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Estimation of mean monthly global solar radiation for Warri- Nigeria (Using angstrom and MLP ANN model)

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ABSTRACT

Measured maximum temperature, relative humidity, cloudiness and sunshine duration measurements between 1991 and 2007 for warri, Delta state of Nigeria were used for the estimation of monthly average mean global solar radiation on horizontal surface using Artificial Neural Network and ANGSTROM-PRESCOTT model technique. This study was based on Multi Layer Perceptron (MLP) which trained and tested using past seventeen years (1991-2007) 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%. Coefficients of determination R^2 for the MLP models 0.958 indicating reasonably strong correlation between estimation and measured values. The values of RMSE for empirical model is 3.39118 indicating higher errors and low prediction and the value for MLP is 0.050106 indicating lower errors and higher prediction accuracy. Also the values of MPE for empirical model and MLP model confirms the evaluation of RMSE in the prediction of solar radiation which are -80-3875 for the former and -84.3124 for the later. The summation of MBE values were found to be -0.3675 for empirical and 0.0625 for MLP. The negative sign indicate under estimation while 0.0625 for MLP indicates low error since the actual values are positive. Figure 2 and 3 shows the graphs comparing the measured and predicted values of the two models of the monthly average mean solar radiation for warri. The result clearly show that there is a good and strong agreement between the MLP predicted and the measured values compared to empirical predicted model and the measured values. Hence comparison between the ANN model and ANGSTROM-PRESCOTT empirical models has shown the superiority of the ANN model in the prediction.

INTRODUCTION

Everyone is trying to forecast the future. Bankers need to predict credit worthiness of customers. Marketing analyst want to predict future sales. Economists want to predict economic cycles. Hospital system is interested in tracking costs and lengths of stay for patients, meteorologist want to forecast the weather condition and everybody wants to know whether the stock market will be up or down tomorrow, etc.

Solar radiation passing through the atmosphere to the ground is known to be depleted through scattering, reflection, and absorption by the atmospheric constituents like air molecules, aerosols, water vapour, ozone and clouds. The reflection of solar radiation is mainly by clouds and this plays a leading role in reducing the energy density of the solar radiation reaching the surface of the earth (6). A global study of the world distribution of global solar radiation requires knowledge of the radiation data in various countries for the purpose of worldwide marketing. The designers and manufacturers of solar equipment will need to know the mean global solar radiation available in different and specific regions (7).

This is usually possible through solar measuring equipment. These devices are not available in most of remote or rural areas that specially have potential of solar installation. Even locations with these devices, the maintenance and logistics are enormous.

Several researchers have used one or more meteorological data to predict global solar radiation in different region with different models. For instance, the development of empirical relation between solar radiation and hours of bright sunshine (8), The uses of Neural Network Approach for Modeling Global Solar Radiation for India (13), etc. All these are areas researchers had estimated global solar radiation.

This work aims at comparing the use of artificial neural network model and empirical (angstrom) models with maximum temperature, cloud cover, relative humidity, and sunshine hour's data to predict global solar radiation of Warri in Delta state of Nigeria.

ARTIFICIAL NEURAL NETWORK

A neural network is a massively parallel distributed processor made up of simple processing units that have a natural power for storing exponential knowledge and making it available for us. Artificial neural network (ANN) is a type of artificial intelligence that mimics the behavior of the human brain. Majorly, we have two types of ANN, the Multi-layer Perceptron (MLP) and Radial Basic function (RBF). In this paper we used MLP for the prediction.

ANGSTROM-PRESCOTT MODEL

There are several types of empirical formulae for predicting the monthly mean daily global solar radiation as a function of readily measured climatic data (11, 12). Among the existing correlations, the Angstrom–Prescott regression equation, which relates the monthly mean daily global solar radiation to the meteorological parameters, has been used in this paper. In addition, it has also been found to a great extent, to predict global solar radiation in several locations

MATERIALS AND MEASUREMENT PROCEDURES

The monthly average mean data for sunshine hours, maximum Temperature, Relative Humanity, Cloudiness, were collected from the Nigerian Meteorological Agency, Federal Ministry of Aviation, Oshodi, 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 Warri, Nigeria (5.02^0N, long 7.88^0E). The monthly averages data processed in preparation for the correlation is presented in Table 3. This study was based on Multi Layer Perceptron (MLP) which were trained and tested using past seventeen years (1991-2007) meteorological data. The chosen weather data were divided into three 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%.

