Time-series Regression Model for Prediction of Monthly and Daily Average Global Solar Radiation in Al Ain City –UAE

Hassan A.N. Hejase [1], Ali H. Assi [2]

Abstract — This study addresses the use of classical regression techniques for predicting the monthly average global solar radiation in the city of Al-Ain, UAE. The mean daily recorded data used were supplied by the National Center of Meteorology and Seismology (NCMS) in Abu Dhabi , UAE or the years of 1995 till 2007. Available weather data included the mean air temperature (^{0}C), mean wind speed (knots), daily sunshine hours, and percent relative humidity in addition to the daily global solar radiation (kWh/m^2). The data was divided into two groups: one data group from 1995-2004 for the prediction model and the second group (2005-2007) for testing the model. The correlation between mean daily global solar radiation (GSR) and the other four variables suggested using all four variables for building the prediction model, although the GSR is highly correlated to the mean temperature and sunshine-hours variations.

The resulting model was tested using the three-year data of the period 2005-2007 yielding a deterministic coefficient R^2 = 90.77 % and RMSE= 0.417 as well as low MBE values. The model was also tested with Artificial Neural Network (ANN) model data yielding very favorable results.

Keywords— Monthly Average Daily Global Solar Radiation, Weather, Regression Model

---

1 INTRODUCTION

The world is adopting more stringent strategic policies to increase dependence on renewable and sustainable energy sources paralleled by a reduction of its dependence on fossil fuel resources to power its domestic and industrial needs. The Arab world and specifically, the gulf region, has witnessed a surge in research endeavours related to the areas of solar energy, abundant in the region, and to less extent on wind energy, bio-fuels and nuclear energy. The establishment of MASDAR in the UAE and the hosting of International Renewable Energy Agency (IRENA) have triggered the interest of the industrial and academic community in energy research. The potential of solar energy harvesting in the UAE is significant, with an average annual sunshine hours of 3568 h (i.e. 9.7 h/day), which corresponds to an average annual solar radiation of approximately 2285 kWh/m2 (i.e. 6.3 kWh/m2 per day) [1].

Numerous authors developed empirical regression models to predict the monthly average daily global solar radiation in their region using various parameters [2- 20]. The mean daily sunshine duration was the most commonly used and available parameter. The most popular model was the linear model by Angström-Prescott [2, 21] which establishes a linear relationship between global radiation and sunshine duration with knowledge of extra-terrestrial solar radiation and the theoretical maximum daily solar hours. Many studies with empirical regression models were done for diverse regions around the world.

Menges et al. [18] reviewed 50 global radiation empirical models available in literature for computing the monthly average daily global radiation on a horizontal surface. They tested the models on data recorded in Konya, Turkey for comparison of model accuracy. The number of weather parameters varied between models. The diverse regression models used include linear, logarithmic, quadratic, third order polynomial, logarithmic-linear and exponential and power models relating the normalized GSR to normalized sunshine hours. Other models included in Menges work used direct regression models involving various weather parameters in addition to geographical data (altitude, latitude) and other weather parameters such as precipitation, cloud cover, etc. Şahin [19] presented a novel method for estimating the solar irradiation and sunshine duration by incorporating the atmospheric effects due to extra-terrestrial solar irradiation and length of day. The author compares his model with Angström's equation with favourable advantages as his method does not use Least Square Method in addition to having no procedural restrictions or assumptions. Ulgen et al. [20] developed two empirical correlations to estimate the monthly average daily global solar radiation on a horizontal surface for Izmir, Turkey. Their models resemble Angström type equations. They compared their models with 25 models previously reported in literature on the basis of statistical error test (MBE, RMSE, MPE, and R^2) with favourable results.

1. *Dr. Hassan A.N. Hejase is with the Department of Electrical Engineering at the United Arab Emirates University, PO Box 17555, Al-Ain, UAE. E-mail: hhejase@uaeu.ac.ae*
2. *Dr. Ali H. Assi is with the Department of Electrical Engineering at the United Arab Emirates University, PO Box 17555, Al-Ain, UAE. E-mail: ali.assi@uaeu.ac.ae*

The main limitation of using many weather parameters is the difficulty of obtaining this data due to the high expense and availability of recording equipment. Some of the regression models are more accurate for monthly data than daily data and most published work only shows monthly data comparison results as the daily mean data are less accurate.

