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ARTICLE

The Refractive Effect of k-Factor on Radio Propagation over Lokoja, Nigeria

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ABSTRACT

The effective earth radius factor (k-factor) has a refractive propagation effect on transmitted radio signals thus making its study necessary for the proper planning of terrestrial radio links and power budget. This study was carried out over the city of Lokoja, Nigeria, using ten years (2011 to 2020) atmospheric data of temperature, pressure and humidity both at the surface (12 m) and at 100 m AGL. The data were retrieved from European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5. The k-factor yearly variation follows the same trend with minimum and maximum values obtained during dry and wet season months respectively. In addition, the highest mean value of 1.00042 was recorded in the month of August while the lowest value of 1.00040 was recorded in the month of January with an overall mean value of 1.0003. This value is less than the recommended standard of 1.33 by ITU-R. The propagation effect corresponding to $k < 1.33$ is sub-refractive. The implication of this on radio wave propagation, especially terrestrial communications is that transmitted wireless signal is prone to losses. This can be mitigated through an effective power budget: Choice of transmitting antenna's height and gain, so as to improve the Quality of Service over the study area.

Keywords: Effective earth radius factor (k-factor); Refractive effect; Terrestrial radio link; Radio signal; Power budget

1. Introduction

Generally, the dynamics in the atmosphere can lead to attenuation of radio signal propagated from the source which is the transmitter to the destination also known as the receiver [1]. The interaction of propagated radio signals with the path of propagation through various mechanisms often leads to signal degradation [2]. This has made path loss-related studies by radio scientists and engineers imperative in

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radio communication industries [3]. Radio scientists and engineers need knowledge of the effective earth radius factor (k-factor) in a local environment for the proper planning of terrestrial radio links and power budget. If the troposphere is homogenous and turbulent free, any wave propagated into the troposphere parallel to the earth's surface will follow the earth's curvature [4] and be maximally received. However, due to the inhomogeneity of the troposphere, radio wave propagated undergoes bending depending on the tropospheric condition which also depends on the interaction of the radio climatic factors in the environment [5].

The k-factor is useful in the prediction of local radio wave propagation conditions. Typically, a design value of k = 1.33 is often assigned in locations where the values are not known. Studies have also shown that its value is location based and should not be assumed constant for all environments [4]. Since k-factor is weather and climate dependent, it is therefore imperative for regular studies to be carried out using up-to-date data in order to capture the effects of climate change. It also represents a spatial average, which can only otherwise be obtained from simultaneous meteorological surroundings along the propagation path. The k-factor is the radius of a hypothetical spherical Earth, without an atmosphere, for which propagation paths follow straight lines [6].

1.1 Radio refractivity

The radio refractivity N can be expressed as:

$$N=\frac{77.6}{T}\left(P+4810\frac{e}{T}\right)(N\text{-}units) \tag{1}$$

It depends on atmospheric parameters of pressure P (hPa), temperature T (K) and water vapour pressure e (hPa) [7,8].

1.2 k-factor

The k-factor can be obtained using two refractivity values as:

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

where N_1 and N_2 are the refractivity values at heights h_1 and h_2 respectively. In this study h_1 and h_2 are at the surface (12 m) and 100 m Above Ground Level (AGL) respectively. The k-factor can be expressed as indicated in Equations (3)-(4) [4,5].

$$k=\frac{1}{\left(1+a\left(\frac{dN}{dh}\right)\right)} \tag{3}$$

where a is the radius of the earth (a = 6371 km = 344 mni) and dN/dh is the rate of change of refractivity indices with height.

k-factor can also be expressed as indicated in Equation (4), which was used for k-factor computations in this work.

$$k=\frac{1}{1+\frac{\left(\frac{dN}{dh}\right)}{157}} \tag{4}$$

2. Review of related work

Transmission of a radio signal in the lower atmosphere is affected by many processes which include variations in air temperature, pressure, and humidity. These variations in weather parameters often result in refractivity changes [9]. These changes can result in abrupt changes in the propagation direction of a radio signal resulting in signal loss. Based on this premise, studies on the effect of radio climatic factors on propagated signals have become imperative for the planning of a reliable radio link in a region. Adediji and Ajewole [8] studied the vertical refractivity gradient in Akure, Nigeria by measuring atmospheric variables using integrated sensor suits (ISS) at different heights above ground level. Results show that propagation conditions have varying degrees of occurrence. Oyedum et al. [10] worked on reduced sea level refractivity in Minna, Central Nigeria. Ayantunji et al. [11] studied the seasonal and diurnal variation of surface radio refractivity in Akure, Nsuka, Minna, Sokoto and Jos (in Nigeria). The result of the work revealed higher values of surface refractivity during the wet season in Nigeria compared to the dry season months. Propagation of radio signal in the troposphere is affected by the interaction of signal with some primary (air temperature, pressure, and humidity) and secondary (radio refractivity, refractivity gradient, k-factor, etc.) radio-climatic factors. Many works have been done locally and internationally, but due to climate change it is necessary that studies employ up-to-date data to ensure the high reliability of findings.

