Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 3 (4): 240-248, 2010
ISSN 1992-1454

Estimation of Global Solar Radiation on Horizontal Surface Using Routine Meteorological Measurements for Different Cities in Iraq

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Abstract: In this study, global solar radiation received on horizontal surfaces, maximum temperatures, sun shine duration and relative humidity for Baghdad, Mosul and Rutba are presented, analyzed, tabulated and plotted on graphs and discussed for three selected locations which represents different weather condition of Iraq. Mosul in the North, Baghdad in the middle, Rutba in the West of Iraq. A correlation between the measurements of global solar radiation and meteorological parameters were given for the considered location. The correlation and regression coefficients, standard errors of estimation, mean bias error, root mean square error and t-statics are calculated. The values of correlation coefficients vary from 89% for Rutba station to 97% for Baghdad station and the error of estimation are between 0.035 and 0.063, t-statics varied between 1.2 and 2.06 for Baghdad and Rutba, respectively. It can be concluded that the presented models reasonably predict the global solar radiation received on horizontal surfaces and the expected solar radiation behavior.

Key words: Solar system, meteorology, Baghdad, Mosul, Rutba, atmospheric radiation

INTRODUCTION

Renewable energy is considered as a key source for the future, not only for Iraq but also for the world. This is primarily due to fact that renewable energy resources have some advantages if compared to fossil fuels. They are, in fact, complementary to each other and can be used effectively alone or in combinations of two or more renewable energy sources (e.g., wind and biomass) (Salaymeh, 2006). The global radiation is an important parameter necessary for most ecological models and an input for different solar systems. It is the ultimate energy for all ecosystems. Although, solar radiation data are available at most meteorological stations, but still there are stations in many region in our country suffers from a shortage concern the solar radiation records, therefore we present simple model with high accuracy depend on data which available in all meteorological stations. Various models have been proposed to estimate solar radiation by Salaymeh (2006), Jibril (1999), Ulgen and Hepbasli (2002) and Shaltout and Fathy (2001), several investigation (UDO, 2002; Akpabio and Etuk, 2003; Safari and Gasore, 2009) have demonstrated the predictive ability of the Angstrom type one-parameter equation correlating the global solar radiation to the percentage of bright sun shine hours in a simple linear regression form (Angstrom, 1924). In order to estimate monthly global solar radiation the maximum-likelihood quadratic fit was

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employed by Poltrneanu *et al.* (2002). There are many empirical formulae have been developed to estimate the solar radiation using different meteorological parameter (Yag, 1994; Gopinathan, 1988; Ksakal and Shafiq, 1999). Iraq geography and climate is well position for solar energy potential and its potential is about 2600 hour per year with average daily solar radiation is 501 W m^{-2} (AL-Riahi and AL-Kayssi, 1998). Although, Iraq has high solar potential, the uses of solar energy in different life sectors are very limited.

Several empirical models were development by many researchers to predict the solar radiation for various location of the world, among these models (Kenisarian and Tkachenkova, 1990). Also, Dincer *et al.* (1995) presented the most simple model, the data in these models were correlated with their respective ambient temperature for estimating the monthly average of daily global solar radiation. Kenisarian and Tkachenkova (1990) noticed that the global solar radiation and ambient temperature changes have periodical character, although the amplitude of these changes in each location can differ from each other significantly. They proposed relation using Fourier series for estimating global solar radiation depending on the ambient air temperature. Empirical models are classified in three categories: sunshine based models, temperature based models, cloud based models (Firoz and Intikhab, 2004; Myers, 2005; Yang *et al.*, 2006; Muneer *et al.*, 2007; Ridha and Ammar, 2008). Recently, some researches on modeling solar radiation have done in developing countries (Bashahu and Nkundabatware, 1994; Museruka and Mutbazi, 2007), but yet comparative researches on techniques and approaches used and results are still needed.

