World Academy of Science, Engineering and Technology
International Journal of Geological and Environmental Engineering
Vol:7, No:8, 2013

Effect of Geographical Co-Ordinates on the Parameters in the Rain Rate Model for Radio Propagation Applications

Olatinwo M. O., Oyeleke Olaosebikan, David Henry O.

Abstract**—**Rain attenuation plays a lot of roles in the design of satellite and terrestrial microwave radio links, hence a good knowledge of its effect is of great interest to Engineers and scientists in that it is often required to give a high level of accuracy of the rainrate distribution that expresses rainrate from the lowest value to the highest. This study proposes a model to express rainrate parameters alpha (α) and beta (β) as a function of geographical location at 0.01% of the time. The tropical locations used in the development of the effect were Ilorin, Ile-Ife, Douala, Dar-es-Selam, Nairobi, Lusaka, and Brazilia.

This expression clearly confirms the variability of rainfall from place to place. When consistency test was carried out using the expression to generate rainrate for each location examined, the result obtained was reliable for rain intensities between 5mm/h and 200mm/h. The variability of α and β with latitude also shows that different latitudes have different cumulative rain distribution. The model proposed in this study would be one of the useful tools to Radio Engineers since the precipitation effect in the design of satellite and terrestrial microwave radio links is among the factors to consider when designing communication systems.

Keywords**—** Rain rate, attenuation, geographical location.

NOMENCLATURE

M_α = Slope obtained through α,

C_α = the intercept on the vertical axes,

θ = Latitude of the station,

M_β = Slope obtained through β,

C_β = the intercept on the vertical axes,

Γ = Percentage of time,

$R_{0.01}$ = Rain rate obtained at 0.01% of time measured in mm/hr.

I. INTRODUCTION

COMMUNICATION satellites are playing important role in long range communications. The most fundamental obstacle in design of satellite communication system at frequencies above 10GHz is attenuation caused by rain. There is the need to study the meteorological variations of humidity and rainfall to predict conditions and effective receiving systems because of the advancement of communication.

Most of the performance and reliability of communication systems especially in tropical countries like Nigeria are critically dependent on attenuation caused by rain.

It is clearly known that rainrate cumulative distribution varies from region to region. In tropics, there is high rain rate and consequently, there is high attenuation.

As electromagnetic wave propagating through the atmosphere suffers: absorptive attenuation by atmospheric gases, atmospheric refraction, atmospheric scintillation, attenuation by rain and other forms of precipitation and clouds, focusing and defocusing , decrease in antenna gain due to wave – front incoherent multipath effects and attenuation by sand dusts [1]. A lot of models have been proposed on cumulative rain rate distribution among them are Log-normal approximation, gamma distribution, Moupfouma's Adimula - Biyant's equation etc.

For measurement made at the University of Ilorin main campus over a period of two years, January 1st, 2001 to December 31st 2002 in an equatorial climate (Latitude 8.30° N and Longitude 4.5°E) [2], an empirical model for rain intensity distribution was proposed as [3]:

$$R_\Gamma(mm/h) = 12.42\Gamma^{-0.430}$$

The equation is of the form

$$R_\Gamma(mm/h) = \alpha\Gamma^{-\beta} \quad \text{or} \quad R_\Gamma\left(mm/h\right) = \frac{\alpha}{\Gamma^\beta}\,[4] \qquad (1)$$

where 'α' and 'β' are parameters obtained by the use of regression program.

In this paper, an attempt is made by expressing both parameters 'α' and 'β' as a function of rainfall intensity during 0.01% and how they vary with Latitude.

0.01% of the time is the percentage of time for rain intensity recommended by the ITU – R to evaluate the availability of terrestrial and satellite radio wave links.

II. RAIN DISTRIBUTION MODELS

Many models have been proposed among them are Log – normal and gamma models.

Olatinwo M O, Oyeleke Olaosebikan, and David Henry O. are with Science Technology Department, School of Applied Sciences and Technology, Federal Polytechnic, Offa. Kwara State, Nigeria (phone; 08056655675, 08073616331, 08066453092; e-mail: mufuolatinwo@ yahoo.com, oyelekeolaosebikan@gmail.com, dherryolatunji@yahoo.com).

