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Rain Attenuation Prediction in Nigeria Using Artificial Neural Network (ANN)

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Abstract: The prediction of rain rate and rain attenuation plays an essential role in the fields of communications, agriculture, military services, etc. This work presents rain attenuation prediction in Nigeria using Artificial Neural Network (ANN). Rainfall data of ten years were collected from measurements made in six different geographical locations. The locations include Enugu (east), Ikeja (south-west), Kano (north-west), Lokoja (north-central), Maiduguri (north-east) and Port-Harcourt (south-south). These locations represent all geographical areas in Nigeria. ANN was trained to predict rain attenuation in these locations using the annual rainfall data given from 2007 to 2016. Conversely, the ANN was trained with sets of data from the year 2007 to 2013, thus, the result of the training was used to predict rain attenuation from the year 2014 to 2016. The rain attenuation results given by ANN were compared to the results given by the International Telecommunication Union (ITU) model which is a well-established model. The results in terms of the mean squared error (MSE) performance show that ANN predicted attenuation agrees closely with the ITU model prediction. Conversely, the resulted ANN training is a useful tool for communication engineers and expatriates to predict rainfall attenuation of subsequent years and to proactively solve the inherent signal attenuation problem facing satellite-to-earth path operation above 10GHz.

Keywords: Rain Attenuation, Rain Rate, ANN, ITU Model, Mean Squared Error

1. Introduction

Rain is an essential substance to human life. Most of the fresh water on earth is deposited by rain. Rain attenuation affects the design of satellite-to-earth path that operates at frequencies above 10GHz [1, 2]. Raindrops absorb and scatter radio waves, thus resulting in signal attenuation, consequently, ensures the reduction in the reliability and availability of the system. The attenuation caused by rain increases with increased frequency [3]. The extent at which rain attenuates electromagnetic signals varies with frequency and climate [4]. It is important to make an accurate prediction of rain attenuation for effective planning of microwave satellite and terrestrial line-of-sight links [5]. The major problem faced by microwave engineers working on higher frequency bands is balancing the compromise between availability of bandwidth and issues of rain-induced attenuation. Although the International Telecommunication Union radio (ITU-R) has created a meteorological approach that predicts rain attenuation, this approach does not work well in some regions like the tropical climates as it is based on data collected from temperate regions [6]. Moreover, atmospheric processes from which rainfall is formed are complex and cannot be accurately predicted using mathematical or statistical models [7]. There are several procedures for rain attenuation prediction on earth-space links, thus, these procedures are grouped into two classes: Empirical and Physical. Empirical classes depend on the measurement of databases from stations in different locations within a particular region, and physical classes attempt to reproduce the physical behavior involved in the process of attenuation [8]. The frequently used method is the empirical method because it makes use of equations and certain variables including rain rate, rain height, latitude and longitude of the earth-station [5]. Although there are some other factors affecting rain attenuation such as size distribution of raindrop [9], it is very difficult to provide the neural network with proper information about the size distribution, conversely, it is not included as the input of the neural network. An empirical method provides an appropriate distribution of rainfall rate at one minute integration time which is needed for the site under study in order to predict rain attenuation for that location accurately [10]. This is based on the fact that rain rates obtained through longer periods of integration might not successfully capture a high-intensity, short-duration rain event, thus not recommended for communication systems [5]. If time series prediction of rain attenuation is possible, fade countermeasure techniques such as adaptive control of signal power, coding and data rate can be effectively implemented [11]. This work aims to emphasize on how ANN could be used to predict rain-induced attenuation and also to establish the comparison between the predicted rain attenuation by ANN and ITU model in certain locations in Nigeria. Also, the study will be helpful for understanding the rain attenuation characteristics over these regions.