In this study, multi linear correlation have been developed for estimation global solar radiation on horizontal surface in different cities in Iraq from a long term records of monthly mean daily maximum temperatures, sun shine duration and relative humidity for Baghdad, Mosul and Rutba.

MATERIALS AND METHODS

In order to evaluate the performance of the proposed solar radiation models for Baghdad, Mosul and Rutba for the period (2004-2008) a statistical comparison is performed using the indicators, proposed by Stone (1993), a t-statistic (t_s). This indicator is used with two well-know parameters Mean Bais Error (MBE) and Root Mean Square Error (RMSE). Both MBE and RMSE have been employed as adjustments of solar-radiation models (Soler, 1990; Halouani and Ngguyen, 1993; Mac and Iqbal, 1984). The RMSE and MBE are defined as shown in statics quantities. The test of MBE provides information on the long term performance of models studied. A positive MBE value gives the average amount of over-estimation in calculated values and vice versa. The test on RMSE provides information on the short-term performance of the models as it allows a term-by-term comparison of the actual deviation between calculated and measured value (Iqbal, 1983). Thus, each test by itself may not be an adequate indicator of models performance because it is possible to have a large value of the RMSE and at the same time, a small value for the MBE and vice versa, therefore, Stone (1993) introduced the t-statistic as a new indicator of adjustment between calculated and measured data, this statistical indicator allows models to be compared and, at the same time, can induced whether or not a models estimates are statistically significant at a particular confidence level. It can be computed using RMSE and MBE and takes in to account the dispersion of the result. The t-statics is defined as shown in statistics quantities.

RESULTS AND DISCUSSION

The monthly mean of daily solar radiation, sun shine duration, maximum temperature and relative humidity, were obtained from the archives of Iraqi meteorological office. The data covered a period of five years of daily data for Baghdad city with latitude and longitude (33.22N°, 44.23E°), Mosul (36.32N°, 43.15E°) and Rutba (33.03N°, 40.28E°) which represented Middle, North and West of Iraq. Unfortunate there are no data of solar radiation for Southern region, which is represented by Basrah station. The monthly average of daily solar radiation have been presented and employed in present paper for each model in multi linear regression for in the following equation:

$$G/G_o = a + b\,(S/S_{max}) + c\,T_{max} + d\,RH \qquad (1)$$

Where:

- G = Monthly mean of daily global solar radiation (Mj/m^2/day)
- G_0 = Monthly mean of daily global extraterrestrial solar radiation on (Mj/m^2/day), this value were computed from following equation:

$$G_o = \frac{24}{\pi} I_o \left(1 + 0.033\cos\frac{2\pi}{365} J\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\phi\sin\delta\right) \qquad (2)$$

From Table 1-3, we can summarize that the Global solar radiation measurements (G) on horizontal surfaces have the maximum values at all considered locations appear in June, while the minimum values were in December, the annual average daily values for the global solar

Table 1: The monthly mean daily global solar radiation (G), extraterrestrial radiation (G_o), clearness index (G/G_o), bright sunshine (S), day length (S_o), ratio of bright sunshine duration to day length, maximum temperature (T_{max}), relative humidity (RH %), for Baghdad station

Month	G	G_o	G/G_o	S	S_o	S/S_o	T_{max}	RH
Jan.	10.60	19.10	0.555	5.7	10.0621	0.5665	16.80	72.00
Feb.	13.3344	23.41	0.5696	6.7	10.8557	0.6172	18.50	63.00
Mar.	17.748	29.90	0.5936	7.9	11.8649	0.6658	23.90	57.00
Apr.	21.60	35.90	0.6017	9.9	12.9164	0.7665	28.80	38.00
May	23.4324	39.90	0.5873	10.1	13.7689	0.7335	33.60	32.00
June	27.036	41.20	0.6562	12.6	14.2065	0.8869	40.30	27.00
July	26.0432	40.60	0.6415	12.3	13.9858	0.9081	44.00	25.00
Aug.	24.6636	37.40	0.6595	12.1	13.2229	0.9151	43.30	28.00
Sep.	20.844	32.10	0.6493	10.5	12.2195	0.8593	40.30	29.00
Oct.	15.8098	25.70	0.6152	9.2	11.1989	0.8215	34.20	39.00
Nov.	11.9016	19.60	0.6011	7.7	10.2674	0.7499	22.30	50.00
Dec.	9.864	16.90	0.5837	6.3	9.799	0.6429	19.50	69.00