Log – normal model gives a good approximation for low rainfall rates while gamma model gives good approximation for high rainfall rates [1].

III. Evaluation of Parameters

From measurement made in the University of Ilorin main campus (latitude 8.3°N and Long 4.5°E) over a period of two years was utilized to propose a model of rain rate distribution for the station. The model is of the form

$$R_{\Gamma}(mm/h) = \alpha\Gamma^{-\beta}$$

where 'Γ' is percentage of time.

This is a power law where R_{Γ} is the rain rate predicted in mm/h.

'α' and 'β' are parameters obtained through regression program.

For the following tropical stations, available rain data for different years was also used to obtain their respective parameters 'α' and 'β' for Ilorin, Ile – Ife, Dar-eS – Salam, Nairobi, Douala , Brazilia and Lusaka.

TABLE I
Values of Parameters 'α' and 'β' for Different Locations Obtained through Regression Program

S/N	Station	Geographical Location		Parameters 'α' and 'β'	
1	Ilorin	8.3°N,	4.5°E	12.42	0.430
2	Lle – Ife	7.49°N,	4.07°E	10.12	0.449
3	Dar-es – Salam	6.15°S,	39.18°E	9.37	0.438
4	Nairobi	1.17°S,	36.5°E	8.35	0.421
5	Douala	4.05°N,	9.43°E	13.0	0.513
6	Brazilia	15.54°S,	47.50°E	5.41	0.483
7	Lusaka	15.54°S,	47.50°E	7.5	0.436

The table above shows that at general extent, there are variations in the values of 'α' and 'β' which indicates that violent convective rain is inch felt in some parts than others.

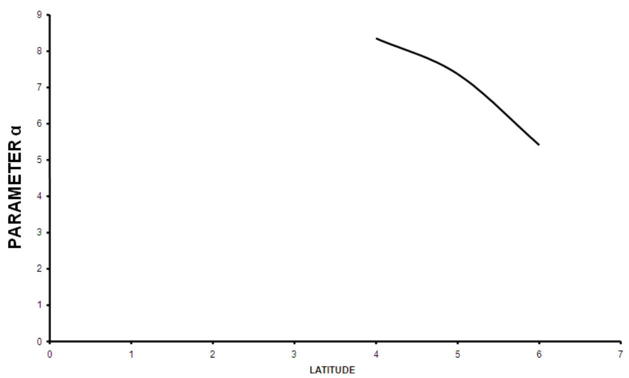

Fig. 1 (a) The graph of parameter α against latitude for the stations considered

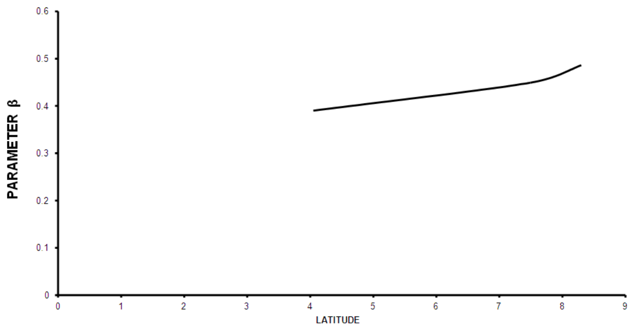

Fig. 1 (b) The graph of parameter β against latitude for the stations considered

The table above shows that at general extent, there are variations in the values of 'α' and 'β' which indicates that violent convective rain is much felt in some parts than others, those effects include wind, strong updraft, temperature changes and other phenomenon associated with thunderstorm rain [5].

An Average value of these parameters may be difficult to obtain for these locations due to the variability in thunderstorm and other effects like topography, mountains and large body of water.

IV. Variability of Rainrate with Latitude

A graph of parameters plotted against latitudes as shown in Figs. 1 (a) and (b), a trend equation of the form

$$\alpha = M_{\alpha} Sin\theta + C_{\alpha} \quad (2)$$

$$\beta = M_{\beta} Sin\theta + C_{\beta} \quad (3)$$

were obtained.

