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Relationship between Meteorological Variables and Effective Earth Radius Factor over Auchi, Edo State, South-South, Nigeria

Ukhurebor K. E[1*] & Odesanya I.[2]

[1,*]Department of Physics, Edo University Iyamho, Edo State, Nigeria
[2]Department of Physics, Federal University Lokoja, Kogi State, Nigeria
ukhurebor.kingsley@edouniversity.edu.ng; ukeghonghon@gmail.com

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Abstract: The effective earth radius factor; *k*-factor is a major parameter in the prediction of the local radio wave propagation conditions of the lower atmosphere from meteorological variables. In this study the *k*-factor values were calculated and analyzed from the measurements of air temperature, relative humidity and atmospheric pressure in Auchi area of Edo State, South-South, Nigeria using a self-implemented cost effective portable weather monitoring device for a period of one year; 2017, so as to determine the relationship between these meteorological variables and the *k*-factor values. The fixed measuring method by placing the weather monitoring device on 188 m height above sea level was employed for the measurements of the various meteorological variables at the administrative block of Edo University Iyamho. The results show that the calculated *k*-factor values range from 1.06 to 1.94 with an average value of 1.47 and were generally higher during the months with much rainfall compared to that of the months with lesser rainfall. The measured meteorological variables were having significant influences on the calculated *k*-factor values during all the months, and these influences were more pronounced during the months with much rainfall compared with the months with lesser rainfall. The influence of the air temperature was higher compared to the other meteorological variables. The results that are obtained from this study should be taken into account for enhancement and improvement purposes in radio communication systems.
Keywords: Lower atmosphere; Air temperature; Atmospheric pressure; Relative humidity; Radio wave

1.0 Introduction

In the prediction of the local radio wave propagation conditions of the lower atmosphere, meteorological variables are very useful because of their influence on radio wave communication links in the atmosphere [1, 2].

The electromagnetic waves that are propagated in the lower atmosphere are mainly affected by the different components that made up the atmosphere, this is as a consequence of the variations of some meteorological variables such as air temperature, atmospheric pressure and relative humidity and these variations made the refractive index of the air in the lower atmosphere to vary from place to place [1, 2, 3, 4]. The path bending of the electromagnetic waves as a result of the non-homogeneous spatial distribution of the refractive index of air causes harsh effects such as multipath fading and interference, attenuation due to diffraction on the terrain obstacles which is also known as the radio holes [3, 5]. The variation in refractivity in the lower atmosphere is a function of meteorological variables [1, 2, 3, 6].

In order to have a good communication link for radio wave, the transmission medium need to be considered in order to have a better signal from the radio communication network, since the radio wave communication links are influenced by meteorological variables [2, 7]. The attitude and phase scintillations, absorption, scattering of radio wave network signals and other numerous complex mechanisms that occur in the lower atmosphere are caused by the random changes in the surface and vertical refractivity which can cause transmission signals lost and co channel interference. The effect of interference as a result of refractivity difference in the lower atmosphere is much in the humid climate than in the temperate climate regions due to the occurrence of high intensity humid rainfall [3, 7].

Some commonly used format of referring the International Telecommunications Union recommendation, (ITU-R) is presently being used in planning of broadcasting services for frequencies greater than 30 MHz, the mostly used radio propagation wave formulae from this recommendation are obtained from measurements carried out in most temperate climate regions of the world like Europe, Asia and North America. Although, the sub-Sahara African climate is different from these temperate climate regions own, these formulae can still be used for the planning of radio wave propagation services in the sub-continent due to the scarcity of accurate data from these regions [2, 5, 7, 8]. The radio refractive index is an important parameter in determining the quality of radio signals [3]. To determine the characteristics of a radio channel, surface and elevated refractivity data are mostly needed. The surface refractivity is more important for the prediction of some propagation effects than the elevated refractivity. Local coverage, refractivity gradient and other statistics of refractivity provide the most crucial explanation of the likely occurrence of refractivity related influence needed for local radio wave prediction methods [2, 5, 7, 9, 10]. The assessment of these meteorological variables will definitely enhance a better local radio propagation conditions that will assist radio network service providers in enhancing their quality of services [3].