Theoretical Background of Angstrom-Prescott

The most convenient and widely used correlation model for predicting solar radiation was developed by Angstrom and later modified by Prescott. The formulae are of the form (for monthly average):

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\ \frac{\bar{S}}{\bar{S}_o} --------- (1)$$

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\ T_m --------- (2)$$

$$\frac{\bar{H}_m}{\bar{H}_o} = a + b\ \frac{\bar{C}}{C} --------- (3)$$

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

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

$\frac{\bar{S}}{\bar{S}_o}$ =fraction of sunshine hour

$\frac{\bar{C}}{\bar{C}}$ = cloudiness index

R= relative humidity

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

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

$\bar{S}$ = the monthly average daily number of hours of bright sunshine.

$\bar{S}_o$ = the monthly average daily maximum number of hours of possible sunshine.

For the correlation the formulae H_m will change to H_p

Where H_p = predicted global solar radiation a and b are regression coefficient and can be calculated from the relation.

a = -0.110+ 0235cos $\emptyset$

$+ 0.323\ (S/S_O) ----(5)$

b = 1.449-0.553cos $\emptyset$

$- 0.694\ (S/S_O) --- (6)$

The extraterrestrial solar radiation on horizontal surface can be calculated from the following

$$\bar{H}_o = \frac{24}{\pi} I_{sc} E_o \left(\frac{\pi}{180}\ \omega_s \sin\emptyset \sin\delta + cos\emptyset\ cos\delta\ \sin\omega_s\right) ----- (7)$$

Where I_{sc} = solar constant

E_o *Eccentricity correlation factor*

$\emptyset$ = *latitude*

δ = *solar declination*

ω_s = *hour angle*

N = characteristic day number.

