

Statistical Analysis of Estimation of Global Solar Radiation with two Models at Uyo

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Abstract
Atmospheric parameters of maximum temperature, relative humidity, sunshine hours and cloudiness for a period of seventeen years (1991-2007) were used to forecast the global solar radiation at Uyo, Nigeria with artificial neural network (ANN) and Angstrom-Prescott models. The error values Angstrom-Prescott model are MBE = (2.0725, 0.0978, 0.0685, -0.0018), RMSE = (2.1955, 0.6356, 0.7501, 0.6463), MPE = (-12.5813, -1.0589, 3.2699 3.8226), while ANN model are MBE = (0.0387, 0.0796, -0.0343, 0.0002), RMSE = (0.5341, 0.2635, 0.0468, 0.0536) and MPE = (-0.5057, 0.2901, -0.1715, 0.0518) for sunshine hours, maximum temperature, relative humidity and cloudiness respectively. The validation results of the two models showed that they have predicting capacity, but ANN has better predicting capacity. It, therefore, becomes clear that ANN has better agreement with measured global solar radiation, hence should be used for forecasting of global solar radiation at Uyo and other locations with similar climatic condition.

Keywords: Angstrom-Prescott, Artificial neural network, MBE, RMSE, MPE and correlation

INTRODUCTION

Atmospheric parameters and energy play important roles in determining the conditions in which living matter can exist and constitute continuous steering power for social, economic, and technological prospective development in Nigeria (Ibeh, 2012). The troposphere is the lower layer of the Earth's atmosphere and most of the weather phenomena, systems, convection, turbulence and clouds occur in this layer, although some may extend into the lower portion of the stratosphere (Ayşegü, 2006). The condition of the atmosphere as dictated by the sun is very dynamic both in space and time scales.

Artificial Neural Network

Neural network is a massively parallel distributed processor made up of simple processing units that have a natural propensity for storing experiential knowledge and making it available for us (Reddy and Ranjan, 2003). Artificial neural network (ANN) is a type of artificial intelligence technique that mimics the behavior of the human brain. ANNs have ability to model linear and non-linear systems without the need to make assumptions implicitly as in most traditional statistical approaches, applied in various aspects of science and engineering. The network usually consists of an input layer, some hidden layers and an output layer. In its simple form, each single neuron is connected to other neurons of a previous layer through adaptable synaptic weights. Knowledge is stored as a set of connection weights. During Training process the connection weights are modified in certain way by using a suitable learning method. The network uses a learning mode, in which an input is presented to the network along with the desired output and the weights are adjusted so that the network attempts to produce the desired output. Therefore, the weights, after training contain meaningful information (Ibeh et al, 2012).

The objective of this study is to use statistical techniques to analyze the results from estimation of global solar radiation using artificial neural network and Angstrom-Prescott models with atmospheric parameters of relative humidity, maximum temperature, sunshine hours and cloud cover. The relevant data was provided by the Nigerian Meteorological Agency, Federal Ministry of Aviation, Oshodi Lagos, Nigeria. The forecasting ability of the two models is accessed using Mean Bias Error (MAE), Mean Square Error (MSE), and Root Mean Square Error (RMSE) (Maliki et al, 2011).

METHOD

Angstrom-Prescott Model

Angstrom (1924) developed an empirical model for the estimation of global solar radiation with meteorological parameters; Prescott (1940) put the model in the convenient form as:

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\,\frac{\bar{n}}{\bar{N}} \qquad (1)$$

According to Iheonu (2001), the monthly mean daily solar radiation reaching a horizontal surface is on earth $\bar{H}_M$ is related to the maximum temperature $\bar{T}_M$ by the formula

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\,\bar{T}_M \qquad (2)$$

Igbal (1983), showed the equation for correlating global solar radiation with cloudiness index as:

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\,\frac{\bar{c}}{c} \qquad (3)$$

Burari and Sambo (2001) reported the equation that correlated solar radiation and relative humidity as:

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\,\frac{R}{100} \qquad (4)$$

Where, $\frac{\bar{H}_m}{\bar{H}_o} = \bar{K}_T$ = clearness index

$\frac{\bar{n}}{\bar{N}}$ =fraction of sunshine hour, $\frac{\bar{c}}{\bar{c}}$ = cloudiness index, R= relative humidity

$\bar{H}_m$= the monthly averaged daily global radiation on a horizontal surface.