Table 2: The monthly mean daily global solar radiation (G), extraterrestrial radiation (Go), clearness index (G/G_o), bright sunshine (S), day length (S_o), ratio of bright sunshine duration to day length, maximum temperature (T_{max}), relative humidity (RH %), for Mosul station

Month	G	G_o	G/G_o	S	S_o	S/S_o	T_{max}	RH
Jan.	6.9503	18.32	0.3794	4.60	9.7938	0.4697	14.7	85.00
Feb.	9.9696	23.33	0.4273	5.00	10.6386	0.47	14.9	78.00
Mar.	13.4176	29.50	0.4548	5.80	11.764	0.493	19.5	74.00
Apr.	17.8645	35.12	0.5087	8.10	12.9291	0.6262	27.1	69.00
May	19.9324	39.11	0.5096	10.00	13.922	0.7183	33.8	47.00
June	22.8274	41.23	0.5537	12.30	14.4449	0.8515	39.6	27.00
July	21.3598	40.50	0.5274	12.00	14.2539	0.8629	42.9	28.00
Aug.	20.9938	37.22	0.564	11.80	13.4466	0.8775	42.3	26.00
Sep.	18.0511	32.30	0.5589	9.70	12.234	0.7864	39.3	30.00
Oct.	12.4989	24.99	0.5002	7.50	11.1648	0.6718	30.6	51.00
Nov.	7.7921	19.45	0.4006	4.30	10.1474	0.4238	19.0	77.00
Dec.	5.3619	16.35	0.3279	4.28	9.573	0.4492	10.6	81.00

Table 3: The monthly mean daily global solar radiation (G), extra terrestrial radiation (G_o), clearness index (G/G_o), bright sunshine (S), day length (S_o), ratio of bright sunshine duration to day length, maximum temperature (T_{max}), relative humidity (RH %), for Rutb station

Month	G	G_o	G/G_o	S	S_o	S/S_o	T_{max}	RH
Jan.	9.288	18.36	0.5059	6.00	10.012	0.5993	15.0	72.00
Feb.	15.156	23.54	0.6438	8.80	10.8266	0.8128	19.0	60.00
Mar.	18.612	29.39	0.6333	8.40	11.8615	0.7082	23.1	55.00
Apr.	21.708	35.45	0.6124	7.90	12.9397	0.6105	28.3	38.00
May	23.436	39.22	0.5976	9.50	13.8145	0.6877	34.3	30.00
June	25.992	41.39	0.628	11.75	14.2639	0.8238	39.6	27.00
July	25.26	40.55	0.6229	12.30	14.0372	0.8762	41.3	23.00
Aug.	24.956	37.41	0.6671	11.20	13.2541	0.845	40.7	26.00
Sep.	22.32	32.11	0.6951	10.30	1202250	0.8425	38.6	28.00
Oct.	15.372	25.44	0.6042	9.20	11.1786	0.823	30.6	38.00
Nov.	10.98	19.29	0.5692	7.30	10.2228	0.7141	23.7	51.00
Dec.	9.00	16.33	0.5688	6.00	9.7417	0.6159	13.9	70.00