2. Description of Rainfall and Rain Attenuation Data

The increase in the size of the raindrop is the main source of signal attenuation along a microwave path [12]. The rainfall data used for the calculation of rain attenuation in Nigeria are collected from 6 geographical locations in the country. The locations include Enugu (east), Ikeja (south-west), Kano (north-west), Lokoja (north-central), Maiduguri (north-east) and Port-Harcourt (south-south). The annual rainfall (mm) of the selected cities in Nigeria are presented in Table 1. The geographical parameters of the selected locations in Nigeria, in terms of Latitude, Longitude and Altitude (m), are presented in Table 2. These parameters are used for calculating rain attenuation in those locations using the international telecommunication union (ITU) model [7]. The rainfall data used consists of data from the year 2007 to 2016, obtained from Nigeria Meteorological Agency or NiMET. The calculated rain attenuation data for the Horizontal polarization, Vertical polarization and the mean attenuation using the ITU model are presented in Tables 3, 4 and 5 respectively. Both the collected rainfall data and the calculated rain attenuation were used to train an Artificial Neural Network (ANN) object.

Table 1. *Annual Rainfall (mm) of some selected Cities in Nigeria (NIMET).*

Year / City	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Enugu	921.335	927.315	913.39	1302	1690	1693	1839	1766	1686.5	1607
Ikeja	760.18	773.04	755.35	976	1196	1279	1722	1501	1441	1382
Kano	487.415	476.04	474.215	610	745	799	981	890	914	938
Lokoja	624.685	614.615	628.185	922	1216	1040	1169	1105	1089	1072
Maiduguri	318.72	303.08	308.22	441	573	430	669	550	560	569
Port-Harcourt	1232.895	1197.59	1220.835	1669	2117	2131	2478	2305	2246	2186

Table 2. *Geographical parameters of the selected locations in Nigeria (NIMET).*

City	Latitude (Degree)	Longitude (Degree)	Altitude (meters)
Enugu	6.5000	7.0000	137.3000
Ikeja	6.5800	3.3300	128.5500
Kano	12.0500	8.5300	475.8000
Lokoja	7.8000	6.7300	62.4000
Maiduguri	11.8500	13.0800	348.0000
Port-Harcourt	4.8500	7.1200	84.5000

Table 3. *ITU-model Rain Attenuation (Horizontal polarization).*

Year / City	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Enugu	1.0386	1.0267	1.0546	0.5292	0.2914	0.2902	0.2360	0.2614	0.2929	0.3291
Ikeja	1.4358	1.3977	1.4504	0.9361	0.6318	0.5496	0.2783	0.3861	0.4237	0.4650
Kano	2.6866	2.7657	2.7787	1.9972	1.4819	1.3241	0.9272	1.1035	1.0532	1.0057
Lokoja	1.9334	1.9787	1.9180	1.0377	0.6108	0.8319	0.6619	0.7403	0.7616	0.7851
Maiduguri	4.2717	4.4783	4.4089	3.0301	2.1781	3.1200	1.7475	2.3013	2.2466	2.1989
Port-Harcourt	0.5936	0.6302	0.6058	0.3005	0.1626	0.1596	0.1037	0.1281	0.1379	0.1488

Table 4. *ITU-model Rain Attenuation (Vertical polarization).*

Year / City	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Enugu	0.9152	0.9047	0.9293	0.4663	0.2568	0.2557	0.2079	0.2303	0.2581	0.2900
Ikeja	1.2651	1.2315	1.278	0.8249	0.5567	0.4843	0.2452	0.3402	0.3733	0.4097
Kano	2.3673	2.4370	2.4484	1.7598	1.3058	1.1667	0.8170	0.9723	0.9280	0.8862
Lokoja	1.7036	1.7435	1.6900	0.9143	0.5382	0.7331	0.5832	0.6523	0.6711	0.6918
Maiduguri	3.7639	3.946	3.8848	2.6700	1.9192	2.7491	1.5398	2.0278	1.9796	1.9375
Port-Harcourt	0.5230	0.5553	0.5338	0.2648	0.1432	0.1407	0.0914	0.1129	0.1215	0.1311

