

Empirical Model for Estimating Global Solar and Diffuse Solar Radiations on Horizontal Surfaces

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Abstract
Solar energy is very attractive because it is non-polluting, nonreplicable, reliable, and pollution free. Four-years intervals measured average daily global solar radiation data on horizontal surfaces at Baghdad and Mosul cities in Iraq were used for the model assessment. Statistical results showed that all four suggested models can accurately predict the solar irradiance on a horizontal oriented surface, indicating the good predictive ability for modeling a horizontal surface. The obtained models have a high value of regression coefficient and give best fit through the measured values. This paper illustrates also the use of mathematical formula to develop a predictive model for the duration of sunshine using measured solar radiation data for above cities. The present work showed that the predicted results were in good agreement with the tabulated data, and the expected solar radiation behavior.
Keywords: Global solar radiation, Beam radiation, Diffuse radiation, and relative sunshine duration, clearness ratio data

1. Introduction

Solar energy occupies one of the most important places among the various possible alternative energy sources. An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for estimates of their performances. Unfortunately, for many developing countries the solar radiation measurements are not easily available for not being able to afford the measurement equipment and techniques involved. Therefore, it is rather important to elaborate methods to estimate the solar radiation on the basis of more readily meteorological data.
An attempt was undertaken to elaborate modeling that can be useful in the estimation of solar radiation on the horizontal surface of ground level and further elaboration for the diffuse radiation as well. Global solar radiation is measured in most of Iraqi cities, but this study is confined namely on Baghdad, and Mosul cities. In Iraq, solar radiation measurements are available only for very limited stations. To overcome this shortage of data, researchers had employed different relations such as linear, multi linear, third order polynomial and various distributions for estimating global solar radiation for different locations in Iraq.
An attempt of using limited metrological data (2004-2008) for the above cities was taken from Iraqi meteorological organization and seismology to estimate the solar radiation at these areas is being employed. Global solar radiation in Iraq are measured at two stations namely Baghdad and Mosul, while diffuse solar radiation are not observed experimentally in any Meteorological station of the country. Therefore, it is rather important to develop method to estimate the global and diffuse solar radiation using climatological parameters. Several empirical formula have been developed to calculate the global solar radiation using various parameters.
Over the years, many models have been proposed to predict the amount of solar radiation using various parameters. Some works used the sunshine duration [1-10,24], others used mean daytime cloud cover or relative humidity and maximum and minimum temperature [11-14], while others used the number of rainy days, sunshine hours and a factor that depends on latitude and altitude [15]. The first empirical correlation using the idea of employing sunshine hours for the estimation of global solar radiation was proposed by Angstrom model [16], and Page model [17]. Other workers, e.g. Reddy [18], Glover and McCullough [19], derived their equations by using sunshine duration, the relative humidity, temperature and latitude of the locations under study.

2. Methodology

To develop the model, monthly average of daily global radiation for a given month was calculated from the following equation:

$$H_o = I_{sc} \times E_o \times \cos\theta_z \text{ ....} \qquad \text{....(1)}$$

Where θ_z is the zenith angle of the sun and E_o is the extraterrestrial radiation measured on the horizontal surface of the dth day of the year, at a surface located at the mean distance between Earth and Sun [20], as follows:

$$E_o = \left[1 + 0.033 \times \cos\left(\frac{360 \times d}{365}\right)\right] \text{..(2)}$$

Where I_{sc} is the solar constant which is equal to 1367 W/m^2, and d is the Julian day of the year, starting from 1 (at 1 January) and ending at 365 (at 31 December).

For a horizontal surface at any time between sunrise and sunset, the cosine of zenith angle can be expressed as follows, [20]:

$$\cos\theta_z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega \ldots\ldots \quad \ldots(3)$$

Where ϕ is the latitude of the place, and ω is the solar hour angle.

Now by combining Equations (1) and (3), Equation (1) becomes:

$$H_o = I_{sc} \times E_o(\sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega) \ldots\ldots .(4)$$

The extraterrestrial daily solar radiation on a horizontal surface can be obtained by integrating Equation (4) over period from sunrise to sunset using $\omega = \omega_s$ as follows[21]:

$$\overline{H}_o = \frac{24}{\pi} I_{sc} \times E_o(\cos\delta\cos\phi\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta) \ldots\ldots (5)$$

Equation (3), can be written as follows:

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \ldots\ldots \quad (6)$$

Where ω_s is the sunset hour angle, and δ is the solar declination angle in (degrees) which given by the following formula such as, [21]:

$$\delta = 23.45 \times \sin\left(360 \times \frac{284+d}{365}\right) \ldots \quad (7)$$

Estimation of Global Radiation

The monthly average of daily global radiation $\overline{H}$ was normalized by dividing on the monthly average of daily extraterrestrial solar radiation $\overline{H}_o$. Therefore, the result $\overline{H}/\overline{H}_o$ is defined as the ratio of measured horizontal terrestrial solar radiation to calculated horizontal extraterrestrial solar radiation which is called the cleanness index ratio, (K_T) and $S/S_{\max}$ is the relative sunshine duration. The values of $S_{\max}$ were computed from the following equation [22]:

$$S_{\max} = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \ldots \quad .(8)$$

Where $S_{\max}$ is monthly average daily maximum day length.

