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Investigation of Point Refractivity Gradient and Geoclimatic Factor at 70 m Altitude in Yenagoa, Nigeria

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Abstract

The quality of services provided via Inter-Terrestrial radio communication links such as GSM networks, Wide Area Network (WAN), Radio and TV broadcasts is largely influenced by some meteorological parameters such as temperature, pressure and humidity. Proper knowledge of these parameters, specifically at microwave antenna heights (about 70m) is important in order to maintain an effective line-of-sight (LOS) link even during the worst weather conditions. The geoclimatic factor is an important quantity that must be considered in the design of terrestrial links for effective wireless communication. This work utilized satellite data from the European Center for Medium-Range Weather Forecasts (ECMWF) to compute the point refractivity gradient and geoclimatic factor for Yenagoa and its environs. The research was necessitated by the paucity of research on this subject matter for Yenegoa. The results of the research show that point refractivity gradient and geoclimatic factor in the study area vary with season. The average point refractivity gradient and geoclimatic factor at 70 m above the ground level are:136.433 N-unit/Km and 6.638633E-05 respectively. This implies that radiowaves propagating in this region at the said altitude is most likely to be super refractive in both rain and clear air atmospheric conditions. Rain or worst condition refers to the period when atmospheric components such as hydrometeor, lithometeor, aerosol have significant effects on propagated radio signals. Clear-air conditions means when maximum possible signal is received such that the most threatening atmospheric components (rain drops) have negligible effects on propagated signal. The results will be useful for radio engineers in the design and configuration of inter-terrestrial microwave links in Yenagoa and Its environs for optimum quality of service.

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Keywords: GSM, WAN, Inter-Terrestrial, Microwave, Geoclimatic Factor, Refractivity Gradient

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1. Introduction

The condition of the atmosphere is very important for proper planning of terrestrial radio links, navigation and remote sensing installations like RADAR [1]. The quality of a radio signal and the extent to which it travels within a particular medium are determined by some atmospheric weather parameters which dictate the medium's refractive index. Temperature, pressure, and humidity are the major atmospheric parameters that determine the refractive index in the troposphere [2]. Temporal and spatial variations in these parameters have a great effect on the propagation conditions. Radio point refractivity gradient and geoclimatic factors are major quantities whose values must be taken into consideration when designing inter-terrestrial radio links. These quantities

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are solely a function of water vapor pressure, temperature, and pressure which are the said atmospheric parameters. Precise estimation of refractivity gradient and geoclimatic factor are highly essential in order to determine the multipath fade depth of a communication link [3].

Fading is a phenomenon whereby there is a gradual drop in the signal strength of a radio wave as it propagates through the atmosphere. The signal is gradually reduced in the atmosphere because of the various obstacles such as hydrometeors, litheometeors, etc. it encounters. The gradual drop in radio signal results in a fractional power of the transmitted signal reaching a target receiving antenna. Multipath fading is a major impairment problem in wireless communication systems such as wireless sensors, mobile telephony, radar systems, TV/Radio broadcast etc [3, 4]. The effects of the clear-air fading mechanism due to extreme refractive layers in the atmosphere include, but are not limited to beam spreading, antenna decoupling, surface multipath, and atmospheric multipath [5]. To achieve a seamless inter-terrestrial communication link within a locality, there is a need to carry out accurate estimation of refractivity gradient and geoclimatic factor values.

A few research works have been carried out to determine refractivity gradient and geoclimatic factors in some areas in Nigeria as presented in Table 1. Unfortunately, none has attended to the computation of these local parameters in Yenagoa except Olla and Oluwafemi (2018) [6] which predicted them using spatial interpolation. The result is adjudged to be grossly unreliable because only six spatial data points were used generate K-Map of Nigeria.

