International Journal of Basic Science and Technology
September, Volume 6, Number 3, Pages 87 - 94
ISSN 2488-8648
http://www.ijbst.fuotuoke.edu.ng/

Estimation of Radio Climatic Variables for the Design of Radio Links in South-western Nigeria

[1]*Abiodun I.C and [2]Obogai L.E
[1]Department of Physics, Federal University Otuoke, Bayelsa State
[2]Department of Mechanical Engineering, Federal University Otuoke, Bayelsa State

Article Information

Article # 01010
Received: 26th July, 2020
Revision: 25th, Aug., 2020.
Acceptance: 2nd Sept., 2020
Available on line: 3rd Sept., 2020

Key Words
Effective earth radius,
link budget, Fade depth,
Geoclimatic factor,
Refractivity gradient

Abstract

Point refractivity gradient, effective earth radius and geoclimatic factor were calculated from atmospheric data obtained from National Aeronautics and Space Administration (NASA) in urban, suburban and rural environments of some states of South-western Nigeria. The measured atmospheric conditions are: temperature (T), atmospheric pressure (P) and relative humidity (H). Monthly data obtained at 1000 and 950 hPa with equivalent height based on pressure level of 111 and 540 m for the one-year period (2017-2018) of field investigation of this research work. The worst month value of point refractivity gradients are - 88 N-unit/km, - 78 N-unit/km and - 67Nunit/km in Akure, Ore and Omifon in Ondo State. In Ekiti State, the worst month value of point refractivity gradient are -74.23 N-unit/km in Ado-Ekiti, -58.37 N-unit/km in Oye-Ekiti and -66.46 N-unit/km in Ilupeju while in Osun State, the worst month vale of point refractivity gradient are -59.87 N-unit/km in Ilesa, -85.08 N-unit/km in Osu and -86 N-unit/km in Olode. The *k*-factor and geoclimatic factor values calculated from the point refractivity values vary with months and season, with the wet season exhibiting the highest values. The geoclimatic factor values estimated in the study are applicable in fade depth calculations while the values of *k*-factor obtained can be applied in radio link design to estimate the height of antenna requirement and diffraction fade estimation in South-western Nigeria.

***Corresponding Author**: Abiodun I.C.; abiodunic@fuotuoke.edu.ng

Introduction

The radio refractive index is a very vital parameter to be considered when planning wireless communication links. The ratio of velocity of radio wave propagation in free space to its propagation velocity in a particular medium is known as radio refractive index. Variations in the radio refractive index value can cause the propagating path of electromagnetic wave to either bend towards the earth or away from the earth. Close to the surface of the earth, the radio refractive index value is around 1.0003 at standard atmosphere conditions (Egbe *et al.*, 2017). Conversely, anomalous radio wave propagation is observed as a result of deviation and variations in atmospheric condition from the standard conditions. Such anomalies are caused by some meteorological conditions such as high evaporation and humidity. In general, atmospheric radio refractive index is dependent on the following primary atmospheric parameters, such as; atmospheric pressure, humidity, air temperature, and water vapour pressure. Furthermore, humidity, atmospheric pressure and air temperature can vary with height above the ground surface. Any changes in any of the primary atmospheric parameters can have major effect on radio wave propagation (Ayantunji and Okeke, 2011). These atmospheric parameters refract radio waves in different directions such as up, down, towards or away from the earth's surface along the curvature of the earth resulting in clear-air fading phenomena (Ojo *et al.*, 2012). The clear-air mechanisms involved following: beam spreading, antenna decoupling, surface multipath, ducting, scintillation and atmospheric multipath. For the design of microwave link, parameters such as the point refractivity gradient, d*N*1, effective earth radius factor, *k*, and geoclimatic factor, K, must be properly estimated from atmospheric parameters in order to optimize its performance.

Efforts have been made by some authors in the tropical region especially Nigeria on modeling the main radio climatic variables: (Falodun and Ajewole, 2006; Adediji and Ajewole, 2008; Adediji *et al*., 2011; Ojo *et al*., 2014). However, the estimation of radio climatological variables have not been seriously studied in different environments such as urban, suburban and rural areas. Hence, this study focuses on the estimation of radioclimatic variable from atmospheric parameters in three different environments of three states in South-western Nigeria for the design of terrestrial line-of-sight (LoS) links.