$$I_{sc} = \frac{1367x\ 3600}{1000000}\ (MJM^{-2}h^{-1}) --- (8)$$

$$E_O = 1 + 0.033\ COS\left(\frac{360N}{365}\right) --(9)$$

$$\delta = 23.45\ sin\left[360\frac{(N+284)}{365}\right] --(10)$$

$$w_s = \cos^{-1}(-\tan\emptyset \tan\delta) --- (11)$$

$$\bar{N} = \frac{2}{15}\cos^{-1}(-tan\emptyset tan\delta) -- (12)$$

RESULTS AND DISCUSSION

In order to compare the performance of ANN models and ANGSTROM-PRESCOTT MODEL quantitatively and ascertain the trend in performance of the models, statistical analysis involving mean bias error (MBE), root mean square error (RMSE) and mean percent error (MPE) was conducted. Equations 1-12 was used to for empirical prediction model and equation 13-18 was used to generate table of error estimation. MBE is an indication of the average deviation of the predicted values from the corresponding measured data and can provide information on long term performance of the models. A positive MBE value indicates the amount of overestimation in predicted global solar radiation and vice versa. RMSE provides information on the short term performance and is a measure of the variation of predicted values around the measured data. The lower the RMSE, the more accurate is the estimation. These statistics were determined as follows: Table 1-2 shows the model and case processing summaries, Table 3-4 shows the measured monthly average of meteorological parameters and predicted values of both models of monthly average mean of solar radiation. Table 3 also shows the monthly values of regression constant a and b. Figure 2-3 shows the graphs that compared the values (measured, predicted MLP and empirical). Finally, table 5 present the result of the estimated errors of the predictions. Table 1 reports the strength of the relationship between the models (ANN and Angstrom-Prescott) and the measured variable. The value of the correlation coefficient (R) for ANN is 0.979 which indicate strong relationship while the value for Empirical model for R is 0.951 indicate that model one has better correlation coefficient. Coefficients of determination R^2 for the ANN models of 0.958 indicates that 95.8 % of the variation in the monthly mean daily solar radiation on a horizontal surface can be explained by the model while R^2 of Empirical model 0.904 indicating 90.4%, the high percentage value of ANN indicating reasonably strong correlation between ANN prediction and measured values. Also, the adjusted R square value of ANN and Empirical model are 0.923 and 0.895, the high value of ANN indicate better model, while the standard error of the estimated values of the models are 0.38835 for ANN and 0.45428 for Empirical model, it indicate how the models has reduce the uncertainty in the prediction, thus, the error provided by ANN model is of low value compared to that of Empirical model, indicate high performance of ANN in prediction. The values of RMSE for empirical model is 3.39118 indicating higher errors and low prediction and the value for ANN is 0.050106 indicating lower errors and higher prediction accuracy. Also the values of MPE for empirical model and MLP model confirms the evaluation of RMSE in the prediction of solar radiation which are -80.3875 for the former and -84.3124 for the later. The summation of MBE values are -0. 3675 for empirical and 0.0625 for MLP, the negative sign indicate under estimation while 0.0625 for MLP indicate low error since the actual values are positive. Figure 2-3 shows the graphs comparing the measured, predicted values of the two models of the monthly average mean solar radiation and the cleanness index, MLP predicted cleanness index, and the empirical predicted cleanness index for Warri. It is clear that there is a good and strong agreement between the MLP predicted and the measured values compare to empirical predicted and the measured values from the graphs.

Table 3: Monthly Average mean values of H/Ho, S/So, Tm (0 C), c/C and R for Warri

MONTH	Tmax ^{0}c	R/100 Hour $^0/_0$	$\bar{c}/\bar{C}$	$\overline{S/\bar{S}_0}$	$\bar{H}_M$ (MJm^{2}day-1)	$\bar{H}_0$ (MJm^{-2} day^{-1})	$K_T = \overline{H_m}/\bar{H}_o$
JAN	33.00	0.50	0.6	0.4020	11.02	34.21	0.3221
FEB	33.68	0.50	0.66	0.4120	12.55	35.06	0.3579
MAR	33.45	0.62	0.69	0.4066	13.76	37.72	0.3648
APR	32.86	0.68	0.69	0.4377	15.94	36.48	0.4369
MAY	31.93	0.73	0.69	0.3963	11.30	36.22	0.3119
JUN	30.53	0.76	0.69	0.3002	12.31	34.13	0.3607
JUL	28.77	0.81	0.70	0.2005	12.91	35.81	0.3605
AUG	29.99	0.82	0.70	0.2289	12.19	35.05	0.3478
SEPT	31.28	0.80	0.70	0.2289	13.55	36.26	0.3737
OCT	32.28	0.75	0.69	0.3702	14.56	36.68	0.3969
NOV	32.74	0.66	0.66	0.4952	13.91	34.58	0.4023
DEC	32.66	0.56	0.68	0.4645	15.98	32.49	0.4918

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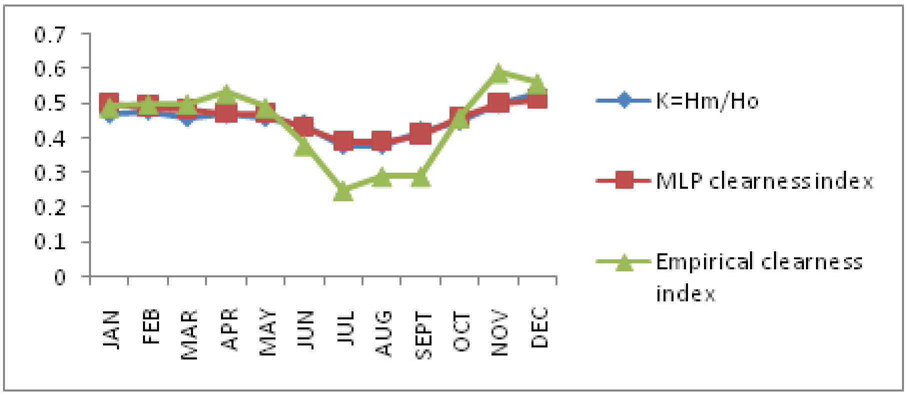

Figure 2: Comparison of graph between measured cleanness index, MLP predicted Cleanness index and Empirical model Predicted of Solar Radiation.

