Estimation of Global Solar Radiation on Horizontal Surfaces over Haditha, Samara, and Beji, Iraq.

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ABSTRACT

Estimations of global solar radiation based on a model of using normalized clearness index and normalized sunshine duration for a period of more than 17 years for Haditha (34°09″N, 42°26′E), Beji (34.55 N, 43.29 E), and Samara (34.11″ N, 43.52″ E), Iraq, for each climatological stations were established. The monthly average total solar radiation was also estimated. This calculation appears to be sufficient to discriminate each station from the others due to the local characteristic of the sites. The reliability index of the calculation varies from 2.1 to 2.9 percent. For the diffuse radiation the Klien method was adapted and the estimations depended on the clearness index as a known and easy method developed for its measurements. The overall results show that for Haditha, the received radiation on the plane surface is higher than for Beji and Samara while the diffuse radiation behaved conversely with Samara showing the highest value.

(Keywords: solar global, solar radiation maximum and minimum temperature, relative sunshine duration, Hargreaves equation, meteorological data)

INTRODUCTION

The duration of solar radiation, which is the most important data for meteorological models, has been studied in the present work for Haditha, Beji, and Samara City; the geographical positions for which are give in Table 1. Meteorological data used in the estimation of the triangular area of North West Iraq, between the rivers of Tigris and Euphrates is shown in Figure.1.

Heditha district is a frontier area to the desert moving toward the plantation of the Rural area. This is by itself represents a problem for investigation due to the fact that the Euphrates river exhibits less water flow every year. Additionally, the manmade lake of Haditha Dam has lost its water reservoir and dried out accordingly.

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

Site	Lat. λ	Long.	Decimal Degrees of Lat.
Haditha	34°09′N	42°26′E	34+09/60
Beji	34°55′N	43°29′E	34+55/60
Samara	34°11′N	43°52′E	34+11/60

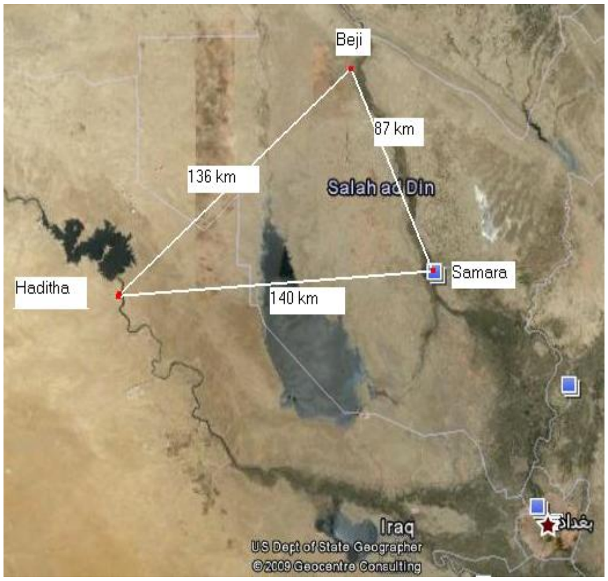

Figure 1: Regional Location of Haditha, Beji, and Samara.

Beji is an industrial city with five industrial plants mainly deals with oil refineries and Samara City has a smaller dam on the river Tigris, then the two manmade lakes of Samara Dam and the

Therthar Valley Lake also support a heavily agricultural area. For this reason a trial of using limited metrological data for the last twenty-five years 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. Only the sunshine duration and weather measurement temperature of it is maximum and minimum were considered reliable.

A trial was undertaken to elaborate modeling that can be useful in the estimation of solar radiation on the flat surface of ground level and further elaboration for the diffuse radiation as well.

Global solar radiation in Iraq is not measured at the three stations, namely Haditha, Beji, and Samara. 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., 1945 [2],* Glove *et al.,* 1958 [3]) ii) The relative humidity and sunshine hours, the declination angle, and the latitude (Liu, *et al*., 1960 [4]), The number of rainy days, sunshine hours, latitude, and locations (Ready, 1977 [5]), sunshine duration, relative humidity, maximum temperature, latitude, altitude, and location (Sabbagh *et al*. 1977 [6]), and the total ppt, water, turbidity, and surface albedo (Hoyt 1978 [7]).

