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Analysis of Clear Air Effects: Implication on Microwave Radio Communication Systems in Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Authors OLO and JSO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author JSO managed the analyses of the study. Author OLO managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The variation of refractivity with height is of major importance in controlling the path of propagation of radio wave in the troposphere. The variation which leads to anomalous propagation such as sub refraction, super refraction and ducting on terrestrial paths is of great importance for microwave links. In this paper, 5-year (2009 – 2013) data of climatological parameters like pressure, temperature and relative humidity among others, at the ground surface and at the first 100 m altitude over five locations across Nigeria (Akure, Minna, Enugu, Jos and Sokoto) are analysed to ascertain their impact on microwave communication links in Nigeria. The analyses involved the influence of refractivity gradient and *k*-factor on the season of the year as well as their implications on microwave communication systems. The results revealed that different locations have different average values of *k*-factor in different seasons of the year. Hence, we can conclude that the fixed value of 1.33 recommended by the ITU may either

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underestimate or overestimate *k*-factor value in Nigeria. The overall results also show a common occurrence of sub-refraction in the arid region and super-refraction in the coastal region of Nigeria.

Keywords: Refractivity; refractivity gradient; anomalous propagation; k-factor.

1. INTRODUCTION

The vertical gradient of the refractive index induces a bending of radio wave path as they propagate through the troposphere. If the refractive index is constant, the trajectories followed by radio wave will be an arc of a circle. However, the extent of the bending of the radio waves are influenced by meteorological conditions, among which are pressure, temperature and relative humidity. These parameters are strongly varying based on the geographical location and the season of the year [1].

The propagation of waves inside the troposphere is essentially a function of the value of refractive index and its gradient. As radio wave propagates in the troposphere the vertical gradient of the refractive index induces a bending of its path which remains at every point of space constrained within the vertical plane. If the refractive index is constant, the trajectories followed by radio wave will be an arc of a circle [2].

In order to achieve a representation of rectilinear propagation which is very important in predicting radio path on earth surface, the notion of the effective radius is always introduced. The effective earth radius is the radius of a hypothetical earth for which the distance to the radio horizon is assumed as rectilinear propagation. It is also the same as that of the actual earth with an assumed uniform vertical gradient of the atmospheric refractive index. The ratio of the effective earth radius to the actual earth radius is called the effective earth radius factor (*k*-factor) [3]. The idea of the effective earth radius has been found to be well suited for temperate climates and the study of links operating at short distance from ground [4]. There is, however, very scanty report on tropical climates and therefore makes it one of the motivations for this study [5].

The knowledge of the statistical distribution of *k*-factor is very important in the planning of radio communication especially from radio propagation point of view. *k*- factor also plays a significant application in the area of radio frequency reuse. Based on the variable climate of the study area, the influence of multipath conditions on line-of sight microwave radio link availability parameters is presented in [6]. Spatial interpolation technique for the determination of geoclimatic factor and fade depth using secondary variables for microwave applications in a tropical location was also are analyzed in [7]. Variations of the radio refractive index at the 100 m heights have also been analyzed in the localities of Akure in [8].

The main goals of this paper were to analyze the clear air effect and the implications on microwave radio communication systems in Nigeria based on 5-year (2009 – 2013) data.

2. THEORETICAL BACKGROUND

This section provides information on the theoretical background of the variables used in the computation radio refractivity, refractivity gradient and *k*-factor. The dynamics of the atmosphere leads to the variation of the refractive index of the troposphere as the height increases from sea level [9] and this consequently has a significant effect on radio signal. ITU-R has provided step -by- step procedure for determining the variation of the refractive index of the troposphere with height (refractivity gradient *–dN/dh*) as in [10]. The radio refractivity, *N*, is:

$$N = 77.6\frac{P_d}{T} + 72\frac{e}{T} + 3.75\times10^5\frac{e}{T^2} \text{ (N-units)} \quad (1)$$

where P_d is the dry atmospheric pressure (hPa), T is the temperature (K) and e is the water vapor pressure (hpa). The parameter e can be obtained with the knowledge of relative humidity H (%). The total atmospheric pressure (hPa), P, can be estimated using:

$$P = P_d + e \quad (2)$$

Since $P_d = P – e$, equation (2) can be rewritten as:

$$N = 77.6\frac{P}{T} - 5.6\frac{e}{T} + 3.75\times10^5\frac{e}{T^2} \quad (3)$$

Equation (3) may be approximated with reduced accuracy as:

$$N = \frac{77.6}{T}\left(P + 4810\left(\frac{e}{T}\right)\right) \quad (4)$$

The radio refractivity gradient, *dN/dh* can be obtained using [11]:

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

where N_1 and N_2 are the radio refractivity at different heights, h_2 and h_1 are the heights at different pressure levels. The parameter e can be obtained with the knowledge of relative humidity H (%).

