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Research Article

Fade Depth and Outage Probability Due to Multipath Propagation in Nigeria

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Abstract: In this study, the multipath fading occurrence in six cities in Nigeria is investigated using the geoclimatic factor approach and ITU-R recommendations P530-14. The cities considered for the investigation are Kaduna $(10^0 20' N, 7^0 45' E)$, Lagos $(6.45^0 N, 3.38^0 E)$, Abuja $(9.07^0 N, 7.39^0 E)$, Port-Harcourt $(4.81^0 N, 7.04^0 E)$, Enugu $(13.00^0 N, 5.24^0 E)$ and Kano $(12.00^0 N, 8.59^0 E)$ in Nigeria. Five-year radiosonde data is used in estimating the percentage of time that a certain fade depth is exceeded and hence outage probability due to atmospheric multipath propagation, assuming the given fade depth leads to the received signal falling below the squelch level. The Inverse Distance Square (IDS) technique was employed to estimate point refractivity gradient not exceeded for 1% of the time in the lowest 65 m above the ground for the selected six cities in the six geopolitical zones within Nigeria. Standard error of the mean and confidence interval for both annual average and seasonal average of point refractivity gradient is calculated to reflect possible deviation in the given readings. The values of point refractivity gradient obtained were used in determining the geoclimatic factor K. The results presented shows monthly, seasonal and annual variation of both point refractivity gradient and geoclimatic factor K. The results confirmed that the geoclimatic factor K is region based.

Keywords: Geoclimatic factor, outage probability, radiosonde data, refractivity, refractivity gradient, troposphere meteorological data

INTRODUCTION

A number of advantages are inherent in the use of terrestrial fixed radio links operating at microwave frequencies on Line-Of-Sight (LOS) paths. Terrestrial fixed radio links are preferred in carrying large numbers of voice, video, wide-band data transmissions, high definition TV channels and high quality audio among others (Grabner *et al*., 2010; Bogucki and Wieloweiyska, 2009). It is pertinent that their performance and availability should be above a particular threshold for it to offer a substantial quality of service. This then necessitates the use of high precision equipment and devices together with good knowledge of the transmission medium. In a terrestrial LOS links, the medium of transmission is troposphere, with variation in the climatic conditions which has a substantial effect on the propagation of the radio waves. Normally, service availability of 99.9% for the worst month is the design target for a fixed links which should result in an outage not exceeding 53 min within a year (ITU-R, 2012).

The probability that a link will not be available in a terrestrial microwave communication systems (for clear air) is mostly determined by the refractive gradient of the wireless medium Understanding the characteristics of propagation play a critical role in the design of LOS links and help in the improvement of system performance and availability. It is reported in literature that the seasonal or diurnal variations of refractivity gradients has an effect on the signal and lead to refractive fading, viz: diffraction fading, beam spreading, multipath fading which results in Rayleigh fading in narrowband systems, selective fading in wideband systems and blackout fading (ducting) (Olsen and Tjelta, 1998). When there is no rainfall, the link outages rely solely on clear air conditions which are determined by the state of atmospheric refractivity. The atmospheric refractivity varies with time and space more or less randomly and full details of it are out of reach in practice. Hence the statistics of atmospheric refractivity and related effects are of interest in link design (Olsen and Tjelta, 1999; Fashuyi, 2006; Fashuyi *et al*., 2006).

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The major factor in microwave systems design is multipath fading which is associated with strong negative gradients more for a fixed links operating below 10 GHz. Effect of multipath can be reduced with higher fade margin. However, if the path has excessive path outage, the performance can be increased by using one of the diversity methods. Aside from clear-air, precipitation (air, fog, etc.) also leads to the attenuation of radio signals. It is essential to note that when the frequency is above 10 GHz, precipitation attenuation will dominate the microwave and millimetre bands. Frequency bands below 10 GHz has to be used whenever there is heavy precipitation (Grabner *et al*., 2010; Bogucki and Wieloweiyska, 2009).

Propagation modelling is used mostly to determine the probability of satisfactory performance of communication systems. The microwave link designer works in ensuring that the outages resulting from these variations are kept at a minimum, thus adequate system fade margins are implemented. Hence, for considering the statistical nature of radio wave propagation, appropriate models are utilized. The prediction models for deep fading range of the multipath fading distribution have been in existence for some years. Most of these are based on the empirical fits of Rayleigh-type distributions to the fading data on individual countries. Those models include Morital model of Japan, the Barnett-vigants model for the united States of America, the Doble and the Pearson for United Kingdom, among others. (Lystad *et al*., 1998).

The models mentioned above have a variable that takes into account the regional/climatic types of the zone of interest. This factor for ITU-R models is the geoclimatic factor K. The geoclimatic factor is indicative of the geographical and climatic characteristics of a given region (Freeman, 1997). It is used in estimating the multipath fading distributions (Olsen *et al*., 2003). A short period outage of a signal is called multipath fading and it is responsible for the performance of a given link. In order to reduce its effect, there is a need to study its characteristics thoroughly.

This study focuses on the characterization and modelling of such effects of clear air on multipath fading in communication links. The characterization of seasonal variation of fading and the influence of meteorological parameters to it provides the way to optimize transmission performance by adapting the transmission equipment design and usage to the amount of fading anticipated at a given site/place and time of the year. On the other hand, the modelling of these effects help in determining the probability of occurrence of fade duration, inter-fade duration and fade slope in a given climatic region; hence in the evaluation of internal parameters of Fade Mitigation Technique (FMT) control loop.

Researches are still ongoing continues on prediction modelling either from fading measurement or from climatological data. Two types of model reported in literature are theoretical models and statistical models. The statistical models that are frequently used are the ray-tracing is a geometrical optics method while parabolic equation is a full way approach to a homogeneous wave equation solution (Odedina and Afullo, 2007). Ray-tracing method has been modelled by different authors (Asiyo and Afullo, 2013; Israel *et al*., 2018; ITU-R, 2003) and parabolic equation method by others. Looking at the two methods, the parabolic equation method provides a more accurate prediction tool because it is able to cater for both diffraction and refraction phenomena. Even though the parabolic equation method is popular, a comparison of its model and actual fading measurements shows some discrepancy, which can be attributed to the fact that the medium of radio propagation is inhomogeneous and the two methods work better for homogeneous media (Odedina and Afullo, 2009; Odedina and Afullo, 2008; Odedina and Afullo, 2010; Al Ansari and Kamel, 2008). A promising solution is to approximate the spatial distribution of the gradient from meteorological ground data using statistical methods (Al Ansari and Kamel, 2008).