Materials and Methods

Study Area

The study areas for this work are locations in urban, suburban and rural of Ondo, Ekiti and Osun States in the South-western region of Nigeria within the rainforest zone. In Ondo state, the urban, considered was Akure, in Ekiti, Ado-Ekiti was considered while Ilesa was considered in Osun State. The suburban measurements were carried out in Ore in Ondo State, Oye-Ekiti in Ekiti State and Osu in Osun State. In rural environments, measurements were considered in Omifon in Ondo State, Ilupeju in Ekiti State and Olode in Osun State. Detailed characteristics of each of the sites are respectively shown in Table 1

Table 1: Features of investigated environments

Location	Coordinate		Elevation (m)	Environment Type
	Latitude(°N)	Longitude(°E)		
Akure	7.254400	5.197166	352	Urban
Ado-Ekiti	7.629275	5.231178	547	Urban
Ilesa	7.624761	4.740411	396	Urban
Ore	6.765633	4.842673	93	Suburban
Oye-Ekiti	7.784006	5.329048	543	Suburban
Osu	7.580258	4.618061	349	Suburban
Omifon	6.830495	4.861581	157	Rural
Ilupeju	7.810266	5.329048	632	Rural
Olode	7.265616	4.632591	244	Rural

Data Collection

The data used are obtained from the National Aeronautics and Space Administration (NASA) in urban, suburban and rural environments of Ekiti, Ondo and Osun States, South-western Nigeria. The data contains temperature (T), atmospheric pressure (P) and relative humidity (H) monthly data obtained at 1000 and 950 hPa with equivalent height based on pressure level of 111 and 540 m for the one-year period of field investigation.

Determination of Atmospheric Radio Refractivity

Due to the great demand and the wide applications of wireless network communications. It is imperative to consider closely those properties that contribute to fading as signal propagates when the air condition is clear on terrestrial LoS links, several atmospheric actions result to signal losses on the propagation link (Mason, 2010), (Zubar, 2011). In the LoS link of terrestrial propagation, multipath fading is one of the most regular fading phenomena in tropospheric propagation (Ononiwu *et al.*, 2015). The most important factors used in the determination of multipath fade depth in radio communication link are geoclimatic factor, radio refractivity, refractivity gradient and effective radius factor. All these factors can be calculated primarily from the meteorological parameters measured at lower atmosphere. The meteorological parameters used are mostly pressure, temperature, vapour pressure and relative humidity. These parameters affect the transmission of signals of microwave at reduced atmospheric heights (at lower atmosphere). To deduce the effects of atmospheric parameters, the radio refractive index is used, it is related to the radio refractivity (N) and hence, radio refractivity gradient (dN_1), effective radius factor (k) as well as geoclimatic factor (K) which are used in estimating fade depth in radio communication link.

This part focusses on the determination of point refractivity gradient, effective radius factor (k) and geoclimatic factor (K) using data obtained from the National Aeronautics and Space Administration (NASA) in urban, suburban and rural environments of Ekiti, Ondo and Osun States, Southwestern Nigeria. The data contains temperature (T), atmospheric pressure (P) and relative humidity (H) monthly data obtained at 1000 and 950 hPa with equivalent height based on pressure level of 111 and 540 m for the period of two years. The refractivity is computed in accordance with the (ITU-R 453-9, 2003) model as:

$$N = N_{dry} + N_{wet} = {}^{77.6}/_{T}\left[P + \left({}^{4810e}/_{T}\right)\right] \tag{1}$$

