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Advances in Applied Science Research, 2012, 3 (1):619-624

ISSN: 0976-8610
CODEN (USA): AASRFC

Application of artificial neural network and Angstrom-Prescott models in prediction of global solar radiation of Uyo City, Nigeria with atmospheric parameters

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ABSTRACT

Prediction of monthly mean global solar radiation (GSR) based on atmospheric parameters, using Multi-layer perceptron (MLP) neural networks and an Angstrom-Prescott model has been studied. Monthly mean maximum temperature, relative humidity, sunshine hours, and cloud cover values between 1991 to 2007 for Uyo city-Nigeria (latitude 5^o N, Longitude 5^o E), were used in this study. The statistical analysis, Angstrom-Prescott model show that MBE=-2.05667, RMSE=4.17173 and MPE=15.4617 while that of ANN model are MBE=-0.12667, RMSE=0.26243 and MPE=0.69231. The low values of ANN model indicates reasonably strong correlation between ANN models prediction and measured values of global solar radiation for Uyo-Nigeria. The value R^2 of ANN model show that 97.2% of is correct while R^2 of Angstrom-Prescott model show that 74.5% is correct, therefore, ANN model is a better model for this prediction.

Keywords: Atmospheric parameters, ANN, Angstrom-Prescott, model, Global solar radiation.

INTRODUCTION

The troposphere is the first layer above the earth's surface which contains 90% of the earth's atmosphere and 99% of the water vapor. All of our normal day-to-day activities and atmospheric weather activities occur at this region.

Atmospheric weather is a state of the atmosphere at any given time and place. Weather occurs because our atmosphere is in constant motion. Weather changes every season because of the earth's tilt when it revolves around the Sun. Some determining factors of weather are temperature, precipitation, fronts, wind, relative humidity, clouds, hurricanes, tornadoes, thunderstorms, etc.

Solar radiation while passing through the earth's atmosphere is subjected to the mechanisms of atmospheric absorption and scattering. A fraction of the radiation reaching the earth's surface is reflected back into the atmosphere and is subjected to these atmospheric phenomenons again; the remainder is absorbed by earth's surface.
The absorption of solar radiation is mainly by ozone, water vapor, oxygen, nitrogen, carbon (IV) oxide, as well as clouds and scattering is due to air molecules, dust and water droplets, these factors are predominantly contain at the troposphere.

The amounts of global solar data are best obtained by installing pyranometer at any site and day to day readings from the instrument give us the data. But because of the unavailability of the instruments in many locations, atmospheric parameters at a particular location are being use to predict the global solar radiation in that location.

Researchers from difference places have used atmospheric parameters to estimate solar radiation (5), correlated the estimated daily global solar radiation with hours of bright sunshine in Turkey (2), developed new correlation of global solar radiation with meteorological Parameters for Bahrain (8), and estimated the global solar radiation using artificial neural networks.

This paper is aimed at comparing the use of ANN and Angstrom-Prescott models in predicting Global Solar Radiation for Uyo-Nigeria, with atmospheric parameters of sunshine.

MATERIALS AND METHODS

The monthly mean daily data for sunshine hours, maximum temperature, relative humidity, cloud cover were collected from the Nigerian Meteorological Agency, Federal Ministry of Aviation, Oshodi, and Lagos, Nigeria.

The global solar radiation data were collected courtesy of Renewable Energy for Rural Industrialization and Development in Nigeria. The data obtained covered a period of seventeen years (1991 – 2007) for Uyo, Nigeria (latitude 5o 30 °N, Longitude5o 41°E). The monthly averages data processed in preparation for the correlations are presented in Table 1.

This study was based on Multi Layer Perceptron (MLP) which trained and tested using past seventeen years (1991-2007) with meteorological data. The chosen weather data were divided into two randomly selected groups, the training group, corresponding to 66.7% of the patterns, and the test group, corresponding to 8.3% of patterns; so that the generalization capacity of network could be checked after training phase. Also three random months were selected as holdout data and it corresponds to 25.0% which is use for validation after training.

The following is an outline of the procedure used in the development of the ANN model:

i) Input and target values were normalized, in the range -1 to 1.
ii) Matrix size of the dataset was defined.
iii) Partition and create training and validation sub-datasets.
iv) The MLP neural network was created
v) The MLP neural network was trained
vi) Automatic Architecture selected
vi) Generate output values.
vii) Un-normalize the output values.
viii) The performance of the neural network was checked by comparing the output values with measured values.