METHODOLOGY

Study area: The study area is Nigeria (Fig. 1) on $9.08^0N, 8.67^0E$. The area is enclosed in the northern, eastern, western and southern parts by the Republic of Niger, Cameroon, the Republic of Benin and the Gulf of Guinea respectively. The total land area is about 923300 km^2 (Odekunle, 2004). Nigeria in general has hot climate throughout the year with slight difference between dry and wet season. The climate of Nigeria is usually classified into two seasons, viz: the Wet and Dry. The wet season is normally from April to October while the dry season which is from November to March. In between June and September, the weather is quite hot, humid and raining (Odekunle, 2004).

Nigeria climate is dominated by the influence of three major atmospheric phenomena, namely: the maritime tropical (mT) air mass, the continental tropical (cT) air mass and the equatorial easterlies (Ojo, 1977). The temperature over the country varies from place to place. The most clearly marked differences are between the coastal areas and the interior and between the high plateau and the lowlands. On the plateau, the mean annual temperature value vary between 21°C and 27°C. On the interior lowlands, the mean annual temperatures registered are over 27°C. The coastal fringes have lower means than the interior lowlands (Adediji and Ajewole, 2008). The seasonal temperature range, as in other tropical countries, is low, with an average value of 6°C. In fact, at some southern cities it may be as low as 3°C.

The specific locations where data were collected for the study are (Kaduna $(10^020'N, 7^045'E)$, Lagos $(6.45^0N, 3.38^0E)$, Abuja $(9.07^0N, 7.39^0E)$, Portharcort

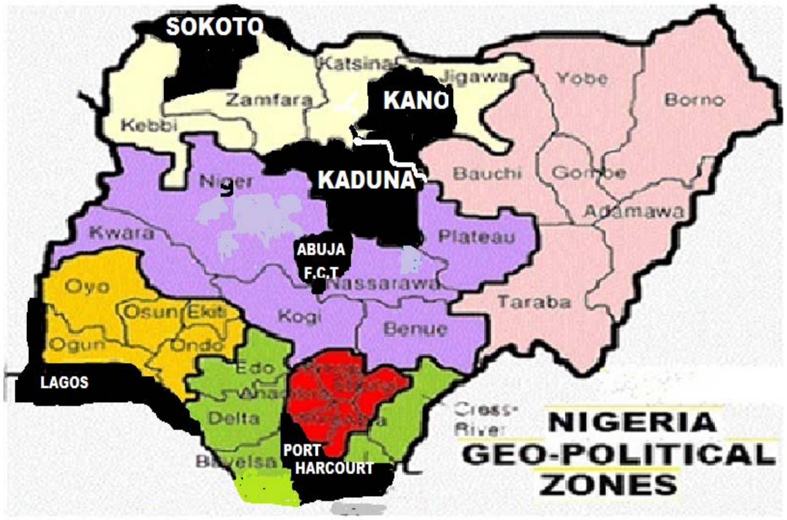

Fig. 1: Map of Nigeria (http://www.bdb.co.za)

($N, 7.0498^0E$), Enugu ($13.00^0N, 5.2476^0E$) and Kano ($12.0022^0N, 8.5920^0E$). Each of the six locations was selected as being representative of the geographical zone (South West, South East, North West, North East, South South and North Central) comprising an area of similar climatic tendency in Nigeria.

Estimation of values in un-sampled places through Spatial interpolation: Spatial interpolation is a method used in data analysis in estimating a set of observations associated with a set of sampled points or places to a set of un-sampled points or places where observations are not obtainable. The rational with spatial interpolation is that points closer to each other incline to have the same values than those far apart (Lystad *et al.*, 1998). Approximations of virtually all spatial interpolation techniques can be characterized as weighted averages of sampled data and they all share the same general approximation method, as seen in (Li and Heap, 2008):

$$\acute{Z}(X_0) = \sum_{i=1}^{n} \lambda_i Z_{(x_i)} \tag{1}$$

where,

$\acute{Z}$ = The assessed value of an aspect at the point of interest X_0
Z = The practical value of the sampled point X_1
λ_i = The weight allocated to the sample point
n = The number of sampled points used for estimation

Techniques that use distance based weighting of the data accept that each datum has a local influence that reduces as the distance increases until a point at which the influence is insignificant. The inverse distance weighting or Inverse Distance Weighted (IDW) method was employed in this study to determine values in un-sampled points. It approximate the values of a feature at un-sampled points using a linear addition of standards at sampled points weighted by an inverse function of the distance from the point of interest to the sampled points. The weighting bias can be represented by (2) (Li and Heap, 2008):

$$\lambda_i = \frac{1/d_i^p}{\sum_{i=1}^{n} 1/d_i^p} \tag{2}$$

where,

$$\sum_{i=1}^{n} \lambda_i = 1 \tag{3}$$

where, d_1 as the distance between X_0 and X_i, p being the power parameter and *n* as defined previously (Li and Heap, 2008):

The major factor influencing the accuracy of IDW is the value of the power parameter, with p being 2, then the method is called Inverse Distance Square. The other influencing factor on the accuracy is the number of sampled points used in estimations which is also selected arbitrarily (Li and Heap, 2008).