The dry season refractivity N_{dry} is expressed as (ITU-R 453-9, 2003):

$$N_{dry} = {}^{77.6P}/_{T} \tag{2}$$

and the wet season refractivity N_{wet} is expressed as (ITU-R 453-9, 2003) model:

$$N_{wet} = 3.725 \times 10^{5}\left({}^{e}/_{T^{2}}\right) \tag{3}$$

P is in hectoPascal (hPa), the water vapour pressure is denoted by (e) in (hPa), T is in Kelvin (K). The relative humidity and water vapour pressure are connected by the expression according to (ITU-RP.453-8, 2000) as:

$$e = {}^{He_s}/_{100} \tag{4}$$

with e_s given as in (ITU-R 453-9, 2003):

$$e_s = a\exp\left({}^{bt}/_{t + c}\right) \tag{5}$$

ISSN 2488-8648
http://www.ijbst.fuotuoke.edu.ng/

H is in (%), t represents the temperature in Celsius (°C), the coefficients a, b and c have values as in [11]; a = 6.1121, b = 17.502 and c = 240.97.

The refractivity gradient is calculated as a function of altitude according to the recommended model (ITU-R 453-9, 2003):

$$\frac{dN}{dh} = {N_2 - N_1}/{h_2} - h_1 \qquad (6)$$

where N_2 and N_1 represent the refractivity at height h_2 and h_1 respectively.

The refractivity gradient in the troposphere around the lower 111 m is an essential parameter to deduce propagation effects like ducting, sub refraction, super refraction, surface refraction, effective earth radius factor and multipath fading on any communication LoS link.

In most literatures, the refractivity gradient is estimated at 65 m above the ground level ((ITU-R 453-9, 2003), (Agbo *et al*., 2013). In this research work, the refractivity gradient is estimated using the expression (Agbo *et al*., 2013), (Abu-Almal and Al-Ansari, 2010):

$$dN1 = {dN}/{dh} = {N_s - N_1}/{h_s} - h_1 \qquad (7)$$

N_s is the surface refractivity at 111 m, N_1 is the upper atmospheric refractivity at 540 m. The k factor is also obtained from the refractivity gradient as (Ojo *et al.*, 2012):

$$k = \left[1 + \left({\frac{dN}{dh}}/{157}\right)\right]^{-1} \qquad (8)$$

The K factor is obtained according to the recommended (ITU-R P.530-14, 2012) procedure which is given as (Ojo *et al.*, 2012):

$$K = 10^{(-4.2-0,0029dN1)} \qquad (9)$$

where dN1 is the refractivity gradient.

Results

The results of the estimated monthly effective earth radius factor, *k*, and geoclimatic factor *K*, for the period of field investigation are presented in this section. The monthly variations of point refractivity gradient (*dN₁*) for the period of field investigation have also been estimated. Results indicate that values of refractivity gradient raging between - 41 N-units/km and - 88 N-units/km were obtained in urban environment, refractivity gradient values of - 44 N-units/km and - 78 N-units/km in suburban environment, and - 43 N-units/km to - 67 N-units/km in rural environment of Ondo State with the worst cases falling in the wet season within the months of May, June, July, August and September with values between – 58 N-units/km and around -88 N-units/km.

In Ekiti State, the values of refractivity gradient in urban environment are between – 39 N-units/km and -74.23 N-units/km, in suburban environment the refractivity gradient values are – 39.33 N-units/km and – 58.37 N-units/km and in rural environment, the refractivity gradient values are between – 40 N-units/km and – 66.46 N-units/km. The wet season (May, June, July, August, September and post wet season period (October) showed the worst cases of refractivity gradient values between – 49N-units/km and about – 74 N-units/km. Also, in Osun State urban environment, the monthly refractivity gradient varied between – 38.29 N-units/km to – 59.87 N-units/km, in the suburban environment, the refractivity gradient varied between – 40.80 N-units/km and – 85.08 N-units/km and in rural environment, the monthly variations of refractivity gradient values were between – 41 N-units/km and – 86 N-units/km with the wet season months exhibiting the highest values of refractivity gradient

Table 2: Geo-climatic and effective earth radius factor for different months in various environments of Ondo State.