$\bar{H}_o$ = the monthly averaged daily extraterrestrial radiation on a horizontal surface.

$\bar{n}$ = the monthly averaged daily number of hours of bright sunshine.

$\bar{N}$ = the monthly averaged daily maximum number of hours of possible sunshine.

The extraterrestrial solar radiation on horizontal surface can be calculated from the expression by Igbal (1983) as follows:

$$\bar{H}_o = \frac{24}{\pi} I_{sc}\, E_o \left(\frac{\pi}{180}\,\omega_s \sin\emptyset \sin\delta + \cos\emptyset \cos\delta\ \sin\omega_s\right) \qquad (5)$$

Where I_{sc} = solar constant, $E_o = Eccentricity\ correlation\ factor\ \emptyset = latitude$

δ = Solar declination, ω_s = Hour angle, N = characteristic day number.

$$I_{sc} = \frac{1367\ X\ 3600}{1000000}\ (MJM^{-2}h^{-1}) \quad (6)$$

$$E_O = 1 + 0.033\ COS\left(\frac{360N}{365}\right) \quad (7)$$

$$\delta = 23.45\ sin\left[360\frac{(N+284)}{365}\right] \quad (8)$$

$$w_s = cos^{-1}(-tan\emptyset\ tan\ \delta) \quad (9)$$

$$\bar{N} = \frac{2}{15}\ cos^{-1}(-tan\emptyset tan\delta) \quad (10)$$

Where $\bar{N}$ = Day length, all other symbols retain their meanings.

Artificial neural network (ANN) model

In other to compute the global solar radiation, 3-2-1 multilayer peceptron (MLP) neural networks were used, which includes the input layer, a linear output layer and a sigmoid hidden function. The weighed sum of the inputs

$$v_k = \sum_{j=1}^{N} x_j\ w_{kj}\ + b_k \quad (11)$$

is calculated at *k*th hidden node.

w_{kj} is the weight on connection from the *j*th to the *k*th node; x_j is an input data from input node; N is the total number of input and b_k denotes a bias on the *k*th hidden node.

Each hidden node then uses a sigmoid transfer function to generate an output

$$z_k = [\ 1+e^{(-v_k)}\ ]^{-1} = f(v_k) \quad (12)$$

between -1 and 1.

We then set the output from each of the hidden nodes, along with the bias b_0 on the output node, to the output node and again calculate a weighted sum,

$$y_k = \sum_{k=1}^{N} v_k z_k + b_k \quad (13)$$

where N is the total number of hidden nodes; and v_k is the weight from the kth hidden node to the sigmoid transfer function of the output node

Evaluation of the Performances of artificial neural network (ANN) and Angstrom-Prescott Model

In order to evaluate the performances of ANN and Angstrom- Prescott models quantitatively and ascertain whether there is any underlying trend in performance of the models, statistical analysis involving mean bias error (MBE), mean percentage error (MPE) and root mean square error (RMSE) were conducted (Ibeh, 2012).

$$\text{MBE}= [\sum \left(\frac{H_{ANGS\,P} - H_{Meas}}{n}\right)] \quad (14)$$

$$\text{MBE}= [\sum \left(\frac{H_{ANN\,P} - H_{Meas}}{n}\right)] \quad (15)$$

$$\text{RMSE}= [\sum (\frac{H_{ANGS\,P} - H_{Meas}}{n})^2]^{1/2} \quad (16)$$

$$\text{RMSE}= [\sum (\frac{H_{ANN\,P} - H_{Meas}}{n})^2]^{1/2} \quad (17)$$

$$\text{MPE} = [\sum (\frac{\frac{H_{Meas} - H_{ANGS\,P}}{H_{Meas}}}{n}) \times 100) \quad (18)$$

$$\text{MPE} = [\sum (\frac{\frac{H_{Meas} - H_{ANN\,P}}{H_{Meas}}}{n}) \times 100) \quad (19)$$

Where

$\overline{H}_{ANGS\,P}$ = Angstrom-Prescott predicted values of solar radiation

$\overline{H}_{ANN\,P}$ = Artificial Neural Network predicted values of solar radiation

$\overline{H}_{Meas}$ = Measured values of global solar radiation n = Number of observation

The table 1 below shows the result between the estimation from artificial neural network, Angstrom-Prescott models and measured global solar radiation of sunshine hours, temperature, relative humidity and cloudiness respectively.