Calculation of geoclimatic factor: The propagation of radio waves in the troposphere is influential on the variations of climatic conditions (temperature, pressure and humidity). These parameters are related to the atmospheric refractivity and can be expressed as:

$$N = (n - 1) \times 10^6 = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \tag{4}$$

where,

N = The atmospheric refractivity
n = The refractive index of the atmosphere
T = The temperature (K)
P = The atmospheric pressure (hpa)

e = The water vapour pressure (hpa) (Freeman, 1997)

The water vapour pressure *e* is given by (5), where *H* (%) is the relative humidity and *t* (°C) is the air temperature:

$$e = \frac{6.1121H}{100}\, exp\left(\frac{17.502t}{t+240.97}\right) \quad (5)$$

The refractivity gradient can be defined as the rate at which the refractivity is varied with respect to the height of antenna. Refractivity gradient is of a greater interest to designers of LOS links because signal do experience multipath fading if the refractivity gradient in the atmosphere varies with height (Bogucki and Wielowieyska, 2009). Equation (6) can be used to compute refractivity gradient with N_1 and N_2 at the refractivity heights h_1 and h_2 respectively (Abu-Almal and Al-Ansari, 2010):

$$\frac{dN}{dh} \approx \frac{N_2 - N_1}{h_2 - h_1} \quad (6)$$

The rate at which the refractivity gradient occur in the first 65 m above the ground level is calculated. Thereafter, cumulative distribution of *dN/dh* is computed from the frequency of occurrence. From the cumulative distribution curve, the point refractivity gradient not exceeded for 1% for each months is then determined. Whenever there is no availability of 1% of the refractivity gradient from the distribution curves, the inverse distance square technique is employed for the estimate of value from the nearest values. Equation (7) can be used to determine the geoclimatic factor (for quick planning) where dN_1 represents the point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year (ITU-R, 2012):

$$K = 10^{-4.2-0.0029dN_1} \quad (7)$$

Estimation of fade depth: Fade depth is a ratio, expressed in decibels, of a reference signal power to the signal power during a fade (Odedina and Afullo, 2008). ITU-R methods are mostly used for the estimation of narrow-band fading distribution at large fade depths in the average worst month while aiming at quick planning and detailed planning (Djuma, 2012). Three steps are basically involved in the estimation of fade depth. They are: estimation of the geoclimatic factor K, followed by the calculation of path inclination and the calculation of percentage of time that a certain fade depth A is exceeded in the average worst month. Path inclination (ε_p) can be calculated from transmit and receive antenna heights h_e (m) and h_r (m), above the sea level and the path length *d* (km) from (8) (ITU-R, 2012):

$$|\, \varepsilon_p \,| = |\, h_e - h_r \,|/\mathrm{d} \quad (8)$$

The third step can then be estimated from Eq. (9) which is meant for the quick planning purpose:

$$P_w = Kd^{3.1}(1+ |\, \varepsilon_p \,|)^{-1.29} f^{0.8} \times 10^{-0.00089h_l - A/10} \quad (9)$$

where,

F = The frequency (GHz)
P_w = The percentage of time that fade depth *A* (dB) is exceeded in the average worst month
h_l = The altitude of the lower antenna (the smaller of h_e and h_r)
d and *K* = Path length and geoclimatic factor, respectively.

With constant variation of propagation medium, the knowledge of the probability of a fade depth of a particular magnitude to occur leads directly to the probability of outage and hence the link availability probability, suppose that the given fade depth results to the received signal falls below the squelch level (Bogucki and Wielowieyska, 2009). In this study, we employed ITU-R method for quick planning with overall standard deviation of error in predictions of 5.9 dB. The precision in the prediction will increase if the ITU-R method for detailed link design, which requires that the terrain data be used. The overall standard deviation of error for detailed applications method is 5.7 dB (ITU-R, 2012).

RESULTS AND DISCUSSION

Geoclimatic factor: Radiosonde data collected from Nigeria Meteorological Agency (NIMET) for five years (2010 to 2014) is used in this study. Radiosonde balloons are launched twice per day at around 10 am in the morning and 11pm in the night. But, in some months data was available only once per day. In some isolated conditions, data is reported thrice per day hence showing the non-uniformity of the monthly samples used in the analysis. It should be noted that radiosonde soundings do not report climatic parameters (i.e., temperature, humidity and pressure) at definite heights. Therefore, the value of dN_1 is estimated using (6) where N_1 is considered at the h_1 value closest to 65 m height, so that h_2 falls within 65±10% m. Generally, for the design of radio communication systems, the essential statistics of the effects of propagation pertain to that of the worst month. The worst month in a year for a preselected threshold for any performance degrading mechanism is that month in a period of the twelve consecutive calendar months, during which the threshold is exceeded for the longest time. It must also be noted that the worst month is not necessarily the

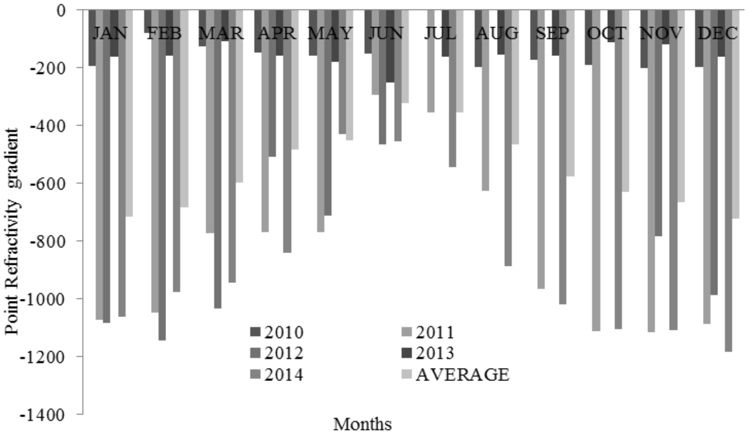

Fig. 2: Monthly variation of point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year for Abuja

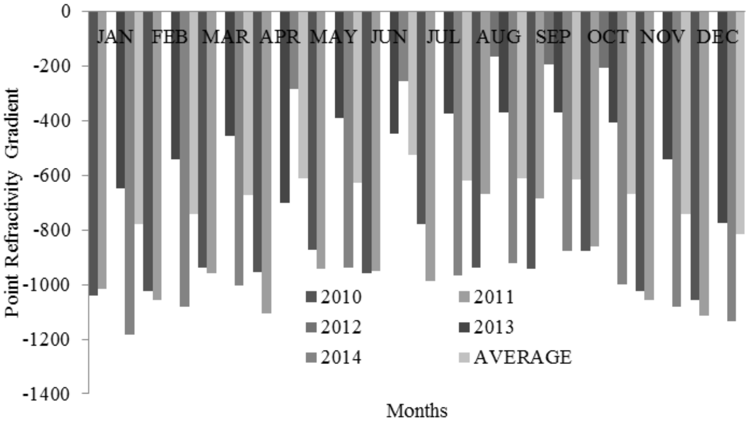

Fig. 3: Monthly variation of point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year for Port Harcourt