Month	Urban (Akure)		Suburban (Ore)		Rural (Omifon)	
	k factor	Geoclimatic Factor K	k factor	Geoclimatic Factor K	k factor	Geoclimatic Factor K
January	1.35	8.34×10^{-5}	1.40	8.60×10^{-5}	1.52	8.53×10^{-5}
February	1.33	7.80×10^{-5}	1.42	8.70×10^{-5}	1.48	8.62×10^{-5}
March	1.41	8.62×10^{-5}	1.50	9.00×10^{-5}	1.41	8.92×10^{-5}
April	1.43	8.71×10^{-5}	1.52	9.20×10^{-5}	1.38	8.93×10^{-5}
May	1.46	9.40×10^{-5}	1.61	1.04×10^{-4}	1.51	9.12×10
June	1.51	1.00×10^{-4}	1.58	1.00×10^{-4}	1.58	1.12×10^{-4}
July	1.53	1.30×10^{-4}	1.58	1.10×10^{-4}	1.56	9.33×10^{-5}
August	1.61	1.80×10^{-4}	1.55	9.30×10^{-5}	1.54	9.20×10^{-5}
September	1.55	1.50×10^{-4}	1.62	1.46×10^{-4}	1.63	1.40×10^{-4}
October	1.49	9.00×10^{-5}	1.53	1.12×10^{-4}	1.52	9.13×10^{-5}
November	1.43	8.73×10^{-5}	1.50	9.05×10^{-5}	1.48	8.98×10^{-5}
December	1.36	8.41×10^{-5}	1.43	8.72×10^{-5}	1.41	8.70×10^{-5}

Table 3: Geoclimatic and effective earth radius factor for different months in various environments of Ekiti State.

Month	Urban (Ado-Ekiti)		Suburban (Oye-Ekiti)		Rural (Ilupeju)	
	k factor	Geoclimatic Factor K	k factor	Geoclimatic Factor K	k factor	Geoclimatic Factor K
January	1.33	8.70×10^{-5}	1.34	7.60×10^{-5}	1.34	8.31×10^{-5}
February	1.25	7.90×10^{-5}	1.29	7.40×10^{-5}	1.36	8.42×10^{-5}
March	1.40	8.61×10^{-5}	1.44	8.80×10^{-5}	1.47	9.13×10^{-5}
April	1.42	8.71×10^{-5}	1.45	8.70×10^{-5}	1.44	8.82×10^{-5}
May	1.47	8.60×10^{-4}	1.48	9.00×10^{-5}	1.45	8.86×10^{-5}
June	1.53	1.20×10^{-4}	1.43	8.82×10^{-5}	1.44	8.77×10^{-4}
July	1.57	1.33×10^{-4}	1.47	8.55×10^{-5}	1.41	8.64×10^{-5}
August	1.60	1.35×10^{-4}	1.45	8.86×10^{-5}	1.47	8.93×10^{-5}
September	1.55	1.58×10^{-4}	1.51	9.06×10^{-5}	1.62	1.20×10^{-4}
October	1.50	9.95×10^{-5}	1.41	8.42×10^{-5}	1.46	9.08×10^{-5}
November	1.42	8.51×10^{-5}	1.37	8.47×10^{-5}	1.39	8.58×10^{-5}
December	1.36	8.32×10^{-5}	1.33	8.30×10^{-5}	1.32	7.98×10^{-5}

Table **4**: Geoclimatic and effective earth radius factor for different months in various environments of Osun State

Month	Urban (Ilesa)		Suburban (Osu)		Rural (Olede)	
	k factor	Geoclimatic Factor K	k factor	Geoclimatic Factor K	k factor	Geoclimatic Factor K
January	1.33	8.31×10^{-5}	1.35	7.80×10^{-5}	1.36	8.66×10^{-5}
February	1.35	8.37×10^{-5}	1.36	7.30×10^{-5}	1.37	8.73×10^{-5}
March	1.41	8.63×10^{-5}	1.41	8.63×10^{-5}	1.45	9.05×10^{-5}
April	1.44	9.10×10^{-5}	1.44	8.77×10^{-5}	1.46	9.14×10^{-5}
May	1.52	9.13×10^{-5}	1.52	8.98×10^{-5}	1.48	9.32×10^{-5}
June	1.48	8.99×10^{-5}	1.53	9.16×10^{-5}	1.54	1.20×10^{-4}
July	1.52	1.30×10^{-4}	1.51	9.25×10^{-5}	1.53	1.24×10^{-4}
August	1.57	1.23×10^{-4}	1.55	9.16×10^{-5}	1.52	9.83×10^{-5}
September	1.51	9.58×10^{-5}	1.42	1.06×10^{-4}	1.56	1.44×10^{-4}
October	1.50	9.07×10^{-5}	1.48	9.02×10^{-5}	1.50	9.35×10^{-5}
November	1.43	8.77×10^{-5}	1.42	8.60×10^{-5}	1.44	9.10×10^{-5}
December	1.35	8.37×10^{-5}	1.36	8.42×10^{-5}	1.38	8.36×10^{-5}

