Computation of Solar Radiation on Horizontal Surface Over Some Iraqi Cities

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Abstract

In this study a simple correlation is developed to predict monthly average daily global solar radiation on a horizontal surfaces for different Iraqi locations. For five-years interval (1981-1985), monthly average daily global solar radiation and sunshine duration data were measured on horizontal surfaces at some Iraqi cities (Kirkuk, Baghdad, Nasiriyah). A mathematical linear correlation represented by (Angstrom correlation) was applied to estimate the global radiation from hours of sunshine duration for these cities at the specified day of each month as shown in tables (2a, b, c). The model was compared with three different mathematical correlations models (quadratic, logarithmic, and exponential) to get the best fit among them. The obtained models have a high value of regression coefficient and give best fit through the measured values. In this study, the monthly average daily diffuse and beam radiations on horizontal surface were estimated from the measured global radiation. The overall results show that, Baghdad city received higher radiation on the horizontal surface than Kirkuk and Nasiriyah.

Keywords: Global solar radiation, Beam radiation, Diffuse radiation, and relative sunshine duration, and meteorological data).

حساب الإشعاع الشمسي على سطح أفقي لبعض مدن العراق

الخلاصة

تم في هذه الدراسة إقامة علاقة متبادلة للتنبؤ بقيمة المتوسط الشهري اليومي للإشعاع الشمسي الكلي على سطح أفقي لعدة مواقع في العراق.حيث استخدمت نتائج متوسط قراءات الإشعاع الشمسي الكلي وقراءات فترة السطوع الشمسي المقاسة لمدة خمس سنوات (1981-1985) على سطح أفقي في بعض مدن العراق (كركوك، بغداد, الناصرية). لتطوير نموذج تنبؤي لحساب قيم المعدل الشهري اليومي للإشعاع الشمسي الكلي لتلك المدن. تم عمل علاقة ربط خطية لحساب قيمة الإشعاع الشمسي الكلي من فترة السطوع الشمسي المقاسة لتلك المدن في يوم محدد من كل شهر وكما موضح في الجداول (2أ، ب،ج).تمت مقارنة نتائج الموديل الخطي مع ثلاثة نماذج مختلفة (تربيعي، لوغاريتمي، أسي) لغرض معرفة دقة النتائج. أظهرت النتائج دقة عالية ما بين النماذج المستخدمة. كما نفذت هذه الدراسة لحساب قيم الإشعاع الشمسي الكلي والمنتشر والموجه من قيم الإشعاع الشمسي الكلي المقاس على ذلك السطح. بينت النتائج الإحصائية أن النماذج الرياضية الأربعة المقترحة يمكنها التنبؤ بشكل دقيق بالإشعاع الشمسي الساقط على سطح أفقي في تلك المدن. بينت النتائج العامة أن مدينة بغداد تتسلم إشعاعا شمسيا اكبر من مدينتي كركوك والناصرية.

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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 the fact that renewable energy resources have some advantages when compared to fossil fuels. The global radiation is an important parameter necessary for most ecological models and an input for different solar systems. Although, solar radiation data are available at most meteorological stations, but still there are stations in many regions in our country suffers from a shortage concern the solar radiation record, there fore we present simple models with high accuracy depend on data which available at all meteorological stations. Kirkuk is a city with a many oil industrial plants mainly deal with oil refineries, it lies approximately at north of Iraq. Baghdad is a big city that assemblage many big factories, and it lies at middle of Iraq, while Nasiriyah is considered as an agricultural city which lies at south of Iraq. An attempt of using limited metrological data (1981-1985) for the above cities was taken from Iraqi meteorological organization and seismology to estimate the solar radiation at these areas is being employed. There are two ways to obtain solar radiation data at ground level: by measurement and by modeling. As far as this investigation is concerned, we found unreliable measurement at these stations. 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 Kirkuk, Baghdad, and Nasiriyah. 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 global solar radiation using various parameters. These parameters include; i) The sunshine hours (Angstrom, 1924 [1], Black, *et al.*, 1954 [2], Glover *et al.*, 1958 [3], Fayadh, *et al*., 2010 [4]) ii) the relative humidity and sunshine hours, the declination angle, and the latitude (Liu, *et al*., 1960 [5]), the number of rainy days, sunshine hours, latitude, and locations (Reddy, 1971 [6]), sunshine duration, relative humidity, maximum temperature, latitude, altitude, and location (Sabbagh *et al*. 1977 [7], Ali, *et al*., 2010 [8]), water turbidity, and surface albedo (Hoyt 1978 [9]). The linear regression model used to correlate the measured global solar radiation data (clearness index($\overline{H}/\overline{H}_o$)with relative sunshine duration ($S/S_{\max}$)) is given by Angstrom (1924 [1]) and later modified by Page (1964 [10]). The Angstrom formula were used in the calculation of the solar radiation component namely, global, diffuse, and direct over the Syrian landmass using several mathematical equations models(Al- Mohamad, 2004 [11]). The objectives of the present study are: 1. to present and analyze the global solar radiation and sunshine duration data at three cities mentioned above, 2. to develop new constants for the first order Angstrom type, quadratic, logarithmic, and the exponential equations correlations (4 models) which may be used for estimating $\overline{H}$ at any location of Iraq,average daily diffuse and beam radiation components from measured global monthly average daily radiation $\overline{H}$ for three cities that mentioned above using Liu and Jordan model (1996).[13].