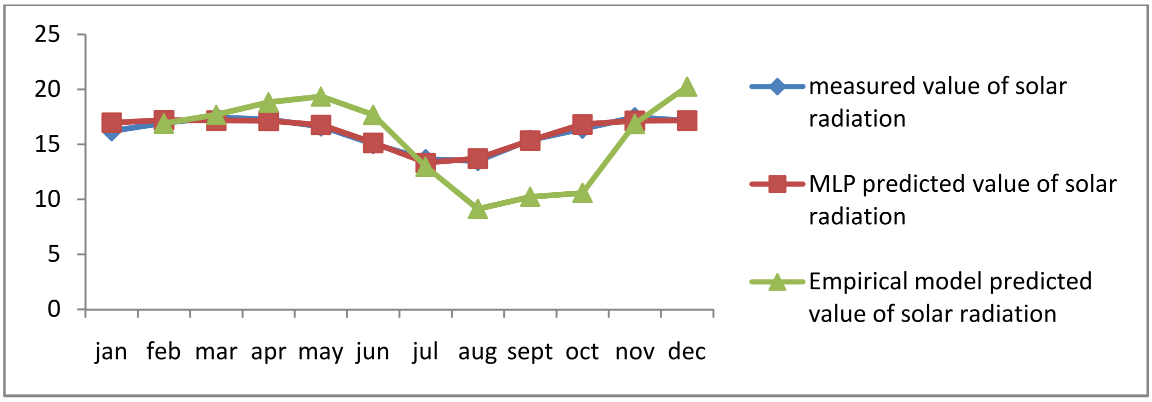

Figure 3: Comparison between Measured, MLP Predicted and Empirical Model Predicted of Solar Radiation

Table 4: Monthly average mean values of a, b, measured values, MLP predicted values, Empirical model predicted values of solar radiation, and cleanness index, MLP predicted cleanness index and Empirical model predicted cleanness for warri.

Month Of the year	a	b	Measured of solar radiation	MLP predicted value of solar radiation	Empirical model predicted value of solar radiation	$K=H_m/H_O$ (cleanness index)	MLP Predicted cleanness index	Empirical model predicted value of cleanness index
JAN	0.091000	1.00257	16.19	16.96	1 16.90	0.47	0.50	0.49
FEB	0.094230	0.9956	16.94	17.19	17.69	0 .48	0.49	0.50
MAR	0.092486	0.9994	17.45	17.15	18.82	0.46	0.48	0.50
APR	0.102531	0.9778	17.26	17.13	19.35	0.47	0.47	0.53
MAY	0.089159	1.0065	16.61	16.76	17.68	0.46	0.47	0.49
JUN	0.058119	1.0732	15.03	15.13	12.98	0.44	0.43	0.38
JUL	0.025915	1.1424	13.65	13.32	9.130	0.38	0.39	0.25
AUG	0.035089	1.1227	13.48	13.70	10.24	0.38	0.39	0.29
SEPT	0.035089	1.1220	15.40	15.34	10.59	0.42	0.41	0.29
OCT	0.080729	1.0246	16.42	16.80	16.87	0.45	0.46	0.46
NOV	0.121104	0.9379	17.44	17.12	20.25	0.50	0.50	0.59
DEC	0.111187	0.9592	17.13	17.15	18.09	0.53	0.51	0.56

Table 5: Comparisons of RMSE , MPE and MBE for the developed ANN(MLP) Model and ANGSTROM-PRESCOTT Empirical model