Empirical Models and Reliability

Among the above mentioned empirical models, the first model is the regression equation of the Angstrom type [16].

$$\frac{\overline{H}}{\overline{H}_o} = \left[a + b\left(\frac{S}{S_{\max}}\right)\right] \ldots\ldots \quad .(9)$$

Where $\overline{H}$ is the monthly average daily global solar radiation falling on a horizontal surface at a particular location. $\overline{H}_o$ is the monthly mean daily radiation on a horizontal surface in the absence of atmosphere. S is the monthly mean daily number of hour of observed sunshine hours, $S_{\max}$ is the monthly mean value of day length at a particular location, a and b are climatologically determined regression constant. $S/S_{\max}$ is often called the percentage of possible sunshine hour.

The second and third models are quadratic and third order polynomial as shown below respectively:

Quadratic model

$$\frac{\overline{H}}{H_o} = a + b(\frac{S}{S_{\max}}) + c(\frac{S}{S_{\max}})^2 \ldots\ldots \quad (10)$$

3rd order polynomial model

$$\frac{\overline{H}}{H_o} = a + b(\frac{S}{S_{\max}}) + c(\frac{S}{S_{\max}})^2 + d(\frac{S}{S_{\max}})^3 \ldots\ldots \quad (11)$$

Glover and McCulloch are presented model depending on latitude of place and sunshine duration [19], as follow:

$$\frac{\overline{H}}{H_o} = 0.29\cos\phi + 0.52(\frac{S}{S_{\max}}) \ldots\ldots \quad (12)$$

This model was modified by authority to make this model suitable for using at Iraqi locations after finding the correlation constants. The presented model may written as follows:

$$\frac{\overline{H}}{H_o} = a(\cos\phi) + b(\frac{S}{S_{\max}}) \ldots\ldots\ldots\ldots \quad (13)$$

Where ϕ is the latitude of the place.

Proper computer programs (Matlab) are prepared for the analysis.

Estimation of Diffuse Radiation

The diffuse solar radiation is not observed experimentally in any meteorological station of the country. Therefore, it is rather important to develop a method to estimate the global and diffuse solar radiation using climatologically parameters. Several empirical formula have been developed to calculate diffuse solar radiation using various parameters. The diffuse solar radiation $\overline{H}_d$ can be estimated by an empirical formula which correlates the diffuse solar radiation component $\overline{H}_d$ to the monthly total radiation $\overline{H}$. The correlation equation which is widely used is developed using Page model, [17] as follows:

$$\frac{\overline{H}_D}{\overline{H}} = 1.0 - 1.13 \times K_T \ldots\ldots\ldots\ldots\ldots \quad (14)$$

Where $\overline{H}_d$ is the monthly mean of the daily Diffuse solar radiation in($MJ/m^2/day$). Another commonly correlation was used to calculate the diffuse radiation by Liu & Jordan of the form, [23]:

$$\frac{\overline{H}_D}{\overline{H}} = 1.39 - 4.027K_T + 5.531K_T^{\,2} - 3.108K_T^{\,3} \ldots\ldots \quad (15)$$

The two models above are verifying to see the agreement between them.

Finally, the monthly average daily beam radiation on horizontal surface was calculated from global and diffuse radiations values as follows, [24]:

$$\overline{H}_B = \overline{H} - \overline{H}_D \ldots\ldots\ldots\ldots\ldots \quad (16)$$

3. Results and Discussion

A new set of constants for Angstrom-type correlation of first order equation was applied to estimate monthly average daily global solar radiation. The monthly average daily global radiation and sunshine duration was obtained for four years interval (2004-2008) from Iraqi organization and seismology for two Iraqi stations (Baghdad and Mosul cities). The linear model was compared with another non-linear models as mentioned above to verify the validity of linear model. While diffuse radiation component was estimated using empirical equations (Page) and (Liu & Jordan) models to verify the results of two models. The diffuse radiation component do not recorded at These cities due to limitation of solar meters instruments at these sites.Firstly, the geographical properties of the two cities were clear in table (1), while tables (2a,b) shows the input parameters that represented with monthly mean daily global radiation $\overline{H}$ and sunshine duration in hours S , which measured at a certain day per each month for Baghdad and Mosul cities as clear in these tables. The extraterrestrial radiation and maximum day length were calculated using Eq. (5) and Eq. (8) respectively. Then the global radiation on horizontal surface was estimated after using the linear model (Angstrom model) as broad in the last column of that table. The computed values of the Angstrom's regression constants a and b , are computed by using EES software or (Engineering Equation Solver) program for Baghdad, and Mosul respectively.

After estimation of global solar radiation, the basic components will be calculated using (Page) model and verified with another model represented with (Liu & Jordan) model as broad in tables (3a,b). The two models are giving good approach to each other.

