Estimation of Geoclimatic Factor for Nigeria through Meteorological Data

Ilesanmi B. Oluwafemi and Moses O. Olla

Abstract — Geoclimatic factor variable is one of the most important radio climatic variables in the planning of the radio links in any region. A fade margin that takes into account multipath fading has to be incorporated in the link budget in the design of terrestrial line of sight communication system. This work involves the determination of the refractivity gradient over the first 100 m above ground level in Nigeria and by using the determined refractivity gradient, the geo-climatic factor (K) was calculated for typical links in Nigeria. The Geo-climatic factor (K) for the six major cities representing each geopolitical zone in Nigeria is determined in order to improve future planning of the radio links in the regions. Measurement of meteorological parameters for five years taken in Ikeja, Lagos (Latitude 6°27’11”N, Longitude 3°23’44”E), Enugu (Latitude 6°27’35.8704”N, Longitude 7°32’56.2164”E), Kaduna (Latitude 10°31’23”N, Longitude 7°26’25”E), Port Harcourt (Latitude 4°47’21”N, Longitude 6°59’54”E), Kano (Latitude 12°3’N, Longitude 8°32’N) and Abuja (Latitude 9°10’32’N Longitude 7°10’50”E) were employed to estimate the country value of K. The pressure, P(hPa), temperature, T(°C) and the relative humidity, (%, for the six location used were taken for a period of five years (2011-2015). The value of humidity were converted to water vapour pressure, e(hPa). In processing of the data, the average values of each month collected over a period of five years was used. The monthly data was used to calculate the values of the refractivity at the ground level and at 100 m altitude. From the calculated values of refractivity, the values of the refractivity gradient of heights of 65 m and at 100 m was computed and thereafter the geo-climatic factor (K) was calculated for the six geopolitical region of the country.

Index Terms — Geo-climatic factor, Meteorological data, Microwave, Refractivity, Refractivity Gradient.

I. INTRODUCTION

Line-of-sight radio links has a very huge effect on long distance communication networks. Now that there is higher demand for bandwidth that could be supported by recent developments in radio communication technology, reliable and efficient performance of radio link are needed for the transmission of high quality signals. With a wireless medium, the propagation of radio waves between radio link terminals is affected by the troposphere. Whenever there is a poor propagation conditions, fluctuation of the output signal would be resulted to, hence leading to fades on microwave links [1]. This occurrence affects the transmitted signal, and the overall communication system may thus not perform well [2]. Therefore, while designing a highly reliable radio communication network, these fades or signal variations are to be put into consideration [3]. In resolving this deficiency related to radio propagation in different areas of the world, various techniques have been proposed by many authors. These techniques were developed based on the radio propagation data of the regions in question [4]-[8]. According to those authors, several prediction variables like the geo-climatic factor being the key influence for both the suggestive of geographical and climatic characteristics of the region of interest, is very important [4]. This work involves the determination of the refractivity gradient over the first 100 m above ground level in Nigeria, using the calculated refractivity gradient, this will then lead to the determination of the geo-climatic factor (K) for typical links in Nigeria.

Tropospheric propagation studies in Nigeria have started for some time. In [1], a study was conducted on the radio refractivity measurement at 150 m altitude in Akure South West, Nigeria. In [9] the K factor was mapped and refractivity for Calabar in the southeast of Nigeria was calculated while in [10], clear air fade depth due to climatological parameter for microwave links application in Akure Nigeria was estimated. In [11] a study was conducted on the cubic trend line model development for each of the months to predict the refractivity of the lower atmosphere (<150 m above sea level) used in predicting multipath fading in terrestrial links. In [12] the inverse distance weighting spatial interpolation technique was used to obtain the missing data at certain height of interest. The results obtained showed that the point refractivity gradient and geo-climatic factor showed monthly and seasonal variations. However, most of the work done so far does not cover the major cities in Nigeria. This paper presents the analysis of the effects of tropospheric factors in the six geopolitical zones in Nigeria to estimate the geo-climatic factor (K).

The rest of the paper is presented as follows. In section II, the overview of the geo-climatic factor is presented while section III presents the findings from the study and finally a conclusion was drawn in section IV.

II. OVERVIEW OF THE GEOCLIMATIC FACTOR

The Geo-climatic factor is determined by initially finding other propagation parameters such as refractivity and refractivity gradient [13], [14]. Radio refractivity and its

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gradient are determined by following the steps recommended by the International Telecommunication Union Radio (ITU-R) in recommendation P.453-8 [15], [16]:

\[ N = (n - 1) \times 10^{-6} \]  

(1)

where \( N \) is the radio refractivity in N-units, expressed by (ITU2003)

\[ N = \frac{77.6}{T} (P + 4810 \frac{e}{T}) \]  

(2)

where \( P \) constitutes the total atmospheric pressure in hector-Pascal (hPa), \( T \) is the absolute temperature (Kelvin), and \( e \) is the partial water vapour pressure (hPa) obtained from the relative humidity of air as:

Equation (2) could be used for all radio frequencies, and for frequencies up to 100 GHz, with error lesser than 0.5%. As seen in P.453-8, the water vapour, \( e \), can be calculated from the relative humidity, \( H \), and saturated water vapour \( e_s \) by these expressions:

\[ e = \frac{H e_s}{100} \]  

(3)

where \( e_s \) is expressed by the expression below:

\[ e_s = 6.1121 \exp \left( \frac{17.5021}{t+240.97} \right) \]  

(4)

Combining equations (3) and (4), we get the expression:

\[ e = H \frac{6.1121 \exp \left( \frac{17.5021}{t+240.97} \right)}{100} \]  

(5)

Having \( H \) as the relative humidity (%), \( T \) as the Celsius temperature (°C), \( e_s \) is the saturation vapour pressure (hPa) at the temperature \( t \) (°C). It has been discovered that the long-term mean dependence of the refractive index \( n \) upon the height \( h \) is well expressed as follows [15]:

\[ n(h) = 1 + N_0 \cdot 10^{-6} \exp \left( -\frac{h}{h_0} \right) \]  

(6)

where \( N_0 \) is average value of atmospheric refractivity extrapolated to sea level, and \( h_0 \) is the scale height (km). \( N_0 \) and \( h_0 \) can be obtained statistically for different climates. \( N_0 = 315 \) and \( h_0 = 7.35 \) km for terrestrial paths [16]. This can be used to calculate the value of refractivity \( N_s \) at the earth’s surface from \( N_0 \) by:

\[ N_s = N_0 \exp \left( \frac{h_s}{h_0} \right) \]  

(7)

Having the \( h_s \) = height of the earth’s surface above the sea level expressed in (km). The radio refractivity gradient \( G \) N-units/km is expressed as (ITU2003):

\[ G = \frac{N_s - N_0}{h_s - h_0} \]  

(8)

With reference to equation (8), \( N_1 \) and \( N_2 \) are radio refractivity values at heights \( h1 \) and \( h2 \) respectively [11]. The

\[ K = 10^{-4.2 - 0.0029 dN_1} \]  

(9)

where \( K \) is the geo-climatic factor and \( dN_1 \) is the point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year and can be estimated as follows:

\[ dN_1 = \frac{dn}{dh} \mid h \leq 65 \text{ m} \]  

(10)

III. RESULT AND DISCUSSION

The data used in this work was measured in the six geopolitical zones of Nigeria (from January 2010 to December 2014) in six different meteorological stations in the country. The first meteorological station is Kaduna with coordinates (Latitude 10°31’23”N, Longitude 7°26’25”E), and elevation 634 m, above the sea level. The second is Enugu station with coordinates (Latitude 6°27’35.8704’N, Longitude7°32’56.2164’E) and elevation 180 m above the sea level. The third is Abuja with coordinates (Latitude 9°10’32’N Longitude 7°10’50’E) with elevation 840 m above the sea level. The fourth is Kano with coordinates (Latitude 12°3’N, Longitude 8°32’N) with elevation 488 m above the sea level and the last is Port Harcourt having coordinates (Latitude 4°47’21’N, Longitude 6°59’54’E) with elevation 20 m above the sea level.

The parameters extracted are monthly records of pressure, \( P \) (hPa), temperature, \( T \) (°C) and the relative humidity, (\%). The values of humidity were converted to water vapour pressure, \( e \) (hPa) by using equation (5) above. In the computation of data, we used the average values for each month collected over the period of five years (2010 to 2014). The monthly data was used to determine the values of surface refractivity at the ground level and at 100 m altitude using equation (2). From the calculated values of refractivity, we calculated the values of refractivity gradient at heights of 65 m and 100 m using equations (8) and (10), respectively. Lastly after finding the \( dN_1 \), the geo-climatic factor \( K \) was calculated using equation (9) and the results presented in Fig. 1 to 3 and Table I to II.

The average monthly values of refractivity statistics for each meteorological stations are shown in Fig. 1 and Table I. Table I shows that the average surface refractivity varies with month to month in a year with higher values between May and September for Kano location, higher value for March and December for Abuja, February and October for Enugu, August and September for Kaduna, May and September in Ikeja-Lagos, January, and July for Port Harcourt. It is also seen that the value of surface refractivity is high in Enugu and low in Ikeja-Lagos.

Fig. 2 indicates the monthly variation of point refractivity gradient figures for the six locations viz: Abuja, Enugu, Ikeja-Lagos, Port Harcourt, Kano, and Kaduna. Results showed the worst case is in the raining season between May and November in those years for the six geopolitical zones.
In order to design the terrestrial line-of-sight systems, a fade margin that takes into account multipath fading has to be integrated into the link budget. The ITU-R (ITU 2015) recommended multipath fading considers frequency of operation, path length, path inclination and the geo-climatic factor of the region of consideration. As showed in [16], the fade margin is directly proportional to the geo-climatic factor. ITU-R suggests that the K value determined from regional data results in accurate prediction of multipath fading.