Other authors worked on prediction models based on artificial neural network techniques and most specifically Multi-Layer Perceptron (MLP) and Radial-Basis Function (RBF) methods [22- 33]. The advantage of the ANN models is their ability to handle large amounts of data as well as the ability to handle random data without worry of incomplete, inaccurate or noise-contaminated data.

Our work follows a similar approach to work done by researchers such as Boland [34], Sulaiman et al. [35], Reikard [36], Zeroual et al. [37], Goh et al. [38] and Zaharim et al. [39] who employ the time-series modeling using regression for the deterministic component and Box-Jenkins Auto-Regressive Integrated Moving Average (ARIMA) modeling [40-41] for the stochastic residual component.

Sulaiman et al. [35] and Zaharim et al. [39] use the ARMA Box-Jenkins method to model GSR data in Malaysia. They model the data using non-seasonal autoregressive models where the model adequacy is checked using the Ljung-Box statistic for diagnostic data. However, only short-term data was used for testing their model. Reikard [36] employs a combination of logarithmic regression and ARIMA modeling to predict solar radiation at high resolution and compares his models with other forecast methods such as ANN and considered the 24-hour daily seasonality not taken into account in most modeling approaches. Boland [34] and Zeroual et al. [37] use a combination of regression model with Fourier series for the deterministic part and ARMA modeling for the residual stochastic part.

This paper uses time-series techniques to predict the monthly average daily global solar radiation data in Al-Ain, UAE. The deterministic component was modelled by decomposing it into a multiple linear regression component as a function of the available weather variables plus a cyclical component accounting for the annual periodicity and a linear trend. Work is underway to study the residual error using Box-Jenkins ARIMA modeling techniques [40-41] for the sake of further enhancing the predicted solar radiation data.

Section 2 explains the time-series regression modeling approach and results are shown and discussed in section 3 followed by conclusions.

2 METHODOLOGY

The database (meteorological data provided by NCMS in Abu Dhabi for the periods between 1995 and 2007 used was divided into two sets: A model data set with daily record of the variables: air temperature, wind speed, sunshine hours and relative humidity for the years 1995- 2004 (10 years), and a test data set for the years of 2005-2007. The missing values were replaced by the average of values from same week. The regression modeling and simulation work were done using SPSS [42] and MATLAB [43].

The correlation between the four independent weather data variables (temperature, wind, sunshine, relative humidity) with the global solar radiation parameter (dependent variable) is shown in Table 1.

Table 1.Correlation between the measured weather data parameters for the city of Al-Ain (years 1995-2004)

Variable	T	W	SH	RH
T				
W	**0.191**			
SH	**0.453**	**-0.110**		
RH	**-0.742**	**-0.217**	**-0.456**	
GSR	**0.795**	**0.143**	**0.697**	**-0.676**

Table 1 implies that the temperature and sunshine hours have dominant effect on the GSR parameter followed closely by relative humidity and with less influence by wind speed. The latter low wind correlation could be attributed to the fact that the wind energy in the UAE is not significant to affect temperatures. The RH has a negative correlation as the sun radiation decreases with increase of RH values. Table 2 show the descriptive data statistics for the Al-Ain weather data.