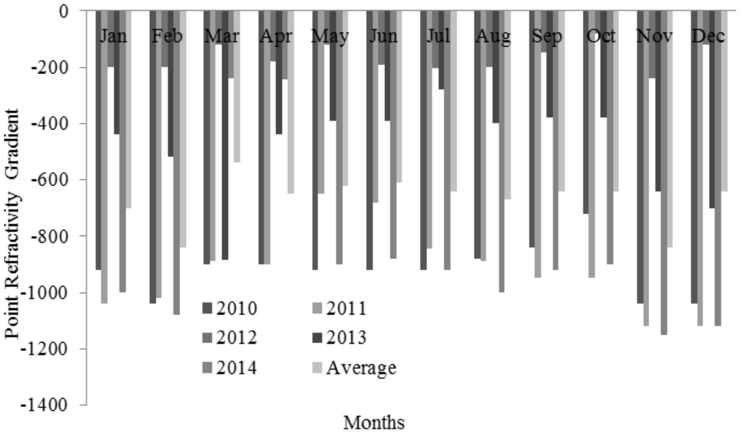

Fig. 4: Monthly variation of point refractivity gradient in the lowest 65m of the atmosphere not exceeded for 1% of an average year for Enugu

same month for all the threshold levels (Al Ansari and Kamel, 2008). Figure 2 to 7 show monthly variations of point refractivity gradient for the five years and their average. Results indicate that the worst cases fall in the raining season apart from Kaduna and Kano that has the worst cases in dry season.

Figure 8 shows yearly average for the point refractivity gradient indicating the confidence intervals

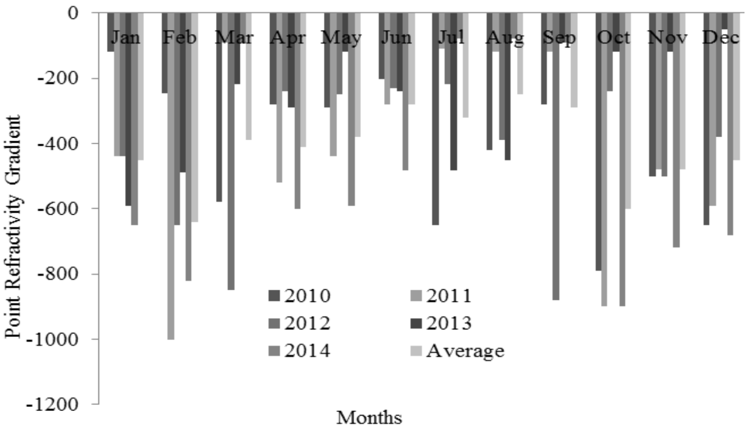

Fig. 5: Monthly variation of point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year for Lagos (Ikeja)

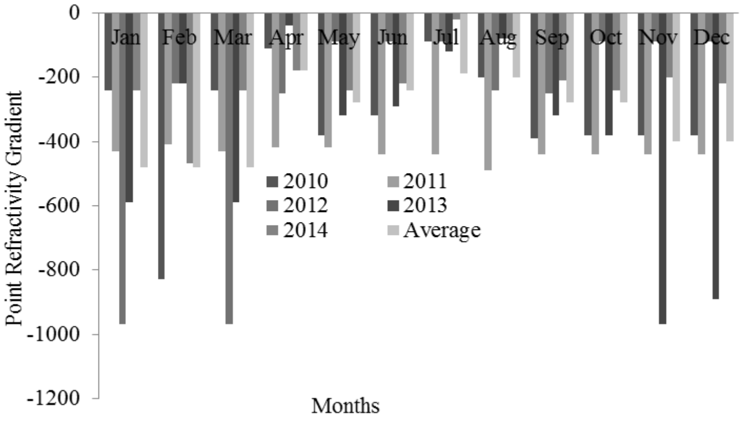

Fig. 6: Monthly variation of point refractivity gradient in the lowest 65m of the atmosphere not exceeded for 1% of an average year for Kaduna

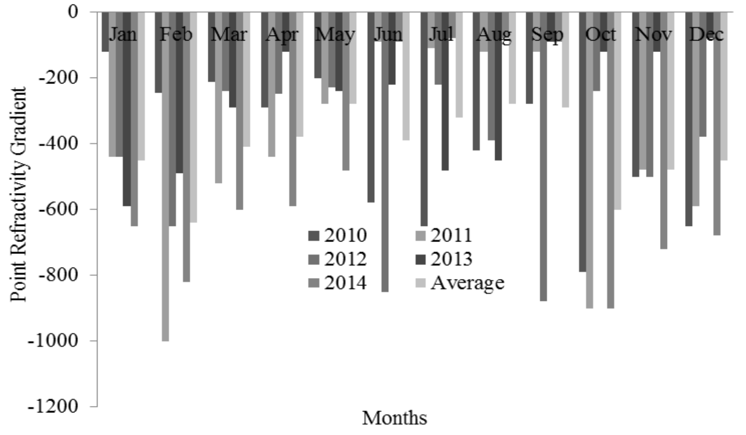

Fig. 7: Monthly variation of point refractivity gradient in the lowest 65m of the atmosphere not exceeded for 1% of an average year for Kanos

of our estimates. The average for the five years is also shown for each of the cities. It is evidenced that point refractivity gradient also varies annually. In this study, the results show that the year 2011 has the lowest value of point refractivity gradient and the value becomes less negative in the succeeding years. The Standard Error (SE) for each year was calculated from: $SE = S = s/\sqrt{n}$, where s is the sample standard deviation and n is the number of samples. From the values of SE, Confidence Intervals (CI) which shows the range in which the