A large variation in the intensities of direct and diffuse radiation components due to degree of scattered of global solar radiation into atmosphere entrance, which depends on many factors, one of them the air mass quantity or the length of path of solar radiation from sun to earth surface, the angle of incidence of solar radiation on earth surface, the present or not of (water vapors, dusts, and clouds) in the sky, in addition to sun position during the months of year.

Table (4) shows the values of the regression constants (a, b, c, d) for the four different correlation models. Statistical results showed that all four suggested models can accurately predict the solar irradiance on a horizontal oriented surface, indicating the good predictive ability for modeling a horizontal surface. The obtained models have a high value of regression coefficient and give best fit through the measured values. For testing of the calculations, a statistical analysis of the results was performed for the $RMSE$, MBE, and MPE which shown in that table to represent the fundamental measured accuracy of the data. The MPE ranging is a very good reliable index to the present calculation. Also, the correlation coefficients were found have high reliability for all cities. This implies that, there are statistically significant relationships between the clearness index and relative sunshine duration.

Tables (5a,b) presents the difference in values of global solar radiation that obtained from using the four above models and comparing with the measured value to validly the accuracy of each model.

Figs. (1a,b) presents the plot of global solar radiation components (beam and diffuse) along the twelve months of year for Baghdad and Mosul cities respectively. The beam radiation component is very significant at summer season in Iraq, due to high altitude angle of sun at that season, which makes the global radiation cross the atmosphere at less distance and incident on earth surface at approximately right angles. While at Winter season (from November to February), the beam and diffuse were approach to each other due to low elevation of sun at that season

Figs. (2a,b) demonstrates the monthly clearness, diffuse to global ratios for (Page) and (Liu and Jordan) models for the two cities above respectively. As clear from this figure, the diffuse radiation behaves conversely to monthly clearness ratio as obvious from Eqs. (14) and (15). Another comment on this figure, at June month the diffuse radiation seems to be drops intensely to minimum value, that is due to orthogonally of global radiation at this month.

Figs. (3a,b) show the beam, diffuse, terrestrial (global), and extraterrestrial radiation types versus the months of year for Baghdad and Mosul cities respectively. From point of view of solar astronomy, the extraterrestrial solar radiation (that estimated in absent of atmosphere) is found approximately same for the two cities. This true due to convergence of the latitude of these cities. The cause of increasing of extraterrestrial radiation value in June, and decreasing in December, as shown in these figures, due to two causes: 1. the elliptical orbit of earth around the sun, which make the earth converge to sun at certain months of year, while it diverge from the sun at other months. 2. due to the declination of earth rotation axis. The measure of terrestrial radiation is depending on characteristic of atmospheric coating, which affected by ozone layer thickness, the amount of haze in the air (dust particles, water vapor), and the extent of the cloud cover. The solar radiation reaching the surface of the earth is reduced below extraterrestrial radiation because large part of it is scattered, reflected back out into space, and absorbed by the atmosphere.

Fig. (4) shows the monthly clearness ratio and sunshine duration to day length ratio over the months of year for Baghdad and Mosul cities. It is clear that the clearness ratio behaves like the global radiation in the previous figures. This graph shows that Baghdad city has a clearness ratio higher than Mosul city due to its geographical and climatically characteristics. Each curve explains the time of year when maximum day length occurs. The maximum day length happened at June, while minimum day length occurred at December month, while the day remains equally (12 hours day and 12 hours night) at September and March as shown in this figure.

Figs. (5a,b) shows the comparison of three global solar radiation models with measured value throughout months of the year for Baghdad and Mosul cities. It is shown clearly, that the maximum value occurred at June, while minimum value occurred at December month. The difference in values of radiation among these cities, due to many factors, one of them is the climate conditions, which implies rain fall distribution amounts, clear and cloudy, dusty, and fog sky, relative humidity, and air temperature.

4. Conclusion

A model for calculating the monthly average of daily global radiation from the sunshine duration has been developed. The model is expressed as a linear relation between the normalized global radiation and the normalized sunshine duration. Another model is presented depending on latitude of place. The performance of the model was investigated at different mathematical models (linear, quadratic, and 3rd degree polynomial models). It was found that global radiation calculated from these models are in good agreement with that obtained from measurement. Therefore, first order or linear correlations between the monthly average daily clearness index and the relative possible sunshine duration for the selected locations have been proposed. It is concluded that the correlation proposed for these sites can be used successfully for estimation of monthly average daily global radiation for any location of Iraq with similar meteorological characteristics. The precision of this model was found to be adequate enough to discriminate between sites which are near to each other but with variable conditions, without the use of sophisticated measuring equipment. The global solar radiation values were used to estimate the monthly average daily beam and diffuse radiations using Page model, [17] and Liu and Jordan model, [23]. The study shows that, Baghdad received radiation more than Mosul city due to its geographical position and another climatic effects.

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Table (1): Geographical Latitude and Longitudinal of the Region Locations.

City	Latitude	Decimal degrees of Latitude	Longitude	Decimal degrees of Longitude
Mosul	36°15' N	36.250	43.05' E	43.083
Baghdad	33°20' N	33.333	44.30' E	44.500

Table (2a): Comparison between measured and estimated radiation values for Baghdad city.