Table 1: Differences between Measured Global Solar Radiation, Artificial Neural Network and Empirical Models Estimations

	Estimation With Sunshine		Estimation With Temperature		Estimation With Relative Humidity		Estimation WITH Cloudiness	
Years	H_M-H_{ANN}	H_M-H_P	H_M-H_{ANN}	H_M-H_P	H_M-H_{ANN}	H_M-H_P	H_M-H_{ANN}	H_M-H_P
1991	**0.4962**	**-1.5997**	**-1.47376**	**-1.2919**	**0.33624**	**-0.66527**	**-0.95376**	**-1.3325**
1992	**-1.6319**	**-1.8785**	**-0.05196**	**-1.8642**	**-0.01196**	**-1.18891**	**-1.26196**	**-1.82853**
1993	**0.1836**	**-2.4541**	**2.35364**	**2.6424**	**0.49364**	**3.03026**	**-0.71636**	**2.68996**
1994	**-0.2099**	**-1.7792**	**0.02002**	**-1.4779**	**0.01002**	**-0.89374**	**-0.93998**	**-1.50661**
1995	**-1.3721**	**-1.6427**	**0.00783**	**-1.3461**	**0.02783**	**-0.69155**	**-0.72217**	**-1.29329**
1996	**-1.4895**	**-1.8241**	**0.00045**	**-0.5442**	**-0.01955**	**0.59718**	**0.66045**	**0.09837**
1997	**1.9445**	**-2.3408**	**0.07459**	**1.1745**	**0.00459**	**2.01860**	**0.49459**	**1.48824**
1998	**-1.4372**	**-1.7562**	**0.00271**	**-0.8606**	**-0.01729**	**0.22375**	**0.00271**	**-0.34449**
1999	**1.3421**	**-1.9930**	**-0.00785**	**0.9920**	**-0.02785**	**1.56095**	**1.70215**	**1.12199**
2000	**1.0758**	**-1.8571**	**0.85586**	**0.9561**	**0.64586**	**1.50301**	**-0.36414**	**1.06475**
2001	**-0.1637**	**-1.8206**	**-0.00372**	**-0.2313**	**-0.02372**	**0.49602**	**0.35620**	**-0.01939**
2002	**-0.2032**	**-2.3758**	**-0.00326**	**0.2490**	**-0.04326**	**0.65441**	**0.00674**	**0.05192**
2003	**0.4450**	**-2.2919**	**0.00508**	**0.2077**	**0.02508**	**0.84784**	**0.00508**	**-0.01923**
2004	**-1.1088**	**-2.3011**	**-0.66881**	**-0.7406**	**-0.89881**	**0.08697**	**-0.81881**	**-0.82494**
2005	**0.3602**	**-2.3640**	**0.00024**	**0.4815**	**0.02024**	**1.09454**	**-0.49976**	**0.46684**

2006	**0.4514**	**-2.4607**	**0.00144**	**-0.3449**	**0.05144**	**0.74272**	**0.00144**	**0.01588**
2007	**0.6603**	**-2.4915**	**0.24031**	**0.3360**	**0.01031**	**0.92739**	**-0.21969**	**0.20123**
TOTAL	**-0.6572**	**-35.232**	**1.3528**	**-1.6625**	**0.5828**	**10.3442**	**0.0232**	**0.0302**

Where H_M = **measured global solar radiation,** H_P = **Angstrom-Prescott estimation of global solar radiation and** H_{ANN} = **Artificial neural network estimation of global solar radiation**