Angstrom-Prescott equation model were used to generate data for the prediction. The monthly mean daily extraterrestrial radiation $\bar{H}_o$ and monthly mean day length $\bar{N}$ was derived from the following formulae:

$$\bar{H}_o = \frac{24}{\pi} I_{SC} E_O \left[\frac{\pi}{180} W_s \sin\Phi \sin\delta + \cos\Phi \cos\delta \cos W_s\right] \text{------------------------------ (1)}$$

$$\bar{N} = \frac{2}{25} Cos^{-1} (-\tan\delta \tan\Phi) \text{ ----------- (2)}$$

$$\delta = 23.45 \sin\left[\frac{360 (N+284)}{365}\right] \text{---------- (3)}$$

$$W_s = \cos^{-1} (-\tan\delta \tan\Phi) \text{ --------------- (4)}$$

Where,
I_{SC}= Solar constant (4.921 MJm-2day-1),
N= characteristic of day Number
Φ= latitude angle
*w*s= sunshine hour angle
δ = Solar angle of declination.

Table 1: Meteorological Data and Global Solar Radiation for Uyo.

Month	$\bar{n}$ hours	$\bar{n}/\bar{N}$	T_m ^oC	R	$\bar{c}/\bar{C}$	$\bar{H}_o$ (MJm^{-2}day^{-1})	Measured SR (MJm^{-2}day^{-1})	Empirical SR (MJm^{-2}day^{-1})	$\bar{K}_T=\bar{H}_M/\bar{H}_o$	ANN Predicted SR (MJm^{-2}day^{-1})
Jan.	4.06	0.34	33.16	0.50	0.64	34.21	14.27	14.56	0.34	15.30
Feb.	4.29	0.36	34.44	0.50	0.66	35.06	14.85	15.71	0.36	15.16
Mar.	3.56	0.30	33.37	0.62	0.69	37.72	16.11	14.29	0.30	14.43
Apr.	3.89	0.33	32.49	0.69	0.69	36.48	15.75	15.11	0.33	14.98
May.	3.84	0.33	31.53	0.73	0.69	36.22	15.07	15.00	0.33	15.14
Jun.	2.86	0.24	30.49	0.76	0.69	34.13	13.57	10.39	0.24	13.95
Jul.	1.91	0.16	29.13	0.81	0.70	35.81	12.47	7.07	0.16	12.08
Aug.	1.79	0.15	28.99	0.82	0.70	35.05	11.39	6.43	0.15	11.77
Sept.	2.59	0.22	29.76	0.80	0.70	36.26	14.01	10.09	0.22	13.55
Oct.	2.84	0.24	30.57	0.75	0.69	36.68	14.75	11.16	0.24	13.95
Nov.	3.79	0.32	31.92	0.66	0.69	34.58	14.37	13.92	0.32	14.99
Dec.	3.73	0.32	32.12	0.56	0.68	32.49	15.25	13.45	0.33	15.04

RESULTS AND DISCUSSION

Table 1, shows the calculated values of measured monthly mean daily sunshine hours $\bar{n}$, possible sunshine fraction hours $\bar{n}/\bar{N}$, measured monthly mean daily maximum temperature T_M, measured monthly mean daily relative humidity R, calculated measured monthly mean daily cloudiness $\bar{c}/\bar{C}$, extraterrestrial solar radiation on a horizontal surface $\bar{H}_0$, measured global solar radiation on a horizontal surface $\bar{H}_M$, empirical global solar radiation on a horizontal surface, the clearness index $\bar{K}_T = \bar{H}_0/\bar{H}_M$ as well as the result of the artificial neural network of global solar radiation on horizontal surface.

A close examination of Table 1, as well as Figures 1 to 3 shows that the minimum values of the monthly mean daily sunshine hours and monthly mean daily global solar radiation on a horizontal surface both for Angstrom-Prescott, ANN measured values, which are 1.79 hours and 6.43, 11.77 and 11.39 (MJm-^{2}day-^{1}), respectively, occur in the month of August. This value is within what is expected of a tropical site (6, and 9).

Figures 4-5 shows the comparison between measured and predicted monthly average daily global solar radiation for the two models, figure 6 shows the comparison between the two models and the measured values of global solar radiation. It is clear that there is a good agreement between the measured and ANN predicted data.

The month of August is characterized by heavy rain falls, therefore is well expected as this rainy season period in Nigeria. It is important to state here that from the records of temperature made during the seventeen year period, August has the lowest monthly mean daily average temperature of 28.99 ^{0}C.

Figure 4 shows the variation of measure and ANN global solar radiation during the year; figure 5 shows the variation of measured and Angstrom-Prescott of global solar radiation. From the two figures, it is clear that August have the minimum value of solar radiation.

In order to evaluate the performance of ANN and angstrom-Prescott models quantitatively and check whether there is any agreement with the measured values, statistical analysis involving mean bias error (MBE), root mean square error (RMSE) and mean percentage error was conducted. MBE is an induction of the average deviation of the predicted values from the corresponding measured data, the lower MBE the better. RMSE provides information on performance, and is a measure of the variation of predicated values around the measured data. The lower the RMSE, the more accurate is the prediction. MPE is also use to check the error of the models in percentage, the lower the value the more accurate of the model.