The effective earth radius factor (k-factor) can also be determined by [12,13]:

$$k = \frac{1}{\left(1 + a\left(\frac{dN}{dh}\right)\right)} \quad (6)$$

where a is the earth radius. The effective earth radius factor, k values obtained using eqn. (6) was used to classify refractive conditions accordingly as [10, 14]:

Sub-refractive, if

$$\frac{4}{3} > k > 0 \quad (7)$$

Super-refractive, if

$$\infty > k > \frac{4}{3} \quad (8)$$

Ducting, if

$$-\infty < k < 0 \quad (9)$$

3. SITE AND INSTRUMENTATION AND DATA ANALYSIS

Five years (2009-2013) data are obtained from the in-situ measurement taken over some locations in Nigeria namely: Akure, Enugu, Minna, Jos and Sokoto. Nigeria lies between latitude 4°N and 14°N and longitude 2°E and 15°E respectively with a total area of 923,768 square kilometer. The country is located within the Equator and the Tropic of Cancer. The latitude of Nigeria falls within the tropical zone but the climatic conditions are not entirely tropical in nature. The climatic condition varies in most parts of the country, in the north the climatic condition is arid and to the south there is an equatorial type of climate. The weather condition can be generally characterized into two seasons. From April to October is the wet season; while from November to March is the dry season in most parts of the country. The selected locations were chosen to cover the main, climatic regions in Nigeria with more emphasis given to the land mass of each region. For example, Sokoto falls within the Sudan savannah with some characteristic of Sahel savannah. Hence, the reason for choosing Sokoto to represent this region in this presents work. Minna, located within the guinea savannah were chosen because of the peculiar nature of this region. Also, Minna is very hot while Jos is very cold due to the plateaus around the region. Enugu and Akure were chosen within the rain forest region. Fig. 1 provides the map of Nigeria showing the sites while Table 1 gives the summary of the characteristics of each of the study locations.

Each of the locations is equipped with Davis 6162 Wireless Pro2 automatic weather station that incorporated an Integrated Sensor Suite (ISS). Detailed descriptions of this equipment are available in the work of [14] and are not re-iterated here for paucity sake. In order to avoid interference, the fixed measuring method by a high tower was adopted with one sensor each placed at the ground level for the surface measurement and the others at different altitudes on the tower. Based on this method, only the sensors are positioned aloft while all other auxiliary devices are on the ground [15]. Calibrations are carried out based on the manufacturer specification. The method adopted for this work provides an accurate measurement of the parameters required for the estimation of refractive index at a fixed height. For the purpose of this study only the data got from the surface and at 100 m height are used in the analysis.

Data extraction from the data logger is carried out by connecting the console to the computer. The error margin of the ISS device for temperature, pressure and relative humidity are ±0.1°C, ±0.5 hPa and ±2 % respectively. The availability of the equipment is about 96%, 92%, 90%, 90% and 89% at Akure, Enugu, Minna, Jos and Sokoto respectively. The remaining percentages are due to equipment maintenance at each of the experimental sites.