In this study the measurement results of air temperature, relative humidity and atmospheric pressure were made at 188 m height above sea level at the Administrative block of Edo University Iyamho, Auchi area of Edo State, South-

South, Nigeria using a self-designed cost effective portable weather monitoring device. The measured meteorological were used to derive and analyze the *k*-factor. To the best of our knowledge from existing literatures this study is unique not only for the fact that we are using a self-implemented inexpensive portable weather monitoring device for the measurements of the meteorological variables but also it is one of the most recent studies on the relationship between meteorological variables and *k*-factor specifically in Auchi area of Edo State, South-South, Nigeria.

2.0 Materials and Methods

2.1 The Weather Monitoring Device

The weather monitoring device was implemented in such a way that it can be used remotely and the readings are displayed on the user friendly LCD display in numerical digital values for atmospheric temperature (°C), atmospheric pressure (mbar), relative humidity (%) and light intensity (lux) which can also be sent to computer via the programmed micro SD card or/and through the serial port; the Arduino SD card module. The user has the option of choosing how often the meteorological variables will be logged, measured, recorded, stored and displayed. The acquired meteorological variables are analyzed and the LCD displays the values respectively. In addition, the meteorological variables for each day are saved on the micro SD card in Excel format on a separate file with each file created with a file name that corresponds to the date and time when the meteorological variables were acquired. The users also have the option to stop the meteorological variables acquisition process at any given time by interrupting the routine. Details of the construction and implementation of the weather monitoring device including its validity is contained in [11].

2.2 Area and Method of Measurements

The measurements were done at the administrative block of Edo University Iyamho, Auchi area of Edo State, South-South, Nigeria which is located within Latitude 7.07°N and Longitude 6.27°E of the Greenwich Meridian at 188 m height above sea level. The area experiences the humid tropical climate, which is characterized by wet and dry seasons; the vegetation is that of the Savannah, with mostly open grassland and few scattered fire resistant trees. The topography is relatively undulating and it slopes from the north of the area to the south [2, 12].

The fixed measuring method by placing the weather monitoring device on 188 m height above sea level was employed for the measurements of the various meteorological variables at the administrative block of Edo University Iyamho, Auchi area of Edo State, Nigeria for continuous measurements. Although, the weather monitoring device measures four meteorological variables as stated earlier, only the daily records of air temperature (°C), atmospheric pressure (mbars) and relative humidity (%) were used for this particular study. The records cover twenty four hours each day from 00 hour to 2300 hours local time at intervals of one hour of which the average values from each day are then copied from the micro SD card to the computer from the weather monitoring device. The measurements of the meteorological variables were made for a period of one year; January to December, 2017.

2.3 Theoretical Background

It has been shown that the electromagnetic waves that are passing through the atmosphere bends, due to the various layers of the atmosphere and its permittivity, but it would have otherwise travel in a straight path if it was homogeneous; as a result of this spatial distribution of the refractive index of the air which causes hostile effects [2, 5]. The atmosphere's refractive index, n and the relative permittivity, $\mathcal{E}_r$ can be connected with [2, 7, 10]:

$$n^2 = \mathcal{E}_r \quad (1)$$

Since the value of the atmospheric refractive index is ≈ 1 and the variation is infinitesimal. A suitable parameter that can be used when modeling the variation of the atmospheric refractive index is the refractivity, N which is defined as;

$$N = (n - 1) \times 10^6 \quad (2)$$

N and meteorological variables such as the air temperature, atmospheric pressure, vapour pressured is connected by;

$$N = \frac{77.60}{T}\left(P + 4810\frac{E}{T}\right) \quad (3)$$

N can thus, be expressed as (ITU-R, 2004);

$$N = 77.60\frac{P}{T} + \left(3.73 \times 10^5 \frac{E}{T^2}\right) \quad (4)$$

The troposphere refractivity can be divided into two proportions, namely; the dry proportion and the wet proportion. The dry proportion contributes about 70% of the total refractivity in the troposphere. This dry proportion increases with increasing density of the gas molecules and changes with their distribution. It is normally stable and can be calculated from the measured air temperature and atmospheric pressure with an accuracy of about 20% [1, 2] using:

$$N_d = 77.60\frac{P}{T} \quad (5)$$

Where P is barometric pressure (millibars) and T is absolute temperature in Kelvin.