From the available data;

M_{α} = 1.13,

C_{α} = 10.80

M_{β} = 0.0235

C_{β} = 0.451

Replacing (2) and (3) for (α) and (β) in (1) respectively gives:

$$R_{\Gamma} = \frac{M_{\alpha} Sin\ \theta + C_{\alpha}}{\Gamma^{\left(M_{\beta} Sin\ \theta + C_{\beta}\right)}}$$

or

$$R_{\Gamma} = \left(M_{\alpha} Sin\theta + C_{\alpha}\right)\Gamma^{-\left(M_{\beta} Sin\theta + C_{\beta}\right)} \quad (4)$$

Let Φ and Ψ represent (2) and (3) respectively, (4) now becomes:

$$R_{\Gamma}(mm/h) = \frac{\phi}{(\Gamma)^{\Psi}}$$

Equation (5) is the predicted equation and can be expressed as:

$$R_P(mm/h) = \frac{\varphi}{(\Gamma)^{\Psi}} \quad (5)$$

V. Consistency Test

Considering Ilorin latitude 8.3^0N and Ile-Ife latitude 7.49^0N and substituting the values obtained from the trend equations (2) and (3), Tables II and III were obtained respectively.

TABLE II
COMPARISON BETWEEN PREDICTED EQUATION AND MEASUREMENT FOR ILORIN LAT(8.3^0N)

% of time	**R_m (mm/hr)**	**R_p (mm/hr)**	**%error**
0.001	198	242.6	22.5
0.003	138	148.2	7.4
0.01	90	85.1	-5.4
0.03	60	52.8	-12.0
0.1	45	30.8	-31.6
0.3	15	18.5	23.3
1.0	13.9	11.0	-20.9

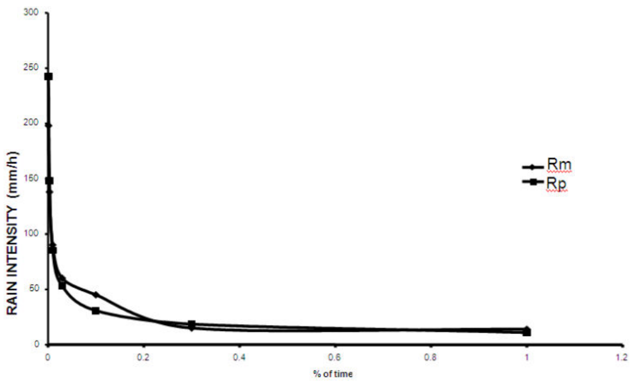

Fig. 2 (a) Comparison between predicted equation and measurement for ilorin

TABLE III
COMPARISON BETWEEN PREDICTED EQUATION AND MEASUREMENT FOR ILE-IFE LAT(7.49^0N)

% time	R_m(mm/hr)	R_p(mm/hr)	% error
0.001	140	225	61
0.003	125	137.3	9.8
0.01	85	80	-5.9
0.03	65	48.9	-24.8
0.1	38	28.5	-25
0.3	15	17.4	16
1.0	10	10.1	1.2

% error was obtained by using equation % error =

$$\frac{R_p - R_m}{R_m} \times 100 \quad (6)$$

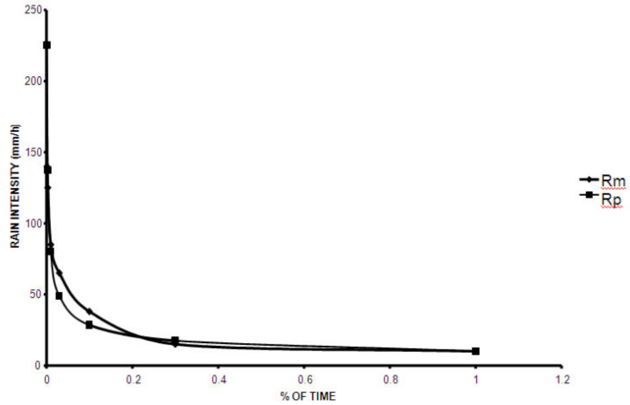

Fig. 2 (b) Comparison between predicted equation and measurement for ILE - IFE

VI. Evaluation of the Parameters at $R_{0.01}$ (MM/H)

The ITU – R formally CCIR plenary assembly held in Geneva during 1982 gave contour maps of rainfall intensity R0.01(mm/h) exceeded for 0.01% of the time in different hydro meteorological regions of the world [6].