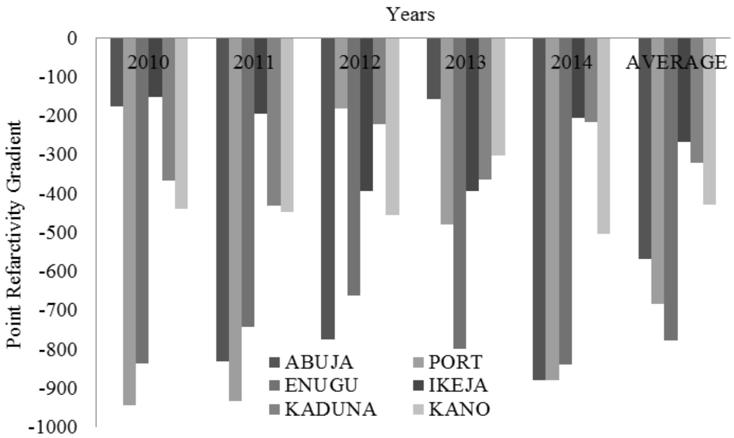

Fig. 8: Confidence intervals graph for the yearly average of point refractivity gradient for each of the six locations in Nigeria

Table 1: Worst month values

Cities	Worst months	Point refractivity gradient	Geoclimatic factor
Lagos	July	-415.056	0.000092
Port Harcourt	August	-846.133	0.000481
Abuja	July	-723.037	0.000550
Kaduna	April	-485.577	0.000167
Kano	May	-658.179	0.000933
Enugu	June	-974.383	0.000134

Table 2: Geoclimatic factor K for Lagos (Ikeja)

			Ikeja(K)			
Months	2010	2011	2012	2013	2014	Average
Jan	0.0000232	0.0000235	0.000217	0.00263	0.00085	0.00071
Feb	0.0000212	0.0000209	0.000021	0.00065	0.00050	0.000298
Mar	0.0000232	0.0000226	0.0000203	0.00432	0.00040	0.00119
Apr	0.0000234	0.0000213	0.0000164	0.05620	0.00161	0.000144
May	0.0000163	0.0000180	0.0000131	0.00567	0.88100	0.000222
Jun	0.0000163	0.0000163	0.0000136	0.00311	0.35800	0.000904
Jul	0.0000132	0.0000148	0.0000113	0.03580	0.00109	0.0000922
Aug	0.0000111	0.0000122	0.0000114	0.00075	0.88600	0.000222
Sep	0.0000101	0.0000127	0.0000114	0.02490	0.01120	0.000342
Oct	0.0000219	0.0000191	0.0000167	0.00099	0.00228	0.000827
Nov	0.0000167	0.0000178	0.0000180	0.00709	0.00190	0.000226
Dec	0.0000176	0.0000163	0.0000163	0.00250	0.000251	0.000172

Table 3: Geoclimatic factor K for Port Harcourt

			Port harcourt			
Month	2010	2011	2012	2013	2014	Average
Jan	0.000000588	0.000000245	0.0000221	0.000824	0.0410	0.0000838
Feb	0.000000268	0.000000246	0.0000171	0.000809	0.0272	0.0000562
Mar	0.00000146	0.000000267	0.0000157	0.000835	0.0328	0.0000672
Apr	0.00000231	0.000000222	0.0000158	0.00103	0.0686	0.0000139
May	0.000000296	0.000000128	0.0000231	0.00253	0.0605	0.0000158
Jun	0.000000677	0.0000000606	0.0000181	0.00665	0.121	0.000319
Jul	0.0000000619	0.0000000815	0.0000156	0.00661	0.199	0.000514
Aug	0.00000309	0.0000000467	0.0000232	0.0552	0.000420	0.000481
Sep	0.000000548	0.0000000463	0.0000132	0.0131	0.000350	0.00034
Oct	0.000000128	0.0000000123	0.0000132	0.00135	0.0545	0.000434
Nov	0.000000251	0.00000129	0.0000222	0.000882	0.137	0.000138
Dec	0.00000132	0.00000121	0.0000151	0.000880	0.0543	0.000138

"true" value of the estimates fall were calculated from: $CI = S = m \pm 1SE$, where m is the mean/average value of point refractivity gradient of each of the years. Monthly variation of point refractivity gradient depends on season with worst months occurring mainly in raining season. However it is observed that, yearly variation seems to follow some cycle which needs to be calculated and we are processing data for more years to ascertain this hypothesis.

Table 1 provides the summary of the worst month for the cities with point refractivity gradient values and their corresponding geoclimatic factor K values. Table 2 to 7 tabularize the values of geoclimatic factor K for each of the months for the five year period under study

Table 4: Geoclimatic factor K for Kano

			Kano(K)			
Month	2010	2011	2012	2013	2014	Average
Jan	0.0000512	0.0000959	0.0000722	0.0000631	0.00422	0.0000900
Feb	0.000423	0.0000583	0.0000772	0.0000631	0.00320	0.000764
Mar	0.0000343	0.0000112	0.0000761	0.000137	0.00234	0.000520
Apr	0.0000613	0.0000551	0.000119	0.000233	0.00806	0.00171
May	0.0000723	0.0000000523	0.000127	0.000217	0.0197	0.00402
Jun	0.0000521	0.0000231	0.000124	0.000130	0.0343	0.00693
Jul	0.0000621	0.0000000294	0.000126	0.000214	0.122	0.0245
Aug	0.0000821	0.000591	0.000125	0.000203	0.142	0.0285
Sep	0.0000722	0.0000494	0.000125	0.341	0.131	0.0944
Oct	0.000233	0.0000542	0.000126	0.405	0.0591	0.0929
Nov	0.000523	0.00000828	0.000132	0.487	0.0109	0.0996
Dec	0.000323	0.000000275	0.000112	0.0351	0.00673	0.00845

Table 5: Geoclimatic factor K for Abuja

			Abuja(K)			
Month	2010	2011	2012	2013	2014	Average
Jan	0.0000451	0.0000122	0.00000507	0.0000749	0.00405	0.000837
Feb	0.0000436	0.0000124	0.00000185	0.000109	0.00307	0.000645
Mar	0.0000477	0.00000114	0.00000631	0.0000934	0.0246	0.00495
Apr	0.0000299	0.000000170	0.0000000876	0.000132	0.0436	0.00875
May	0.0000189	0.0000000783	0.0000000374	0.0000940	0.0101	0.0202
Jun	0.0000174	0.0000000537	0.0000000588	0.0000755	0.0148	0.0296
Jul	0.0000171	0.0000000511	0.000000111	0.000953	0.275	0.0550
Aug	0.0000164	0.0000000478	0.00000717	0.000139	0.149	0.0298
Sep	0.0000179	0.0000000424	0.00000607	0.000135	0.0982	0.0197
Oct	0.0000204	0.000000117	0.0000523	0.0000924	0.0982	0.0197
Nov	0.0000343	0.00000302	0.000000632	0.0000912	0.0439	0.00881
Dec	0.0000234	0.00000784	0.0000332	0.0000978	0.00414	0.000860