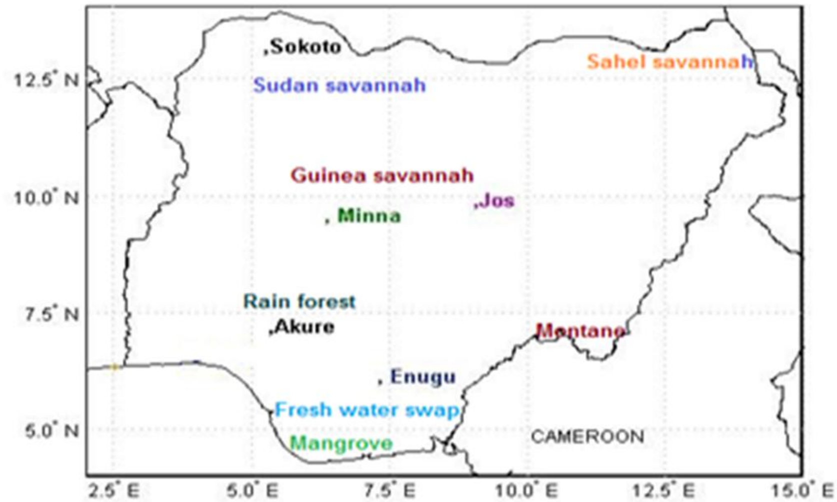


Fig. 1. Map of Nigeria showing the sites

Table 1. Summary of the characteristics of each of the study locations

Location	Climatic region	Coordinate (Degree)	Altitude (m)	Annual mean precipitation (mm)	Average temperature (Degree Celsius)
Akure	Rain Forest	5^{o} 12″E, 7^{o} 15″N	358	1485.57	27.1
Enugu	Fresh water swap mangrove	7^{o} 27″E, 6^{o} 25″N	223	1876.30	26.7
Minna	Guinea savannah	6^{o} 33″E, 9^{o} 36″N	281	1196.75	27.0
Jos	Guinea savannah	8^{o} 53″E, 9^{o} 55″N	1400	1186.89	23.0
Sokoto	Sudan savannah	5^{o} 13″E,13^{o} 04″N	500	567.21	28.3

4. RESULTS AND DISCUSSION

This section presents discussion on the results obtained based on the values of *dN/dh* and *k*-factors.

4.1 Influence of Refractivity Gradient on the Season of the Year

Fig. 2 presents the dependence of the monthly average value of radio refractivity gradient in the seasons of the year over the study locations. The results were presented to show how *dN/dh* varies within the study period. The result shows that a very negative large value of about-170 N-units/km could be observed in the month of October, which is the commencement of dry season in Sokoto, followed by Minna with point *dN/dh* of about-152 N-units/km. Consequently, the lowest point *dN/dh* of about-100 N-units/km occurred in the month of November in Jos. The value later becomes less negative in the other locations. This result is in agreement with what was observed earlier by [15]. In their report, it was observed that *dN/dh* at Enugu becomes less negative at values ranges from about -25 dB to -12 dB in the months of January to March which is the end of dry season months. We also noticed that the values of refractivity gradients are not consistent with those given for Nigeria in Ref. [10]. The reason been that ITU maps was generated based on estimation and the data used to model the maps was based on data from other tropical locations like India, Malaysia, and Indonesia [6,8,14].

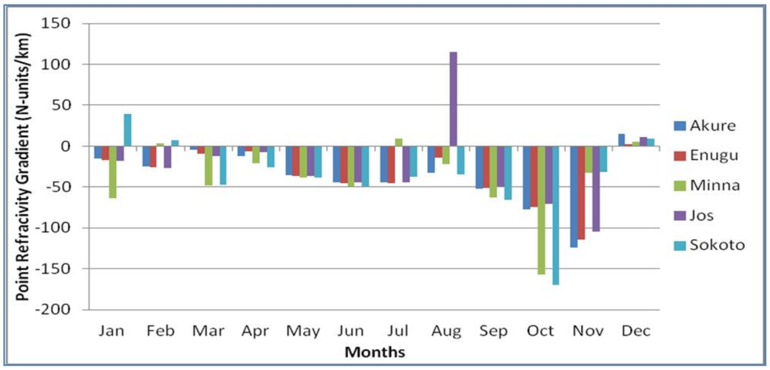
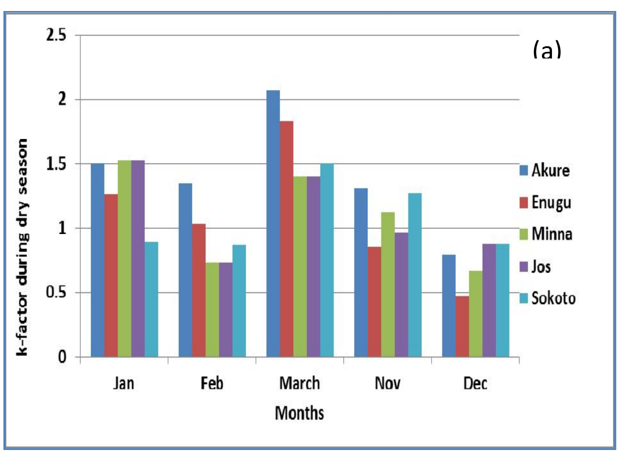