Month	Averaged day	Mean sunshine hours (S)	Max day length hours (S_{max})	(S/S_{max})	$\overline{H}_o$ Calculated	$\overline{H}$ Measured	$K_T=\overline{H}/\overline{H}_o$ Measured / Calculated	$\overline{H}$ Calculated
					MJ/m^2/day	MJ/m^2/day	Dimensionless	MJ/m^2/day
JAN	17	5.7	10.06	0.5666	19.1	10.6	0.555	10.595
FEB	16	6.7	10.855	0.6172	23.41	13.33	0.5694	13.318
MAR	16	7.9	11.865	0.6658	29.9	17.748	0.5936	17.423
APR	15	9.9	12.916	0.7665	35.9	21.600	0.6017	21.929
MAY	15	10.1	13.769	0.8	39.9	23.43	0.5872	24.007
JUN	11	12.6	14.206	0.8869	41.2	27.04	0.6563	26.567
JUL	17	12.3	13.986	0.84	40.6	26.04	0.580	26.422
AUG	16	12.1	13.223	0.83	37.4	24.664	0.5348	24.412
SEP	15	10.5	12.219	0.8593	32.1	20.844	0.5607	20.448
OCT	15	9.2	11.199	0.8215	25.7	15.81	0.6148	16.099
NOV	14	7.7	10.267	0.75	19.6	11.9	0.6071	11.884
DEC	10	6.3	9.799	0.6429	16.9	9.86	0.5834	9.738

Table (2b): Comparison between measured and estimated radiation values for Mosul city.

Month	Averaged day	Mean sunshine hours (S)	Max day length hours (S_{max})	(S/S_{max})	$\overline{H}_o$ Calculated	$\overline{H}$ Measured	$K_T=(\overline{H}/\overline{H}_o)$ Measured / Calculated	$\overline{H}$ Calculated
					MJ/m^2/day	MJ/m^2/day	Dimensionless	MJ/m^2/day
JAN	17	4.6	9.794	0.4697	18.32	6.95	0.3794	7.466033
FEB	16	5	10.639	0.47	23.33	9.97	0.4273	9.510568
MAR	16	5.8	11.764	0.493	29.5	13.417	0.4548	12.29597
APR	15	8.1	12.929	0.6265	35.12	17.865	0.5087	16.49843
MAY	15	10	13.922	0.7183	39.11	19.932	0.5096	19.81027
JUN	11	12.3	14.445	0.8515	41.23	22.827	0.58	23.07096
JUL	17	12	14.254	0.83	40.5	21.359	0.5274	22.84632
AUG	16	11.8	13.446	0.8	37.22	20.994	0.50	21.21244
SEP	15	9.7	12.234	0.7929	32.3	18.051	0.47	17.23672
OCT	15	7.5	11.165	0.6717	24.99	12.499	0.5002	12.19539
NOV	14	4.3	10.147	0.47	19.45	7.792	0.4006	7.571052
DEC	10	4.28	9.573	0.4471	16.35	5.362	0.328	6.529723

Table (3a): Monthly average daily diffuse and beam radiations for Baghdad city.

Month	$\overline{H}$ Measured	$K_T = (\overline{H}/\overline{H}_o)$	$(\overline{H}_d/\overline{H})$ Page model	$\overline{H}_d$ Page model From eq. (10)	$(\overline{H}_d/\overline{H})$ Liu & Jordan model	$\overline{H}_d$ Liu & Jordan model From eq. (11)
	MJ/m^2/day	Dimensionless	Dimensionless	MJ/m^2/day	Dimensionless	MJ/m^2/day
JAN	10.6	0.555	0.37288	3.952524	0.327089	3.467138
FEB	13.33	0.5694	0.356561	4.752962	0.316167	4.214512
MAR	17.748	0.5936	0.329181	5.842956	0.298021	5.289874
APR	21.600	0.6017	0.320111	6.914407	0.292022	6.307681
MAY	23.43	0.5872	0.336444	7.882874	0.302824	7.095173
JUN	27.04	0.6563	0.258369	6.986296	0.250413	6.77116
JUL	26.04	0.580	0.3446	7.5812	0.308224	6.780926
AUG	24.664	0.5348	0.395722	7.914439	0.342637	6.852749
SEP	20.844	0.5607	0.366355	6.594393	0.322707	5.808732
OCT	15.81	0.6148	0.305292	4.823611	0.282193	4.458654
NOV	11.9	0.6071	0.313929	3.73575	0.287927	3.426335
DEC	9.86	0.5834	0.340722	3.359518	0.305655	3.013762

Table (3b): Monthly average daily diffuse and beam radiations for Mosul city.