Table 2- Descriptive data statistics for measured weather parameters for Al-Ain (years 1995-2004)

Variable	T	W	SH	RH	GSR
Mean	**36.501**	**7.531**	**9.947**	**44.045**	**6.333**
SE Mean	**0.128**	**0.033**	**0.262**	**0.278**	**0.023**
StdDev	**7.725**	**1.990**	**1.585**	**16.816**	**1.396**
Variance	**59.669**	**3.959**	**2.512**	**282.766**	**1.949**
CoefVar	**21.16**	**26.420**	**15.93**	**38.18**	**22.05**
Min	**16.2**	**208.4e-3**	**0.80**	**7.375**	**1.135**
Median	**37.6**	**7.251**	**10.20**	**43.417**	**6.554**
Max	**49.1**	**22.794**	**12.80**	**97.23**	**8.821**
Skewness	**-0.30**	**1.60**	**-1.52**	**0.20**	**-0.36**
Kurtosis	**-1.21**	**5.73**	**3.77**	**-0.70**	**-0.90**
MSSD	**1.665**	**2.094**	**1.079**	**42.719**	**0.155**

The skewness test (σ_k) measures the asymmetry of the four weather independent variables data around their mean. For σ_k =0 , the data have a Gaussian distribution, while σ_k < 0 indicates that data are spread out more to the left of the mean than to its right, and σ_k > 0 indicates that data are spread out more to the right .

Results shown in Table 2 imply that T, SH and GSR data are spread out to the left of their mean while W and RH data are spread to the right. Temp, RH and GSR data seem to have a quasi-Gaussian distribution. The W and SH data are more divergent away from normal distribution.

The Kurtosis test also measures the degree of normality of each variable. We can clearly see that variables RH, GSR, and T are, simultaneously, closer to normality than the other variables (k_u closer to zero).

Fig. 1 shows the time-series plot of the mean daily GSR for years 1995-2004 with leap days excluded. The plot shows a clear periodicity of one year (365 days).

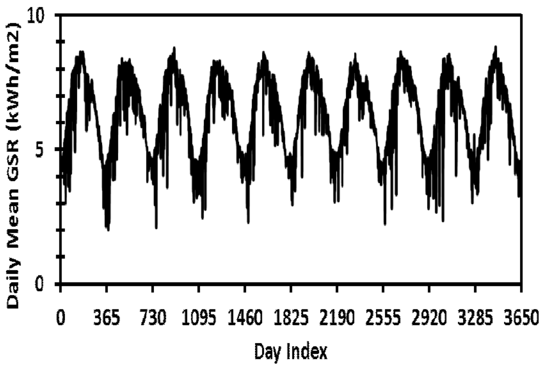

Fig. 1. Daily mean Global Solar Radiation (GSR) in Al-Ain, UAE for years 1995-2004 (leap days excluded)

2.1 Multiple Linear Regression model between GSR and four weather variables

We first use partial least square regression to model the relation between GSR data for ten years (1995-2004) and the four aforementioned dependent weather variables. The resulting relation obtained with SPSS is given by:

$$GSR(t) = a_1 + a_2 * T(t) + a_3 * W(t) + a_4 * SH(t) + a_5 * RH(t) + GSR_{residue}(t) \quad (1)$$

where $GSR_{residue}(t)$ is the residue error and the regression coefficients are given in Table 3.

Table 3.Regression coefficients of eq. (1)

Coefficient	Value
a_1	**-1.197**
a_2	**0.097**
a_3	**0.051**
a_4	**0.385**
a_5	**- 0.005**

The regression model of eq. (1) has a deterministic coefficient R^2= 0.7824 and MSE= 0.424657.

2.2 Trend and Seasonality components of the residual regression error

The residual component $GSR_{residuel}(t)$ was then sketched to examine its trends and/or seasonality. We used SPSS and MATLAB to find the trend and seasonality of the residual error yielding the following equation:

$$\boldsymbol{GSR_{residue}(t) = GSR_{trend}(t) + GSR_{seasonal}(t) + GSR_{residue2}(t)} \quad (2)$$

where the linear trend equation is given by:

$$\boldsymbol{GSR_{trend}(t) = 0.07705 - 0.000042211 * t} \quad (3)$$

The mathematical model for the seasonal component data obtained from SPSS was reconstructed using MATLAB with FFT algorithm using a period of NT=365 days. The resulting model is:

$$\boldsymbol{GSR_{seasonal}(t) = \sum_{k=1}^{\frac{NT-1}{2}} \left[a_k \cos\left(\frac{2\pi}{NP}\, k\, t\right) + b_k \sin\left(\frac{2\pi}{NP}\, k\, t\right)\right]} \quad (4)$$