Methodology

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

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

Where E_o is the extraterrestrial radiation measured on the horizontal surface of the nth day of the year, at a surface located at the mean distance between Earth and Sun [12] as follows:

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

Where I_{sc} is the solar constant which is equal to 1367 W/m^2, and θ_z is the zenith angle of the sun. For a horizontal surface at any time between sunrise and sunset, according to Liu and Jordan [13], the cosine of zenith angle can be expressed by:

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

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:

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

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[12]:

$$\overline{H}_o = \frac{24\times 3600}{\pi} I_{sc}\times E_o(\cos\delta\cos\phi\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta) \quad ....(5)$$

For normal radiation incidence, the zenith angle is equal to 90^o, and the hour angle becomes equal to sunset angle ($\cos\theta_z = 0$, and $\omega = \omega_s$), Equation (3), can be written as follows:

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

Where ω_s is the sunset hour angle, and δ is the solar declination angle in (radians) which given by the following formula:

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

Where d is the Julian day ranging from 1 (at 1 January) to 365 (at 31 December). Then 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 development of the model is as follows:

The most widely used relationship to estimate monthly average daily global radiation on a horizontal surface $\overline{H}$ is the linear regression model used in correlating the measured global solar radiation data $\overline{H}/\overline{H}_o$ with relative sunshine duration $S/S_{\max}$, which is given by Angstrom (1924) [1]. Second and third order Angstrom type correlations have been also proposed by different authors [El-Sebaii and A. A. Trabea 2005] [15]. The Angstrom linear regression formula was given by the following equation:

$$\overline{H} = \overline{H}_o\left[a + b\left(\frac{S}{S_{\max}}\right)\right] \qquad \text{......(8)}$$

where a, and b are the regression constants that depend on the location characteristics.

The values of $S_{\max}$ were computed from the following equation [14]:

$$S_{\max} = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \quad \text{....(9)}$$

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

The monthly average daily diffuse radiation can be calculated from Liu and Jordan model [13], as follows:

$$\frac{\overline{H}_D}{\overline{H}} = 1.39 - 4.027K_T + 5.531K_T^2 - 3.108K_T^3 \quad \text{... (10)}$$

Where $\overline{H}_D$ is the monthly average daily diffuse radiation in($MJ/m^2/day$).

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

$$\overline{H}_B = \overline{H} - \overline{H}_D \qquad \text{.....(11)}$$

The three models that used are to calculate correlation parameters are:

Quadratic $$\frac{\overline{H}}{H_o} = a + b\left(\frac{S}{S_{\max}}\right) + c\left(\frac{S}{S_{\max}}\right)^2 \qquad \text{....(12)}$$

Logarithmic

$$\frac{\overline{H}}{H_o} = a + b\log\left(\frac{n}{N}\right) \qquad \text{....(13)}$$

Exponential $$\frac{\overline{H}}{H_o} = a \times e^{b\left(\frac{S}{S_{\max}}\right)} \qquad \text{.....(14)}$$

Proper computer programs (Fortran 90) are prepared for the analysis. The monthly mean daily extraterrestrial radiation $\overline{H}_o$ and the maximum possible monthly average daily sunshine duration $S_{\max}$ needed for the calculations are estimated using the standard procedure as discussed later in the analysis.

Estimation Of Global Radiation

Climatic data like the length of days according to sunshine duration in the specific geological area as well as air temperature, humidity, wind speed and sky conditions (clouds, mist, fog, and aerosol) are usually available at some locations, but sometimes limited metrological data is more handy and more accurate for long period of time. The need for radiation data covering entire areas led to the development of radiation models that allow the calculation of radiation parameters within certain margins of error. The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), the Root Mean Square Bias Error ($RMSE$), and the Mean Percentage Error (MPE). The linear expressions for the MBE (MJ/m^2/*day*), $RMSE$ ($MJ/m^2/day$), and MPE (%) is stated by El–Sebaii et al. (2005) [15] and Correlation Coefficient as follows:

$$RMSE = \left[\sum\left(\overline{H}_{cal} - \overline{H}_{obs}\right)^2 / M\right]^{\frac{1}{2}} \quad (15)$$

$$MBE = \left[\sum\left(\overline{H}_{cal} - \overline{H}_{obs}\right) / M\right] \quad (16)$$

$$MPE = \left[\sum\left(\frac{\overline{H}_{obs} - \overline{H}_{cal}}{\overline{H}_{obs}} \times 100\right)\right] / M \quad (17)$$

Where M is the number of observed points, $\overline{H}_{cal}$ is the calculated global radiation, and $\overline{H}_{obs}$ is the observed global radiation on horizontal surface.

Result And Discussions

Weather pattern effects by surrounding features like the hills which is found in Kirkuk, flat surface ground in Baghdad, and the desert like surroundings of Nasiriyah were also considered. However the effect of these surrounding governed by the wind direction blowing, relative humidity, and air temperature. The geographical coordinates of these cities are shown in table (1).