Month	$\overline{H}$ Measured	$K_T = (\overline{H}/\overline{H}_o)$	$(\overline{H}_d/\overline{H})$ Page model	$\overline{H}_d$ Page model From eq. (10)	$(\overline{H}_d/\overline{H})$ Liu & Jordan model	$\overline{H}_d$ Liu & Jordan model From eq. (11)
	MJ/m^2/day	Dimensionless	Dimensionless	MJ/m^2/day	Dimensionless	MJ/m^2/day
JAN	6.95	0.379	0.571	3.970643	0.488472	3.394879
FEB	9.97	0.427	0.517	5.155469	0.436431	4.351212
MAR	13.417	0.455	0.486	6.521476	0.409973	5.500613
APR	17.865	0.509	0.425	7.595957	0.363373	6.491652
MAY	19.932	0.509	0.424	8.453308	0.362596	7.227271
JUN	22.827	0.580	0.345	7.866184	0.308224	7.035827
JUL	21.359	0.527	0.404	8.630265	0.348414	7.441778
AUG	20.994	0.500	0.435	9.13239	0.3705	7.778277
SEP	18.051	0.470	0.469	8.464114	0.396205	7.151899
OCT	12.499	0.502	0.435	5.434804	0.370367	4.629223
NOV	7.792	0.401	0.547	4.264584	0.464413	3.618708
DEC	5.362	0.328	0.629	3.374925	0.554478	2.973113

Table (4): Regression coefficient, reliability index and percentage of errors.

Site	Model	Equation No.	a	b	c	d	r^2
Baghdad	Linear	(9)	0.39535	0.28131	----	-----	96.00%
	Quadratic	(10)	0.55818	-0.16218	0.29495	----	96.54%
	polynomial	(11)	-0.2653	3.2506	-4.3538	2.08234	96.73%
	Presented	(13)	0.9823	-0.06977	----	-----	95.14%
Mosul	Linear	(9)	0.2205	0.3982	----	----	92.77%
	Quadratic	(10)	-0.1177	1.5142	-0.8583	------	93.15%
	polynomial	(11)	-0.3839	2.8093	-2.8848	1.0244	93.18%
	Presented	(13)			----	----	

Table (5a): Estimation of monthly mean daily global radiation from various models for Baghdad city.

Month	$\overline{H}$ Measured	$\overline{H}$ Linear	$\overline{H}$ Quadratic	$\overline{H}$ 3rd polynomial	$\overline{H}$ Presented model
JAN	10.60	10.595	10.71469	10.64902	10.25525
FEB	13.33	13.318	13.35412	13.39158	13.18569
MAR	17.75	17.423	17.37053	17.44805	17.59676
APR	21.60	21.929	21.79691	21.75829	22.00714
MAY	23.43	24.007	24.62644	24.53475	25.26585
JUN	25.04	26.567	26.63026	26.60347	27.98443
JUL	22.01	26.422	25.58066	25.47138	26.57114
AUG	20.07	24.412	23.44089	23.33835	24.20356
SEP	18.01	20.448	20.43533	20.36327	22.1213
OCT	15.80	16.099	16.03681	15.96744	17.20546
NOV	11.91	11.884	11.80797	11.80153	12.39268
DEC	9.86	9.738	9.731498	9.773756	9.744742

Table (5b): Estimation of monthly mean daily global radiation from various models for Mosul city.

Month	$\overline{H}$ Measured	$\overline{H}$ Linear	$\overline{H}$ Quadratic	$\overline{H}$ 3rd polynomial	$\overline{H}$ Presented model
JAN	6.95	7.466033	7.40395	7.425512	7.758791
FEB	9.97	9.510568	9.433569	9.461502	10.15763
MAR	13.41	12.29597	12.39624	12.4698	12.4622
APR	17.86	16.49843	17.35142	17.41032	18.65484
MAY	19.93	19.81027	20.61497	20.54228	21.75457
JUN	22.83	23.07096	22.64885	22.63671	24.89835
JUL	21.36	22.84632	22.18603	22.12186	23.95148
AUG	20.99	21.21244	20.26063	20.16434	22.18812
SEP	18.05	17.23672	17.54859	17.46122	16.87104
OCT	12.49	12.19539	12.79875	12.79504	13.57353
NOV	7.79	7.571052	7.865104	7.888433	7.302327
DEC	5.36	6.529723	6.339208	6.327755	6.62492