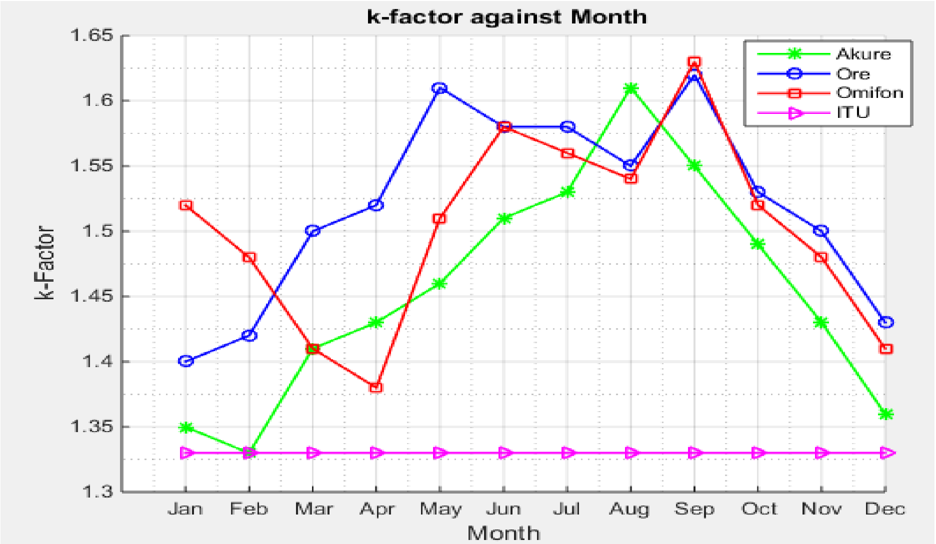

Figure **1**: Variation of effective earth radius with months for Ondo State environments

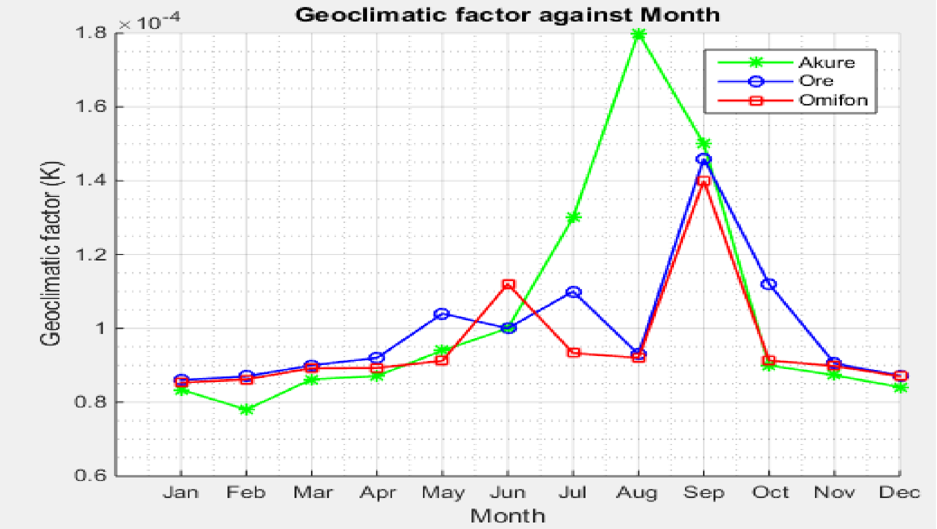

Figure **2**: Variation of geoclimatic factor with months for Ondo State environments