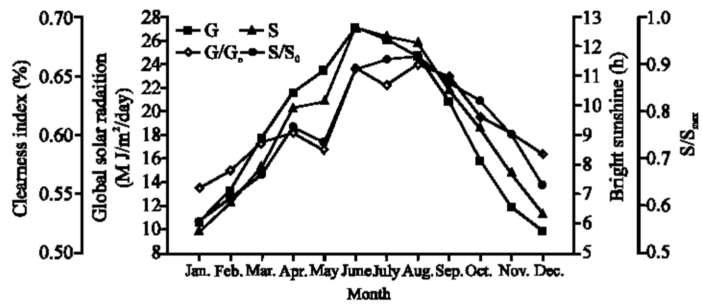

Fig. 1: Monthly mean variation of global solar radiation, clearness index, bright sunshine and S/S_{max} for Baghdad station

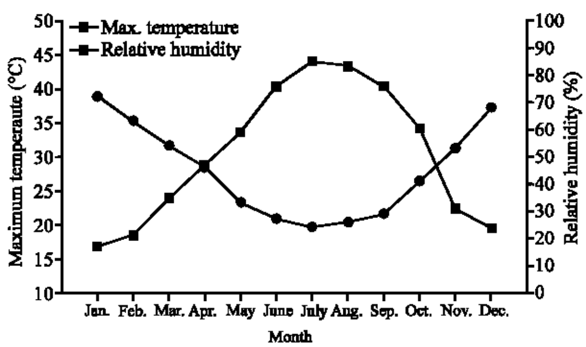

Fig. 2: Monthly mean variation of maximum temperature, relative humidity for Baghdad station

radiation on horizontal surface at Baghdad is 18.57 M J/m^2/day, at Mosul is 14.75 M J/m^2/day and at Rutba is 18.53 M J/m^2/day, The maximum temperature has higher values in July and lower in December and January at all places. The annul mean of the maximum temperatures decrease towards the North (Mosul station), where these values are 30.45, 28.5 and 27.8°C at Baghdad, Rutba and Mosul, respectively. The relative humidity has the maximum in January at all considered stations. Monthly variation of (maximum temperature and relative humidity, global solar radiation and sunshine duration), (G/G_o and S/S_o) are shown by Fig. 1, 3 and 5 for all considered stations, from the results is clear that:

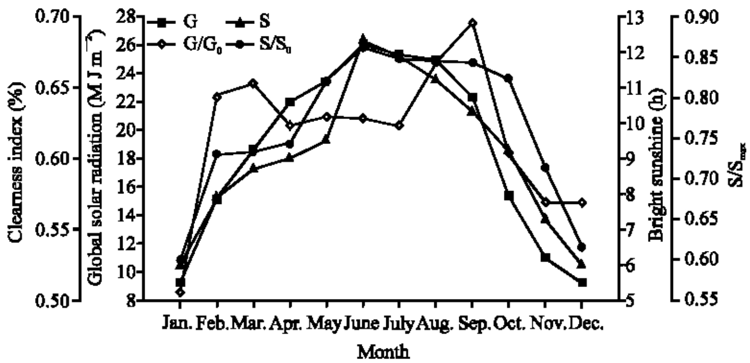

Fig. 3: Monthly mean variation of global solar radiation, clearness index, bright sunshine and S/S_{max} for Rutba station

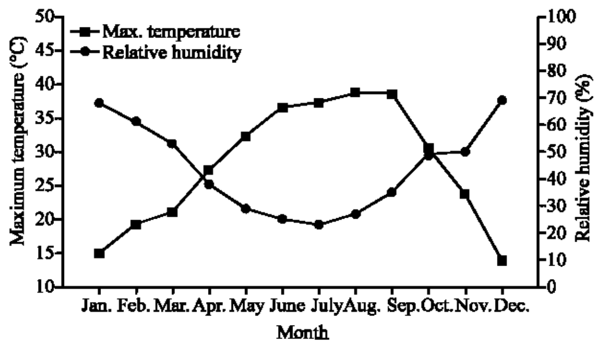

Fig. 4: Monthly mean variation of maximum temperature, relative humidity for Rutba station