Table 2 (a, b, and c): shows a comparison between measured (as taken from Iraqi meteorological organization and seismology for some Iraqi cities) and estimated global radiation values that estimated using a linear model (Angstrom model) as a sample of the estimation of global solar radiation values over these cities. The observed and calculated values depending of Equation (8). The computed values of the Angstrom's regression constants a and b, are found to be equal (0.3846248, 0.363282), for Baghdad, (0.10697122, 0.6694011), for Kirkuk, and (0.2196196, 0.5198024) for Nasiriyah respectively. The method of estimation of this constants was observed clearly in Equation (8), which similar in form to first order linear equation ($y = a + bx$). The values of y represent the clearness index ratio (K_T), while x values represent the relative sunshine duration (S/S_{max}). By substituting these values as shown in tables 2(a, b, c) in the linear equation, the constants a, b can be obtained. The other regression constants were also computed and the correlations proposed for Iraq cities can be used for estimating global, diffuse and direct solar radiation if the available meteorological parameters are known.

Table 3 (a, b, and c): shows the results of diffuse and beam solar radiation that estimated from the monthly average daily measured global solar radiation.

Table 4 shows the values of the regression constants (a, b, c) 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. Table 4 shows also, values of the accuracy of the estimated and observed global solar radiation values was tested by calculating the Mean Bias Error (MBE), the Root Mean Square Bias Error ($RMSE$), and the Mean Percentage Error (MPE). From point of view of solar astronomy, the extraterrestrial solar radiation (that estimated outside of atmosphere) is found slightly different among these cities. This is because of the convergence of latitude between these cities. The cause of increasing of extraterrestrial radiation value in June, and decreasing in December, as shown in figures 1(a, b, c), 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 form the sun at other months. 2. due to the declination of earth rotation axis. The earth rotation axis is tilted toward the sun at Summer season which allow to earth to receive more radiation in that season, over that for Winter season when the earth rotation axis is tilted away from the sun. The other type of solar radiation, is the terrestrial radiation, which is measured inside of atmosphere. 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. The two types of radiations are shown in Fig. (1).

Fig. (1a, b, c) shows the monthly average daily measured, calculated and extraterrestrial global radiations variation through the year. Accordingly the comparison between the observed and estimated values that presented at that figure, the model shows that it is quite sensitive to discriminate between these sites, however these sites are not far away enough from each other. The general overall distribution of the solar radiation of each of the site graphs behave rather well with that of the observed values.

The other indirect solar radiation, namely the monthly average daily solar diffuse radiation which calculated from Equation (10) were confirmed well with geological and climatologically effect on these three district cities as shown in fig. (1a, b, c). The maximum value of beam radiation occurred at Baghdad city, while the maximum value of diffuse radiation is occurred at Nasiriyah city.

Fig. (2) shows the monthly cleanness ratio for these cities over the months of year. It is clear that the clearness ratio behaves like the global radiation in the previous figure. This graph shows that Baghdad city has a clearness ratio higher than Kirkuk and Nasiriyah due to its geographical and climatically characteristics. The crossing curves of Kirkuk and Nasiriyah due to the percentage of error that may happened during the measurement process at these cities.

Fig. (3) shows the global solar radiation distribution throughout months of the year for (Baghdad, Kirkuk, and Nasiriyah) 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.

Fig. (4) shows the maximum day length in three cities of Iraq. 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.

Fig. (5a, b, c) shows the linear correlation between global radiation and sunshine duration (using Angstrom equation) for Baghdad, Kirkuk, and Nasiriyah cities respectively. The used model had a high value of regression coefficients and give best fit through the measured values. Each figure shows the reliability index and percentage of error values. These figures are accomplished using curve expert software. This software is used to calculate the values of regression coefficients a, b, and c that shown in table 4. The value of a represent the intercept of y-axis while the value of b represent the slope of the straight line.

For testing of the calculations, a statistical analysis of the results was performed for the $RMSE$, MBE, and MPE which shown in table 4 represent the fundamental measured accuracy of the data. It is observed from the results that the maximum error is no more 9%.

The $RMSE$ test provides information on the short-term performance of the studied model as it allows a term-by term comparison of the actual deviation between the calculated value and the measured value. Iqbal (1993) [14], Almorox (2005) [16], and Che et al. (2007) [17] have recommended that a zero value for MBE is ideal and a low $RMSE$ is desirable. MPE value provides information on under estimation since it is negative while if it s positive it is overestimation in the calculated value. A low value of MPE is desirable by Akpabio et al. (2004) [18]. The MPE is the reliability index as given in table 4, it is show that it is equal to (-0.04547) for Baghdad, (-0.12862) for Kirkuk, and (-0.05745) for Nasiriyah city respectively. 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.

Conclusions

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. The coefficients of the model are stated as functions of latitude. The performance of the model was investigated at different mathematical 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 Liu and Jordan model [13]. The study shows that, Baghdad received radiation more than Kirkuk and Nasiriyah.

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Appendix -A-

Sunshine duration in hours and monthly average daily global radiation in MJ/m^2/day tables as taken from meteorological organization and seismology for some Iraqi cities.

Table a1: Sunshine duration in hours for Baghdad city for five years (1981-1985).

Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	6.0	6.7	8.0	9.4	10.1	12.7	12.7	12.1	10.5	9.2	7.7	6.3
1982	4.6	6.5	8.7	7.2	9.6	12.0	12.7	12.1	9.8	8.6	7.2	6.2
1983	6.1	7.5	8.0	8.9	8.1	12.0	12.6	12.0	10.7	9.7	7.5	6.5
1984	7.0	7.8	7.0	8.9	10.2	11.8	10.3	11.7	10.5	7.7	6.1	7.1
1985	6.1	7.7	7.9	8.2	9.9	13.2	12.8	11.9	10.9	9.6	7.5	7.2
Average	5.96	7.24	7.92	8.52	9.58	12.34	12.22	11.96	10.48	8.96	7.2	6.66

Table a2: Sunshine duration in hours for Kirkuk city for five years (1981-1985).

Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	5.4	5.5	6.6	7.9	9.3	11.0	11.0	11.5	10.5	8.5	6.6	4.8
1982	4.4	6.6	7.3	6.7	9.2	11.8	11.6	11.6	9.0	7.9	5.6	5.7
1983	5.4	6.0	6.4	7.6	7.2	10.4	11.2	11.1	10.0	8.5	5.8	5.2
1984	5.6	6.5	5.8	7.6	7.9	9.8	9.0	10.4	9.9	7.7	4.0	5.9
1985	4.4	4.7	6.8	7.4	9.3	11.5	11.4	10.8	11.0	8.6	6.8	5.6
Average	5.04	5.86	6.58	7.44	8.58	10.9	10.84	11.08	10.08	8.24	5.76	5.44

Table a3: Sunshine duration in hours for Nasiriyah city for five years (1981-1985).

Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	6.4	7.5	7.8	8.7	8.3	10.7	8.7	9.0	9.6	8.7	7.6	5.6
1982	5.3	6.7	7.2	7.5	8.2	9.3	9.9	7.5	9.3	7.7	8.2	5.8
1983	6.0	8.0	7.7	7.8	7.4	8.0	8.9	8.8	9.7	9.5	7.8	6.9
1984	7.1	7.6	6.3	7.6	9.1	7.7	9.6	8.5	9.4	8.3	6.2	6.9
1985	6.8	7.9	7.5	8.3	9.5	9.4	9.4	11.0	10.4	9.5	6.5	6.5
Average	6.32	7.54	7.3	7.98	8.5	9.02	9.3	8.96	9.68	8.74	7.26	6.34

Table a4: Monthly average daily global radiation in $MJ/m^2/day$ for Baghdad city for a period (1981-1985).

Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	11.832	14.86	19.72	24	26.176	30.048	30.048	27.42	23.072	17.568	13.224	10.972
1982	9.768	14.04	20.052	20.212	24.2	28.468	29.048	26.204	21.132	17.016	13.032	10.98
1983	12.136	16.008	19.088	22.344	22.296	27.516	27.724	26.064	23.176	19.032	13.456	10.572
1984	12.336	16.108	16.984	21.948	24.252	27.128	25.304	25.956	23.184	17.016	11.46	11.548
1985	11.576	15.956	19.948	22.024	25.484	29.616	28.784	27.596	25.388	20.428	14.32	12.268
Average	11.529	15.394	19.158	22.105	24.481	28.555	28.181	26.648	23.190	18.212	13.098	11.268

Table a5: Monthly average daily global radiation in $MJ/m^2/day$ for Kirkuk city for a period (1981-1985).

Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	9.116	9.924	14.984	18.328	21.296	27.328	25.356	24.884	21.008	15.192	9.916	7.156
1982	8.688	11.816	14.568	17.768	22.244	26.84	26.268	24.572	19.832	14.34	8.744	7.548
1983	7.776	10.76	14.848	18.78	19.78	25.936	26.564	24.52	20.86	15.46	9.600	7.236
1984	8.584	11.772	12.6	18.392	21.732	25.724	28.556	23.62	20.424	14.284	7.336	7.636
1985	6.988	8.7	14.052	17.752	22.624	25.788	25.216	22.972	20.876	14.584	9.704	7.248
Average	8.2304	10.594	14.210	18.204	21.535	26.323	26.392	24.113	20.6	14.772	9.06	7.3648

Table a6: Monthly average daily global radiation in MJ/m^2/day for Nasiriyah city for a period (1981-1985).

Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	10.684	14.744	18.476	22.388	23.6	26.568	23.644	22.896	20.824	16.112	12.292	10.428
1982	9.4	13.236	17.036	19.452	20.804	23.612	23.656	20.14	23.8	14.404	11.908	9.068
1983	10.46	13.636	17.34	19.752	20.804	21.248	22.276	19.94	19.68	17.328	12.408	10.572
1984	11.272	14.34	16.488	19.992	23.424	22.384	23.836	22.352	20.104	18.16	11.192	10.824
1985	11.26	15.764	13.204	21.936	23.792	24.436	23.86	23.864	21.236	18.04	14.332	9.96
Average	10.615	14.344	16.508	20.704	22.484	23.649	23.454	21.838	21.128	16.808	12.426	10.170

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

City	Latitude	Longitude	Decimal degrees of Latitude
Baghdad	33°20' N	44°30' E	33.333
Kirkuk	35°28' N	44°21' E	35.466
Nasiriyah	31°00' N	46°16' E	31.000

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	5.96	10.029	0.594	19.114	11.529	0.603	11.478
FEB	16	7.24	10.813	0.669	24.077	15.394	0.639	15.117
MAR	16	7.92	11.754	0.674	30.121	19.158	0.636	18.958
APR	15	8.52	12.832	0.664	36.218	22.105	0.610	22.667
MAY	15	9.58	13.717	0.698	40.015	24.482	0.612	25.543
JUN	11	12.34	14.187	0.869	41.489	28.555	0.688	29.068
JUL	17	12.22	13.996	0.873	40.755	28.182	0.691	28.602
AUG	16	11.96	13.233	0.904	37.728	26.648	0.706	26.898
SEP	15	10.48	12.194	0.859	32.396	23.19	0.716	22.574
OCT	15	8.96	11.152	0.803	26.006	18.212	0.700	17.593
NOV	14	7.2	10.247	0.703	20.323	13.098	0.644	13.004
DEC	10	6.66	9.810	0.679	17.762	11.268	0.6343	11.212