***Table 5.** Mean Rain Attenuation of some selected Cities in Nigeria (ITU model).*

City \ Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Enugu	0.9769	0.9657	0.9920	0.4978	0.2741	0.2730	0.2220	0.2459	0.2755	0.3096
Ikeja	1.3505	1.3146	1.3642	0.8805	0.5943	0.5170	0.2618	0.3632	0.3985	0.4374
Kano	2.5270	2.6014	2.6136	1.8785	1.3939	1.2454	0.8721	1.0379	0.9906	0.9460
Lokoja	1.8185	1.8611	1.8040	0.9760	0.5745	0.7825	0.6226	0.6963	0.7164	0.7385
Maiduguri	4.0178	4.2122	4.1469	2.8501	2.0487	2.9346	1.6437	2.1646	2.1131	2.0682
Port-Harcourt	0.5583	0.5928	0.5698	0.2827	0.1529	0.1502	0.0976	0.1205	0.1297	0.1400

3. Procedure for the Creation of ANN Object for Rain Attenuation Prediction

This work utilizes ANN to predict the rain attenuation of a location when the rainfall rate is supplied to the ANN object as input. So instead of calculating the rain attenuation using the ITU algorithm, ANN is used directly. Figure 1 shows a flowchart of how the ANN training process is carried out. The first step is to load the rainfall and rain attenuation data. The rainfall data is the Input data to the ANN while the corresponding rain attenuation data is the Target output.

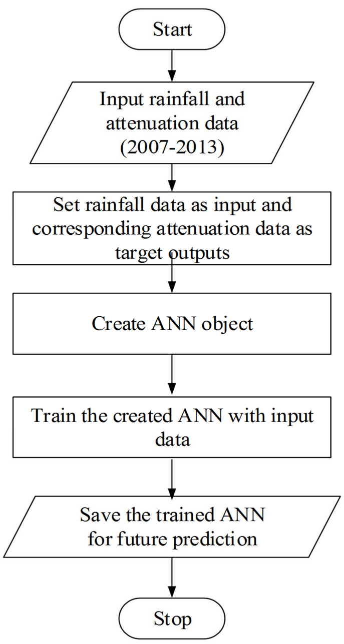

***Figure 1.** ANN training process for Rain Attenuation Prediction.*

The ANN object is created using a feedforward backpropagation neural network learning algorithm [13] with other network parameters as shown in Table 6. After the ANN object has been created, it is therefore trained with the input data which is the rainfall rate data collected from NIMET. The ANN continues to learn the correlation of the rainfall data to the corresponding attenuation values until the performance goal is met. The performance goal is to stop the training as soon as the mean squared error (MSE) of the training falls below $10e^{-2}$ threshold. The trained ANN object is then saved for future use to predict rain attenuation for a given rainfall data of the geographical locations used. The year 2007 to 2013 rainfall data were used to train the ANN.

***Table 6.** The ANN training parameters.*

Parameter	Value
Architecture	4-layer (1 input layer, 2 hidden layers and 1 output layer)
Training algorithm	Feedforward Back-propagation neural network (BPNN)
Transfer function	{tansig, purelin}
Maximum training epoch	10^2
Performance function	Mean-Squared Error (MSE)
Performance goal	$10e^{-2}$
Hidden neurons	10

Some important parameters necessary to calculate the ITU model include:

1. Probability (p) = $1e^{-2}$
2. Angle of elevation of antenna (θ) = 10^0
3. Constant for horizontal polarization (k) = 0.0188
4. Constant for vertical polarization (k)= 0.0168
5. Alpha value for horizontal polarization (α) = 1.217
6. Alpha value for vertical polarization (α) = 1.200

The following equations: equation 1, 2, 3, 4, 5, 6 and 7 were used to estimate the effective rain height, the Slant-path length, the horizontal projection, the reduction factor, the specific attenuation (dB/km), the estimated attenuation and the attenuation respectively.

$$h_R = h_s - 0.075Km \tag{1}$$

$$L_S = \frac{h_R - h_S}{Sin\,\theta} \tag{2}$$

$$L_g = L_s Cos\theta \tag{3}$$

$$r = \frac{1}{1 + \frac{L_g}{L_0}} \tag{4}$$

$$\gamma = k(R_{0.01})^{\alpha} \text{ db/km} \tag{5}$$

$$A = \gamma L_s r \tag{6}$$

$$\text{Attenuation} = \text{A x 0.12 x } p^{(-(0.546+0.043*\log(p)))} \tag{7}$$

where;

K and α depend on frequency, polarization, raindrop size distribution and temperature.