Fig. 2. Monthly average of dN/dh

4.2 Influence of k-factor on the Season of the Year

Figs. 3a and 3b also present the mean values of the *k*- factor over the study locations during the dry and wet season months respectively. It could be seen that irrespective of the location, the *k*-factor shows seasonal type dependence [16]. For example, during the dry season months (Fig. 3a), the mean *k*-factor value in Akure range from 0.79 to 2.07 with maximum value in the month of March and minimum in the month of December. The month of March represents the end of dry season when the moisture begins to gather ready for the commencement of rainy season while the month of December is when much dryness occurs in the atmosphere. The average value of *k*-factor during the dry season is about 1.40. This implies that the propagation condition could largely be super-refractive for Akure, and it's environed during this season. The same trend could be observed in other locations although with different values of mean *k* –factor and at different propagation conditions.

For wet season months as presented in Fig. 3b, the *k*-factor is generally higher in the rainy season months than in the dry season months. The average value of *k*-factor during the wet season months was about 1.52. This is purely an evidence of super-refractive during this season. The same trend could also be observed in other locations, although with different values of *k* –factor and with different associated propagation phenomena. Hence, the prescribed values of 1.33 recommended by the ITU [10] may either underestimate or overestimate the *k*-factor in these regions. Fig. 4 presents the average *k*-factor over Nigeria. The results show that *k*-factor decreases from the coastal region to the arid region of Nigeria.



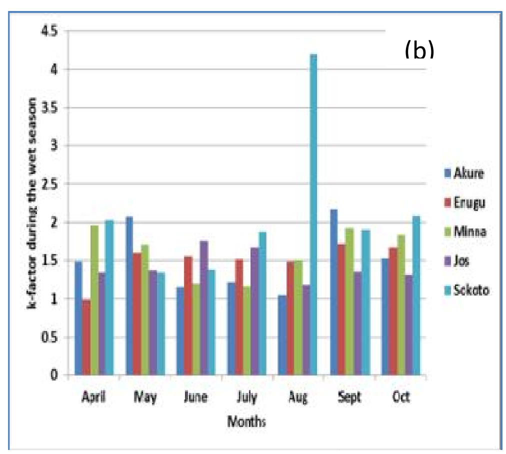


Fig. 3. The mean values of *k*-factor during (a) the dry season months and (b) wet season months over each of the study locations