These values are highly interesting since they are used for radio wave attenuation predictions both on line – of – sight and earth space links [6].

In Table IV, the values of both parameters are 'α' and 'β' computed using a regression program and rainrates (mm/h) exceeded during 0.01% of the time in various locations.

TABLE IV
PARAMETER 'α' AND 'β' WITH $R_{0.01}$ % OF TIME FOR LOCATIONS CONSIDERED

Locations	α	β	$R_{0.01}$ mm/hr
Brazilia	5.41	0.483	50
Nairobi	8.35	0.421	58
Dar-eS-Salam	9.37	0.438	72
Ile-Ife	10.12	0.449	80
Ilorin	12.42	0.430	90
Douala	13.0	0.513	138
Australia	11.401	0.401	75

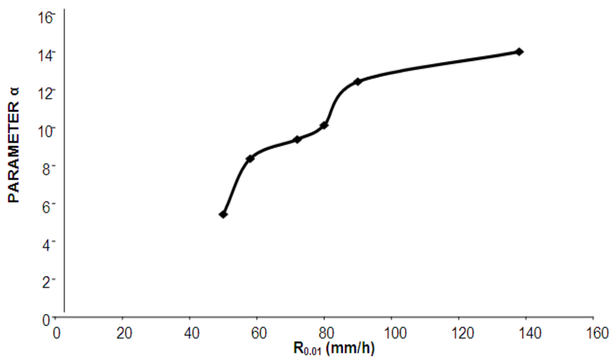

Fig. 3 (a) The graph of parameter α against R0.01

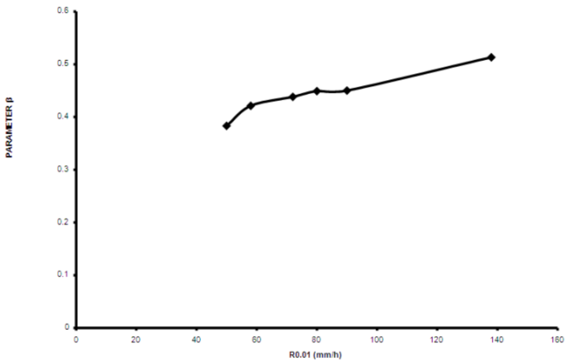

Fig. 3 (b) The graph of parameter β against R0.01

For Parameter 'α' plotted in Fig. 3 (a) against the values of rainfall intensity exceeded during the 0.01% of the time for each location in Table IV. The corresponding points can be fitted using the relation

$$'\alpha' = 0.97\, R^{K}_{0.01}(0.01) \quad (7)$$

from which table V was prepared.

Equation (7) can be expressed as $\alpha = xR_{0.01}\left(y^{\beta}\right)$

For Parameter 'β' plotted in Fig. 3 (b) against the values of rainfall intensity exceeded during the 0.01% of the time for each location in Table IV.

The corresponding points can be fitted using the relation;

$$\beta = 0.2888 R_{0.01}^{0.1025} \quad (8a)$$

from which Table VI was prepared.

This can produce a very good agreement with power law relation of the form

$$Q\, R^{K}_{0.01} \quad (8b)$$

There is a good agreement between the values obtained from the predicted equation and the values obtained from the measurement as shown in Tables V and VI. Figs. 4 (a) and (b) compare the predicted values with the measurement. A close look at the two figures shows that error margin is low since the graphs have approximately the same trend.

TABLE V
COMPARISON BETWEEN MEASUREMENT AND PREDICTED FOR α

$R_{0.01}$ mm/hr	Parameter 'α'$_m$	Parameter 'α'$_p$	% error
50	5.41	6.64	22.7
58	8.35	7.66	-8.3
72	9.37	8.87	-5.3
75	11.40	9.16	-19.7
80	10.12	9.64	-19.7
90	12.42	10.59	-14.7
138	13.0	14.75	13.5

α_m and α_p are values obtained from measurement and from the predicted equation respectively.