On the other hand, the wet proportion which is as a result of the polar nature of water molecules, contributes the main variation of refractivity in the atmosphere and can be calculated [1, 3] using:

$$N_w = 3.73 \times 10^5 \frac{E}{T^2} \quad (6)$$

Where E is partial pressure of water vapor (millibars) and can be calculated from;

$$E = \frac{RH}{100} \times E_s \quad (7)$$

Where RH is the relative humidity (%) and E_s which is the saturated vapour pressure (millibars) by:

$$E_s = 6.11 \times 10^{\frac{17.27\,(T-273.15)}{T-35.85}} \quad (8)$$

If the height; h of a ray above the earth's surface, the radius; r of the ray curvature and the vertical gradient of refractive index; dN/dh, the horizontal angle of the path; θ to a given point can be written as:

$$\frac{1}{r} = \frac{1}{N}\left(\frac{dN}{dh}\right)\cos\theta \quad (9)$$

According to [13], r may be connected to the relative earth radius; R in terms of the refractive index gradient:

$$\frac{r}{R} = k \quad (10)$$

Where k is the effective earth radius factor which can now be expressed as:

$$k \approx \frac{1}{1 + R\left(\frac{dN}{dh}\right)} \quad (11)$$

[14] in their work show that the *k-factor* can be used for categorizing the refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting as the case may be.

Recall that $R \approx 6370$ km. Thus, Eqn. (11) may now be expressed in terms of *N* as:

$$k \approx \frac{1}{1+(\frac{dN}{dh})/157} \qquad (12)$$

Within the earth's surface, $dN/dh \approx$-39 N-units/km and this will give a *k*-factor value of 1.33; with such value we will have what is known as normal refraction or standard atmosphere. Here, radio signals are transmitted along a straight line path on the earth's surface and go into space unimpeded. If $1.33 > k > 0$, we will have sub-refraction; which implies that the radio waves propagate abnormally away from the earth's surface. But when $\infty > k > 1.33$ we will have super-refraction and this signifies that the radio wave signals spread irregularly towards the earth's surface; thus, extending the radio horizon and increasing path clearance thereby giving irregularly huge ranges above the line of view as a result of multiple reflections. But, if $-\infty < k < 0$, there will be ducting and this will make the radio waves to bend downwards with a curvature greater than the earth's own. The radio signals can become trapped between a layer in the lower atmosphere and the surface duct which is the earth's or sea's surface or between two layers in the lower atmosphere which is the elevated duct. In this wave guide-like propagation, very high radio signal strengths can be obtained at a very long range which is far above the line of view [2, 3, 7].

3.0 Discussion of Results

The analysis for this study was done procedurally via calculation of *k*-factor from the measured meteorological variables; air temperature, relative humidity and atmospheric pressure using Eqn. 1 to Eqn. 12 accordingly. The monthly calculated *k*-factor values for the period under consideration range from 1.06 to 1.94 with an average value of 1.47. Some statistical analysis was also done so as to determine their variability. Comparisons of the various measured meteorological variables and the calculated and the *k*-factor values were also respectively done graphically. The average monthly measured meteorological variables of each of the measured meteorological variables and the calculated *k*-factor are contained in Table I. The mean values for air temperature, relative humidity and atmospheric pressure were 25.46 °C, 73.08 % and 1004.56 mbar respectively for the period of the measurements; January to December, 2017.