The linear regression model used in correlating the measured global solar radiation data the clearness index (H/Ho) with relative sunshine duration (S/Smax) is given by Angstrom (1924 [1]) and later modified by Page (1964 [8]). The Angström formula were used in the calculation of the solar radiation component namely, global, diffuse, and direct over the Syrian landmass using several mathematical equations (Al-Mohamad, 2004 [9]).

The objective of the present study is to present and analyze the global solar radiation and sunshine duration data recorded at three cities (Haditha, Beji, and Samara), and to develop new constants for the first order Angström type correlations which may be used for estimating *H* at any location of Iraq.

THE GLOBAL AND CLEARNESS INDEX

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

$$\overline{H} = \sum_{J=1}^{NY}\left[\left(\sum_{I=1}^{ND} H_{I,J}\right)/ND\right]/NY$$

where H = monthly average of daily global radiation
Hi, j = daily global radiation
ND = total number of days in the month
NY = total number of year of data
I = index representing a day
J= index representing a year

$$H_0 = I_{sc} E_0 \cos\theta_Z \quad \textbf{(1)}$$

where E_0 =Extraterrestrial radiation measured on the plane of the nth day of the year, and represented the relative distance between Earth and Sun [10] as follows:

$$E_0 = \left(1 + 0.033 * COS\left(\frac{360n}{365}\right)\right)$$

I_{sc} =Solar constant=1367 Wm^{-2}

and $\theta_z =$ zenith angle of the sun

For a horizontal surface at any time between sunrise and sunset, according to Liu and Jordan [11], the cosine of zenith angle can be expressed by:

$$\cos\theta_Z = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma$$
$$+\cos\gamma\cos\phi\cos\beta\cos\omega + \cos\gamma\sin\phi\sin\beta\cos\gamma\cos\omega \quad \textbf{(2)}$$
$$+\cos\sin\beta\sin\gamma\sin\omega$$

Considering $\beta = 0$ and $\gamma = 0$, then Equation 2 can be rewritten as:

$$\cos\theta_z = \sin\delta\sin\phi + \cos\phi\cos\omega\cos\delta \quad \textbf{(3)}$$

Combining Equations (1) and (3) we have:

$$H_0 = I_{sc} E_0 s(in\delta \sin\phi + \cos\phi \cos\omega \cos\delta) \quad \textbf{(4)}$$

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

$$H_0 = \frac{24*3600}{\pi} * I_{sc} E_0 \left(\cos\phi \cos\delta \cos\omega_s + \frac{2\pi\omega_s}{360} \sin\phi \sin\delta \right) \quad \textbf{(5)}$$

if we consider $\cos\theta_s = 0$ and $\omega = \omega_s$.then using Equation 2, we have:

$$\omega = Cos^{-1}(-\tan\phi \tan\delta)$$

δ :celestial declination[radians] given as follow:

$$\delta = 23.45^0 \sin\left(360 * \frac{284 + J.}{365}\right) \quad \textbf{(6)}$$

where, J the Julian day ranging from 1 (1 January) to 365 or 366 (31 December).

Then the monthly average of daily global radiation $\overline{H}$ was normalized by dividing with the monthly average of daily extraterrestrial radiation $\overline{H}_0$. Therefore, $(\overline{H}/\overline{H}_0)$ is defined as the ratio of the measured horizontal terrestrial solar radiation ($\overline{H}$), to the calculated horizontal extraterrestrial solar radiation ($\overline{H}_0$), where $(\overline{H}/\overline{H}_0)$ is the cleanness index 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 that given by Angström [1], Equation (7). Second and third order Angström type correlations have been also proposed by different authors [*El*-Sebaii and A. A. Trabea 2005] [13]. They concluded that the second and third order Angström type correlations do not significantly improve the accuracy of estimation of the monthly average daily global radiation incident on a horizontal surface.

$$\overline{H} = \overline{H}_0 \left(a + b\left(\frac{\overline{S}}{\overline{S}_{\max}} \right) \right) \quad \textbf{(7)}$$

where *a*, and *b* are the regression constants that depend on the location and where $\overline{H}$ is the monthly global solar radiation in MJm^{-2}. The linear regression model used in correlating the measured global solar radiation data ($\overline{H}/\overline{H}_0$) data with relative sunshine duration $(S/S_{\max})$is given by Angstrom (1924) [1] and later modified by Page (1964) [7].