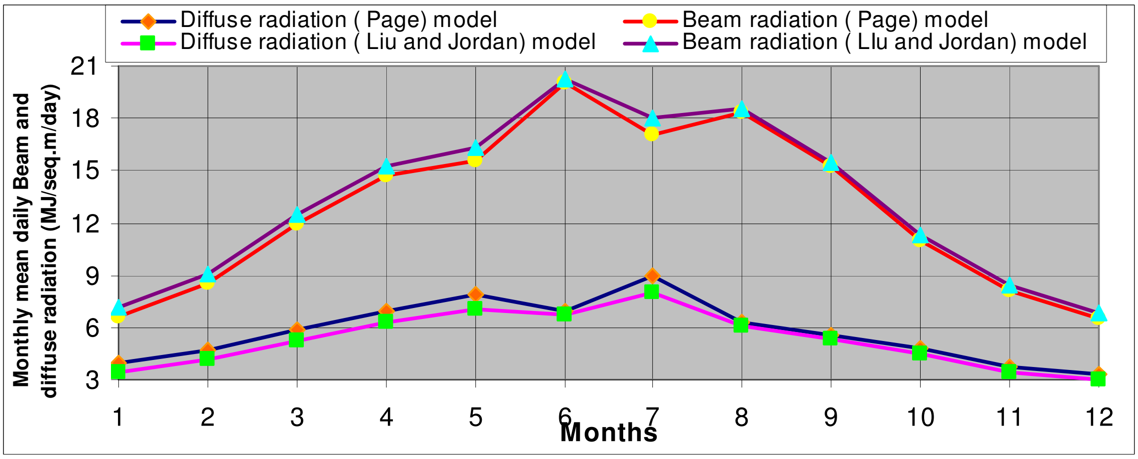

Fig. (1a) Monthly mean daily beam and diffuse radiation component for Baghdad city.

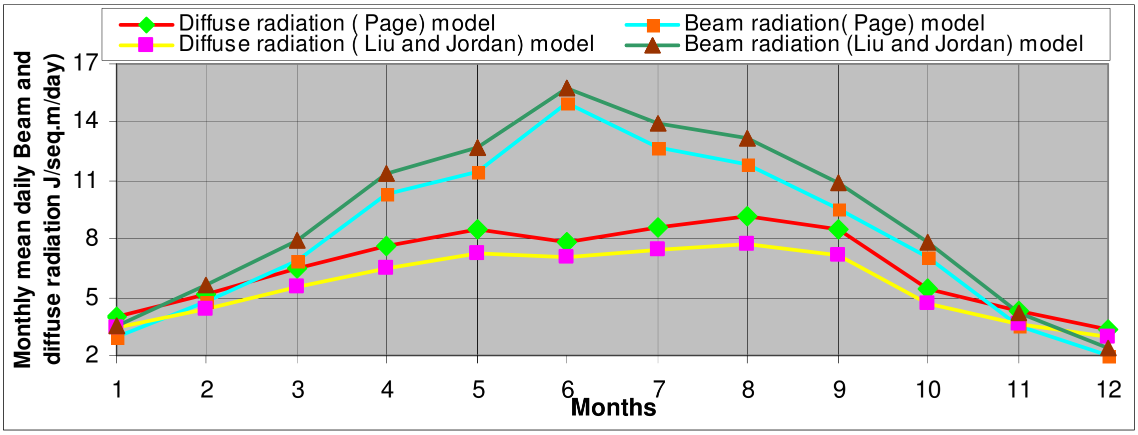

Fig. (1b) Monthly mean daily beam and diffuse radiation component for Mosul city.

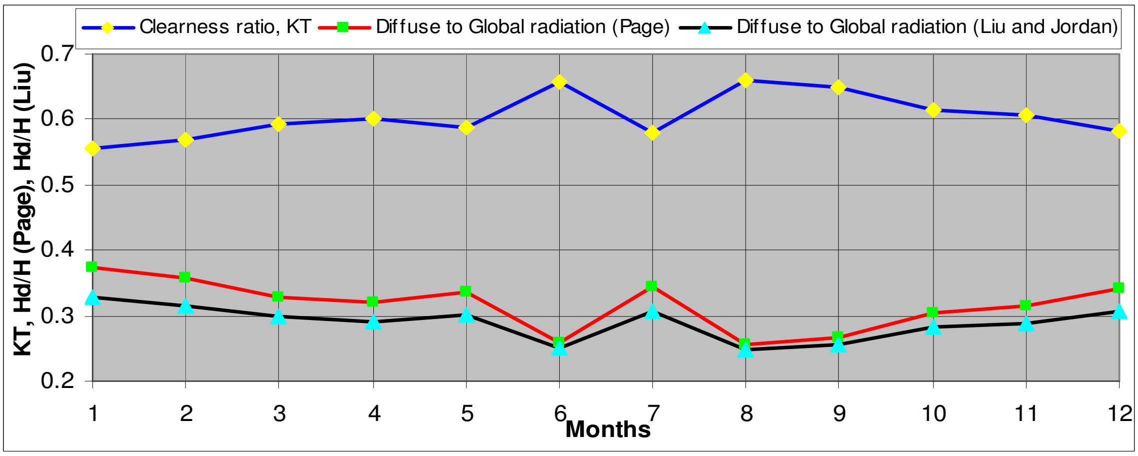

Fig. (2a) Monthly mean daily clearness ratio and diffuse to global radiation ratio for Baghdad city.