A design value of 1.33 is often assigned for k-factor in line of sight link especially where information about the actual value of k-factor for that location is not available [7,4]. P. E. Okpani et al. [12] investigated the effect of radio climatic variables on signal propagation over Nsukka, Nigeria. Results have shown that k-factor values ranged from 1.555-1.652. Ojo et al. [4] worked on the characterization of secondary radio-climatic variables for microwave and millimeter wave link design in Nigeria, using five years of data (2009-2013). The study location included Akure, Enugu, Minna, Jos, and Sokoto cities. Results revealed average values of 1.476, 1.940, 1.860 and 1.287 respectively in Akure, Minna, Jos and Sokoto respectively. Ukhurebor and Odesanya [5] investigated k-factor over Auchi area of Edo State, South-South, Nigeria. The work determined k-factor mean value of 1.470 over Auchi which is slightly greater than ITU-R standard. Abu-Almal and Al-Ansari [6] calculated the k-factor and point refractivity gradient in United Arab Emirates (UAE). Fourteen years of radiosonde meteorological data were employed. Results revealed k-factor monthly variation from 1.43 to 3.17.

3. Methodology

This study was carried out in the city of Lokoja. Lokoja is the state capital of Kogi State, in North Central, Nigeria. Secondary atmospheric data of temperature, pressure and humidity both at the surface (12 m) and at 100 m AGL for Lokoja were retrieved from ECMWF ERA5 in December 2021. The data are high-resolution satellite-data with high reliability covering 2011-2020. ECMWF is an independent intergovernmental organization, which was established in 1975. They produced global numerical weather forecasts for worldwide users [13]. Equations (1)-(4) were used to determine the k-factor values for the years under study. The mean annual values were used for analysis to enhance the reliability of the results.

Data analysis and ITU-R recommendation on k-factor

Necessary analyses such as sorting, calculation of mean values and plotting of graphs were carried out using Excel. The ITU-R Recommendation on k-factor standards on refractive conditions of the atmosphere and the subsequent attenuation effect was equally used at achieving the set objectives. The ITU-R Recommendation on k-factor and associated propagation effects are presented in **Table 1**. The determined values of k-factor obtained for the years and seasons were compared with ITU-R standard in order to predict the refractive propagation effects over the study areas.

Table 1. ITU-R standards on k-factor and the associated propagation effects [5,7,14].

k-factor's range of values	Propagation effect on radio communications
$k = 1.33$ standard atmosphere	In this case, radio signals are transmitted along a straight line part on the earth's surface and go into space unimpeded.
$1.33 > k > 0$ Sub-refraction	Here, a portion of the radio wave (signal) propagates abnormally away from the earth surface, resulting to interference and coverage limitation.
$\infty > k > 1.33$ Super-refraction	Here, the radio wave signals (e. g microware link, GSM, satellite) spread irregularly toward the earth's surface thus, surface extending the radio horizon and merge the path clearance giving rise to irregular huge waves above the line of view due to multiple reflection.
$-\infty < k < 0$ Ducting	Here, there will be ducting which will make the radio waves to bend downwards with a curvature greater than the earth's.

4. Results

Figure 1 presents the yearly variation of k-factor covering 2011 to 2020 over Lokoja. The variation follows the same trend for the ten years under study with minimum and maximum values obtained during dry and wet season months respectively. **Figure 2** presents the mean variation of k-factor over the months of the years under study using mean values for the ten years in Lokoja. Observation from the figures shows lower values were obtained during the dry season months of January-March and October-December while higher values were obtained during the wet season months of April to September. **Tables 2** and **3** present the determined correlation coefficient(s) between k-factor and atmospheric parameters at the surface (12 m) and at 100 m respectively.

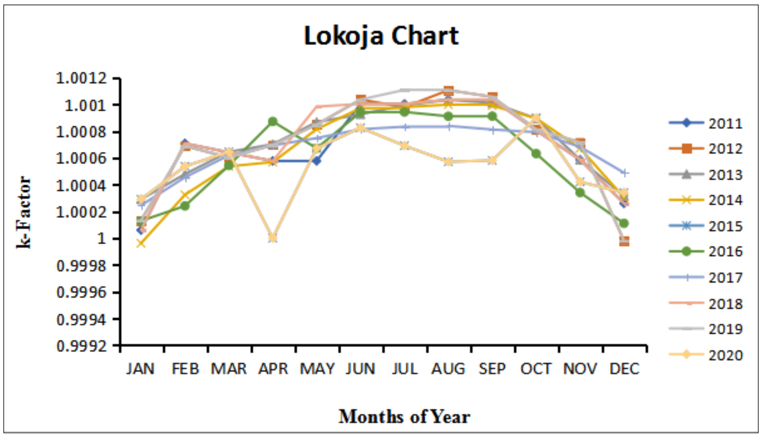

Figure 1. Yearly variation of k-factor covering the ten years (2011-2020) under study over Lokoja.