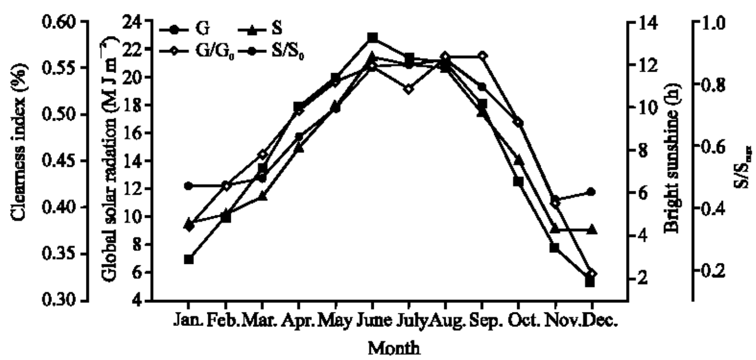

Fig. 5: Monthly mean variation of global solar radiation, clearness index, bright sunshine and S/S_{max} for Mosul station

The monthly variation of global solar radiation and sunshine duration have same trends where the maximum values each mentioned parameter were in June and the minimum in January and the clearness index (G/G_0)and (S/S_0)have the same behavior for all stations. Figure 2, 4 and 6 clarify that monthly variation of maximum temperature and relative humidity has opposite behavior with all considered locations. From Table 4, the formulae of empirical models investigated in present study can be written as the follows:

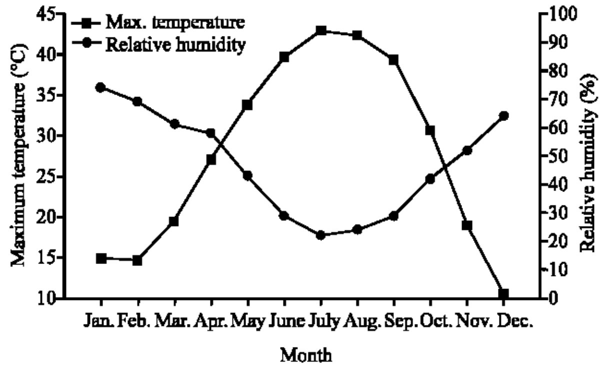

Fig. 6: Monthly mean variation of maximum temperature, relative humidity for Mosul station

Table 4: Geographic location of the selected stations and correlation coefficients, regression coefficients, standard errors, mean bias error, root mean square error and t-statics

Station	Lat. (N°)	Long. (E°)	CC (%)	SE	a	b	c	d	MBE	RMSE	t-statics
Baghdad	33.23	44.23	97	0.035	10.78	0.071	0.0026	-0.00078	0.002	0.014	1.20
Rutba	33.03	40.28	89	0.063	15.07	0.104	0.00139	-0.00112	0.007	0.027	2.06
Mosul	36.32	43.15	96	0.038	8.86	0.301	0.0035	0.00157	0.006	0.024	1.98

Baghdad Model:

$$G/G_o= 10.78+0.071(S/S_0)+0.0026T_{max}-0.00078RH \quad (3)$$

Rutba Model:

$$G/G_o=15.07+0.104(S/S_0)+0.00139T_{max}-0.00112RH \quad (4)$$

Mosul Model:

$$G/G_o=8.86+0.301(S/S_0)+0.0035T_{max}+0.00157RH \quad (5)$$

From Table 4, we can notice that the Correlation Coefficient (CC) at Baghdad is the best, where it is value is (97%) with standard error (SE) of estimation is 0.035. The lowest value of CC is (89%) at Rutba and SE is 0.0653. The values of global solar radiation estimated using the proposed models (Eq. 5-7) and compared with the corresponding measured values. The results are shown Fig. 7a-c for considered stations. The models performance examined using mean error (MBE) and Root Mean Square Error (RMSE). The test RMSE provides in for motion on the short term performance of the proposed model as it allows a term-by term comparison of the actual deviation between calculated and measured value. Iqbal (1983), Halouani and Ngguyen (1993), Almorox (2005) and Che *et al.* (2007) have recommended that a Zero value for MBE is ideal and low RMSE is very desirable. According to these supposition and from Table 4 we can considered that Baghdad station which has the lowest values of MBE (0.002), RMSE (0.014) and t-statics (1.2) is the better among the presented models in this study and the indicate that Baghdad station model give the lowest overestimation for estimated values.