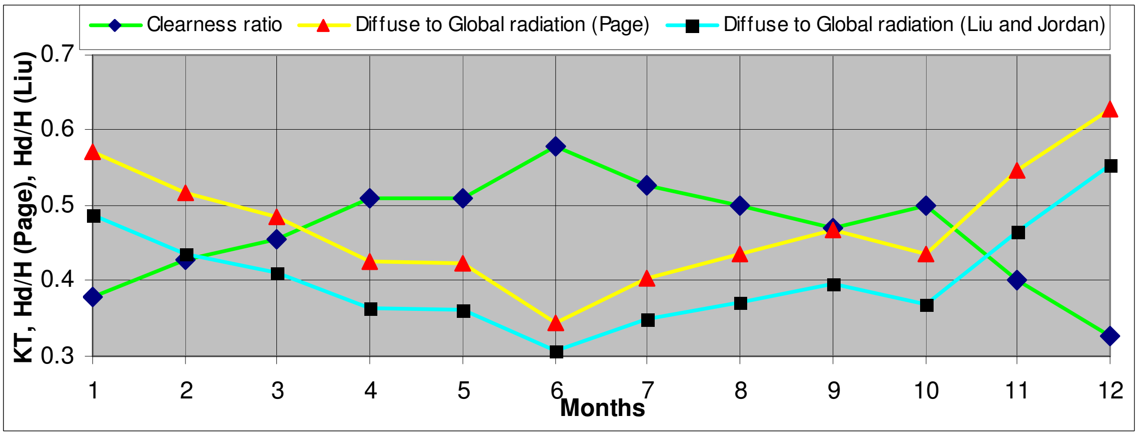

Fig. (2b) Monthly mean daily clearness ratio and diffuse to global radiation ratio for Mosul city.

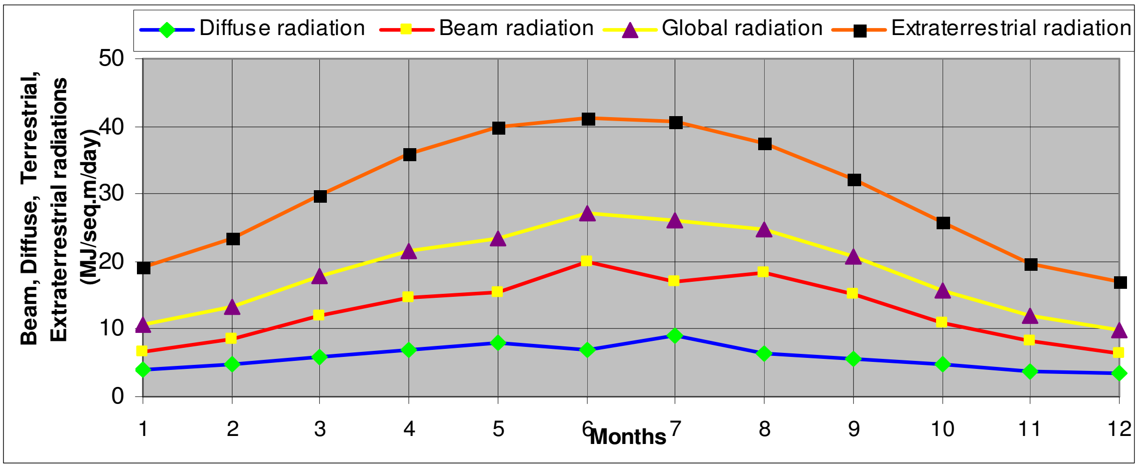

Fig. (3a) Monthly mean daily beam, diffuse, global, and extraterrestrial radiation components for Baghdad city.

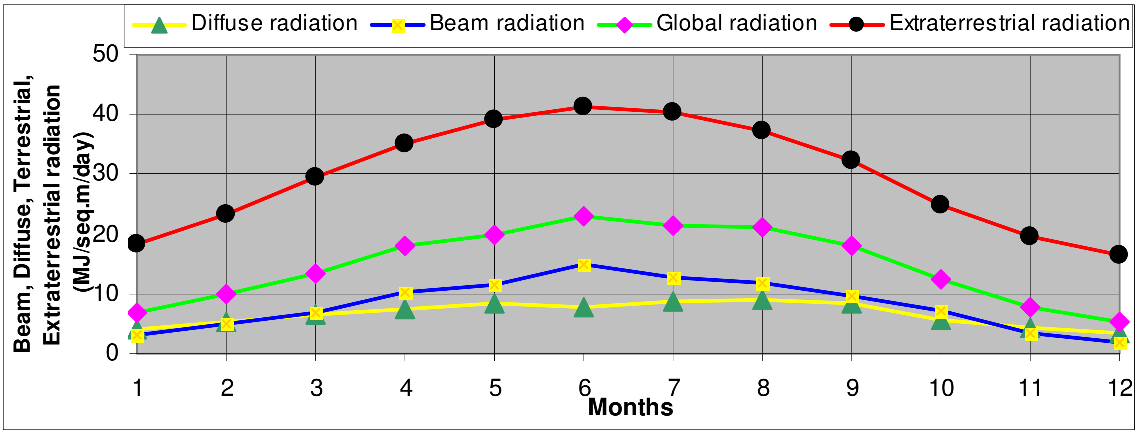

Fig. (3b) Monthly mean daily beam, diffuse, global, and extraterrestrial radiation components for Mosul city.