The predicted equation

$$\alpha = 0.97\, R_{0.01}\, (0.01)^{\beta}.$$

TABLE VI
COMPARISON BETWEEN MEASUREMENT AND PREDICTED FOR β

$R_{0.01}$ mm/hr	Parameter 'β'$_m$	Parameter 'β'$_p$	% error
50	0.483	0.431	10.6
58	0.421	0.433	4.1
72	0.438	0.448	2.3
75	0.401	0.450	12.2
80	0.449	0.453	0.2
90	0.430	0.458	5.6
138	0.513	0.479	3.8

β_m is the value of β obtained from the measurement while β_p is the values obtained from predicted equation

$$\beta = 0.288 R_{0.01}^{0.1025}$$

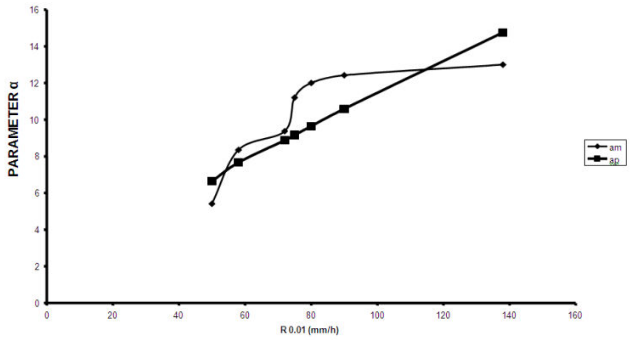

Fig. 4 (a) Comparison between measurement and prediction of parameter α evaluated $R_{0.01}$

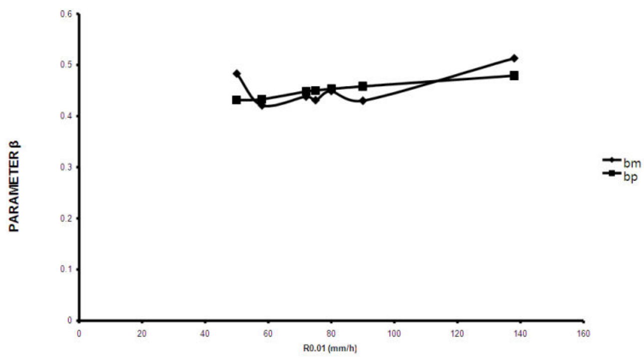

Fig. 4 (b) Comparison between measurement and prediction of parameter β evaluated using $R_{0.01}$

VII. CONSISTENCY TEST FOR THE MODEL

When the parameters obtained from the predicted equation was used to generate rain data for different percentage of time between 0.001 to 1.0, the tables below shows the performance of the predicted equation when compared with the values obtained.

TABLE VII
CONSISTENCY TEST BETWEEN MEASUREMENT AND PREDICTION FOR ILORIN

R % of time	R_m (mm/hr)	R_p (mm/hr)	% error
0.001	198	248.6	25.6
0.003	138	150.9	9.3
0.01	90	87.4	-2.9
0.03	56	53.1	-5.2
0.1	28	30.7	9.6
0.3	17	18.7	10
1.0	12	12.6	5

TABLE VIII
CONSISTENCY TEST BETWEEN MEASUREMENT AND PREDICTION FOR BRAZILIA

R % of time	R_m (mm/hr)	R_p (mm/hr)	% error
0.001	95	119.8	26.1
0.003	65	75.5	16.1
0.01	52	52	0
0.03	32	32.4	1.3
0.1	18	19	5.6
0.3	11	12.1	10
1.0	5	5.4	8

TABLE IX
CONSISTENCY TEST BETWEEN MEASUREMENT AND PREDICTION FOR NAIROBI

R % of time	R_m (mm/hr)	R_p (mm/hr)	% error
0.001	98	125.2	27.8
0.003	80	95	6.3
0.01	55	56.2	2.2
0.03	35	34.8	-0.6
0.1	20	20.5	2.5
0.3	12	12.7	5.8
1.0	8.5	7.5	11.8