Since the average value of the calculated *k*-factor is 1.47 and $\infty > k >$ 1.33, we can inferentially say that the local radio wave propagation condition for Auchi, area of Edo State, South-South, Nigeria is predominantly super-refractive. This signifies that the radio wave signals spread irregularly towards the earth's surface, hence extending the radio horizon and increasing path clearance, thereby giving irregularly huge ranges above the line of view as a result of several reflections.

In Fig. 1 the *k*-factor values for the period under consideration; 2017 on monthly basis which were obtained from the monthly records is shown. A critical look at this figure revealed that the months with higher relative humidity (occasion with much rainfall); April, May, June, July, August, September and October have greater values compared to the ones with lower relative humidity (occasion with lesser rainfall); November, December, January, February and March, the values range from 1.20 to 1.94 during the months with high relative humidity;

while, the values for the months with lower relative humidity range from 1.06 to 1.62 for the period under consideration. This result again agrees very well with the results of [7, 15].

Fig. 2 shows the plot of the measured air temperature against the calculated *k*-factor values during the various months; January to December, 2017, Fig. 3 shows the plot of the measured relative humidity against the calculated *k*-factor values during the various months; January to December, 2017, while Fig. 4 shows the plot of the measured atmospheric pressure against the calculated *k*-factor values during the various months; January to December, 2017. It was observed that these measured meteorological variables were having significant influences on the calculated *k*-factor values during all the months in 2017, and these influences were more pronounced during the months with higher relative humidity which are; March, April, May, June, July, August, September and October; rainy season, compared with the months with lower relative humidity which are; November, December, January and February; dry season.

The measured air temperature was observed to have much influence on the calculated *k*-factor values all through the months in 2017 compared to the other two meteorological variables (relative humidity and atmospheric pressure), this again affirm that fact that air temperature have significant influence on other meteorological variables [3, 16, 17].

4.0 Conclusion

The measurements of air temperature, atmospheric pressure and relative humidity were made at 188 m height above sea level in the administrative block of Edo University Iyamho, Auchi area of Edo State, South-South, Nigeria for a period of one years; 2017 using a self-implemented inexpensive portable weather monitoring device so as to analyze the relationship between these meteorological variables and *k*-factor values. The results that were obtained from this study would assist in the enhancement and improvement of radio communication systems.

Deductively, the summarized results obtained from this study are:

The local radio wave propagation condition for Auchi area of Edo State, South-South, Nigeria is predominantly super-refractive.

The measured air temperature, relative humidity and atmospheric pressure were having significant influence on the calculated *k*-factor during all the months in 2017 and these influences were much during the months with higher relative humidity. The measured air temperature was having much influence on calculated *k*-factor all through the months in 2017.

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Month	Average Air Temperature (°C)	Average Relative Humidity (%)	Average Atmospheric Pressure (mbars)	Calculated *k*-factor
Jan	**28.20**	**42.70**	**1001.70**	**1.16**
Feb	**31.80**	**48.20**	**1002.50**	**1.30**
Mar	**30.10**	**68.70**	**1004.60**	**1.50**
Apr	**29.30**	**85.20**	**1007.10**	**1.40**
May	**28.40**	**92.10**	**1005.70**	**1.30**
June	**26.30**	**92.40**	**1005.90**	**1.58**
July	**25.00**	**95.30**	**1004.70**	**1.72**
Aug	**26.60**	**78.60**	**1003.90**	**1.88**
Sept	**25.50**	**78.40**	**1005.40**	**1.40**
Oct	**25.70**	**68.90**	**1005.60**	**1.44**
Nov	**27.80**	**68.20**	**1004.70**	**1.40**
Dec	**26.50**	**58.30**	**1002.90**	**1.52**
Mean	25.46	73.08	1004.56	1.47

Table I: Average Measured Meteorological Variables and Calculated k-factor for 2017

