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 6º27´11´´N, Longitude 3º23´44´´E), Enugu (Latitude 6º27´35.8704´´N, Longitude 7º32´56.2164´´E), Kaduna (Latitude 10º31´23´´N, Longitude 7º26´25´´E), Port Harcourt (Latitude 4º47´21´´N, Longitude 6º59´54´´E), Kano (Latitude 12º3'N,Longitude 8º32´N) and Abuja (Latitude 9º10´32´´N Longitude 7º10´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]:

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

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

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \quad (2)$$

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:

$$e = \frac{He_s}{100} \quad (3)$$

where e_s is expressed by the expression below:

$$e_s = 6.1121\, exp\left(\frac{17.502t}{t+240.97}\right) \quad (4)$$

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

$$e = H\frac{6.1121\exp\left(\frac{17.502t}{t+240{,}97}\right)}{100} \quad (5)$$

Having H as the relative humidity (%), T as the Celsius temperature (ºC), e_s is the saturation vapour pressure (hpa) at the temperature t (ºC). 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]:

$$n(h) = 1 + N_0 . 10^{-6} exp\left(\frac{-h}{h_0}\right) \quad (6)$$

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:

$$N_s = N_0 \exp\left(\frac{h_s}{h_0}\right) \quad (7)$$

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):

$$G = \frac{N_1 - N_2}{h_1 - h_2} \quad (8)$$

With reference to equation (8), N1 and N2 are radio refractivity values at heights h1and h2 respectively [11]. The proceedings for determining the geo-climatic factor (K) are stated in [10]. In order to calculate K, a fairly accurate estimate can be made from the expression [16]:

$$K = 10^{-\,4.2 - 0.0029 dN_1} \quad (9)$$

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:

$$dN_1 = \frac{dN}{dh} \mid h \le 65 \text{ m} \quad (10)$$

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 10º31´23´´N, Longitude 7º26´25´´E), and elevation 634 m, above the sea level. The second is Enugu station with coordinates (Latitude 6º27´35.8704´´N, Longitude7º32´56.2164´´E) and elevation 180 m above the sea level. The third is Abuja with coordinates (Latitude 9º10´32´´N Longitude 7º10´50´´E) with elevation 840 m above the sea level. The fourth is Kano with coordinates (Latitude 12º3´N, Longitude 8º32´N) with elevation 488 m above the sea level and the last is Port Harcourt having coordinates (Latitude 4º47´21´´N, Longitude 6º59´54´´E) with elevation 20 m above the sea level.

The parameters extracted are monthly records of pressure, P (hPa), temperature, T (ºC) 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 of 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	Refractivity, N-units					
	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	135.586	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					
	Kaduna	Enugu	Lagos	Abuja	Kano	Port Harcourt
Jan	0.0000522	0.000138	0.000710	0.0000837	0.000981	0.0000838
Feb	0.000240	0.000280	0.000298	0.0000647	0.000744	0.0000562
Mar	0.0000483	0.000363	0.00119	0.0000495	0.000102	0.0000672
Apr	0.000167	0.000551	0.000144	0.000147	0.000256	0.0000139
May	0.000124	0.000713	0.000222	0.000202	0.0000933	0.0000158
Jun	0.0000752	0.000134	0.000904	0.000298	0.000156	0.000319
Jul	0.000229	0.000264	0.0000922	0.000550	0.000282	0.000514
Aug	0.000899	0.000158	0.000222	0.000298	0.000362	0.000481
Sep	0.000893	0.000138	0.000342	0.000363	0.00126	0.000340
Oct	0.0000863	0.000155	0.000827	0.000264	0.000154	0.000434
Nov	0.0000618	0.000615	0.000226	0.000110	0.000166	0.000138
Dec	0.0000636	0.000588	0.000172	0.000141	0.000139	0.000138
Average	0.000245	0.000297	0.000446	0.000214	0.000319	0.000239

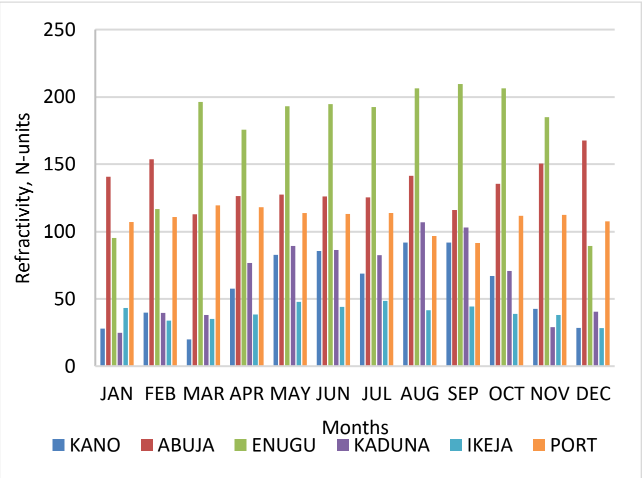

Fig. 1. Average monthly variation of refractivity in Kano, Abuja, Enugu, Kaduna, Ikeja and Port-Harcourt.

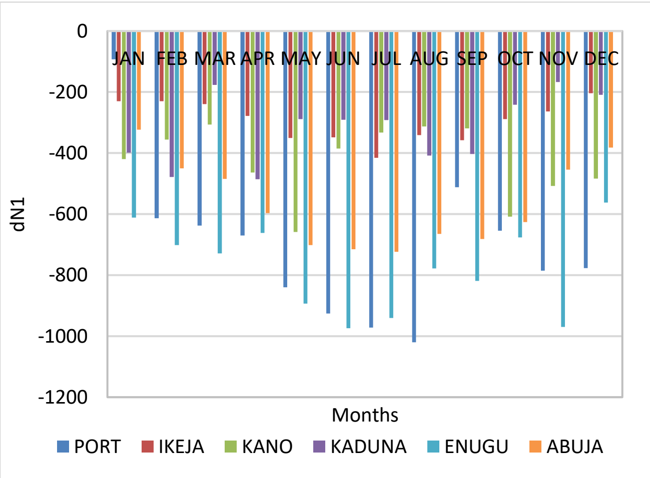

Fig. 2. Point refractivity gradient for Port-Harcourt, Ikeja, Kano, Kaduna, Enugu, and Abuja.

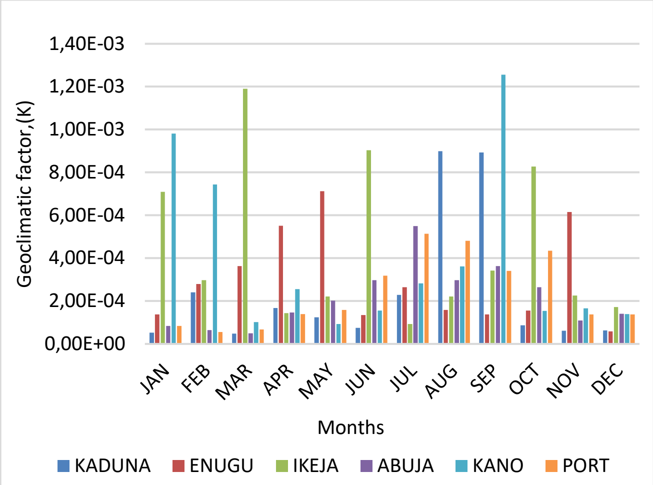

Fig. 3. Geo-climatic factor (K) variation for Kaduna, Enugu, Ikeja, Abuja, Kano, and Port-Harcourt.

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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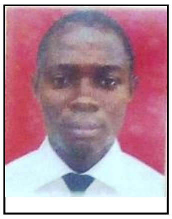

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