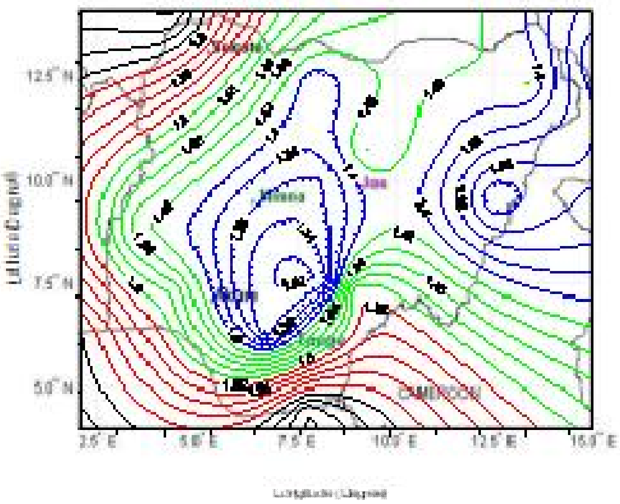


Fig. 4. *k*-factor over Nigeria

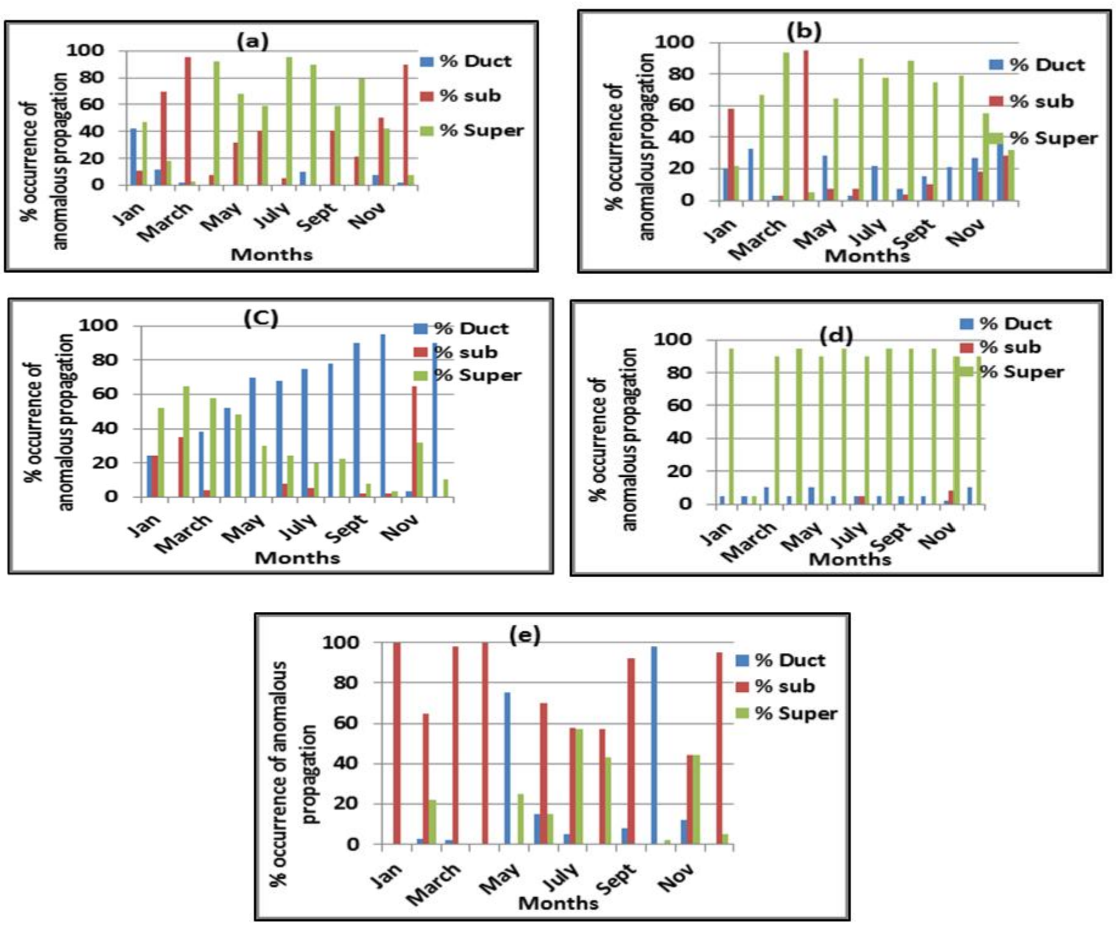


Fig. 5. Percentage occurrence of anomalous propagation over (a) Akure, (b) Enugu, (c) Minna, (d) Jos and (e) Sokoto

4.3 Implication of Clear Air Effect on Microwave Radio Communication Systems

Figs. 5 (a) to 5 (e) represent the monthly statistics of occurrence of clear air propagation conditions at (a) Akure (b) Enugu (c) Minna (d) Jos and (e) Sokoto respectively. The propagation conditions revealed varying degrees of occurrence in all the stations. In Fig. 5 (a) for example (Akure), super-refractive dominates during most of the months. Ducting and super-refraction are the predominant conditions in the month of January while sub-refraction predominates the months of February, March, November and December. It is also noticed that the rest of the calendar months (April – October) are majorly dominated by super-refraction.

The implication is that when sub-refraction is prevalent, radio signals will have reduced the horizon and frequent outage may be experienced at the receiving end in the region. However, when super-refraction and ducting is prevalent, interference from distant stations may be observed at the location. This occurred especially when the signals operate at nearly the same frequency with local transmitting station. The same trend could be seen in Fig. 5 (b) for Enugu, although with little variation in the months of the anomalous occurrence. In Fig. 5 (c) which is for Minna, ducting predominates most especially in the wet season months as well as in December, while the months of January and February is predominated by Super-refraction. Fig. 5 (d) to 5 (e) present the percentage occurrence of anomalous propagation over Jos and Sokoto respectively. An entirely different pattern could be observed in these figures, for example in Fig. 5 (d) super-refractivity is dominant in all the months irrespective of the season. This may be as a result of climatic nature of this locality which is mainly characterized with high humidity. The implication is that interference of co-channel signals will be a common problem in this region and the signal strength may highly exceed that of the free space.