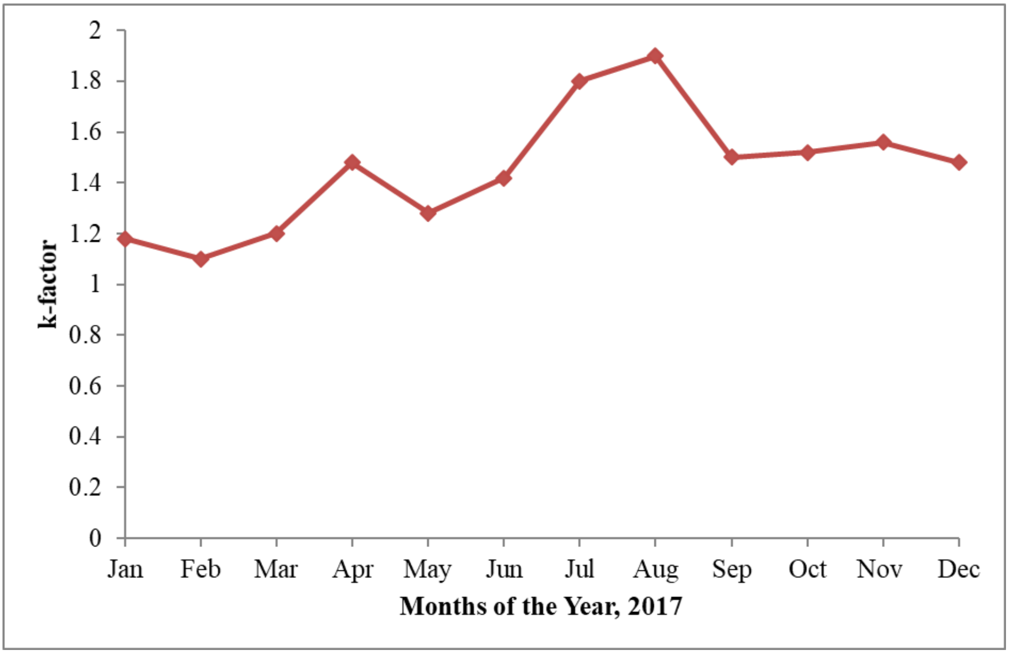

Fig. I: Monthly Variations of k-factor

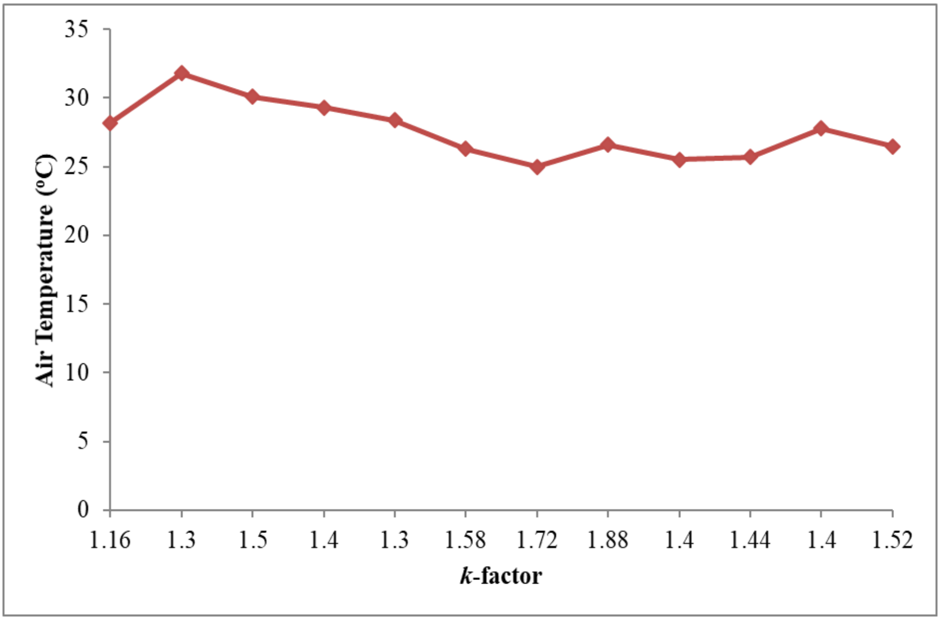

Fig. II: Air Temperature with the k-factor