Table (2b): Comparison between measured and estimated radiation values for Kirkuk 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	5.04	9.853	0.512	17.758	8.230	0.463	7.980
FEB	16	5.86	10.708	0.547	22.865	10.594	0.463	10.823
MAR	16	6.58	11.732	0.561	29.196	14.210	0.487	14.085
APR	15	7.44	12.905	0.577	35.745	18.204	0.509	17.618
MAY	15	8.58	13.870	0.619	39.956	21.535	0.539	20.820
JUN	11	10.9	14.384	0.758	41.654	26.323	0.632	25.586
JUL	17	10.84	14.175	0.765	40.829	26.392	0.646	25.268
AUG	16	11.08	13.342	0.831	37.445	24.114	0.644	24.823
SEP	15	10.08	12.211	0.825	31.652	20.600	0.651	20.876
OCT	15	8.24	11.077	0.744	24.894	14.772	0.593	15.060
NOV	14	5.76	10.090	0.571	19.007	9.060	0.477	9.297
DEC	10	5.44	9.614	0.566	16.385	7.365	0.449	7.958

Table (2c): Comparison between measured and estimated radiation values Nasiriyah 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/m²/day	MJ/m²/day	Dimensionless	MJ/m²/day
JAN	**17**	6.32	10.194	0.619	20.435	10.615	0.519	11.073
FEB	**16**	7.54	10.910	0.691	25.242	14.344	0.568	14.612
MAR	**16**	7.3	11.774	0.620	30.988	16.508	0.533	16.792
APR	**15**	7.98	12.763	0.625	36.633	20.704	0.565	19.951
MAY	**15**	8.5	13.575	0.626	40.021	22.485	0.562	21.815
JUN	**11**	9.02	14.004	0.644	41.282	23.649	0.573	22.888
JUL	**17**	9.3	13.829	0.672	40.634	23.454	0.577	23.128
AUG	**16**	8.96	13.132	0.682	37.957	21.838	0.575	21.798
SEP	**15**	9.68	12.178	0.795	33.082	21.128	0.639	20.934
OCT	**15**	8.74	11.221	0.779	27.066	16.808	0.621	16.903
NOV	**14**	7.26	10.392	0.699	21.602	12.426	0.575	12.589
DEC	**10**	6.34	9.994	0.634	19.110	10.17	0.532	10.499

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

Month	$\overline{H}$	$K_T = (\overline{H}/\overline{H}_o)$	$(\overline{H}_D/\overline{H})$	$\overline{H}_D$ From eq. (10)	$\overline{H}_B$ From eq. (11)
	MJ/m²/day	Dimensionless	Dimensionless	MJ/m²/day	MJ/m²/day
JAN	11.529	0.603	0.299	3.445	8.084
FEB	15.394	0.639	0.269	4.137	11.257
MAR	19.158	0.636	0.271	5.201	13.957
APR	22.105	0.610	0.293	6.472	15.633
MAY	24.482	0.612	0.292	7.138	17.344
JUN	28.555	0.688	0.228	6.522	22.033
JUL	28.182	0.691	0.226	6.361	21.821
AUG	26.648	0.706	0.213	5.685	20.963
SEP	23.19	0.716	0.205	4.761	18.429
OCT	18.212	0.700	0.218	3.977	14.235
NOV	13.098	0.644	0.265	3.465	9.633
DEC	11.268	0.6343	0.273	3.074	8.194

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

Month	$\overline{H}$	$K_T = (\overline{H}/\overline{H}_o)$	$(\overline{H}_D/\overline{H})$	$\overline{H}_D$ From eq. (10)	$\overline{H}_B$ From eq. (11)
	MJ/m^2/day	Dimensionless	Dimensionless	MJ/m^2/day	MJ/m^2/day
JAN	8.230	0.463	0.428	3.524	4.706
FEB	10.594	0.463	0.428	4.537	6.057
MAR	14.210	0.487	0.404	5.744	8.466
APR	18.204	0.509	0.382	6.957	11.247
MAY	21.535	0.539	0.355	7.635	13.899
JUN	26.323	0.632	0.275	7.235	19.088
JUL	26.392	0.646	0.263	6.939	19.452
AUG	24.114	0.644	0.265	6.389	17.725
SEP	20.600	0.651	0.259	5.342	15.258
OCT	14.772	0.593	0.307	4.535	10.236
NOV	9.060	0.477	0.414	3.754	5.305
DEC	7.365	0.449	0.443	3.263	4.102

Table (3c): Monthly average daily diffuse and beam radiations for Nasiriyah city.