The resulting refined regression model including the variable dependence, trend and seasonal components yields the following equation:

$$GSR_{regression}(t) = a_1\, T(t) + a_2\, W(t) + a_3\, SH(t) + a_4\, RH(t) + GSR_{trend}(t) + GSR_{seasonal}(t) + GSR_{residue2}(t) \quad (5)$$

The residual error of the regression model is shown in Fig. 2. Note that the residual error appears to be stationary. The residual statistics from SPSS yield a zero mean and a standard deviation of 0.6484 kWh/m^2. The predicted GSR using regression has a mean of 6.3357 kWh/m^2 and standard deviation of 1.2325 kWh/m^2. A further enhancement of the residual error is underway using Box-Jenkins Methods with ARIMA modeling [40-41].

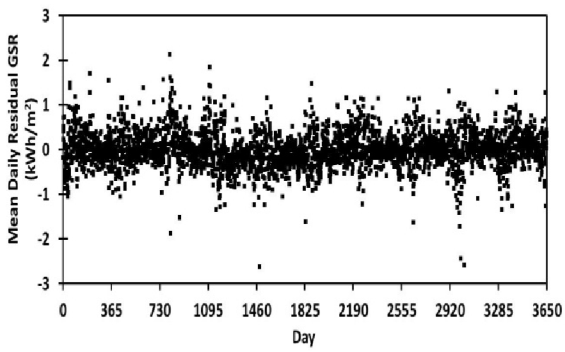

Fig.2. Residual error plot of the mean daily global solar radiation for Al-Ain, UAE over the model period 1995-2004 (10 years or 3650 points with leap year days removed)

3 Results and Discussion for Regression Model Data

3.1 Model data analysis results (1995-2004)

The statistics of the measured and predicted GSR data for years 1995-2004 are given in Table 4.

Table 4.Descriptive statistics of measured and predicted GSR data for years 1995-2004 in Al-Ain

Statistic	$GSR_{measured}$	$GSR_{predicted}$
Mean	6.336	6.336
Variance (n-1)	1.939	2.020
Std. Deviation (n-1)	1.393	1.421

The correlation between the predicted and measured mean daily data is shown in Fig. 3 which indicates a deterministic coefficient of R^2= 92.4 % implying a good regression model.

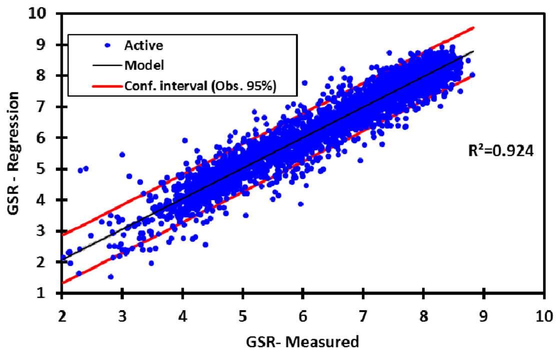

Fig.3. Correlation between predicted and measured mean daily GSR data for Al-Ain, UAE for years 1995-2004

The mean monthly data comparison for the modeling years is shown in Fig. 4. Note the excellent agreement between measured and predicted data.

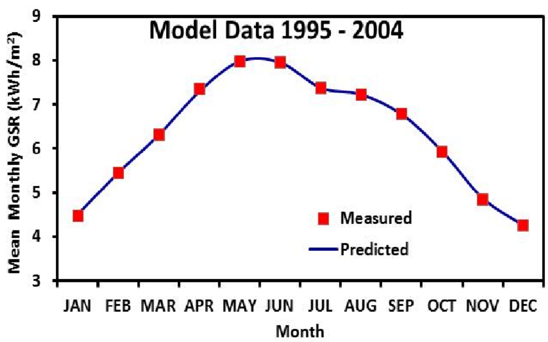

Fig.4. Measured and predicted mean daily GSR for Al-Ain, UAE during the model period 1995-2004.