From the statistical analysis, the summation of Angstrom-Prescott model, MBE= -2.05667, RMSE=4.17173 and MPE=15.4617 while the summation of ANN model, MBE=-0.12667, RMSE=0.26243 and MPE=0.69231. The low values indicate reasonably strong correlation between ANN models prediction and measured values of global solar radiation for Uyo-Nigeria.

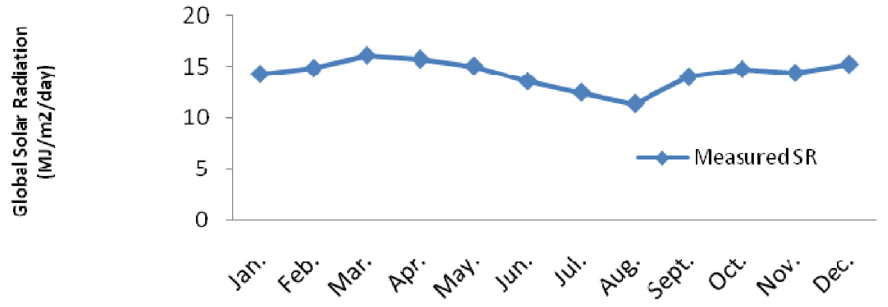

Figure 1: Graph of Measured Solar Radiation

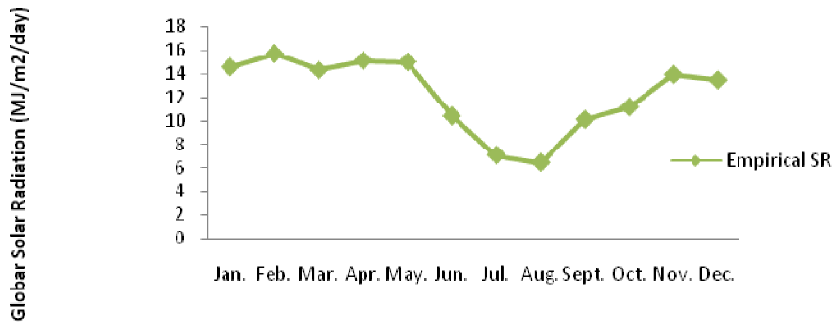

Figure 2: Graph of Empirical Global solar Radiation

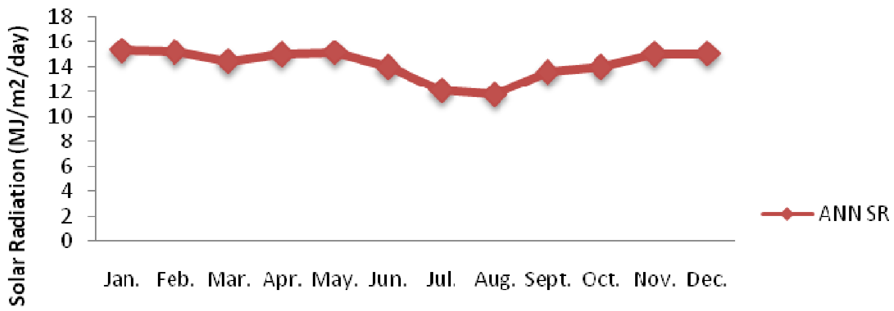

Figure 3: Graph of ANN predicted Global Solar Radiation

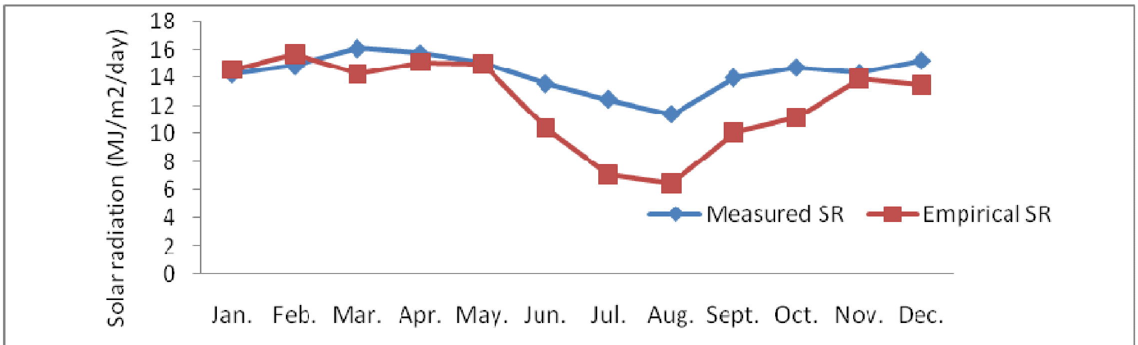

Figure 4: Graph of measured and ANN solar Radiation

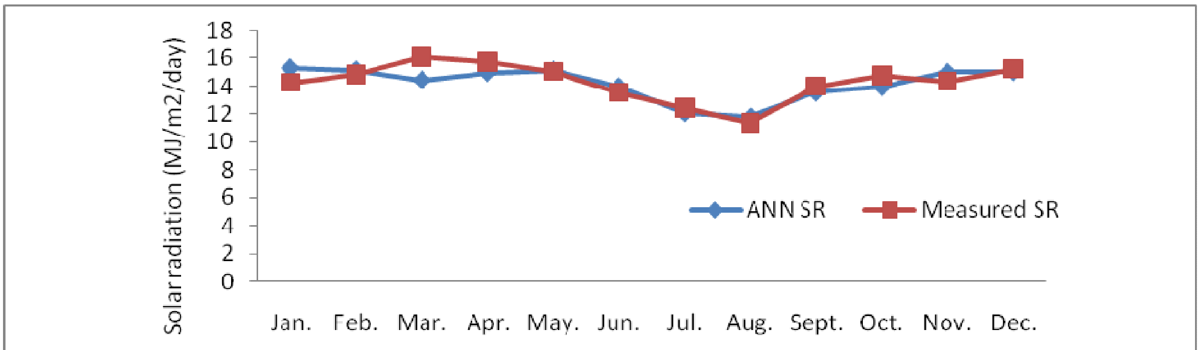

Figure 5: Graph of measured and ANN solar Radiation

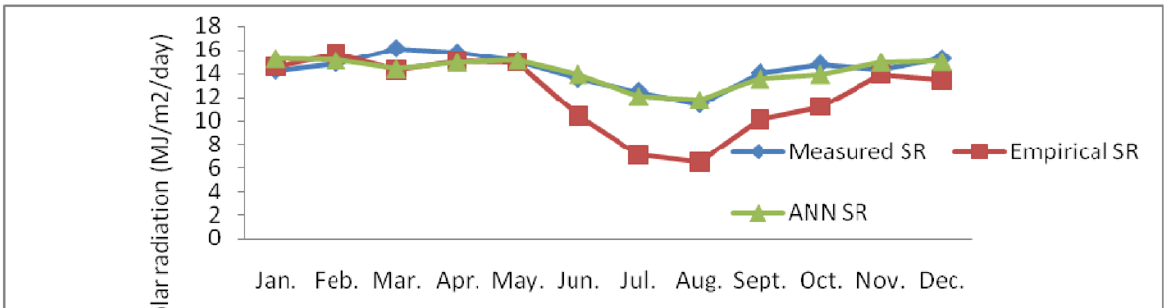

Figure 6: comparison Between Measured, ANN and Empirical solar Radiation

The values of the correlation coefficient for ANN model R = 0.986 and the coefficient of determination R^2 = 0.972.

The value of R (0.989) indicates that there is a high positive correlation between ANN predicted and the monthly mean daily global solar radiation on a horizontal surface. Also, the value of R^2 (0.972) indicates that 97.2% of the variation in the monthly mean daily solar radiation on a horizontal surface can be explained by the model.

The value of R and R^2 of Angstrom-Prescott model is 0.863 and 0.745 indicates that 74.5% of the variation in the monthly mean daily solar radiation on a horizontal surface can be explained by the model. The low value and low percentage indicates lower performance of prediction compare to ANN model.

CONCLUSION