A major item in multipath fade margin determination is the value of K at the worst month. This corresponds to the month with the highest value of K. Fig. 3 shows the monthly variation of the geo-climatic factor for the six cities employed for the study.

For Kaduna, the months of August and September give a high value of K, with the peak of K=0.000899 in September. In Enugu, the high value of K takes place in April, May, November, and December with a peak K=0.000713 in May.

For Ikeja Lagos, the high value of K takes place in January, March, June, and October with a peak K=0.00119 in March. For Abuja, the high value of K takes place between June and October with a peak K =0.000550 in July. Furthermore, Kano has the high values of K in January, February, and August with the highest value of K = 0.000981 in January. Finally, for Port Harcourt, the high values of K occur between July and October, with a peak K=0.000514 occurring in July. Thus, Kano exhibits the highest values of K in the cities considered and is thus most prone to high rates of multipath fading. Note that for Akure Southwest Nigeria, the highest value of K=0.00092 occurred in October and the lowest value of 0.000132 occurred in December [10]. The average value of K for Akure is 0.000327, which is comparable to the average values for Abuja, Kaduna, Ikeja, Port Harcourt, Enugu and Kano which is 0.000214, 0.000245, 0.000446, 0.000239, 0.000297 and 0.000319, respectively.

TABLE I: AVERAGE MONTHLY VALUES OF REFRACTIVITY

| Calendar Months | Kano | Abuja | Enugu | Kaduna | Lagos | Port Harcourt |
|-----------------|------|-------|-------|--------|-------|---------------|
| Jan             | 28.033 | 140.837 | 95.343 | 24.893 | 43.273 | 107.182       |
| Feb             | 39.888 | 153.653 | 116.652 | 39.599 | 34.022 | 110.881       |
| Mar             | 20.034 | 112.871 | 196.265 | 37.866 | 35.066 | 119.301       |
| Apr             | 57.723 | 126.276 | 175.575 | 76.649 | 38.508 | 117.088       |
| May             | 82.861 | 127.525 | 192.945 | 89.413 | 47.944 | 113.181       |
| Jun             | 85.392 | 126.131 | 194.683 | 86.523 | 44.201 | 113.120       |
| Jul             | 68.836 | 125.437 | 192.429 | 82.398 | 48.715 | 113.085       |
| Aug             | 91.787 | 141.471 | 206.246 | 106.913 | 41.461 | 96.981        |
| Sep             | 91.929 | 116.036 | 209.539 | 103.015 | 44.366 | 91.274        |
| Oct             | 67.015 | 155.586 | 206.378 | 70.789 | 38.811 | 111.181       |
| Nov             | 42.707 | 150.609 | 184.841 | 29.057 | 37.933 | 112.060       |
| Dec             | 28.374 | 167.538 | 89.515 | 40.681 | 28.149 | 107.147       |

TABLE II: GEO-CLIMATIC FACTOR (K) FOR DIFFERENT MONTHS FOR KADUNA, ENUGU, LAGOS, ABUJA, KANO AND PORT HARCOURT

| Calendar Months | Geo-climatic Factor, K |
|-----------------|------------------------|
| Kano            | Abuja                  |
| Kaduna          | Enugu                  |
| Lagos           |                          |
| Jan             | 0.0000522              | 0.000138 |
| Feb             | 0.000240               | 0.000280 |
| Mar             | 0.0000483              | 0.000363 |
| Apr             | 0.000167               | 0.000551 |
| May             | 0.000124               | 0.000713 |
| Jun             | 0.0000752              | 0.00134 |
| Jul             | 0.000229               | 0.00264 |
| Aug             | 0.000899               | 0.00158 |
| Sep             | 0.000893               | 0.00138 |
| Oct             | 0.0000663              | 0.000155 |
| Nov             | 0.0000618              | 0.000615 |
| Dec             | 0.0000636              | 0.000588 |
| Average         | 0.000245               | 0.000297 |

Fig. 1. Average monthly variation of refractivity in Kano, Abuja, Enugu, Kaduna, Ikeja and Port-Harcourt.

Fig. 2. Point refractivity gradient for Port-Harcourt, Ikeja, Kano, Kaduna, Enugu, and Abuja.
IV. CONCLUSION

In this paper, the Geo-climatic factor (K) variable, which is one of the most important radio climatic variables in the planning of the radio links in the region, has been calculated for Abuja, Kaduna, Ikeja, Port Harcourt, Enugu, and Kano in the six geopolitical zones in Nigeria. It is observed that as the values of dN1 become more negative, the Geo-climatic factor increases. The average of the geo-climatic factor is 0.000245 for Kaduna, 0.000297 for Enugu, 0.000446 for Ikeja, 0.000214 for Abuja, 0.000319 for Kano and 0.000239 for Port Harcourt. The worst month values of K are determined to be 0.000889 for Kaduna in August, 0.000615 for Enugu in November, 0.000827 for Ikeja in October, 0.000550 for Abuja in July, 0.000981 for Kano in January and a high value of 0.000514 for Port Harcourt in July.

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