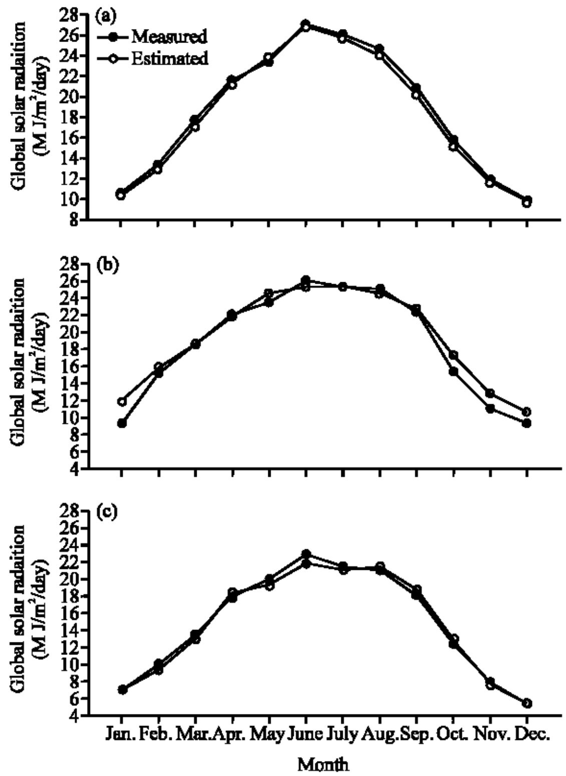

Fig. 7: Comparison of the measured and estimated global solar radiation values. (a) Baghdad, (b) Rutba and (c) Mosul models, respectively

CONCLUSION

The results of this study, clearly indicate the primary importance of developing empirical approaches for formulating the global solar radiation on horizontal surface reaching the earth at different geographical sites in Iraq. Baghdad model shows a good agreement between calculated and measured values of the monthly mean of daily global solar radiation, from the above results and considerations, the values of the correlation coefficients vary between 97% at Baghdad and 89% at Rutba and the standard error did not exceed 0.063. Equation 3-5 are used with high accuracy to estimate the global radiation on horizontal surfaces at the selected sites using common meteorological parameters.

NOMENCLATURE

Astronomical Quantities and Solar Quantities

$\delta = (23.5\pi/180)\sin(2\pi 284+J)/365$	: Solar declination (radian)
$J = 1$ to 365	: Julian day
$\phi = (2\pi/360)\times$Latitude	: Latitude of the place (radian)
$\omega_s = \arccos(-\tan\phi\tan\delta)$	: Sunset hour angle (radian)
$\pi = 4\times\arctan(1.0)$	

$I_0 = 1367\ W\ m^{-2}$	:	Solar constant
G_0	:	Monthly average daily Extraterrestrial solar radiation (MJ/m²/day)
G	:	Monthly average daily global solar radiation on horizontal surface (MJ/m²/day)
$S_0 = 2/15\omega_s\,180/\pi$	:	Day length
S	:	Daily sunshine duration (hour)

Statistics Quantities

A, b, c, d	: Coefficients of regressions
Qmes	: Measured value
Qest	: Estimated value
N	: No. of observations

Mean bias error:

$$MBE = \sum_{i=1}^{N} \frac{(Qmes - Qest)}{N}$$

Root mean square error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (Qmes - Qest)^2}{N}}$$

t-statics:

$$t_s = \sqrt{\frac{(N-1)(MBE)^2}{(RMSE - MBE)}}$$

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