Table 6: Geoclimatic factor K for Enugu

			Enugu (K)			
Month	2010	2011	2012	2013	2014	Average
Jan	0.0000152	0.00000644	0.00000475	0.05914	0.00997	0.0138
Feb	0.0000114	0.000000211	0.000000517	0.0055	0.00852	0.00280
Mar	0.000000487	0.000000536	0.000000615	0.00647	0.1168	0.0247
Apr	0.000000270	0.000000485	0.000000296	0.01587	0.01174	0.00552
May	0.000000110	0.000000491	0.000000118	0.01813	0.0175	0.00713
Jun	0.000000118	0.000000151	0.000000116	0.03485	0.03241	0.0135
Jul	0.000000154	0.000000138	0.000000250	0.05494	0.07709	0.0264
Aug	0.000000153	0.000000126	0.0000128	0.0326	0.04647	0.0158
Sep	0.000000238	0.000000980	0.000000537	0.02274	0.04677	0.0139
Oct	0.000000477	0.000000342	0.0000475	0.03621	0.04135	0.0155
Nov	0.000202	0.000000961	0.0000336	0.00736	0.02335	0.00615
Dec	0.0000401	0.000000254	0.000218	0.01845	0.01077	0.00590

Table 7: Geoclimatic factor K for Kaduna

			Kaduna(K)			
Month	2010	2011	2012	2013	2014	Average
Jan	0.0000241	0.0000613	0.0000723	0.000154	0.0000878	0.00008
Feb	0.0000214	0.0000613	0.0000772	0.000950	0.0000924	0.000240
Mar	0.0000283	0.0000614	0.0000760	0.000631	0.0000127	0.0000483
Apr	0.0000371	0.0000613	0.000120	0.00807	0.0000641	0.00167
May	0.0000491	0.0000613	0.000113	0.000605	0.0000631	0.000178
Jun	0.0000338	0.0000613	0.000125	0.0000929	0.0000631	0.000752
Jul	0.0000148	0.0000613	0.000127	0.000879	0.0000631	0.000229
Aug	0.0000179	0.0000613	0.000125	0.0447	0.0000631	0.00899
Sep	0.0000321	0.0000613	0.000125	0.0443	0.0000631	0.00892
Oct	0.0000980	0.0000613	0.000126	0.0000595	0.0000870	0.0000864
Nov	0.0000135	0.0000613	0.00136	0.0000209	0.0000767	0.0000618
Dec	0.0000234	0.0000613	0.000137	0.0000330	0.0000776	0.0000664

in the six-geopolitical zones in Nigeria. As expected the values of geoclimatic factors are inverse to those of point refractivity gradients. It should be noted that, in estimating the average values of the geoclimatic factor,

Table 8: Comparison of ITU-R and estimated values of point refractivity gradient and geoclimatic factor K

	Point refractivity gradient		Geoclimatic factor k	
Cities	Mean	Worst months	Mean	Worst months
Lagos	-415.056	-362.493 (Jul)	0.000446	0.000092
Port harcourt	-687.558	-867.123 (Jul)	0.000239	0.000481
Abuja	-556.91	-723.037(Jul)	0.000214	0.000550
Kano	-429.395	-658.179 (May)	0.000391	0.000093
Kaduna	-319.949	-458.179(Apr)	0.000245	0.000167
Enugu	-776.255	-974.383 (Jun)	0.000297	0.000134
Average	-532.521	-678.465	0.000305	0.000253
ITU-R		-400		0.000302

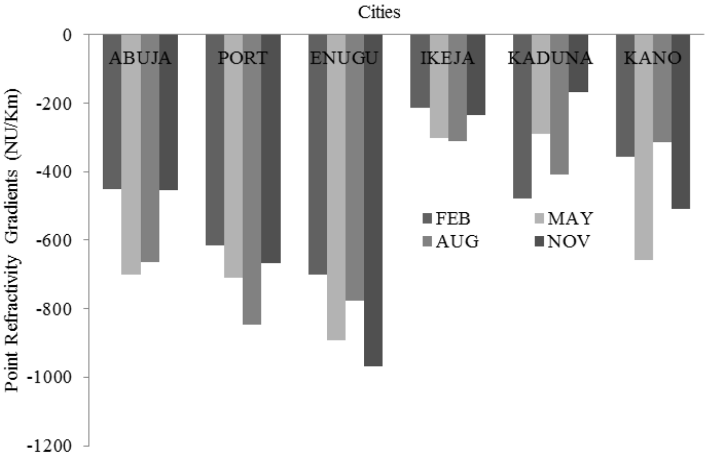

Fig. 9: Seasonal variation of point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year

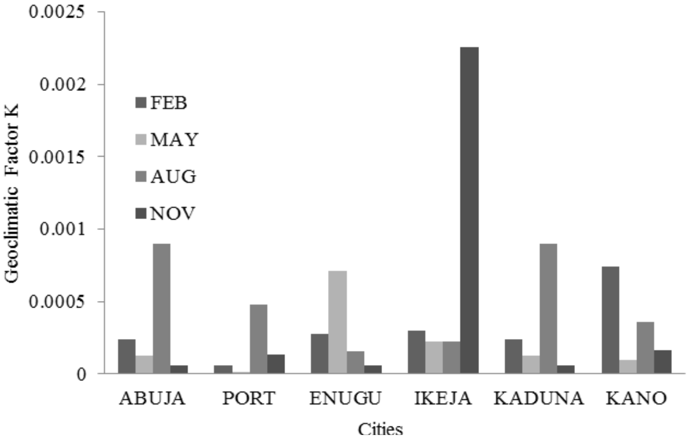

Fig. 10: Seasonal variation of geoclimatic factor K in the lowest 65 m of the atmosphere not exceeded for 1% of an average year

we first find the average of point refractivity gradient values and then we apply (7) to approximate the geoclimatic factor values.