TABLE X
CONSISTENCY TEST BETWEEN MEASUREMENT AND PREDICTION FOR DAR - ES – SALAM

R % of time	Rm(mm/h)	Rp(mm/h)	% error
0.001	98	120	22.5
0.003	88	97.5	10.8
0.01	72	69.8	-3.1
0.03	45	42.7	-5.1
0.1	24	24.9	3.8
0.3	15	15.2	1.3
1.0	9.0	8.9	-1.1

TABLE XI
CONSISTENCY TEST BETWEEN MEASUREMENT AND PREDICTION FOR LUSAKA

R % of time	Rm(mm/h)	Rp(mm/h)	% error
0.001	92	115	25.0
0.003	75	90.6	20.8
0.01	54	53.6	-0.7
0.03	35	33.2	-5.1
0.1	20	19.6	-2.0
0.3	12	12.2	1.7
1.0	6	7.2	20

VIII. DISCUSSION OF RESULTS

From the data obtained at University of Ilorin Physics department for two years, there is an appreciable variability in the year to year rain – rate.

Figs. 1 (a) and (b) are the graphs of parameters ‘α’ and ‘β’ plotted against latitude of the stations listed. The two graphs are fairly linear with parameter ‘α’ Versus Latitude slopping from left to right while graph of parameter ‘β’ versus latitude slopes from right to left, this shows that the higher the latitude the higher the parameter ‘β’ while reverse is the case for parameter ‘α’.

It should be noted that only stations on the north of latitude is treated for this purpose.

Fig. 2 is a graph that compares rain rate at Ilorin and Ile – Ife respectively with the model obtained. Fig. 3 (a) is a graph of α versus $R_{0.01}$; it rises progressively from left to right and descends before rising again. Actually, there is an evidence of higher torrential rainfall in Ilorin.

A graph of β versus Rain rate at 0.01% of time is approximately linear and slopping from right to left. This shows that there is no uniformity in the rising pattern of parameter ‘α’ against Rain rate at 0.01% of the time, but empirically, when evaluated, ‘α’ is linear expression obtained in the form; $\alpha = xR_{0.01}(y^{\beta})$, when linearized, x is the slope obtained from the graph.

Also,

$$\text{‘}\beta\text{’} = Q\, R^{K}_{0.01}.$$

obtained as a form of power law.

When data is generated with these expressions, Figs. 4 (a) and (b) show how the measurement is consistent with the model.

IX. CONCLUSION

Owing to the interest raised by the precipitation effect in the design of satellite and terrestrial microwave radio links, simple and valuable mathematical model which can represent the whole rain rate distribution with minimal error, the use of rain data collect at Ilorin for over two years and models proposed from the set of data obtaining the parameters ‘α’ and ‘β’ from the data extracted from various tropical stations where ‘α’ and ‘β’ are parameters obtained by regression has given a good fit. When used directly with the measurement. The variability of ‘α’ and ‘β’ with latitude also shows that different latitudes have different cumulative rain distribution.

Evaluating with the Latitudes using the expressions gives

$$\alpha = M_{\alpha} \sin\theta + C_{\alpha} = \Phi$$
$$\beta = M_{\beta} \sin\theta + C_{\beta} = \Psi$$

with this, the model

$$R_p(mm/h) = \frac{\alpha}{\Gamma^{\beta}}$$

can be written as in (5)

$$Rp(mm/h) = \frac{\phi}{(\Gamma)^{\Psi}}$$

rainfall intensity $R_{0.01}$(mm/h) exceeded for 0.01% of time in different tropical stations were studied and a model equation based on the rain rate that exceeded the 0.01% of time obtained gave (8b)

$$\beta = QR^{K}{}_{0.01}.$$

for the station considered.

Q and K are 0.289 and 0.1025 respectively.

Also, for parameter α,

$$\alpha = xR_{0.01}\left(y^{\beta}\right)$$

It should be noted that R0.01 is a function of location because for each station, there is variability of rainfall recorded at 0.01% of time.