MBE of empirical model	MBE of MPL	RMSE of empirical model	RMSE OF MLP	MPE of empirical model	MPE OF MPL
0.059167	0.064167	0.021004	0.024704	-7.34962	-7.38050
0.062500	0.020833	0.023438	0.002604	-7.29062	-7.04465
0.114167	-0.025000	0.078204	0.003750	-7.53342	-6.73590
0.174167	-0.010830	0.182004	0.000704	-7.90408	-6.83223
0.089167	0.012500	0.047704	0.000938	-7.48599	-7.02442
-0.170830	0.008333	0.175104	0.000417	-5.94422	-7.13628
-0.376670	-0.027500	0.851267	0.004538	-4.43637	-6.99437
-0.270000	0.018333	0.437400	0.002017	-5.20703	-7.34600
-0.400830	-0.005000	0.964004	0.000150	-4.44719	-7.01753
0.037500	0.031667	0.008437	0.006017	-7.19338	-7.15785
0.234167	-0.026670	0.329004	0.004267	-8.22270	-6.72709
0.080000	0.001667	0.038400	1.67E-05	-7.37285	-6.91556

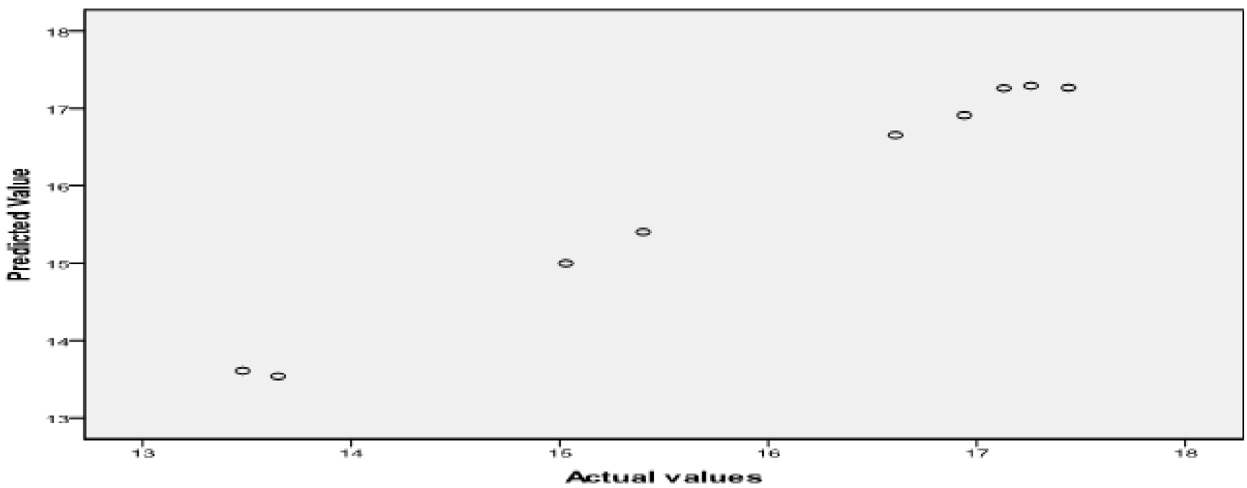

Figure 4: Predicted by observable chart

CONCLUSION

Four meteorological parameters were used for the analysis of solar irradiation in Warri, Delta State of Nigeria. MLP of ANN and ANGSTROM-PRESCOTT Empirical models were employed to obtain the predicted values of the average monthly mean solar radiation. The result shows an excellent agreement between measured and MLP predicted values with coefficient of determination of 0.958, maximum percentage error of -80-3875 and -84.3124 and root-mean-square error of for empirical model is 3.39118 and the value for MLP is 0.050106. The comparison between the ANN model and ANGSTROM-PRESCOTT empirical models has shown the superiority of the ANN model and the shape of figure 4 further prove the relationship between predicted and actual values. The result has confirmed the application of the ANN model in the prediction of solar radiation and shows that ANN model predicts better than other models.

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