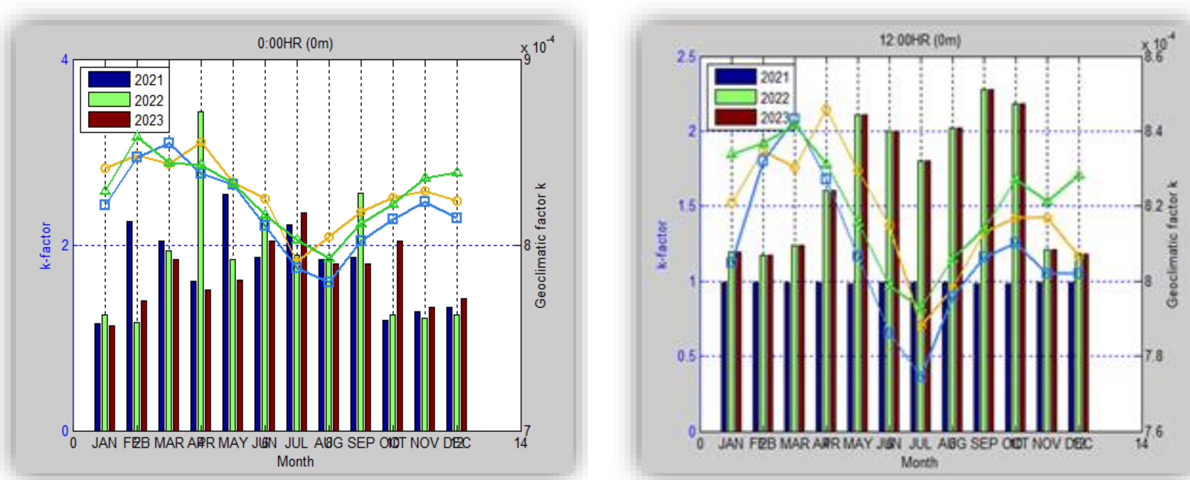
Fig. 4a: Refractivity gradient at 12:00 hour 0m for 2021, 2022 and 2023 and Fig. 4b: Refractivity gradiet at 12:00 hour 100m for 2021, 2022 and 2023

Lagos has higher humidity. The higher moisture content in the lower atmosphere causes a larger negative refractivity gradient and higher refractivity near the surface, even though some surface heating still happens. Signals may experience modest super-refraction as a result, bending more in the direction of the Earth. According to estimates, depending on the amount of rainfall and relative humidity, daytime refractivity gradients in Lagos during the rainy season can range from -30 N/km to -80 N/km (Akpootu *et al*., 2017).

The refractivity gradient in Lagos can become much more negative at night during the rainy season; it frequently ranges from -80 N/km to -150 N/km and, in severe circumstances, approaches -200 N/km (Akpootu *et al*., 2017; Oyedum *et al*., 2006). Strong temperature inversions and high humidity are the main causes of this dramatic drop, and they both become more noticeable during and after rain episodes. Because to the combination of marine air masses and land-sea temperature differential, these circumstances are especially common in coastal regions such as Lagos. These result correspond with above research. The reason for the high value of refractivity can be due to temperature variation and large water body around Lagos.

4.2 K-Factor and Geoclimatic Factor-K

Geoclimatic factorsr efers to atmospheric and environmental parameters that have an impact on electromagnetic signal propagation, especially in the microwave frequency range. These elements affect the attenuation, refraction, and scattering of microwave signals. They include temperature, humidity, rainfall, and air pressure. Comprehending the impact of these variables is essential for optimizing microwave communication systems, particularly in areas with heterogeneous meteorological patterns such as Lagos, Nigeria. Temperature, humidity, and topography are only a few examples of the local environmental elements that contribute to signal fading; other parameters included in this description include the geoclimatic factor. When a signal travels through several pathways to reach the receiver—due to reflections off of surfaces, structures, or other objects this phenomenon is known as multipath fading. Signal bending caused by atmospheric refraction can also result in fading.Both the duration and the degree of multipath fading are influenced by the geoclimatic component k. This factor can be used to quantify the impact of meteorological circumstances on signal fading when used with path loss models. The propagation of microwave signals is greatly influenced by geoclimatic conditions as temperature, humidity, precipitation, and air pressure. These variables impact how the environment behaves, especially with regard to the refractive index, which has an impact on the power, speed, and caliber of microwave signal transmission.



(a) **(b)**

Fig. 5a: k-factor and Geoclimatic factor k against month at 0:00 hour (100m). and Fig. 5b: k-factor and Geoclimatic factor k against month at 12:00 hour (100m)

Fig. 5a: In this research, the k-factor and geoclimatic values where evaluate against the month of the year. it was discovered that at 0:00 hour at 0m height the height value of k-factor was 3.4, the value of propagation super-refra ction. During the wet season, the geoclimatic factor-k was low.

The refractive index gradient normally needs to be smaller than -157 N-units/km for ducting to take place. Longer propagation distances with little signal loss result from this situation, which prevents the microwave signal from escaping the air duct. Temperature inversions, in which warmer air rests above colder air, and precipitous drops in humidity with height are frequent

Fig. 3b: At 12:00 hour the k factor was highest during rainy season from April to October, and low during during dry season the value of geoclimate factor k varies in the three years but lowest in July. The refractive index of the atmosphere is influenced by temperature, which has an effect on the propagation of microwave signals. In Lagos, a tropical coastal city, high temperatures can intensify atmospheric turbulence and alter the signal path, resulting in signal attenuation or fading. Warmer temperatures cause the air to become less thick, which hinders the atmosphere's capacity to effectively transmit information. As a result, signal loss may increase with distance (Das *et al*., 2020).

5. 0 Conclusion

The findings of this study on microwave propagation conditions in Lagos City, Nigeria, have been presented, focusing on k-factor, geoclimatic factor-k, and refractivity (N) variations from January 2021 to December 2023. The analysis revealed significant diurnal and seasonal fluctuations in these parameters, driven by atmospheric conditions such as temperature, humidity, and rainfall.

At 00:00 hours, the k-factor reached a maximum value of 3.4 at ground level (0 m), indicating super-refractive propagation conditions, which enhance microwave signal propagation over longer distances with minimal loss. During the wet season (April to October), the geoclimatic factor-k was relatively low, reflecting improved propagation conditions due to higher atmospheric moisture. Conversely, the dry season (November to March) was characterized by lower refractivity values and higher attenuation risks, particularly in January and February, which mark the peak of the dry months.

At 12:00 hours, the k-factor was highest during the wet season and lowest during July, showing clear seasonal variation. High temperatures during the dry season, particularly in tropical coastal environments like Lagos, exacerbate atmospheric turbulence and signal attenuation, leading to increased fading and reduced transmission quality.

The refractive index gradient was observed to fall below -157 N-units/km during ducting events, creating favorable conditions for extended microwave signal propagation within air ducts. These occurrences were typically associated with temperature inversions and rapid humidity drops with height.

The geoclimatic factor-k, which encapsulates atmospheric and environmental influences such as temperature, humidity, and precipitation, played a pivotal role in signal fading and attenuation. Its interaction with local topography and environmental factors highlighted the challenges of maintaining reliable microwave communication systems in tropical regions.

Overall, the study confirms that the propagation environment in Lagos is predominantly super-refractive, with propagation conditions improving during wet months and deteriorating during dry months. These findings provide critical insights for the design and optimization of microwave communication systems in tropical regions with heterogeneous meteorological patterns.

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Compliance with Ethical Standards

Declaration

Ethical Approval

Not Applicable

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Authors' Contributions

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