For the sunshine durations, the monthly average of daily values for a given month were computed by the following equation:

$$\overline{S} = \sum_{J=1}^{NY} \left[\left(\sum_{I=1}^{ND} S_{I,J} \right) / ND \right] / NY \quad \textbf{(8)}$$

where $\overline{S}$ = monthly average of daily sunshine duration and $S_{I,J}$ = daily sunshine duration.

As with the case of global radiation, the monthly average of daily sunshine duration (S) was divided by the monthly average of daily day length ($S_{\max}$). The values of $S_{\max}$ were computed from the following equation [12]:

$$S_{\max} = 2/15 * Cos^{-1}(-\tan\phi \tan\delta) \quad \textbf{(9)}$$

where $S_{\max}$ = monthly average of daily day length
δ = solar declination at the middle of the month
λ = latitude of the station.

Proper computer programs are prepared for the analysis. The monthly mean daily extraterrestrial radiation $\overline{H}_0$ and the maximum possible monthly average daily sunshine duration *N* needed for the calculations are estimated using the standard procedure as discussed later in the analysis.

ESTIMATION OF GLOBAL SOLA 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 readily available, 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.

Previous modeling efforts of total incoming solar radiation (*R*) have been conducted. Liu 1996[11] and Monteith 1965 [14] used solar radiation which varies as a sine function through the day:

$$R = R_{noon} \sin\left(\frac{t}{D}\right)$$

where *R* is the solar radiation at time *t*, R_{noon} is the solar radiation at solar noon, and *D* is day length.

The major limitation is that the R_{noon} value is still needed. Bristow and Campbell (1984) [15] developed of an empirical algorithm for estimating *R* using daily maximum and minimum air temperatures. Their model reduces the total daily solar radiation incident at the top of the atmosphere (R_e) by a correction factor calculated from the temperature extremes and is given by:

$$R = R_e\left[A\left(1-e^{-B(\Delta T)^C}\right)\right]$$

where *A, B,* and *C* are empirical coefficients unique to each location and ΔT is the difference between $T_{\max}$ and $T_{\min}$.

McVicar and Jupp (1999) [16] gave an estimation for Bristow and Campbell model involved a large amount of meteorological data (including solar radiation) which requires calibrations for the varies parameters of the model, its calculations are numerically complex.

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 expressions for the MBE ($MJ.m^{-2}day^{-1}$), RMSE ($MJ.m^{-2}day^{-1}$), and MPE (%) is stated by El–Sebaii et al. (2005) [13] and Correlation Co-efficient as follows:

$$\begin{aligned} RMSE &= \left(\left[\sum\left(\overline{H}_{cal.}-\overline{H}_{obs.}\right)^2\right]/M\right)^{1/2}, \\ MBE &= \left[\sum\left(\overline{H}_{cal.}-\overline{H}_{obs.}\right)\right]/M, \\ MPE &= \left[\sum\left(\frac{\overline{H}_{obs.}-\overline{H}_{cal}}{\overline{H}_{obs.}}\times 100\right)\right]/M \end{aligned} \quad \textbf{(14)}$$

$$r = N\Sigma\left(\frac{\overline{H}}{\overline{H}_0}\right)\left(\frac{\overline{S}}{\overline{S}_{\max}}\right)-\left(\Sigma\frac{\overline{H}}{\overline{H}_0}\right)\left(\Sigma\frac{\overline{S}}{\overline{S}_{\max}}\right) / \sqrt{\left(\left[N\Sigma\left(\frac{\overline{S}}{\overline{S}_{\max}}\right)^2\right]-\left(\Sigma\left(\frac{\overline{S}}{\overline{S}_{\max}}\right)\right)^2\right]\left[N\Sigma\left(\frac{\overline{H}}{\overline{H}_0}\right)^2-\left(\Sigma\left(\frac{\overline{H}}{\overline{H}_0}\right)\right)^2\right]\right)} \quad \textbf{(15)}$$

RESULT AND DISCUSSIONS

For this study, three sites which differed in climatological characteristics and geographical positions were chosen. Weather pattern effects by surrounding features like the manmade lake in samara, industrial plants in Beji, and the desert like surroundings of Haditha were also considered. However the effect of these surrounding governed by the wind direction blowing for most of the years considered in a North-Westerly mode.