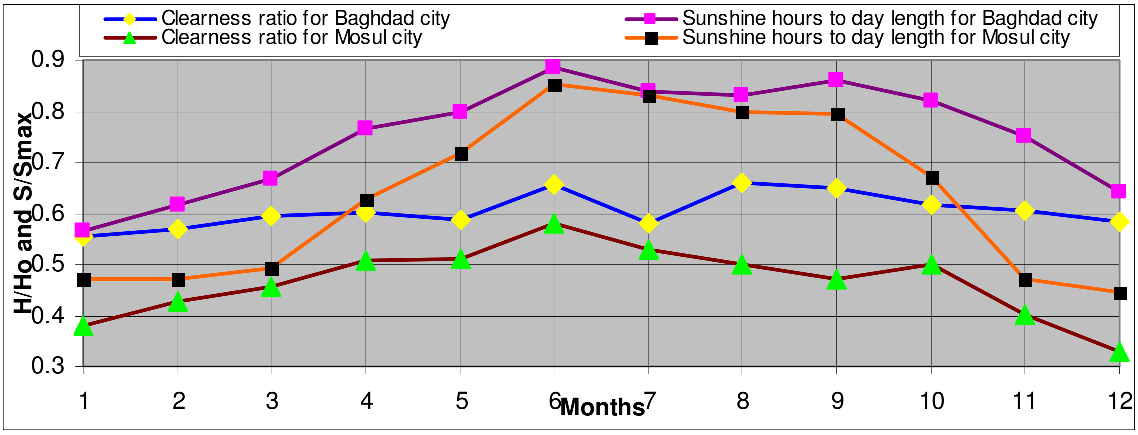

Fig. (4) Monthly mean daily clearness ratio and sunshine duration for Baghdad and Mosul city.

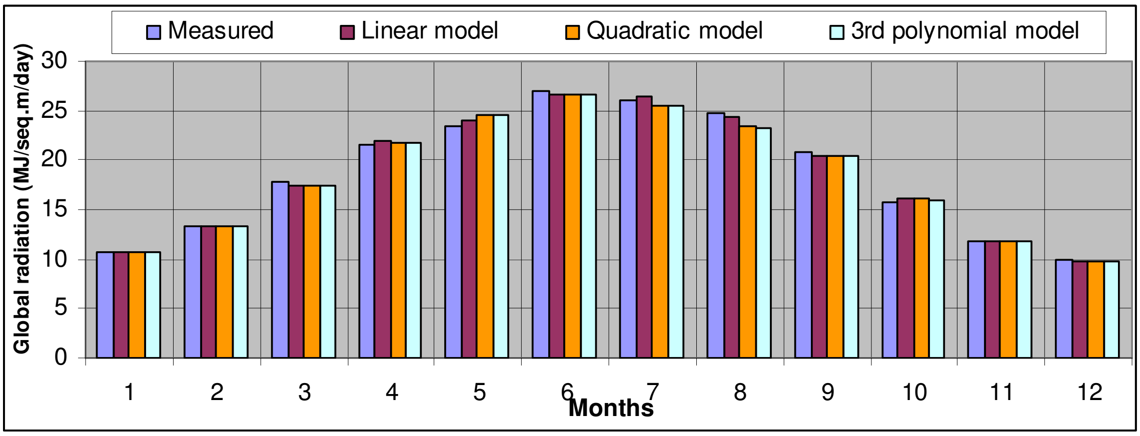

Fig. (5a) Monthly mean daily global radiation models for Baghdad city.

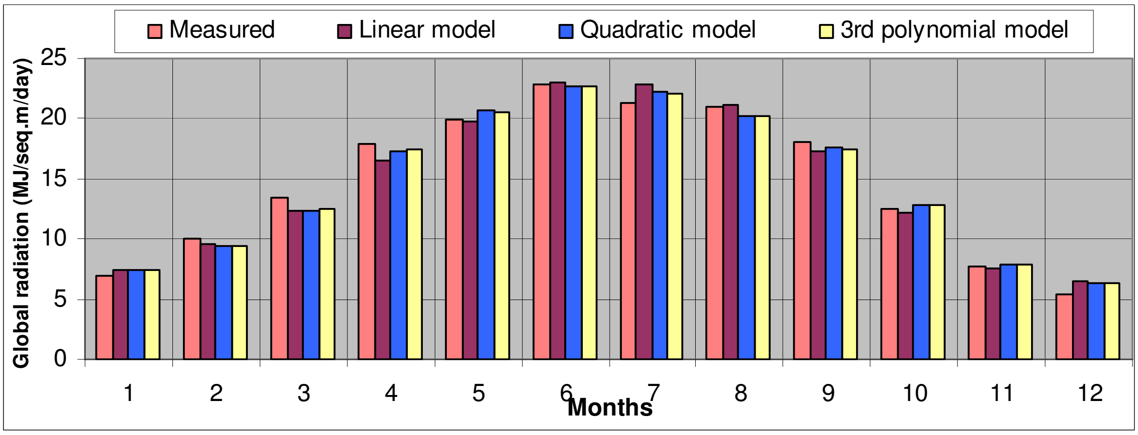

Fig. (5b) Monthly mean daily global radiation models for Mosul city.