Also in Fig. 5 (e), sub-refraction is predominant in Sokoto. However, an appreciable degree of super-refraction and ducting are observed in the rainy season with ducting observed in May and October. The implication is that with predominant sub-refraction in this region, a reduced radio horizon is expected from microwave signals, hence high occurrence of outage could be observed. In overall, sub-refraction predominates in the arid region and super-refraction in the coastal region. Also, *k*-factor decreases from the coastal region to the arid region of Nigeria.

5. CONCLUSION

In this paper, the influence of clear air effect on microwave links has been examined based on *k*-factor. The main finding shows that the monthly variation of point *dN/dh* depends on the season with worst months occurring mainly in wet season months. Results of variability of *k*-factor show that the value of 1.33 recommended by the ITU will either underestimate or overestimate *k*-factor value in Nigeria. The result further recommends using the calculated mean k-factor value of 1.52 and 1.40 for wet and dry season respectively for the microwave design to get the required availability for this region. Also, the average statistical distributions of clear-air effect over the study locations show the tendency of persistence sub-refractive conditions in the arid region and the prevalence of super-refraction in the coastal regions of the country.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Korak shaha PN. The physics of the earth and its atmosphere, John and Sons Inc., New York, USA; 2003.
2. Skolnik MI, Introduction to radar systems, McGraw-Hill, New York, NY, USA, 3rd edition; 2001.
3. Olsen RL and Tjelta T. Worldwide techniques for predicting the multipath fading distribution on terrestrial LOS links: Background and results of tests IEEE Transactions on Antennas and Propagation. 1999;47:1.
4. Brooker HG and Walkinshaw W. The mode theory of tropospheric refractionand its relation to wave-guides and diffraction. Physics and Meteorological Societies. 1945; 80-127.
5. Afullo TJ, Odedina PK. On the k- factor distribution and diffraction fading for South Africa, South African Institute of Electrical Engineers Journal. 2006;97(2):172-181.
6. Adediji AT, Ajewole MO, Falodun SE. Variation of radio refractivity gradient and effective earth radius factor (k-factor) over

Akure, Sourth western Nigeria. Journal of Atmosphere and Solar Terrestrial Physics. 2011;73(16):2300-2304.

7. Ojo OL, Ojo JS, Omole OV. Application of spatial interpolation technique for the determination of geoclimatic factor and fade depth using secondary variables for microwave applications in a tropical location. Nigerian Journal of Space Reserach. 2016;14(1):1-7.
8. Falodun SE, Ajewole MO. Radio refractive index in the lowest 100 m layer of the troposphere in Akure, South Western Nigeria. Journal of Atmospheric and Solar-Terrestrial Physics. 2006;68:236-243.
9. Afullo TJ, Motsoela T, Molotsi DF. Refractivity gradient and k-factor in Botswana. Radio Africa. 1999;107–110.
10. ITU – RP. The radio refractive index: Its formula and refractivity data. ITU Radio Communication Assembly. ITU-R P – Series. 2015;453-11.
11. Dominguez MA, Benarroch A, Riera JM. Refractivity statistics in Spain: First Results, Tech. Rep. CP 5 2004, COST 255, May 1998.
12. ITU-R P.310-9, Definitions of terms relating to propagation in non-ionized media, The ITU Radiocommunication Assembly, ITU-R P – Series. 1994;310-9.
13. Abdulhadi Abu-Almal and Kifah Al-Ansari. Calculation of effective earth radius and point refractivity gradient in UAE, International Journal of Antennas and Propagation. 2010, Article ID 245070, 4 pages. DOI:10.1155/2010/245070
14. Adediji AT, Ajewole MO. Vertical profile of radio refractivity gradient in Akure, South-West, Nigeria. Progress in Electromagnetic Research C. 2008;4:157–168.
15. Ayantunji BG, Okeke PN. Diurnal and Seasonal variation of surface refractivity over Nigeria. Progress in Electromagnetics Research B. 2011;30:201-222.
16. Chaudhary N. Kumar, Trivendi DK, Gupta R. The impact of k-factor on wireless link in Indian semi-desert terrain, Int. J. Advanced Networking and Applications. 2011;02(04): 776-779.

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