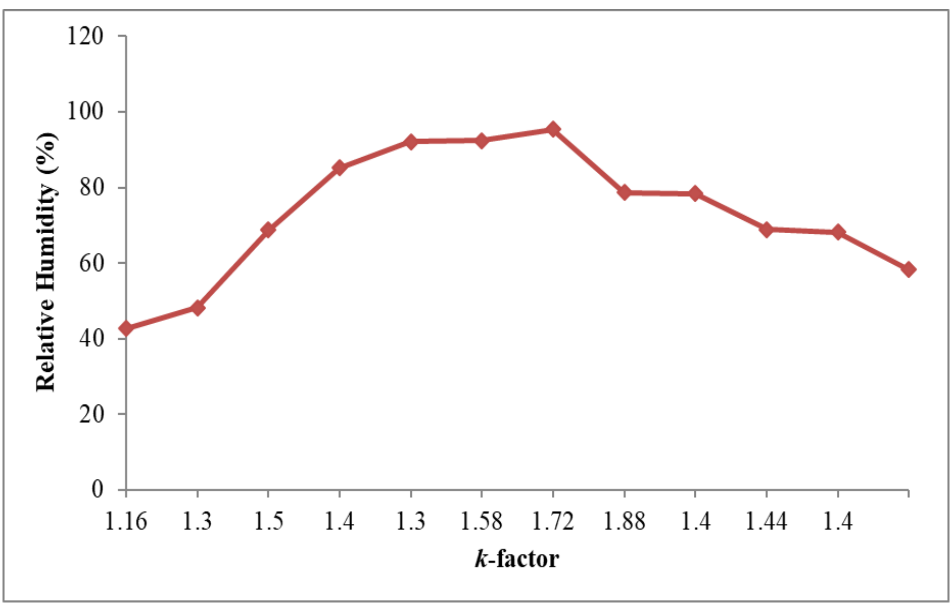

Fig. III: Relative Humidity with the k-factor

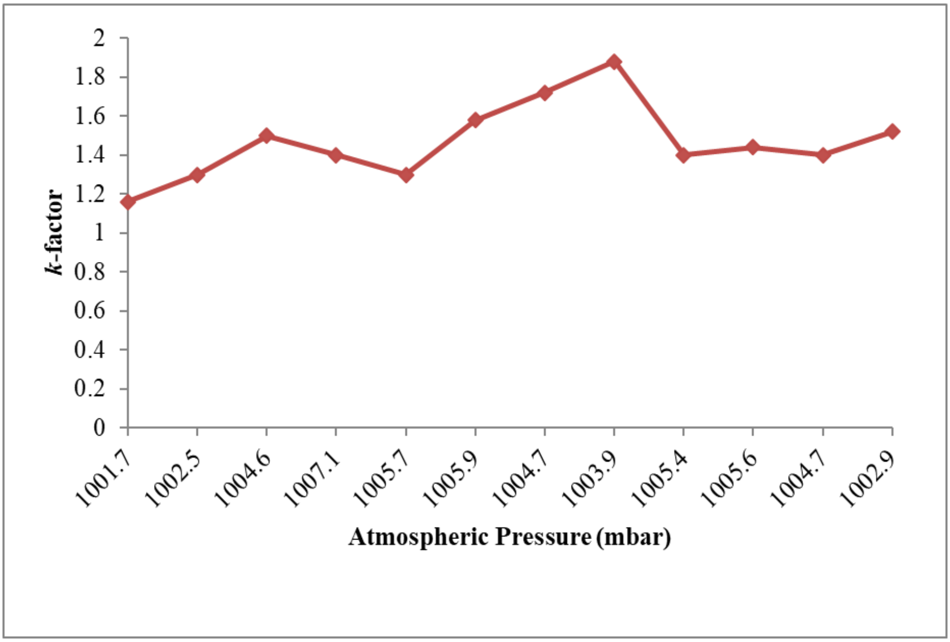

Fig. IV: Atmospheric Pressure with the k-factor