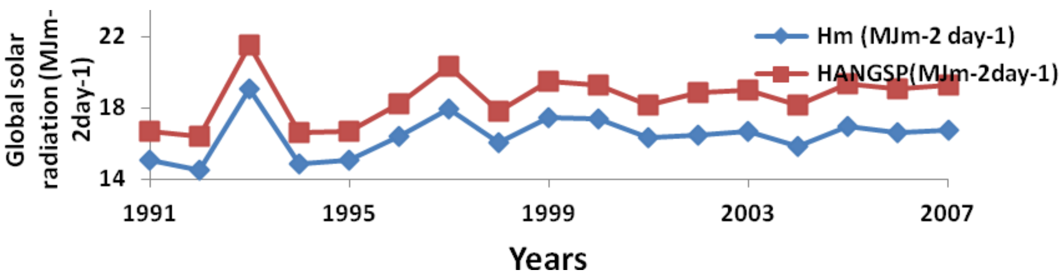

Figure 1: Graph of Measured and Angstrom-Prescott Solar Radiation with Sunshine

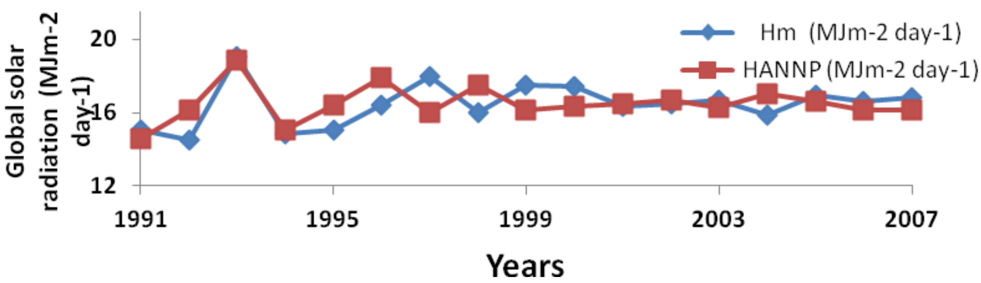

Figure 2: Graph of Measured and Artificial Neural Network Solar Radiation with Sunshine

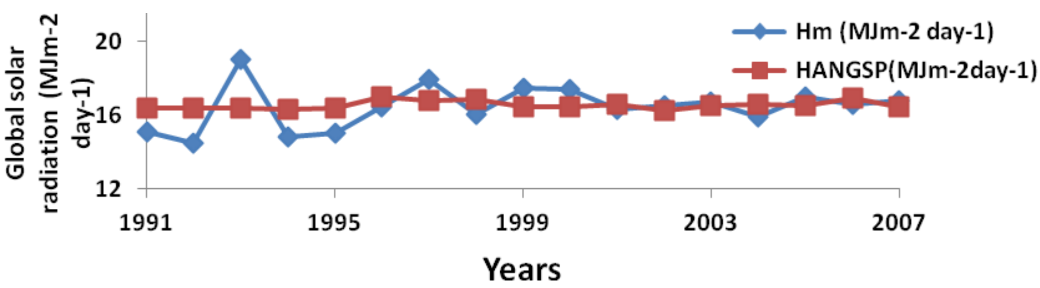

Figure 3: Graph of Measured and Angstrom-Prescott Solar

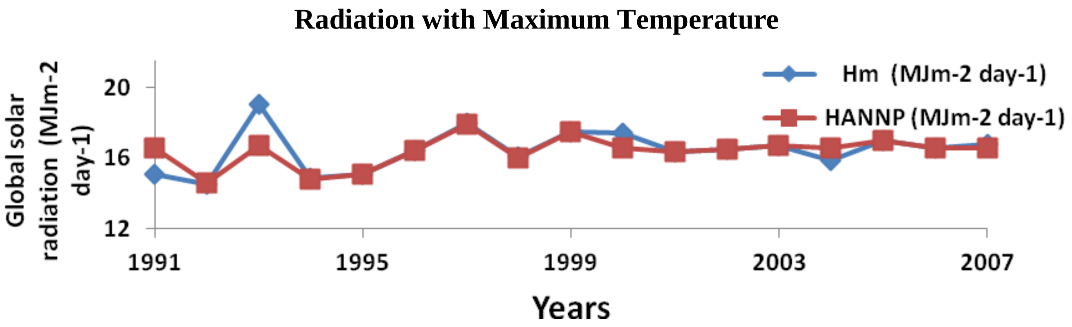

Figure 4: Graph of Measured and Artificial Neural Network Solar Radiation with Maximum Temperature