Month	$\overline{H}$	$K_T = (\overline{H}/\overline{H}_o)$	$(\overline{H}_D/\overline{H})$	$\overline{H}_D$ From eq. (10)	$\overline{H}_B$ From eq. (11)
	MJ/m^2/day	Dimensionless	Dimensionless	MJ/m^2/day	MJ/m^2/day
JAN	10.615	0.519	0.372	3.954	6.660
FEB	14.344	0.568	0.328	4.712	9.631
MAR	16.508	0.532	0.360	5.946	10.561
APR	20.704	0.565	0.331	6.858	13.845
MAY	22.485	0.561	0.334	7.513	14.971
JUN	23.649	0.572	0.324	7.675	15.973
JUL	23.454	0.577	0.320	7.524	15.929
AUG	21.838	0.575	0.322	7.041	14.796
SEP	21.128	0.638	0.269	5.690	15.437
OCT	16.808	0.621	0.283	4.772	12.035
NOV	12.426	0.575	0.322	4.007	8.418
DEC	10.17	0.532	0.360	3.668	6.501

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

Site	Model	Equation No.	a	b	c	r^2	MBE	RMSE	MPE
Baghdad	Linear	8	0.3846248	0.363282	-	0.9331	0.00425	0.257786	-0.04547
	Quadratic	12	0.216293	0.813394	-0.295549	0.9346	-	-	-
	Logarithm	13	0.73838	0.274044	-	0.9339	-	-	-
	Exponent	14	0.434818	0.54846	-	0.9318	-	-	-
Kirkuk	Linear	8	0.10697122	0.6694011	-	0.9721	0.100417	0.3478535	-0.12862
	Quadratic	12	-0.194879	1.58926	-0.68052	0.9742	-	-	-
	Logarithm	13	0.740936	0.44667	-	0.9735	-	-	-
	Exponent	14	0.247465	1.19264	-	0.9686	-	-	-
Nasiriyah	Linear	8	0.2196196	0.5198024	-	0.9103	0.095583	0.33111	-0.05745
	Quadratic	12	0.33562563	0.1870814	0.2365707	0.91054	-	-	-
	Logarithm	13	0.71450234	0.3631779	-	0.90911	-	-	-
	Exponent	14	0.3124597	0.8898632	-	0.91057	-	-	-

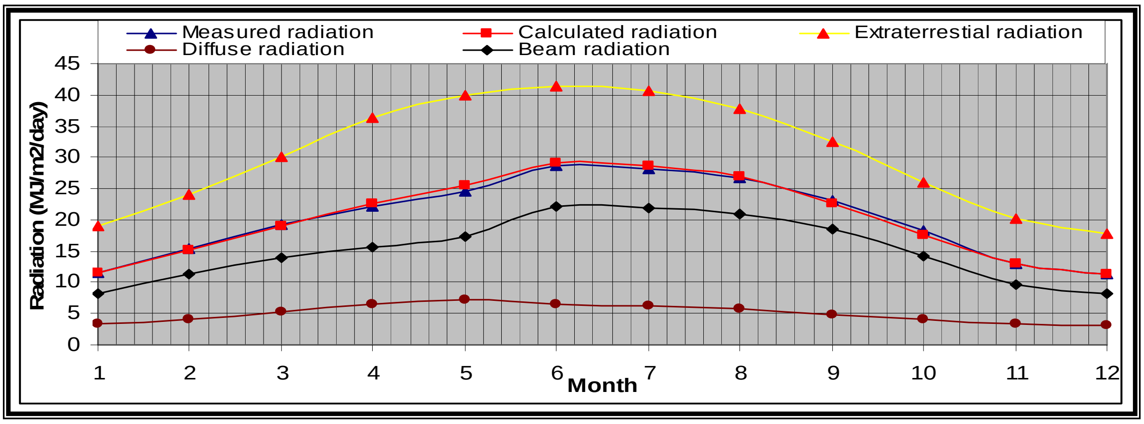

Figure (1a) Monthly average daily, Measured global radiation, calculated global radiation, extraterrestrial radiation diffuse radiation, and beam radiation for Baghdad city.

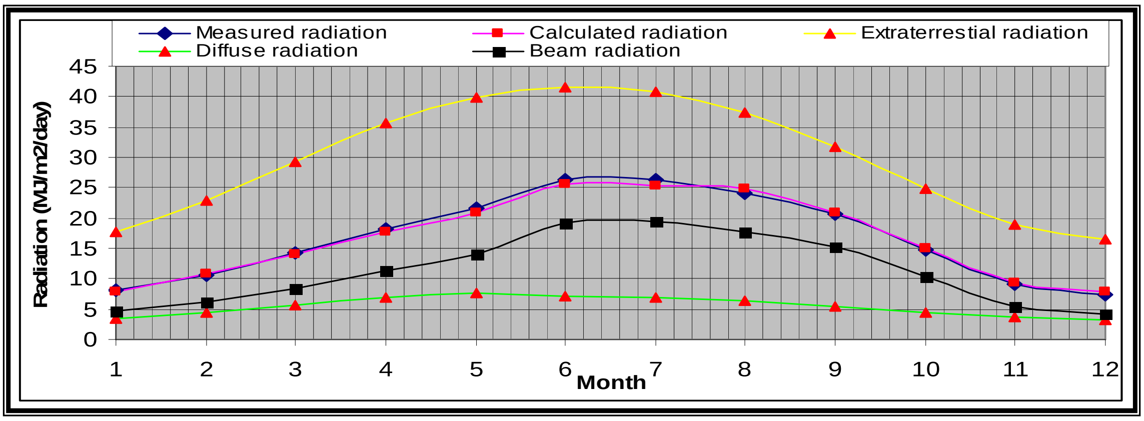

Figure (1b) Monthly average daily, Measured global radiation, calculated global radiation, extraterrestrial radiation diffuse radiation, and beam radiation for