h_R= effective rain height

hs= height above sea level

L_s = Slant-path length

L_g = horizontal projection

r = reduction factor

γ = specific attenuation (dB/km)
A = estimated attenuation

4. Procedure for Testing Created ANN Object for Rain Attenuation Prediction

After the ANN object has been properly trained, it can then be used to predict the rain attenuation for the particular locations it was trained for. To predict the rain attenuation of any location, the rainfall data of the location is loaded into the trained ANN as input [14] as shown in the process represented by the flow chart of Figure 2. The data is simulated with the ANN object, consequently, the ANN output the attenuation data for every value of rainfall it has predicted. The GUI displayed during training of the ANN is shown in Figure 3.

Figure 4 presents the regression (R) performance of the trained ANN. The value obtained from the training carried out is 0.99975. This value reveals that the ANN is well trained with the data because the best training gives R = 1, and the value obtained is approximately one. Figure 5 shows the performance goal of the trained ANN having the best training performance when the mean square error is 0.0034935 dB at epoch 4 and the training performance goal when the mean square error is 10^0 dB which is equal to 1dB at epoch 4.

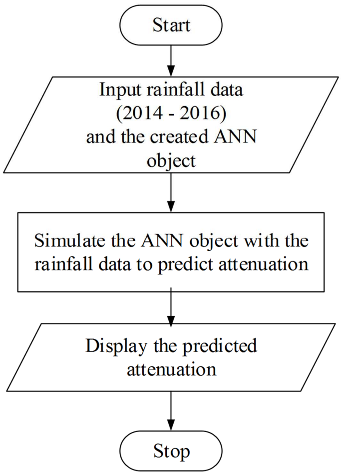

Figure 2. *ANN testing process for Rain Attenuation Prediction.*

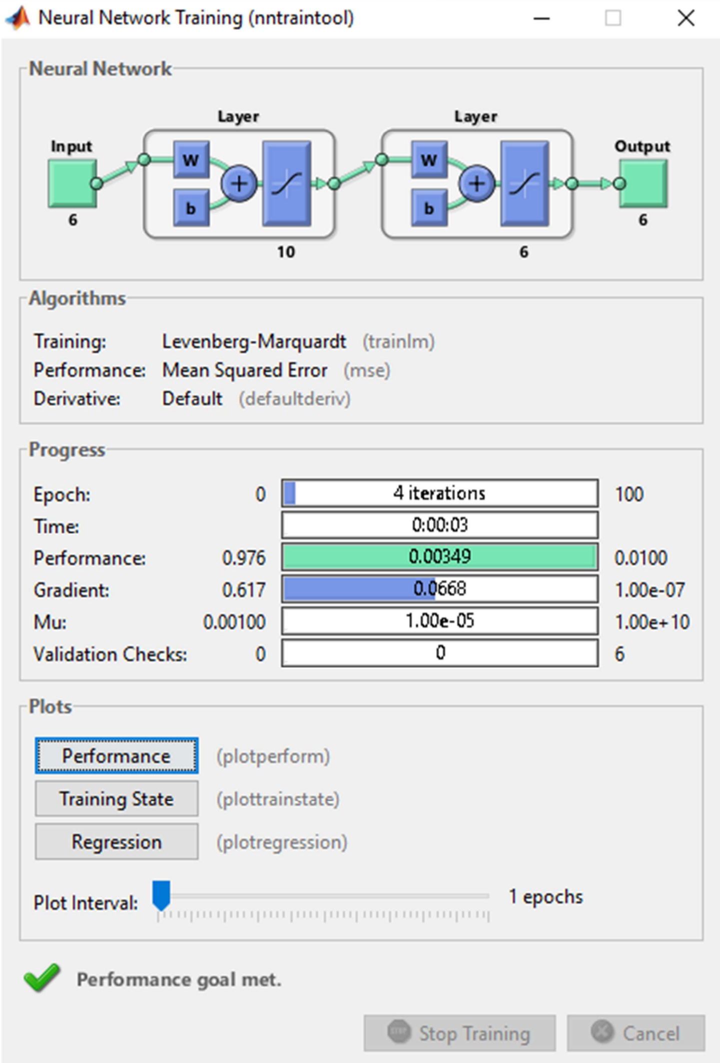

Figure 3. *Training of the ANN in MATLAB Environment.*

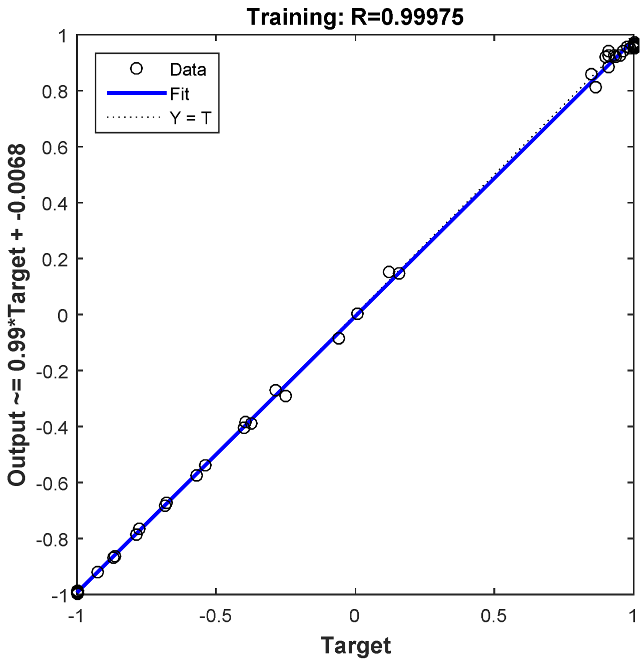