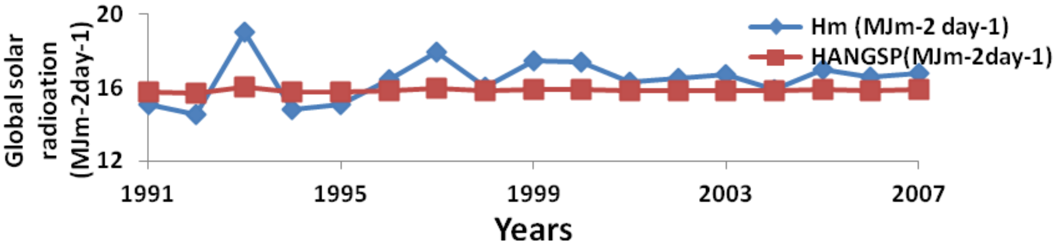

Figure 5: Graph of Measured and Angstrom-Prescott Solar Radiation with Relative Humidity

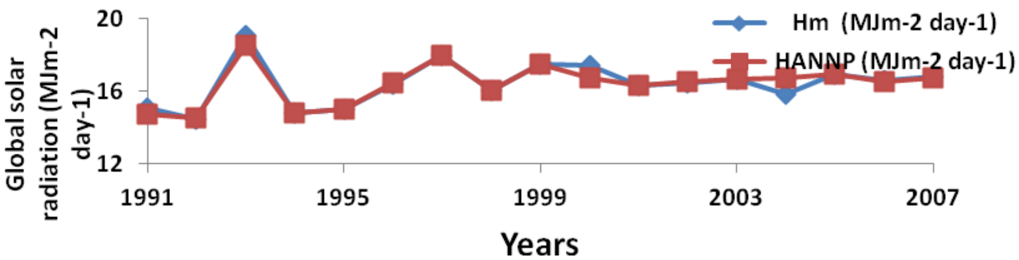

Figure 6: Graph of Measured and Artificial Neural Network Solar Radiation with Relative Humidity

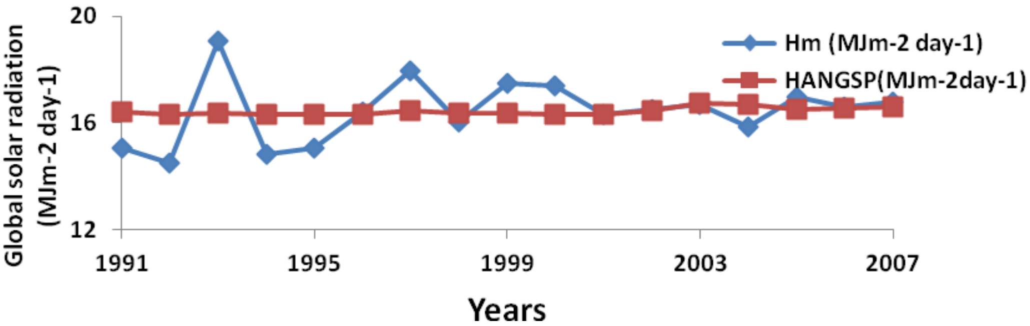

Figure 7: Graph of Measured and Angstrom-Prescott Solar Radiation with Cloudiness

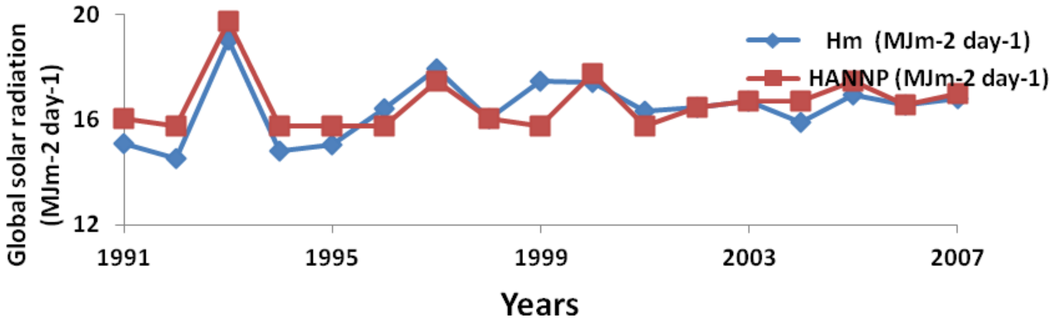

Figure 8: Graph of measured and Artificial Neural Network Solar Radiation with cloudiness