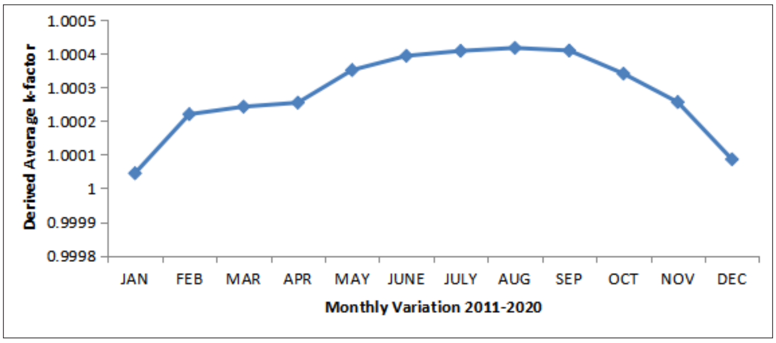

Figure 2. The mean monthly variation of k-factor for the ten years under study over Lokoja.

Table 2. Correlation coefficient between k-factor and atmospheric parameters at surface (12 m, AGL).

	Temp (C)	Humidity (%R.H)	Press. (hPa)	Rainfall (mm)	k-factor
Temp	1				
Humidity	–0.810	1			
Press.	–0.923	0.687	1		
Rainfall	–0.603	0.849	0.578	1	
k-factor	–0.620	0.949	0.715	0.784	1

Table 3. Correlation coefficient between k-factor and atmospheric parameters at 100 m, AGL.

	Temp (C)	Humidity (%R.H)	Press. (hPa)	Ammount Rainfall (mm)	k-factor
Temp	1				
Humidity	–0.846	1			
Press.	0.923	–0.676	1		
Rainfall	–0.756	0.840	–0.590	1	
k-factor	–0.872	0.955	–0.724	0.784	1

5. Discussion

In addition, the highest value of 1.00042 was recorded in the month of August while the lowest value of 1.0004 was recorded in the month of January. The overall mean value for the ten years under study is 1.00029 or approximately equal to 1.0003. This value is less than the recommended standard of 1.33 (i.e 1.33 > k > 0) standard by the International Telecommunication Union, Radio Study Group (ITU-Rec. 530-16, 2015). The propagation effect corresponding to k < 1.33 is sub-refraction; by interpretation, the atmosphere for the ten years under study in Lokoja is sub-refractive. The effect of this on radio wave propagation is that a certain portion of the propagated radio signals has the tendency to propagate abnormally by not following the earth's curvature. This often leads to interference and signal degradation before the expected points of reception. In this kind of situation the quality of reception of radio signals on the microwave, Satellite, VHF (Very High Frequency) and UHF (Ultra High Frequency) bands are affected. As a result of the finding of this work which employed ten years of recent data, the probability that Lokoja will experience sub-refraction in the subsequent years ahead is high. The implication of this on radio wave propagation especially terrestrial communications is that transmitted wireless signal is prone to losses due to sub-refractive. Based on these results, terrestrial radio communication engineers and various stakeholders of radio propagation systems in Lokoja should make deliberate efforts at mitigating sub-refractive losses. This can be achieved through an effective power budget; choice of transmitter power and antenna height and gain. In addition, existing terrestrial radio communication stations over the study areas may need to increase their antenna's height or by employing the use of repeater station(s), so as to improve the Quality of Service (QoS) over the study location.

The correlation coefficient between k-factor and temperature, pressure, humidity and rainfall at the surface are –0.62, 0.72, 0.95 and 0.79 respectively. Here, a high positive correlation coefficient was obtained between k-factor and humidity and k-factor and rainfall. The implication is that the higher the humidity and rainfall over the location, the higher the k-factor. This is consistent with the results depicted in **Figure 2**. On the other hand, using the atmospheric parameters at 100 m AGL, the correlation coefficient between k-factor and; temperature, pressure, humidity are –0.87, –0.72, 0.96 respectively. Here, a high positive correlation coefficient was obtained between k-factor and humidity again.

6. Conclusions

The variation of the effective earth radius factor (k-factor) for a period of ten years over the city of Lokoja was investigated. The refractive propagation effect of this secondary radio climatic factor on radio communication was revealed as sub-refractive based on the ITU-R standard of categorization. The implication of this on radio wave propagation especially terrestrial communications is that transmitted wireless signal is prone to losses due to sub-refractive. Based on these results, terrestrial radio communication engineers and various stakeholders of radio propagation systems in Lokoja should make efforts at mitigating sub-refractive losses. This can be achieved through an effective power budget; choice of transmitter power and antenna height and gain. In addition, existing terrestrial radio communication stations over the study areas may need to increase their antenna's height or by employing the use of repeater station(s), so as to improve the Quality of Service (QoS) over the study location.

Author Contributions

1) Author 'AA' (#1): Designed the study, made data available, read through the manuscript and made useful corrections.

2) Author 'FNI' (#2): Proof read the manuscript and made a contribution.

3) Author 'AOI' (#3): Carried out the study, wrote the first draft.

Conflict of Interest

There is no conflict of interest.

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