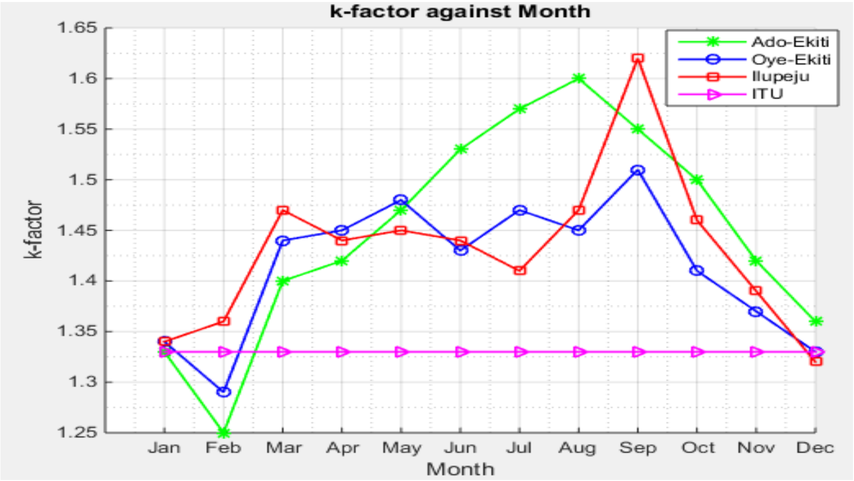

Figure 3: Variation of effective earth radius with months for Ekiti State environment

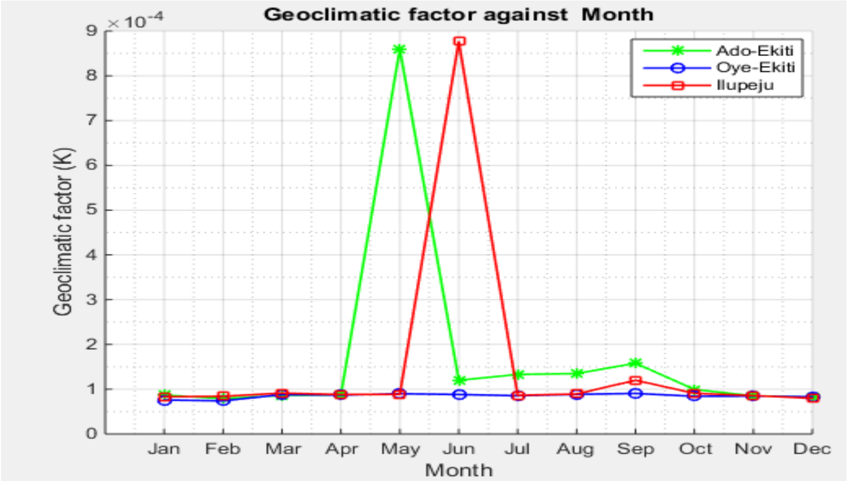

Figure **4**: Variation of geoclimatic factor with months for Ekiti State environments

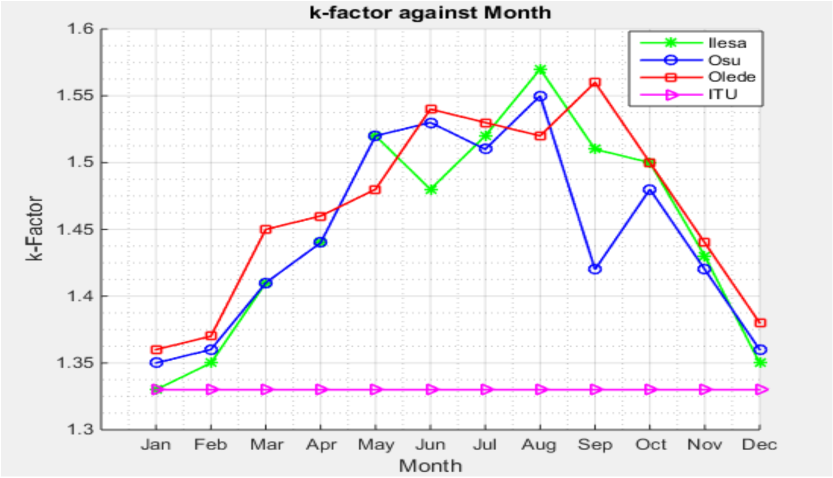

Figure **5**: Variation of effective earth radius with months for Osun State environments