Geoclimatic factor is an important parameter in the planning and design of inter-terrestrial radio links. Accurate estimation of geoclimatic factor within a blanket of altitude aids in the identification of worst month condition. Thus, leading to proper adjustment of propagation parameters to minimize fade depth margin. The spatial and temporal variability of geoclimatic factor has made it a parameter of interest for local radio engineers. Geoclimatic factor is a function of refractivity gradient. Consequently, refractivity gradient is a variable that depends on refractivity, a scale-up term for refractive index. According to ITU-R, equation (1) expresses the relationship between refractivity N and refractive index n [10].

$$N = (n-1) \times 10^6 \tag{1}$$

The value of refractivity gradient determines the degree of curvature of radio signal propagating in the atmosphere for a particular range of altitude. The relationship between refractivity and altitude in the first kilometer above the ground level is linear [11, 12, 13]. For instance, If refractivity N_1 is measured at an altitude h_1 (km) and another value N_2 is obtained at a higher altitude h_2 (km) which are less than or equal to 1 km, then the refractivity gradient dN/dh is given by equation (2) [13]. This equation is always negative due to a decrease in the value of refractivity N as altitude increases.

$$\frac{\mathrm{dN}}{\mathrm{dh}} = \frac{N_2 - N_1}{h_2 - h_1} \tag{2}$$

The degree of curvature of radio signals is generally classified into four categories based on the value of refractivity gradient for a given height range [14, 15]. A radio signal is said to be normally refracted if the refractivity gradient is −40 N/km, otherwise, it is abnormally refracted according to equations (3a)-(3d) [16].

$$\text{Sub-refraction; } \frac{\partial N}{\partial h} > -40\ N/km \tag{3a}$$

$$\text{Standard Refraction; } \frac{\partial N}{\partial h} = -40\ N/km \tag{3b}$$

$$\text{Super Refraction; } -157N/Km < \frac{\partial N}{\partial h} < -40\ N/km \tag{3c}$$

$$\text{Ducting; } \frac{\partial N}{\partial h} < -157N/km \tag{3d}$$

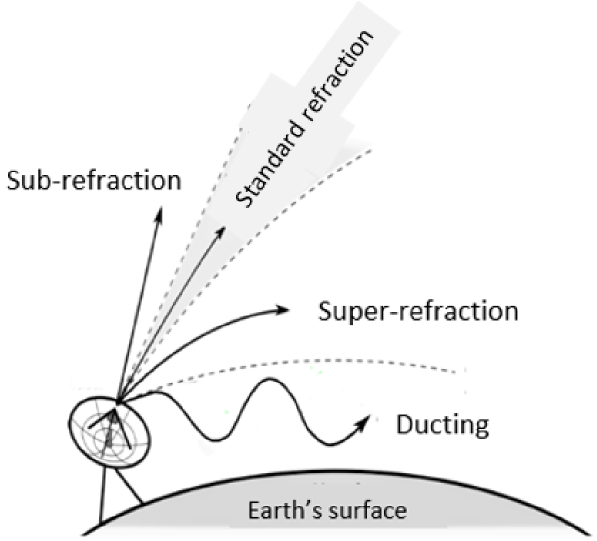

Figure 1: Common classification of atmospheric refraction conditions [17]

A sub-refracted radio signal is one with a very large refractivity gradient such that the radio path bends towards the earth but with a curvature less than that of standard refraction as illustrated in Figure 1. Super refraction is a condition in which the rays bend more rapidly towards the earth when compared with normal refraction. Ducting is an extreme case of super refraction in which the degree of curvature of radio signals exceeds that of the earth's surface curvature. During this condition radio signals especially from radar, may hit the earth surface and suffer multiple reflections instead of hitting the intended target. Although ducting may be of great advantage for long-distance non-line-of-sight transmission, such transmitters must be equipped with sufficient transmitting power.