Accordingly, noticeable climatologically parameters for the average of a minimum of a ten-year period are required for the sunshine duration, the maximum and minimum temperature, and clearness index for Haditha, Beji, and Samara (Table 2 a ,b, and c).

These values were summarized for maximum and minimum values and are given in Table 3. From this table it is observed that sunshine duration is up to 90 percent throughout the year.

Table 2a: Comparison between Measured Metrological Data Estimated Values for Haditha.

Month	*Mean sunshine* (hours) n	Max day length(N) (hours)	*n*/N	H_0	$MJm^{-1}day^{-1}$ Measured	Calculated	$K_T = \left(\bar{H}/H_0\right)$	Tmax.	Tmin.
JAN	5.875	10.002	0.587	18.83	11.91	12.18	0.647	13.53	2.46
FEB	7.229	10.764	0.672	23.56	15.64	16.34	0.693	16.51	4.3
MAR	7.954	11.783	0.675	29.96	20.89	20.84	0.695	21.4	7.94
APR	8.379	12.872	0.651	36.05	26.25	24.58	0.682	28.03	13.34
MAY	9.992	13.773	0.725	39.96	30.3	28.91	0.723	34.24	18.31
JUNE	11.95	14.236	0.839	41.48	31.83	32.63	0.787	39.18	22.87
JULY	11.942	14.026	0.851	40.64	31.86	32.25	0.793	42.23	25.2
AUG	11.408	13.251	0.861	37.47	29.44	29.93	0.799	41.78	24.69
SEP	10.267	12.199	0.842	32.06	25.43	25.26	0.788	38.44	21.02
OCT	8.558	11.111	0.77	25.5	19.37	19.08	0.748	31.23	15.25
NOV	7	10.204	0.686	19.93	14.46	13.98	0.701	21.87	7.29
DEC	5.792	9.758	0.594	17.36	10.63	11.28	0.65	14.84	4.45

Table 2b: Comparison between Measured Metrological Data Estimated Values for Beji.

Month	*Mean sunshine* (hours) n	Max day length(N) (hours)	*n*/N	H_0	$MJm^{-1}day^{-1}$ Measured	Calculated	$K_T = \left(\bar{H}/H_0\right)$	Tmax.	Tmin.
JAN	5.765	9.966	0.578	18.55	9.64	10.23	0.551	14.43	3.89
FEB	6.529	10.742	0.608	23.31	12.84	13.18	0.565	17.15	5.3
MAR	6.988	11.779	0.593	29.78	16.75	16.63	0.558	21.08	8.72
APR	7.871	12.887	0.611	35.95	21.38	20.38	0.567	28.1	14.28
MAY	9.041	13.805	0.655	39.95	24.05	23.49	0.588	34.05	19.89
JUNE	11.382	14.276	0.797	41.51	27.01	27.25	0.656	40.2	23.65
JULY	11.265	14.062	0.801	40.66	26.72	26.76	0.658	43.29	26.41
AUG	11.029	13.273	0.831	37.41	24.89	25.17	0.673	42.64	25.35
SEP	10.047	12.203	0.823	31.91	21.31	21.35	0.669	39.09	21.67
OCT	8.135	11.096	0.733	25.27	15.94	15.81	0.626	31.74	16.2
NOV	6.294	10.172	0.619	19.66	11.65	11.22	0.571	22.95	9.23
DEC	5.318	9.717	0.547	17.07	8.96	9.16	0.536	16.05	5.29

Table 2c: Comparison between Measured Metrological Data Estimated Values for Samara.