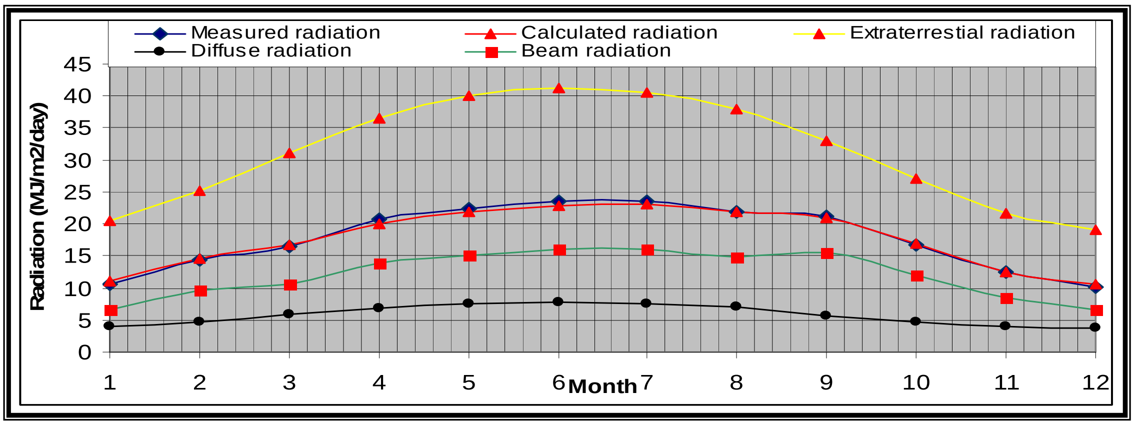

Figure (1c) Monthly average daily, Measured global radiation, calculated global radiation, extraterrestrial radiation diffuse radiation, and beam radiation for Nasiriyah city.

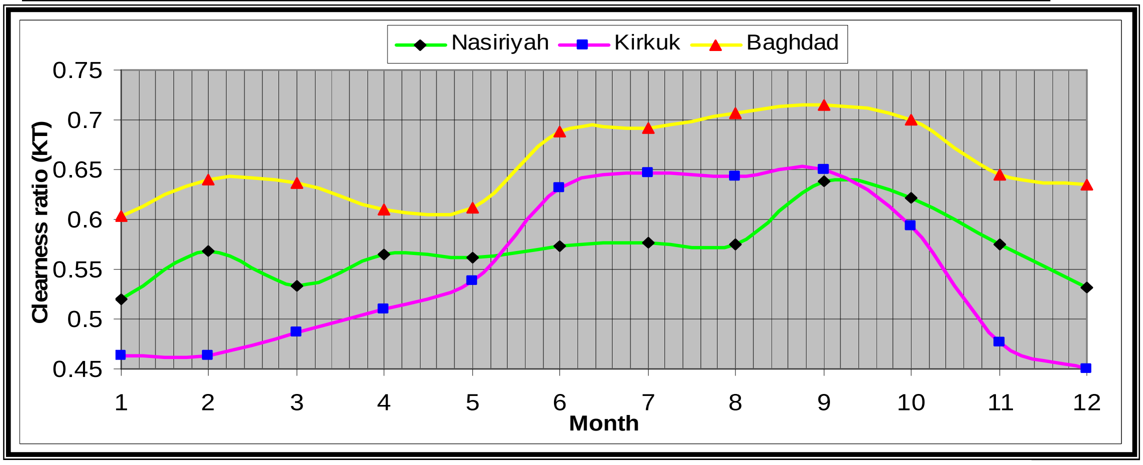

Figure (2) Monthly average daily clearness ratio distribution through the year for Baghdad, Kirkuk, and Nasiriyah cities.

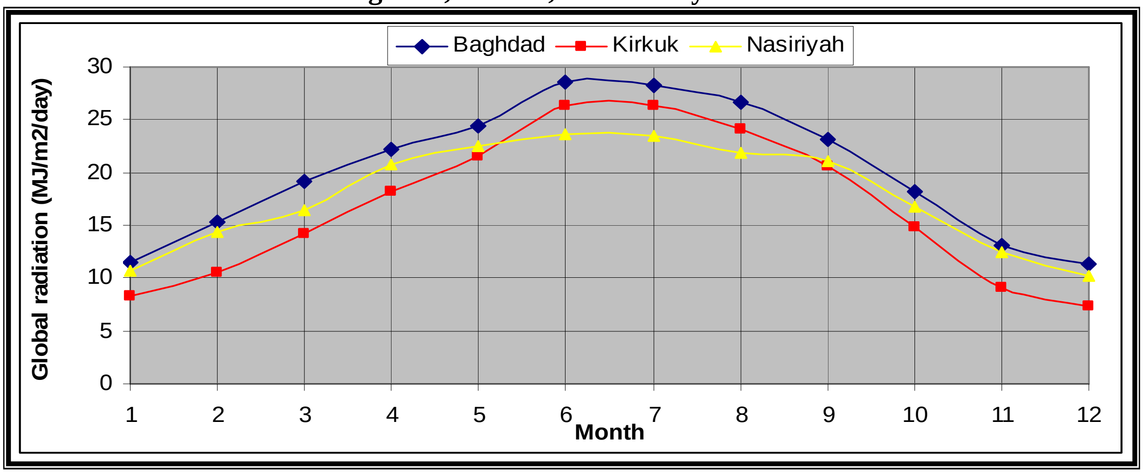

Figure (3) Monthly average daily global radiation estimated through the year for Baghdad, Kirkuk, and Nasiriyah cities.