The ITU-R P.453-9 (ITU-R, 2003) normally recommends seasonal estimation of point refractivity gradient. February to cater for January to March, May to cater for April to June, August to cater for July to September and lastly November for October to December. Our seasonal values are provided in Fig. 9 with their corresponding geoclimatic factor K values in Fig. 10. These figures also indicate that for all the regions, the worst month falls in November which is winter apart from Port Harcourt with the worst month being August. In addition to seasonal variability, the geoclimatic factor K also varies with region/climatic types as expected.

Table 8 shows the comparison of the estimated values of point refractivity gradient and geoclimatic factor K values with the ITUR value (ITU-R, 2003) for Nigeria. The results imply that the ITU-R value (-400NU/km) under-estimates the geoclimatic factor K and it does not consider the worst month situation.

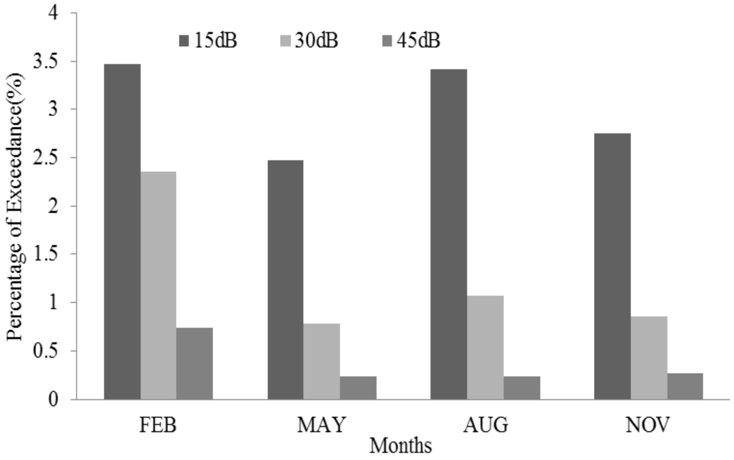

Fig. 11: Percentage of time a certain fade depth A (dB) is exceeded in Kaduna

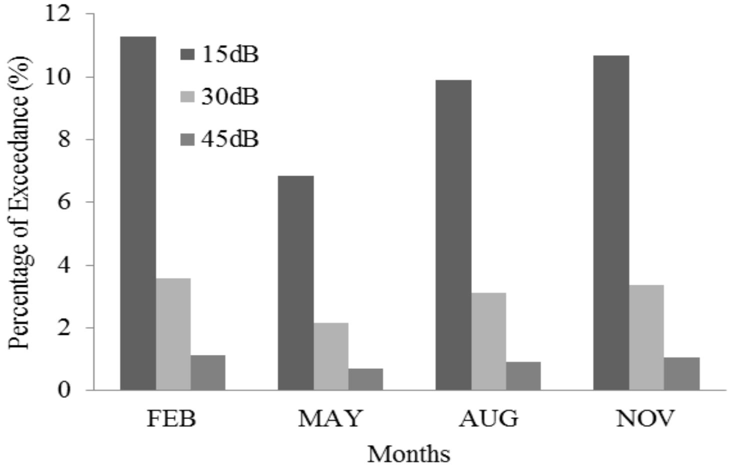

Fig. 12: Percentage of time a certain fade depth A (dB) is exceeded in Enugu

Moreover, ITU-R assumes one value of point refractivity gradient for the whole of Nigeria, which should never be the case. Geoclimatic factor which is a function of point refractivity gradient is a representative of both topology and climatic conditions of a region. Nigeria has more than one climatic type scattered across its regions, hence, it is not a good assumption that it can have one value of point refractivity across all its regions.

Fade depth and outage prediction: The knowledge of fading phenomena is very important in the design and performance of wireless systems. Microwave link attenuation due to multipath is not a permanent occurrence and its probability of occurrence needs to be known for a reliable terrestrial link (Bogucki and Wielowieyska, 2009). It has been mentioned earlier that multipath fading is a random phenomena which can only be described statistically. The ITU-R method is used in estimating the percentage of time that a certain fade depth is exceeded. Prediction of fading phenomena can be made at a fixed value of fade depth or estimated at a certain percentage of outage. The values of geoclimatic factor K as determined in the previous sub-section are used in the prediction of the percentage of time a certain fade depth is exceeded. Equation (9) requires link parameters and the following parameters for the two coastal towns (Port Harcourt and Ikeja) were adopted in the analysis:

$f = 11$ GHz, $h_e = 124$ m, $h_r = 76$ m and d = 48.25 km

Figure 11 to 14 show the probability in percentages, that a certain fade depth is exceeded for Kaduna, Enugu, Kano and Abuja respectively. For these inland locations, the link parameters used were adjusted to take their altitudes into effect but still maintaining the path inclination constant as for the coastal towns. This is to make sure that the variation in percentage of time that a certain fade depth is exceeded is due to the geoclimatic factor K of the area. For Ikeja, Kano, Abuja, Enugu and Portharcourt the worst month is in February (dry season) which compares well with the work of (Akinloye *et al*., 2016) in which the highest probability of duct occurrence was found to be in