Month	*Mean sunshine* (hours) n	Max day length(N) (hours)	*n*/N	H_0	$MJm^{-1}day^{-1}$ Measured	Calculated	$K_T = \left(\bar{H}/H_0\right)$	Tmax.	Tmin.
JAN	5.876	10	0.588	18.82	8.41	8.37	0.445	14.56	9.03
FEB	6.9	10.763	0.641	23.55	10.78	11.09	0.471	16.77	10.97
MAR	7.614	11.783	0.646	29.96	14.67	14.19	0.474	21.78	15.13
APR	8.71	12.872	0.677	36.04	16.21	17.6	0.488	28.51	22.91
MAY	9.962	13.775	0.723	39.96	19.81	20.42	0.511	35.1	28.29
JUNE	11.033	14.238	0.775	41.48	21.45	22.25	0.536	40.29	32.88
JULY	10.652	14.027	0.759	40.65	21.9	21.49	0.529	43.25	35.21
AUG	10.224	13.252	0.772	37.47	20.57	20.03	0.535	43.17	34.82
SEP	8.929	12.199	0.732	32.06	17.69	16.52	0.515	39.71	31.27
OCT	7.867	11.111	0.708	25.49	12.78	12.84	0.504	31.54	24.58
NOV	6.452	10.202	0.632	19.92	9.31	9.3	0.467	22.14	16.09
DEC	5.29	9.756	0.542	17.34	7.5	7.33	0.423	15.53	10.35

Table 3: Average of Metrological Data.

Site	Sunshine Duration	Tmax	Tmin	Kt
Haditha	60-86%	42	2.4	64-80%
Beji	55-83%	43	3.5	53-67%
Samara	54-77%	43	9.0	42-53%

As far as the estimation of solar radiation values over these areas limited to the metrological data (max and min. Temperatures), the observed values and calculated depending of Equation 7. The results of these calculation are presented in Table 2 a, b, and c. For these three areas the extraterrestrial radiation is nearly the same.

The analysis of the measured and calculated *H* shows that for all locations, the maximum values of global solar radiation are observed in June while the minimum values appeared in December. The observed value changes for these site depends largely on its geographical surrounding mainly Haditha located in a desert like environment, despite the nearby Euphrates and the manmade lake, due to the winds blowing from the desert area.

Beji has two factors effecting it is environment, the mountain areas surrounding it which raise secondary reflection of the sun's rays and the presence of aerosol emitting factories. On the other hand, Samara was affected by the two nearby manmade lakes and heavily agriculture area which raise the air humidity.

The metrological data for the three sites of (the average sunshine duration, and the maximum and minimum temperature) are shown in Table 2 a, b, and c. Also the average observed solar radiation values that obtained from those data is shown in the same tables.

Furthermore, in order to relate the observed values of clearness index with sunshine duration, employing these parameters the regression constant "a" and "b" are evaluated Inserting these values in Equation (7) the monthly average daily global solar radiation H is estimated. These parameters are fitted in an empirical equation as follows:

$$H = H_0\left(0.3203 + 0.5557\left(\frac{n}{N}\right)\right) \quad \text{Haditha}$$

$$H = H_0\left(0.2733 + 0.4805\left(\frac{n}{N}\right)\right) \quad \text{Beji}$$

$$H = H_0\left(0.15833 + 0.4878\left(\frac{n}{N}\right)\right) \quad \text{Samara}$$

Accordingly the comparison between the observed and estimated values represented in each district as shown in Figure 2 a, b, and c. This model shows that it is quite sensitive to discriminate between these sites, however these sites are not far away from each other by (less than 136 km). 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 solar diffuse radiation predicted by Klien [21] were confirmed well with geological and climatologically effect on these three district. The results of the diffuse radiation calculation are presented in the same Figure 2.

In Haditha it appears to be below 5% of the total radiation due to the fact that the air stream blows in a North-Westerly manner, locally named Al-Sumom, over Haditha which is low in humidity due to crossover of the desert-like area between Iraq and Syria. This pattern changes in Beji which is only 136 km east of Haditha due to the existence of mountains which reflects indirect sunshine and also an aerosol presence from five industrial plants mainly oil refinery and electrical power generating stations, and to a lesser extent fertilizer and detergent plants. The highest diffuse radiation is observed in Samara which lies South-Easterly of Haditha. Accordingly, due to the fact that Al-Sumom blows over two manmade lakes, the Samara Dam Lake and Altherthar Valley Lake, higher humidity levels are present in the air and minute levels of dust are present in the summer and winter, alike.