Table 2 and table 3 below shows the result of MBE, RMSE and MPE errors of the estimation of global solar radiation with atmospheric parameters of the two models

Table 2: Summary table of all the errors in respect of each model

Error	Estimation With Sunshine Hours		Estimation With Maximum Temperature		Estimation With Relative Humidity		Estimation With Cloudiness	
	ANGS	ANN	ANGS	ANN	ANGS	ANN	ANGS	ANN
MBE	2.0725	0.0387	0.0978	0.0796	0.0685	-0.0343	-0.0018	0.0002
RMSE	2.1955	0.5341	0.6356	0.2635	0.7501	0.0468	0.6463	0.0536
MPE	-12.5813	-0.5087	-1.0589	0.2901	3.2699	-0.1715	3.8226	0.0518

Table 3: Correlation coefficient (R) and coefficient of determination (R^2) of Angstrom-Prescott and Artificial Neural Network

	ANGSTROM-PRESCOTT				ARTIFICIAL NEURAL NETWORK			
	Sunshine Hours	**Maximum Temperature**	**Relative Humidity**	**Cloudiness**	**Sunshine Hours**	**Maximum Temperature**	**Relative Humidity**	**Cloudiness**
R	**0.53**	**0.64**	**0.59**	**0.45**	**0.73**	**0.67**	**0.93**	**0.84**
R^2	**0.28**	**0.41**	**0.35**	**0.43**	**0.54**	**0.45**	**0.86**	**0.70**

For better analysis, validation of MBE, RMSE, MPE, correlation coefficient and coefficient of determination were developed and the results are summarized in Table 2 and 3.

The error values Angstrom-Prescott model are MBE = (2.0725, 0.0978, 0.0685, -0.0018), RMSE = (2.1955, 0.6356, 0.7501, 0.6463), MPE = (-12.5813, -1.0589, 3.2699 3.8226), while ANN model are MBE = (0.0387, 0.0796, -0.0343, 0.0002), RMSE = (0.5341, 0.2635, 0.0468, 0.0536) and MPE = (-0.5057, 0.2901, -0.1715, 0.0518) for sunshine hours, maximum temperature, relative humidity and cloudiness respectively.

The correlation coefficient and coefficient of determination results of the two models for sunshine hours, maximum temperature, relative humidity and cloud cover are as follows R = 0.53,O.64, 0.93, 0.84 for angstrom-Prescott model and 0.73, 0.67, 0.93 and 0.84 for ANN model respectively. While R^2 = 0.28, 0.41, 0.35 and 0.43 for Angstrom-Prescott model and 0.54, 0.45, 0.86 and 0.70 for ANN model respectively.

The error values for the two models were checked based on the reference value of zero. The closer the value to zero the better the estimation, and close examination of the error values of the two models shows that ANN has better values (i.e error values that is closer to the reference point zero), and thus has better predictive capacity.

CONCLUSION

The amount of solar data is best obtained by pyranometer at any site and day – to – day readings from the instrument gives the data (Augustine and Nnabuchi, 2009). However, because of the unavailability of the instrument in many locations, atmospheric parameters at a particular location are being to predict the global solar radiation in that location. A comparison between the prediction of global solar radiation using the Angstrom-Prescott and ANN models were studied based on the available climatic parameters of sunshine hour, maximum temperature, relative humidity, and cloudiness cover. The predicted values were checked with MBE, RMSE, MPE correlation coefficient and coefficient of determination in other to validate the efficiency of the models. From the validation results and considerations, statistical analysis has shown that Angstrom-Prescott and ANN models have estimation capacity, but ANN shows an excellent result.

Acknowledgement

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