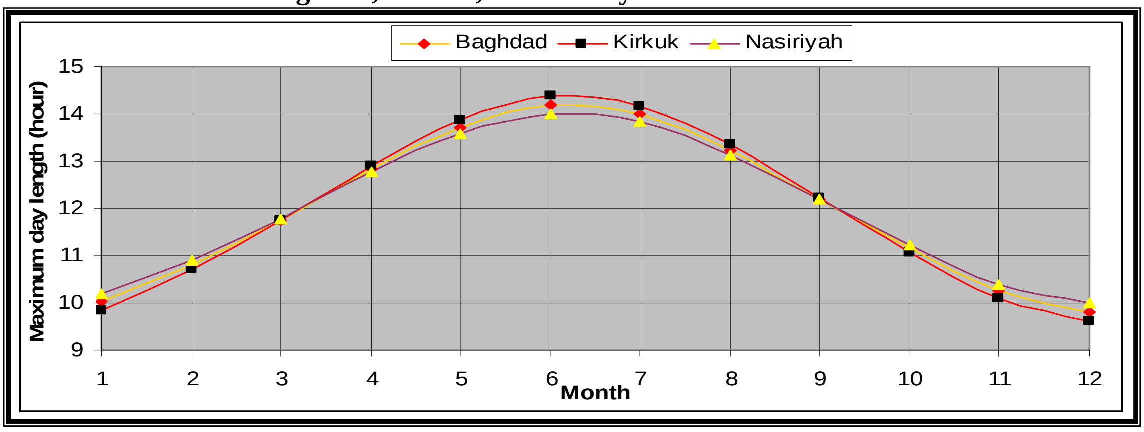

Figure (4) Maximum day length in hours estimated through the year for Baghdad, Kirkuk, and Nasiriyah cities.

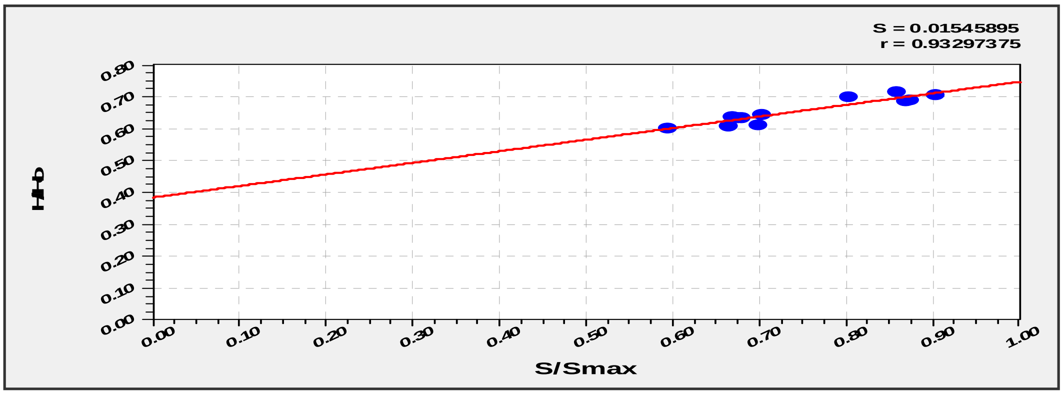

Figure (5a) Monthly average daily clearness ratio versus sunshine duration to day length ratio for Baghdad city.

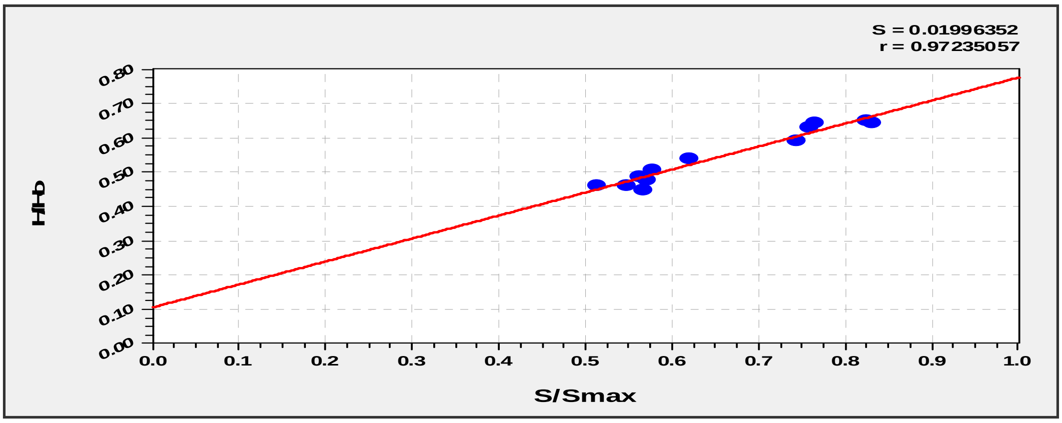

Figure (5b) Monthly average daily clearness ratio versus sunshine duration to day length ratio for Kirkuk city.