The results of statistical error calculations between the measured and predicted GSR data for years 1995-2004 are given in **Table 5** for daily and monthly mean data, respectively. The statistical parameters used in comparing our model data to other available data are defined in **[1]**. They are mainly RMSE, MBE, MABE, MAPE, and R^2. The definition of the deterministic coefficient and nomenclatures of some variables are found in the Appendix.

Table 5. Statistical error data for the comparison of mean daily and monthly predicted and measured GSR data for years 1995-2004

Mean GSR Data Comparison	RMSE	MBE
Daily	0.393	-1.10 E-06
Monthly	0.023	-1.47 E-04

Table 5 shows even higher accuracy for monthly mean data with R^2 nearly 100 % (99.98 %) which implies a very strong correlation between the measured data and the regression model data. The low MBE values (-1.10×10^{-6} and -1.47×10^{-4} kWh/m^2 for daily and monthly means) indicate a good long term performance. The low RMSE values (0.393 and 0.023 kWh/m^2) confirm the good accuracy of our estimation model. It is also a good indicator of short-term performance and how close are the predicted values from measured data. The low MABE values assure the goodness of the regression model fit. The model forecast accuracy is implied by the low MAPE values (4.85 % and 0.26 % for mean daily and monthly data).

3.2 Model testing results (2005-2007)

The validation of the regression model is done by testing it with measured data during years 2005-2007 in the city of Al-Ain, UAE. We employed MATLAB to generate the code for the regression model. The output results for the mean daily global solar radiation data (3 years= 1095 points) were also used to generate the mean monthly GSR data. Results of comparison between measured test data and regression fit data are displayed in Fig. 5 with very good agreement.

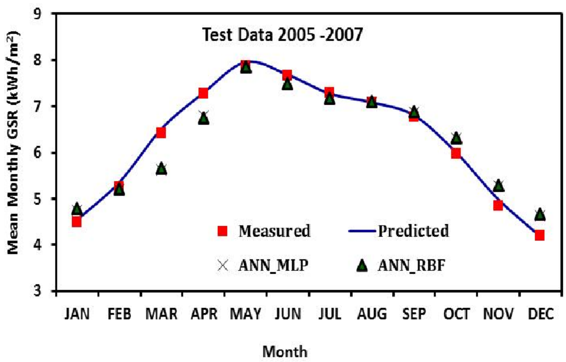

Fig.5. Mean monthly predicted and measured test data for years 2005-2007 in Al-Ain, UAE

Fig. 5 also compares the regression model fit data with that obtained using MLP and RBF ANN methods [44]. Results shown in Fig. 5 show better agreement of the regression model results in comparison to the ANN techniques used. The error statistics resulting from the test data for years 2005-2007 for mean daily and monthly data are displayed in Table 6.

Table 6. Statistical error data for validation of the mean daily and monthly GSR data for the predicted regression model (2005-2007)

Mean GSR Data Comparison	Daily	Monthly
RMSE	0.416	0.068
MBE	-0.046	-0.048
MABE	0.308	0.053
MAPE	5.37 %	0.92 %
R^2	90.77 %	99.85 %

Table 6 shows a much better accuracy for the monthly mean data with R^2 = 99.85% which validates the use of the regression model obtained in eq. (5) for forecasting the global solar radiation monthly data in the city of Al-Ain. All error statistics obtained confirm the validity for short and long term performance. The correlation between the regression model data and the test mean daily GSR data set for years 2005-2007 is also shown in Fig. 6 with the corresponding 95% prediction error bounds.

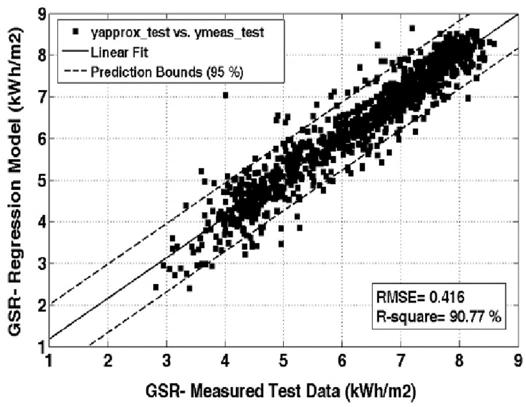

Fig. 6. Correlation between predicted and measured mean daily GSR data for Al-Ain, UAE for years 2005-2007.