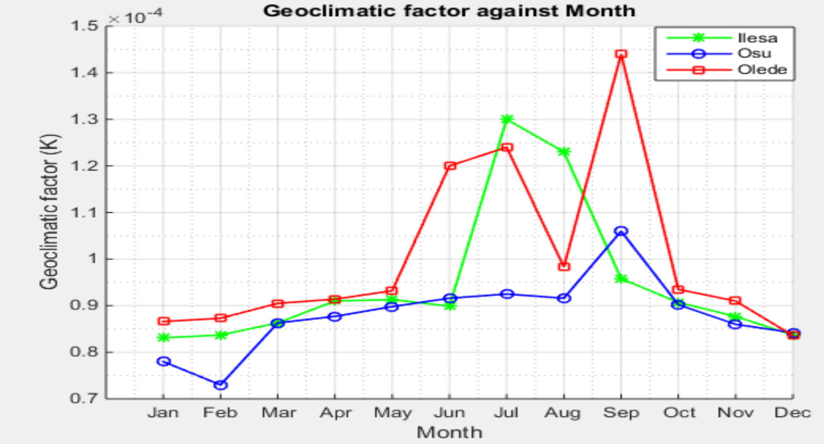

Figure **6**: Variation of geoclimatic factor with months for Osun State environments

Discussion

From the estimated values of refractivity gradient, it is noticed that most of the months in South-western Nigeria are predominated by super-refraction. The result implies that the ITU recommended value of – 60.20 N-unit/km value of refractivity gradient is not a good assumption, because it does not put into consideration the monthly variation of the refractivity gradient and the worse month situations. These results are in conformity with the work of (Ojo *et al.*, 2012).

Tables 1 to 3 present the geoclimatic factor *K* and effective earth radius (*k*-factor) monthly variables for different environments of Ondo, Ekiti and Osun states respectively, estimated based on the monthly refractivity gradient calculated from the acquired atmospheric parameters.

The values of effective earth radius factor are needed in radio link design to estimate the required antenna height and fades due to diffraction with a standard value of 1.33 for link design (Adediji *et al.*, 2014). The geoclimatic factor (*K*) values are applicable in the calculation of fade depth, it has no standard value but it is determined using atmospheric parameters of the environment where the link design is required (ITU-R 453-9, 2003).

Figures 1 to 6 present the variation of effective earth radius (*k*-factor) and geoclimatic factor with months for the different environments of the considered states. The results indicate that the worst cases of k-factor and geoclimatic factor falls in the rainy months (June, July, August and September). The highest value of the k-factor is 1.63 in rural environment of Ondo State in the month of September. While the highest value of geoclimatic factor is 8.77×10^{-4} in rural environment of Ekiti State in the month of June. The effect is that during the rainy months, the refractivity gradient refracts more of the mean bending angle of the transmitted signals along the line-of-sight links depending on the level of the atmospheric turbulence, this could lead to seasonal fluctuations of the transmitted signal at the receiving end (Ojo *et al.*, 2012).

However, from the effective earth radius factor presented in Figs. 1.0 to 6.0, show that using the standard value of 1.33 for *k*-factor in the investigated environments, the required height of antenna for LoS communication link set up will not be achieved. This may result in overestimation or underestimation of the required link budget needed for Southwestern urban, suburban and rural environments.