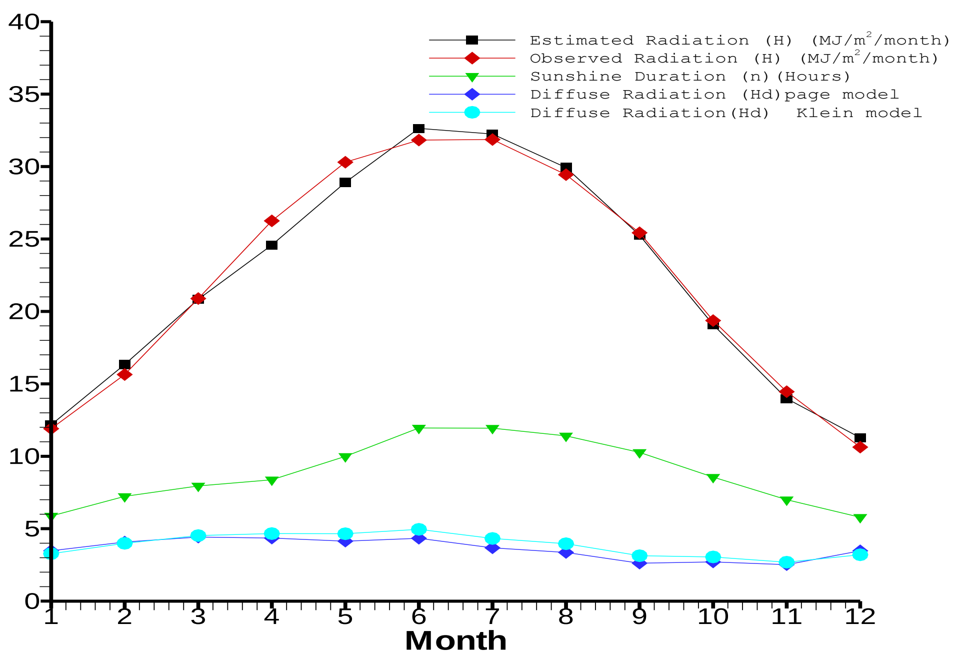

Figure 2a : Monthly variation of H,n,Hd(Page and Klein Model) for Haditha-Iraq.

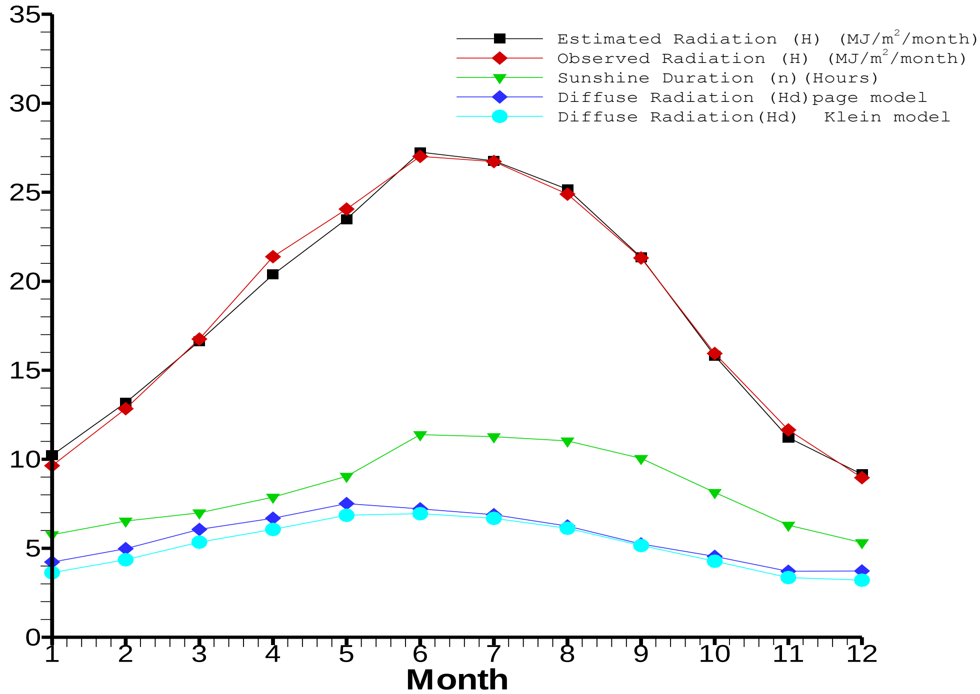

Figure 2b: Monthly variation of H,n,Hd(Page and Klein Model) for Beji-Iraq.