4 CONCLUSION

The global solar radiation can be adequately predicted using regression models using the daily recorded weather variables of maximum temperature, mean wind speed, sunshine hours, and relative humidity. The model obtained compares favourably to the ANN techniques used by other authors. The only problem is that the regression model data are strongly dependent on the knowledge of the weather data variables in contrast to other methods used such as Box Jenkins methods and ANN methods that tolerate contaminated, incomplete and random data. Regression models are, however, easy to produce and require less learning curve.

Model validation results for test data in years 2005-2007 yield a deterministic coefficient for mean daily GSR data R^2=99.85 % in addition low MBE, MABE, MPE and RMSE data. These error statistics support the use of the prediction model in forecasting the global solar radiation in the city of Al-Ain, UAE. Other models are being developed for other UAE cities targeting a unified UAE weather model.

5 APPENDIX

The statistical parameters used in comparing our model and test data are defined in [1]. They are mainly RMSE, MBE, MABE, MAPE, and R2. The correlation coefficient is computed from:

$$R = \frac{\sum_{i=1}^{N}\left(GSR_m^i - \overline{GSR_m}\right)\left(GSR_C^i - \overline{GSR_C}\right)}{\sqrt{\sum_{i=1}^{N}\left(GSR_m^i - GSR_m^i\right)^2 \sum_{i=1}^{N}\left(GSR_C^i - \overline{GSR_C}\right)^2}}$$

where GSR_m^i and GSR_C^i are the mean measured and calculated (predicted) global solar radiation values, respectively. $\overline{GSR_m}$ and $\overline{GSR_C}$ are the mean measured and calculated GSR values, respectively.

Nomenclatures

T = Mean Daily temperature (^{0}C)
W= Mean wind speed (knots)
SSH= Mean daily Sunshine Hours
RH= Mean daily relative humidity
GSR= Mean Daily Global Solar Radiation (kWh/m^2)
RMSE= Root-Mean Square Error
MBE= Mean Bias Error
MABE= Mean Absolute Bias Error
MAPE= Mean Absolute Percentage Error
R= Correlation coefficient
R^2= Deterministic Coefficient
ANN= Artificial Neural Network
MLP= Multi-Layer Perceptron
RBF= Radial-Basis Function
ARIMA=Auto-Regressive Integrated Moving Average

6 ACKNOWLEDGMENT

The authors would like to thank the National Center of Meteorology and Seismology (NCMS), Abu Dhabi for providing the weather data. This work was financially supported by the UAE University Research Affairs under the contract #1542-07-01-10.

REFERENCES

[1] A. Assi and M. Jama, "Estimating Global Solar Radiation on Horizontal from Sunshine Hours in Abu Dhabi – UAE", Proceedings of the 4th International Conference on Renewable Energy Sources (RES'10), pp. 101-108, May 03-06, 2010, Sousse, Tunisia.

[2] G. Podestá, L. Núñez, C. Villanueva, and M. Skanski, "Estimating daily solar radiation in the Argentine Pampas," *Agricultural and Forest Meteorology*, Vol. 123, pp. 41-53, 2004.

[3] Almorox, J., M. Benito, and C. Hontoria, "Estimation of global solar radiation in Venezuela," *Interciencia*, 33(4):280-283, 2008.

[4] Falayi, E.O., J.O. Adepitan, and A.B. Rabiu, "Empirical models for the correlation of global solar radiation with meteorological data for Iseyin, Nigeria," *International Journal of Physical Sciences, Vol. 3, No.9, pp.* 210-216, 2008.

[5] J. Fortin, F. Anctil, L. Parent, and M. Bolinder, "Comparison of empirical daily surface incoming solar radiation models," *Agricultural and Forest Meteorology*, Vol. 148, pp. 1332-1340, 2008.