Conclusion

The refractivity gradient between 111 and 540 m has been estimated from obtained atmospheric parameters of the investigated environments in South-western region of Nigeria. The worst month value of point refractivity gradient is about -88 N-unit/km in Akure, -78 N-unit/km in Ore and -67N-unit/km in Omifon in Ondo State environment. In Ekiti State, the worst month values of point refractivity gradient for Ado-Ekiti, Oye-Ekiti and Ilupeju are -74.23 N-unit/km -58.37 N-unit/km and -66.46 N-unit/km respectively. While in Osun State, the worst month value of point refractivity gradient are -59.87 N-unit/km in Ilesa, -85.08 N-unit/km in Osu and -86 N-unit/km in Olede. Geoclimatic factor (*K)* values for the studied locations have been predicted from the various values of point refractivity gradient. It has been shown that the geoclimatic factor which caters for geographical and climatic conditions in multipath fading distribution varies with the month and season of the year. Finally, values of *k*-factor calculated are applicable in radio link design to estimate the height of antenna requirement and diffraction fade estimate.

Acknowledgment: The authors are grateful to National Aeronautics and Space Administration (NASA) for providing access to the atmospheric parameters.

References

Abu-Almal ,A. and Al-Ansari, K. (2010). Calculation of effective earth radius and point refractivity gradient in UAE. *International Journal of Antenna and Propagation*.

Adediji, A.T. and Ajewole, M. O. (2008). Vertical profile of radio refractivity gradient in Akure, South-west Nigeria. *Progress in Electromagnetics Research C*, Vol. 4, pp. 157-168.

Adediji, A.T. Ajewole, M.O. Falodun, S.E. (2011). Distribution of radio refractivitygradient and effective earth radius factor (k-factor) over Akure, South Western Nigeria. *Journal of Atmospheric and Solar-Terrestrial Physics,* 73: 2300–2304.

Adediji, A.T. Mandeep, J.S. and Ismali, M. (2014). Variation of radio field strength and radion horizon distance over three stations in Nigeria. *Journal of Atmospheric and Solar Terrestrial Physics*, 109, pp. 1-6.

Agbo, G.A. Okoro, O.N. and Amechi, A.O. (2013). Atmospheric refractivity over Abuja.Nigeria. *International Research Journal of Pure and Applied Physics*, pp. 37-45.

Ayantunji, B. G and Okeke, P. N. (2011). Duirnal and seasonal variation of surface refractivity over Nigeria. *Progress in Electromagnetic Res. B.*30: 201-222.

Egbe, J.N Ozuomba, S. and Enyenihi, H.J. (2017). Modelling and Application of Vertical Refractivity Profile for Cross River State. *World Journal of Applied Physics.* 2(1): 19-26

Falodun, S.E. and Ajewole, M.O. (2006). Radio refractivity index in the lowest 100 m layer of the troposphere in Akure, South-western Nigeria. *Journal of Atmospheric and Solar terrestrial Physics,* 68: 236-243.

International Telecommunications Union (2000). The radio refractive index, its formula and refractive data. *International Telecommunications Union, Geneva,* Recommendation of ITU-453-8.

International Telecommunications Union (2003). The radio refractive index, its formula and refractive data. *International Telecommunications Union,* Recommendation of ITU-4539.

International Telecommunications Union (2012). Propagation data and prediction methods required for the design of terrestrial LOS systems. *International Telecommunication Union Recommendation.* ITU- P.530-14.

Mason, P. S. (2010). Atmospheric effects on radio frequency wave propagation in a humid Near-surface environment. Nava Postgraduate School Monterey *CA.*

Ojo, O.L. Ajewole, M. Adediji, A. and Ojo, J.S. (2012). Estimation of clear-air fades depth due to Radio Climatological parameters for microwave link applications in Akure Nigeria. *International Journal of Engineering,* 7 (3): 1-8.

Ojo, O.L. Ajewole, M. O. Adediji, A.T. and Ojo, J.S. (2014). Microwave Anomalous Propagation Conditions in the First 100-m Altitude in a Tropical Location. *Journal of Microwave Power and Electromagnetic Energy,* 48 (2): 131-137.

Ononiwu, G. Simon, O. and Constance, K. (2015). Determination of the dominant fading and the effective fading for the rain zones. *European Journal of Mathematics and Computer Science,* Vol.22.

Zubar, M. (2011). Atmospheric influences on satellite communications. *Przglad Elektrotechnczny,* 87 (5): 261-264.