Table 1: Reports of previous studies on determination of geoclimatic factors

Previous Studies	Methodology	K-factor for nearest station	K-factor for Yenagoa	Remarks
Etokebe *et al.*, (2016) [7]	NiMet data was employed to determine G and K at 65m height for Calabar.	6.537E05 (Calabar)	Nil	
Emmanuel *et al.*, (2018) [8]	ECMWF data was employed to determine G and K at 100m height for 17 stations excluding yenagoa	2.39E04 (Port Harcourt)	Nil	Neither G nor K was computed for Yenagoa
Olla and Oluwafemi (2018)[6]	NiMet data was employed to determine G and K at 65m height for 6 stations excluding Yenagoa. The results were used to generate K-map for Nigeria	2.791E04	2.791E04	Six (6) data points are insufficient to generate data map of Nigeria by Interpolation and extrapolation Techniques
Oluwafemi and Olla (2021)[9]	NiMet data was employed to determine G and K at 65m height for 6 stations excluding Yenagoa.	2.39E04 (Port Harcourt)	Nil	

A propagating radio wave, as shown in Figure 1, may miss its target if the actual refractivity gradient within the site is not taken into consideration.

2. Methodology

2.1. Research Location

This research work evaluates the necessary point refractivity gradient and geoclimatic factor for the propagation of tropospheric radio waves in Yenagoa and its environment. The study area is Yenagoa, the capital of Bayelsa State, a coastal city in the South-South geo political zone of Nigeria. Yenagoa is bounded between latitude 4.90 – 4.92° N and longitude 6.07 – 6.27° E. About 65% of the entire state is covered by water from the Atlantic Ocean, while the area covered by land is about 15 metres above mean sea level [18, 19]. It is characterized by two climatic seasons: dry and wet seasons. Generally, rainfall is experienced in all months of the year in the Niger Delta region of Nigeria. December, January, February and March which are the months with least amount of rainfall make up the dry season [20, 21, 22]. The land mass witnesses a frequent high volume of annual rainfall due to its proximity to the Atlantic Ocean. This accounts for the reason why attenuation due to rain remains a major threat to radio signals, especially during the rainy season. This research focuses on the determination of radio refractivity gradient and geoclimatic factor which are localized radio propagation parameters.

2.2. Data Acquisition and Computational Analysis

Ten years (2009-2018) monthly meteorological data of Yenagoa containing air temperature, relative humidity, pressure and dew point temperature at ground level and 70 m above were retrieved from the archive of the European Center for Medium-Range Weather Forecast (ECMWF) [23]. The ECMWF Era-Interim satellite has a grid and temporal resolutions of 0.75° by 0.75° lat/long and 24 hours respectively [24]. The values of Relative humidity at the two levels were converted to water vapor pressure, e, by using equation (4) while the refractivity was calculated using equation (5) [25]. The data analysis was carried out using Microsoft Excel Software while sorting of the refractivity gradients was accomplished using the necessary empirical equations for determining normal and abnormal refractions (Sub-refraction, super-refraction, and ducting). The necessary empirical equations and conditions for the classification of radio refractions in the troposphere are indicated in equations (3a)-(3d). The surface and point refractivities N at 70 m above the ground surface were computed using equation (4) [26].

$$N = \frac{77.6P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \tag{4}$$

$$e = H \times \frac{6.1121 \exp\left(\frac{17.502t}{t+240.97}\right)}{100}, \tag{5}$$

where P = atmospheric pressure (hPa), t = temperature in degree Celsius (°C), e = water vapour pressure (hPa) defined by equation (5) [27], H = Relative Humidity (100 %) and T = absolute temperature (K).

The refractivity gradients were calculated using equation (2), where N_1 is the refractivity at the ground surface (h_1), N_2 is the refractivity at 70 m height (h_2). h_1 is the ground surface height (i.e 0 m) and h_2 is 70 m. The ITU-R recommended formula for computing geoclimatic factor K is given in equation (6) [10, 28, 29]

$$K = 10^{-4.6-0.0027dN_1}, \tag{6}$$

where dN_1 is the point refractivity gradient, a simple notation representing $\frac{dN}{dh}$, the subject of equation (2). The monthly, seasonal, and annual variations of K were studied based on available data. Statistical analysis was also carried out to deduce the prevailing type of refraction in the study area and give appropriate recommendations.