Figure 4. *Regression Performance of the trained ANN.*

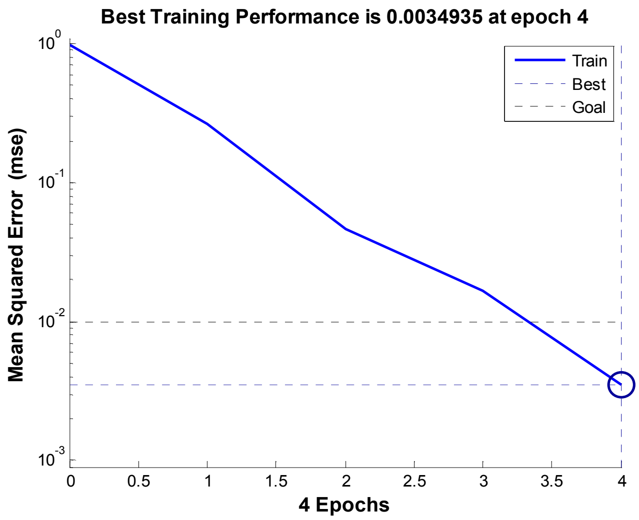

Figure 5. *Performance goal of the trained ANN.*

5. ANN Prediction Performance of the Rain Attenuation

In order to test the ability of the trained ANN object to properly predict the rain attenuation when the rainfall rate is supplied to it, the rainfall data for the year 2014 to 2016, which were not part of those used to train the ANN, were used. The test was carried out for the three years separately to predict the rain attenuation for each of the years. The predicted mean rain attenuation (MRA) for 2014, 2015 and 2016 is presented in Tables 7, 8 and 9 respectively. To evaluate the ANN model, the results of the rain attenuation prediction of ANN model and a well-established model (ITU model) must be adequately compared [15].

The results obtained by calculation using the ITU model is termed 'Actual' while the results obtained from the ANN is termed 'Predicted'. It is expected that the data for the two models should be exact or approximately equal and the errors should not be greater than the training performance mean square error of 1dB. Table 7 shows the mean squared error (MSE) between the predicted and actual values for Enugu, Ikeja, Kano, Lokoja, Maiduguri, and Port-Harcourt to be 2.6579e-04, 0.0063, 0.0161, 0.0032, 0.2179 and 4.9885e-04 respectively. This reveals that the predicted values from the ANN almost agree with the ITU calculated values with the highest MSE of 0.2179 in Maiduguri, which is relatively low. This shows that the ANN predictions are relatively accurate.