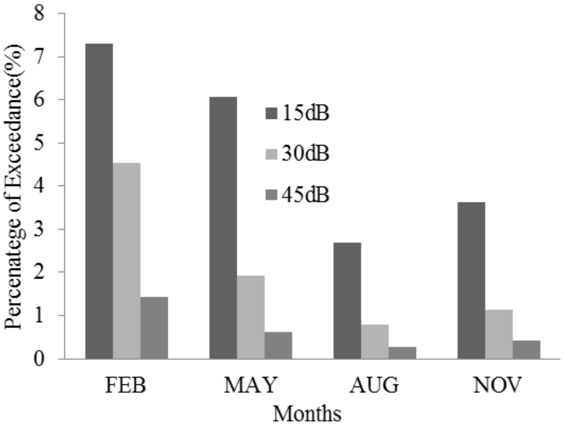

Fig. 13: Percentage of time a certain fade depth A (dB) is exceeded in Abuja

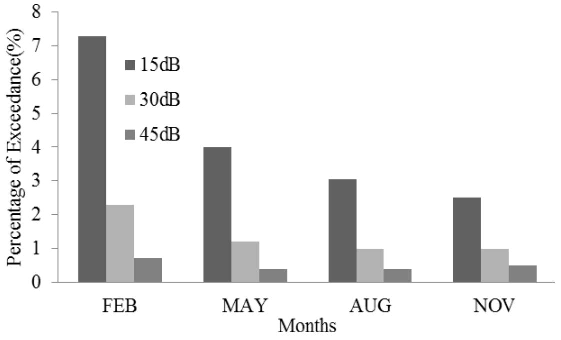

Fig. 14: Percentage of time a certain fade depth A (dB) is exceeded in Kano

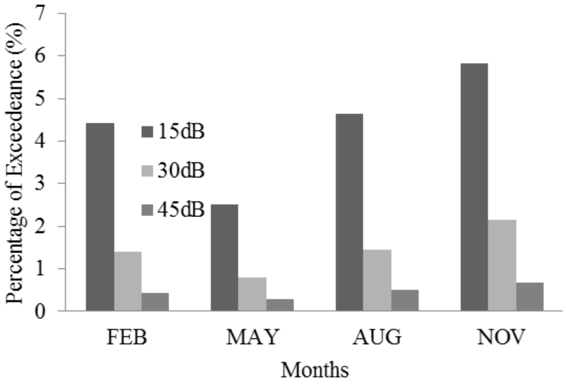

Fig. 15: Percentage of time a certain fade depth A (dB) is exceeded in Port-Harcourt

February. ITU-R (ITU-R, 2003) also confirms the same for the probability of duct occurrence. Duct occurrence has high correlation with multipath fading (Akinloye *et al*., 2016).

Figure 15 and 16 shows seasonal variation of the percentage of time various values of fade depth are exceeded for Port Harcourt and Ikeja respectively. It can be seen that for both cases, the percentage of time that a certain fade depth varies from season to season.

Table 9: Comparison of Point refractivity gradient and geoclimatic factor in Nigeria

Location	Refractivity gradient	K-Factor
Lagos (May) (Israel *et al*., 2018)	-300.17	1.0E-03
Lagos (May) (Determined Value)	-300.00	2.22E-04
Lagos (June) (Israel *et al*., 2018)	-310.00	6.90E-04
Lagos (June) (Determined Value)	-268.21	9.04E-04
Lagos (July) (Israel *et al*., 2018)	-247.16	5.10E-04
Lagos (July) (Determined Value)	-360.00	9.22E-05
Lagos (Oct.) (Israel *et al*., 2018)	-270.76	7.90E-04
Lagos (Oct.) (Determined Value)	-260.00	8.27E-04
Lagos (Nov.) (Israel *et al*., 2018)	-342.64	2.10E-03
Lagos (Nov.) (Determined Value)	-225.00	2.26E-03
Calabar (Mar) (Iniobong *et al*., 2016)	-256.57	1.23E-04
Portharcourt (Mar) (Determined Value)	-133.301	6.72E-05
Calabar (April) (Iniobong *et al*., 2016)	-111.33	5.618E-05
Portharcourt (April) (Determined Value)	-131.40	3.40E-04
Calabar(Sept.) (Iniobong *et al*., 2016)	-92.52	4.46E-05
Portharcourt (Sep.) (Determined Value)	-133.44	3.40E-04
Calabar (Oct.) (Iniobong *et al*., 2016)	-186.86	8.03E-05
Portharcourt (Oct) (Determined Value)	-130.44	4.34E-04

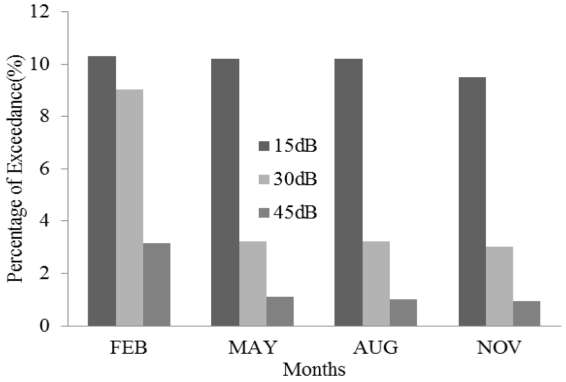

Fig. 16: Percentage of time a certain fade depth A (dB) is exceeded in Ikeja

For this reason, (ITU-R, 2012) recommends planning around the worst month. In considering the worst month for both locations, Port Harcourt has higher percentages of occurrence than Ikeja even though both are coastal towns. This can be attributed to their difference in climatic types and this stresses the need to determine the Geo-climatic factor K for each region for more accurate predictions.

Comparison of results: The results obtained in this research is compared with some of the results carried out earlier in some regions in Nigeria. Table 9 shows point refractivity gradient and geoclimatic factor for Calabar, Portharcout and Lagos (Ikeja) during the raining and dry seasons. These values were compared with values obtained in Lagos by Israel *et al*. (2018) and the vales obtained in Calabar by Iniobong *et al*. (2016). Results obtained indicate similar value in the region of similar climatic region.

CONCLUSION

In this study, multipath fading has been examined in relation to the distribution of refractivity gradient in the lowest 65 m above the ground, from which the point refractivity gradient was estimated. However, in cases where the value was not observable, the Inverse Distance Square (IDS) method has been used to approximate the value. The point refractivity gradient estimated for the regions was found to be more negative than the ITU-R value for Nigeria. The ITU-R value of point refractivity gradient for the region is -400NU/km while the estimated value derived from five year radiosonde data was found to be -532.521 Nunits/km. The worst month values of point refractivity gradient for Enugu, Abuja and Port-Harcourt occur in June, July and July are -974.383NU/km, -723.037NU/km and -867.123NU/km respectively. The worst month values of point refractivity gradient for Ikeja, Kaduna and Kano occur in July, April and May are -362.493/km, -458.179NU/km and -658.179 NU/km respectively. Geo-climatic factor K for the various regions has been predicted from the various values of point refractivity gradient. It was confirmed that the Geo-climatic factor which caters for geographical and climatic conditions in multipath fading distribution varies with the month, season and year. The value is also region based and hence there is need to determine the value for regions of interest for more accurate prediction of fading phenomena. The results also indicate that the worst month varies annually and it generally occurs in the raining (season) months in most of State of Nigeria apart from Savannah region (Kaduna) and Sahelian geographic region (Kano) where it occurs in dry season (April and May).

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