[6] I Togrul, and H. Togrul, "Global solar radiation over Turkey: Comparison of predicted and measured data," *Renewable Energy*, Vol. 25, No. 1, pp. 55-67, 2002.

[7] B. G. Akinoglu and A. Ecevit, "A further comparison and discussion of sunshine based models to estimate global solar radiation," *Energy*, Vol. 15, pp. 865-872, 1990.

[8] T. Samuel, "Estimation of solar radiation for Sri Lanka," *Solar Energy*, Vol. 47, pp. 333 –337, 1991.

[9] D. B. Ampratwum and A.S.S. Dorvlo, "Estimation of solar radiation from the number of sunshine hours," *Appl. Energy*, Vol. 63, pp. 161-167, 1999.

[10] C. Walthall, W. Dulaney, M. Anderson, J. Norman, H. Fang, and S. Liang, "A comparison of empirical and neural network approaches for estimating corn and soybean leaf area index from Landsat ETM+ imagery," *Remote Sensing of Environment*, Vol. 92, pp. 465-474, 2004.

[11] K. Bakirci, "Correlation for estimation of daily global solar radiation with hours of bright sunshine in Turkey," *Energy*, Vol. 34, pp. 485-501, 2009.

[12] F. J. Newland, "A study of solar radiation models for the coastal region of south China," *Solar Energy*, Vol. 31, pp. 227-235, 1988.

[13] N. Elagib and M.G. Mansell, "New approaches for estimating global solar radiation across Sudan," Energy Conversion Management, Vol. 41, pp. 419-434, 2000.

[14] M. T. Y. Tadros, "Uses of sunshine duration to estimate the global solar radiation over eight meteorological stations in Egypt," *Renewable Energy*, Vol. 21, pp. 231-246, 2000.

[15] A. Al-Lawati, A. S. S. Dorvlo, and J. A. Jervase, "Monthly average daily solar radiation and clearness index contour maps over Oman," *Energy Conversion and Management*, Vol. 44, pp. 691-670, 2003.

[16] Zhou J, Yezheng Wu, Gang Y, "General formula for estimation of monthly average daily global solar radiation in China," *Energy Conversion and Management* , Vol. 46, pp. 257–268, 2005.

[17] R. A. Ball, L. C. Purcell and S. K. Carey, "Evaluation of Solar Radiation Prediction Models in North America," *Agronomy Journal*, Vol. 96, No. 2, pp. 391-397, 2004.

[18] H. O. Menges, C. Ertekin, and M. H. Sonmete, "Evaluation of solar radiation models for Konya, Turkey," *Energy Conversion and Management*, Vol. 47, pp. 3149-3173, 2006.

[19] A.D. Şahin, "A new formulation for solar irradiation and sunshine duration estimation," *International Journal of Energy Research*, Vol. 31, pp. 109-118, 2007.

[20] K. Ulgen and A. Hepbasli, "Comparison of solar radiation correlations for Izmir, Turkey," *International Journal of Energy Research*, Vol. 26, pp. 413- 430, 2002.

[21] A. Angström, "Solar and terrestrial radiation," *Quart. J. Roy. Met. Soc.*, Vol. 50, pp. 121-125, 1924.

[22] A. Assi, M. Al-Shamisi, and M. Jama "Prediction of Monthly Average Daily Global Solar Radiation in Al Ain City–UAE Using Artificial Neural Networks", Proceedings of the 4th International Conference on Renewable Energy Sources (RES'10), pp. 109-113, May 03-06, 2010, Sousse, Tunisia.

[23] A. Assi and M. Al-Shamisi, "Prediction of Monthly Average Daily Global Solar Radiation in Al Ain City–UAE Using Artificial Neural Networks", Proceedings of the 25th European Photovoltaic Solar Energy Conference, pp. 508-512, September 06-10, 2010, Valencia, Spain.

[24] M. Bocco1, E. Willington, and M. Arias, "Comparison of Regression and Neural Networks Models to estimate Solar Radiation," *Chilean Journal of Agricultural Research*, Vol. 70, No. 3, pp.428-435, July-Sept. 2010.