In this paper, ANN and Angstrom-Prescott model were use to predict the monthly average daily global solar radiation on a horizontal surface for Uyo city in Nigeria. Atmospheric parameters between 1991 and 2007 were used. Table 1 shows the atmospheric parameters use for the prediction. The chosen weather data were divided into three randomly selected groups, the training group, corresponding to 66.7% of the patterns, the test group, corresponding to 8.3% of patterns and as holdout data and it corresponds to 25.0% which is use for validation after training so that the generalization capacity of network could be checked after training phase. The predications of Global Solar Radiation (GSR) were made using five combinations of data sets. Figure 4 and 5 show the correlation between the measured and ANN, and measured and Angstrom-Prescott model. Figure 6 shows the comparison between measured, ANN and Angstrom-Prescott value of the monthly mean daily global solar radiation on a horizontal surface. From the figures it is clear that ANN model has strong agreement and relationship with the measured monthly mean daily global solar radiation on a horizontal surface, thus the better model and should be use for prediction of monthly mean daily global solar radiation on a horizontal surface.

Acknowledgement
The authors wish to express their profound gratitude to the management and staff of the Nigerian Meteorological Agency, Oshodi, Lagos for supplying the data for atmospheric parameters for this work and the Renewable Energy for Rural Industrialization and Development in Nigeria for making the solar radiation data available.

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