3. Results and Discussion

3.1. Monthly Variation of Point Refractivity Gradient

The monthly point refractivity gradients for all the months between 2009 and 2018 inclusive were computed and presented in Figure 2. According to the classifications of atmospheric refractions in equations (3a)-(3d), it was observed that the prevailing propagation conditions are super-refraction and ducting. Similar conditions were reported by [12] for the same station. The results, as presented in Figure 2, indicate that refractivity is generally high during the rainy months while low values are predominant in the dry months. The trend of the refractivity gradients shows that the monthly variation has the shape of a stretched letter "M" with double peaks annually. The first peak was observed between May and June which signifies the intense period of the rainy season in the coastal region as reported by [7, 30, 31]. The dip in August could be attributed to the famous August-break which results in a low refractivity gradient due to a decrease in rainfall [31, 32]. The second peak occurred in September which signifies the resumption of frequent rainfall after the august break.

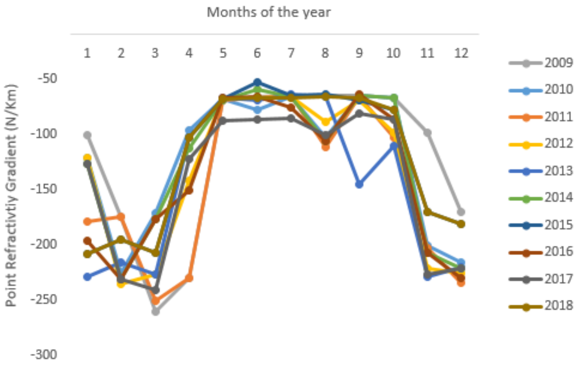

Figure 2: Annual Variation of Point Refractivity Gradient

Table 2: Monthly Average Point Refractivity Gradient and K-Factor for Yenagoa (2009-2018)

Months	Refractivity Gradient (N-Unit/km)	K-Factor (K)
January	-161.604	6.86011E-05
February	-227.353	0.000103241
March	-214.234	9.51548E-05
April	-139.13	5.96557E-05
May	-70.0804	3.88344E-05
June	-67.9087	3.83137E-05
July	-68.2645	3.83985E-05
August	-87.6277	4.33106E-05
September	-75.8705	4.02578E-05
October	-84.3443	4.24355E-05
November	-230.899	0.000105542
December	-209.879	9.26135E-05
Annual Average	-136.433	6.38633E-05

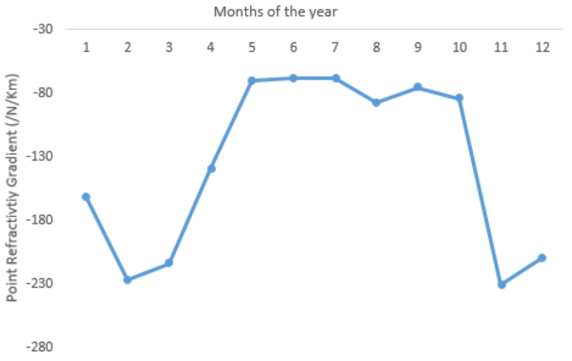

Figure 3: Monthly Average Point Refractivity Gradient for Yenagoa (2009-2018)

4. Seasonal Variation of Refractivity Gradient and K-Factor

The seasonal variation of refractivity gradient and geoclimatic factor were studied based on the computed monthly values. Figure 2 depicts that each month exhibits a unique trend over the years of study. For instance, there is a consistent gradual decrease in the refractivity gradient from January to March of every year. The unique nature of each month informed the decision to average the refractivity gradient values of the corresponding months for all the years. Table 2 and Figure 3 present the monthly mean of the refractivity gradients from 2009 to 2018. The figure revealed the variation of the refractivity gradient over the two seasons.