This expression clearly confirms the variability of rainfall from place to place. When consistency test was carried out using the expression to generate rainrate for each location examined, the result obtained was reliable for rain intensities between 5mm/h and 200mm/h. The variability of α and β with latitude also shows that different latitudes have different cumulative rain distribution.

X. Recommendation

High rain rates and the consequent high rain attenuation in the tropics is arguably the greatest constraint to the usability of the Ku and ka bands in the tropics.

Generally, the model for the rain rate prediction here depends on certain parameters taken to be 'α' and 'β' they are functions of rain intensity their values are greatly affected by local climatology and geographical locations, there is therefore the need for more data from high rainrate locations in order to provide a reliable value of the parameters since the physical quantity used to determine attenuation is rain rate it would be better to use a single parameter that remains substantially the same in most environment.

The weather elements such as pressure, temperature, humidity, winds and the resultant phenomenon such as clouds, storms and other forms of precipitation have to be measured in regular intervals in order to facilitate weather predictions for attenuation [7].

The model proposed in this study would be one of the useful tools to Radio Engineers since the precipitation effect in the design of satellite and terrestrial microwave radio links is among the factors to consider when designing communication systems.

Acknowledgments

The authors wish to acknowledge TETFUND, Nigeria for sponsoring us to conference at Paris France. We also thank the Management of the Federal Polytechnic Offa, Kwara State, Nigeria for granting us permission to attend this conference holding on August 2013 at Paris France.

Reference

[1] G O Ajayi , ed,(1996) Hand Book on Radio Propagation Related to satellite communications in tropical and subtropical countries ICTP. Pp16

[2] Y.B Olayinka ,. (1999) Senior Secondary Atlas, Longman Nigerian PLC.pp18-19,21-22

[3] O. Oyeleke, (2003) Rainrate model for tropical regions for radio propagation application, an M.Sc Thesis submitted to the department of Physics, University of Ilorin pp55

[4] I.A Adimula,., J.O Oyinloye,. and I.E Owolebi; (1991) Rain intensity measurement in Nigeria for microwares application, Proc 3rd Biregional African – Latin American conference on radio propagation and spectrum management FoZ do Iguacu, Brazil.pp172

[5] I.F Adeniyi,. (1992).The prevalence of thunder and its effect on Rain water quality at Ile – Ife. Discovery and Inovation volume 4 no 4.pp6

[6] CCIR (1982) 5th plenary Assembly ,Geneva,V,reports 338-4 and 564-2

[7] T.O Aro,. (1982) The Atmosphere of Physics and Physics of the Atmosphere Unilorin 7th Inugual lecture pp20.

Olatinwo Mufutau O (Dr) is the Rector, Federal Polytechnic Offa, Kwara State,Nigeria. He holds PhD degree in geophysics. He has been a lecturer in Nigerian tertiary institution for many years. He is currently a chief lecturer at Federal Polytechnic Offa, Kwara State, Nigeria .He has been a long time academic papers reviewer for academic journals and External examiner to Federal University of Technology Akure, Nigeria. Also he is currently the Rector, Federal Polytechnic Offa, Kwara State,Nigeria.

Oyeleke Olaosebikan is a Senior lecturer at Federal Polytechnic Offa, Kwara State,Nigeria. He holds MSc degree in communication Physics. He has been a lecturer in Nigerian tertiary institution for many years. He is currently the Deputy Director; Entrepreneurship Studies Centre at Federal Polytechnic Offa, Kwara State, Nigeria .He is a academic papers reviewer for academic journals in Nigeria. Also he is currently a PhD student at Ladoke Akintola University of Technology Ogbomosho, Nigeria.

David Henry O is a chief lecturer at Federal Polytechnic Offa, Kwara State,Nigeria. He holds MTech degree in communication Physics. He has been a lecturer in Nigerian tertiary institution for many years. He is currently the Head of Science Technology Department at Federal Polytechnic Offa, Kwara State, Nigeria .He is an External Assessor to some Polytechnics in Nigeria. Also he is currently a PhD student at Federal University of Technology Akure ,Nigeria.