Table 8 presents the results for the year 2015. The mean squared error (MSE) between the predicted and actual values for Enugu, Ikeja, Kano, Lokoja, Maiduguri, and Port-Harcourt are 0.0020, 0.0116, 0.0041, 0.0079, 0.1972 and 9.9009e-04 respectively. This also reveals that the predicted values from the ANN almost agree with the ITU calculated values with the highest MSE of 0.1972 in Maiduguri, which is relatively low. This shows that the ANN predictions are relatively accurate. The results for year 2016 is presented in Table 9. Enugu, Ikeja, Kano, Lokoja, Maiduguri, and Port-Harcourt give MSE values of 0.0061, 0.0195, 1.6493e-04, 0.0138, 0.1672 and 0.0017 respectively. The results show that the highest MSE of 0.1672 is obtained in Maiduguri. This value indicates that the ANN prediction is relatively accurate.

The results for the three years considered generally show that the ANN give very good prediction performance in comparison to the ITU model nevertheless of the observed highest MSE in Maiduguri for the three years considered. Hence, ANN can be used in place of the calculations by the ITU model. Also, ANN can help in predicting very large number of locations at the same time with little or without computational complexity as against the ITU algorithm that requires that each location be calculated separately, which consumed so much time and more complex to handle.

Table 7. *Mean Rain Attenuation for 2014.*

City	ITU model (Actual)	ANN model (Predicted)	Mean Squared Error
Enugu	0.2475	0.2311	2.6579e-04
Ikeja	0.3656	0.2856	0.0063
Kano	1.0448	0.9169	0.0161
Lokoja	0.7009	0.6444	0.0032
Maiduguri	2.1789	1.7092	0.2179
Port-Harcourt	0.1213	0.0988	4.9885e-04

Table 8. *Mean Rain Attenuation for 2015.*

City	ITU model (Actual)	ANN model (Predicted)	Mean Squared Error
Enugu	0.2774	0.2327	0.0020
Ikeja	0.4012	0.2929	0.0116
Kano	0.9972	0.9329	0.0041
Lokoja	0.7211	0.6319	0.0079
Maiduguri	2.1271	1.6801	0.1972
Port-Harcourt	0.1306	0.0988	9.9009e-04

Table 9. *Mean Rain Attenuation for 2016.*

City	ITU model (Actual)	ANN model (Predicted)	Mean Squared Error
Enugu	0.3116	0.2333	0.0061
Ikeja	0.4403	0.2997	0.0195
Kano	0.9522	0.9393	1.6493e-04
Lokoja	0.7434	0.6253	0.0138
Maiduguri	2.0820	1.6703	0.1672
Port-Harcourt	0.1409	0.0989	0.0017

6. Conclusion

In this literature, the attenuation of electromagnetic signals caused by Rain has been investigated. Mathematical modeling has been developed for the estimation of specific attenuation (Db/km) applicable to different regions in Nigeria. The study has employed a semi-empirical approach for the formulation of the rain attenuation prediction models. This approach has involved knowledge of the rain rate exceedance characteristics, drop size distribution and scattering properties of raindrops. The rainfall data used for the calculation of rain attenuation in Nigeria are collected from 6 geographical locations in the country. The locations include Enugu (east), Ikeja (south-west), Kano (north-west), Lokoja (north-central), Maiduguri (north-east) and Port-Harcourt (south-south). The geographical parameters of the selected locations in Nigeria are in terms of Latitude, Longitude, and Altitude (m). These parameters are used for calculating rain attenuation in those locations using the international telecommunication union (ITU) model. The rainfall data used consists of data from the year 2007 to 2016, obtained from Nigeria Meteorological Agency or NiMET. The calculated rain attenuation data for the Horizontal polarization, Vertical polarization, and the mean attenuation were recorded. Both the rainfall data and rain attenuation were used to train an Artificial Neural Network (ANN) object. The results obtained by the ANN prediction was discussed and analyzed in this literature. These results were compared with already established results of ITU and the Mean Squared Errors were recorded showing that the ANN prediction model is effective in predicting Rain Attenuation. Rain-induced specific attenuation calculator is also developed using MATLAB's graphic user interface. So, the user can directly get the specific attenuation by putting frequency and rain rate, without going through any complex mathematics or programming.

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