[25] M. Mohandes, S. Rehman, and T. O. Halawani, "Estimation of Global Solar Radiation Using Artificial Neural Networks," *Renewable Energy*, Vol. 14, pp.179-184, 1998.

[26] M. Mohandes, A. Balghonaim, M. Kassas, S. Rehman, and T.O. Halawani, "Use of Radial Basis Functions for Estimating Monthly Mean Daily Solar Radiation," *Solar Energy*, Vol. 68, No. 2, pp. 161-168, 2000.

[27] S. Rehman and M. Mohandes, "Artificial neural network estimation of global solar radiation using air temperature and relative humidity," *Energy Policy*, No. 36, pp. 571-576, 2008.

[28] S. Al-Alawi and H. Al-Hinai, "An ANN-based Approach for Predicting Global Solar Radiation in Locations with no Measurements," *Renewable Energy*, Vol. 14, pp.199–204, 1998.

[29] I. Tasadduq, S. Rehman, and K. Bubshait, "Application of neural networks for the prediction of hourly mean surface temperature in Saudi Arabia," *Renewable Energy*, Vol. 25, pp.545–554, 2002.

[30] T. Krishnaiah, S. Srinivasa Rao, K. Madhumurthy, and K. S. Reddy, "A Neural Network Approach for Modelling Global Solar Radiation," *Applied Science Research*, Vol. 3, No. 10, pp.1105-1111, 2007.

[31] H. Elminir, F. Areed, and T. Elsayed, "Estimation of solar radiation components incident on Helwan site using neural networks," *Solar Energy*, Vol. 79, pp. 270-279, 2005.

[32] M.A. Behrang, E. Assareh, A. Ghanbarzadeh, and A.R. Noghrehabadi, "The potential of different artificial neural network (ANN) techniques in daily global solar radiation modeling based on meteorological data," *Solar Energy*, Vol. 84, pp. 1468-1480, 2010.

[33] M. Benghanem, A. Mellit, and S.N. Alamri, "ANN-based modeling and estimation of daily global solar radiation data: A case study," *Energy Conversion and Management*, Vol. 50, pp. 1644-1655, 2009.

[34] G.E.P. Box, G.M. Jenkins and G.C. Reinsel, Time Series Analysis- Forecasting and Control. Prentice-Hall International, 1994.

[35] W. Enders, Applied Econometric Time Series. 3rd edition, John Wiley and sons, 2010.

[36] A. Zaharim, A. M. Razali, T. P. Gim, and K. Sopian, "Time Series Analysis of Solar Radiation data in the Tropics," *European Journal of Scientific Research*, Vol. 25, No. 4, pp. 672- 678, 2009.

[37] M. Y. Sulaiman, W. M. Hlaing Oo, M. A. Wahab and Z. A. Sulaiman, "Analysis of residuals in daily solar radiation time series," *Renewable Energy*, Vol. 11, Issue 1, pp. 97-105, May 1997.

[38] T.N. Goh and K.J. Tan, "Stochastic modelling and forecasting of radiation data," *Solar Energy*, Vol. 19, pp. 755–757, 1977.

[39] J. Boland, "Time series analysis of climate variables," *Solar Energy*, Vol. 55, pp. 377–388, 1995.

[40] Gordon Reikard, "Predicting solar radiation at high resolutions: A comparison of time series forecasts," *Solar Energy*, Vol. 83, pp. 342–349, 2009.

[41] A.Zeroual, M. Ankrim, and A.J. Wilkinson, "Stochastic modelling of daily global solar radiation measured in

Marrakesh, Morocco," *Renewable Energy*, Vol. 6, No. 7, pp. 787 -793, 1995.

[42] IBM SPSS Statistics for Windows, Version 19.0.0, 2010. SPSS Inc.

[43] MATLAB version 7.10.0.499 (R 2010 a), 2010. The MathWorks Inc.

[44] M. Al-Shamisi and A. Assi, ANN GSR unpublished results for Al-Ain provided by personal communication, January 2011.