Refractivity gradient rises gradually at the onset of the rainy season specifically from March and becomes fairly steady at a mean value of -68.27 N-units/km between May and July. This is the maximum average refractivity gradient for the entire study period. There is a slight fall in August due to rainfall seizure associated with this month. The slight fall observed during the August-break is due to the movement of Inter-Tropical Discontinuity (ITD) between the northern and southern parts of Nigeria. Generally, the ITD reaches its maximum northward position in August translating to a low amount of precipitation in the south [32]. Hence, the refractivity gradient dropped to -87.63 N-units/km. The surge between September and October is due to the resumption of frequent rainfall which signifies the end of rainy seasons in the coastal region. The sharp decline between October and November is occasioned by the cessation of the rainy season. It was observed that the refractivity gradient reduces significantly from -84.34 N-units/km in October to -230.90 N-units/km in November. The month of January is commonly characterized by intense harmattan which causes lower humidity and temperature compared with previous months [33]. This accounts for the slight increase to -161.6 N-units/km in January, followed by a continuous reduction in humidity due to severe solar radiation between February and June [34]. The overall average refractivity gradient during the rainy and dry seasons stands at -75.68 N-units/km and -197.18 N-units/km, respectively.

The geoclimatic factor which is an exponential function of

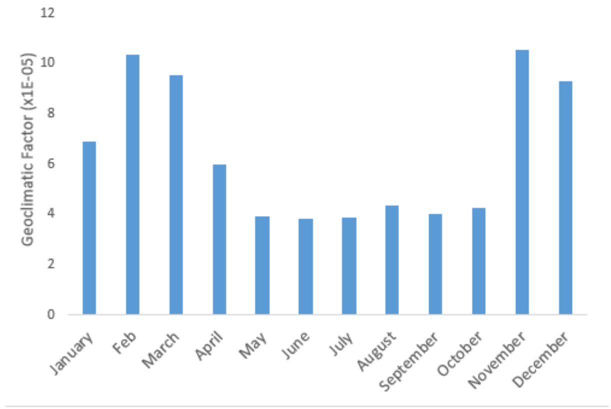

Figure 4: Monthly Average Geoclimatic Factor for Bayelsa (2009-2018)

the point refractivity gradient exhibit a similar trend but in the inverse order. High values prevail during the dry season while low values were dominant during the rainy season as depicted in Figure 4. The months of November, February, and March recorded maximum monthly means of 1.06E-04, 1.03E-04, and 9.53E-05, respectively. On the contrary, low values of 3.83E-05, 3.84E-05, and 3.88E-05 were recorded in June, July, and May, respectively. The mean values during the rainy and dry seasons are 4.03E-05 and 8.75E-05. The overall annual average point refractivity gradient and geoclimatic factor are -136.43 N-units/Km and 6.39E-05, respectively. These results are closely in agreement with the values obtained for Calabar by Etokebe *et. al.,* (2016) [7]. Calabar is also a coastal region in southern Nigeria and shares the same climatic features as Yenagoa [35]. The results also align closely with the work of [9] which obtained an average geoclimatic factor of 2.39E4 for Port Harcourt, another coastal city located about 94 km away from Yenagoa.

5. Conclusion

The monthly point refractivity gradient and geoclimatic factor for Yenagoa between 2009 and 2018 have been computed using meteorological data retrieved from the archive of ECMWF. The values obtained are similar to results obtained for other coastal stations in Nigeria as evidenced in previous studies. Although, refractivity gradient is generally low during the dry months, the lowest value was observed in November as shown in Figure 4. This implies that extremely poor propagation condition (ducting) is likely to occur in November due to the extreme values of point refractivity gradient and geoclimatic factor. The derived parameters are recommended for link budget calculations in the design of terrestrial microwave links.

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