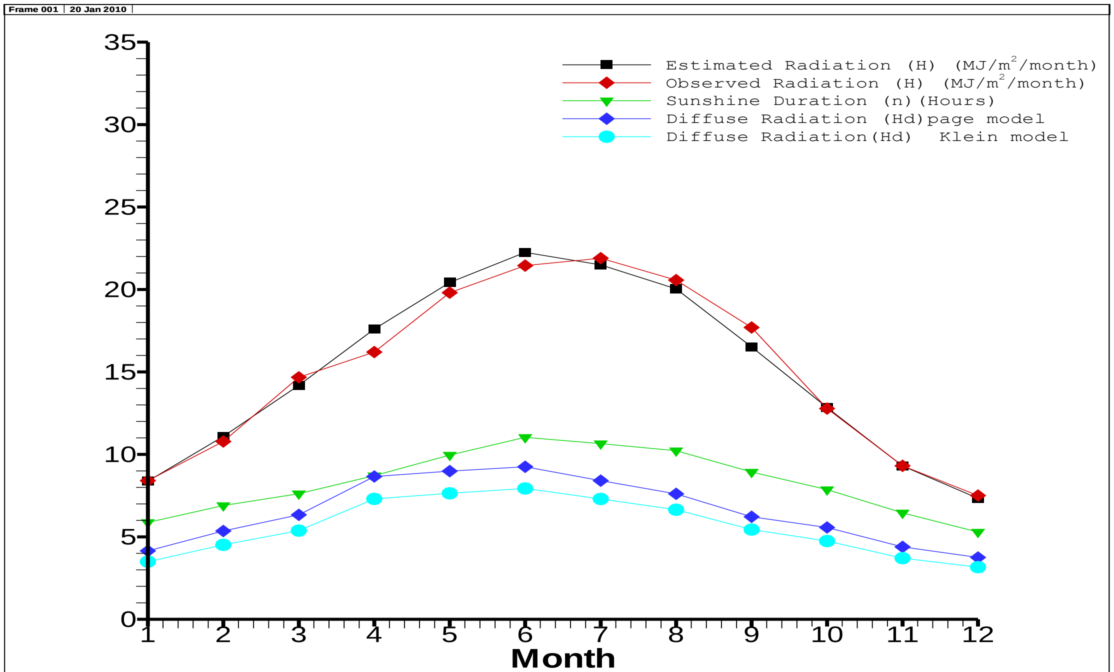

Figure 2c: Monthly variation of H,n,Hd(Page and Klein Model) for Samara-Iraq.

For testing of the calculations, a statistical analysis of the results was performed for the RMSE, MBE, and MPE which represent the fundamental measured accuracy of the data. It is observed from the results that the maximum error is no more 4.3%.

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. Igbal (1993) [12], Almorox (2005) [22], and Che et al. (2007) [23] 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) [24].

The MPE is an indicator weather the model is over predicted or under the measured values. The MPE value 0.0 is an equal distribution between positive and negative error. While MPE is the reliability index as given in Table 4 the MPE ranging from 2.1 to 2.9 is a very good reliable index to the present calculation.

Table 4: Regression Coefficient and Reliability Index.

Site	a	b	MBE	RMSE	MPE
Haditha	0.320	0.556	-0.1332	3.5159	2.9083
Beji	0.273	0.481	-0.083	2.793	2.126
Samara	0.158	0.488	-0.1398	3.8403	2.9975

Also, correlation coefficients (0.956 - 0.987) are high for all of the variables. This implies that, there are statistically significant relationships between the clearness index and relative sunshine duration.

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. The coefficients of the model are stated as functions of latitude. The performance of the model was investigated. It was found that global radiation calculated from the model is in good agreement with that obtained from measurement.

Therefore, first order or linear correlations between the monthly average daily clearness index H / Ho and the relative possible sunshine duration n / N for the selected locations have been proposed. It is concluded that the correlation proposed for these site can be used successfully for estimation of H 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 intensity values produced by this approach can be used in the designed and estimation of performance of solar applications system which is gaining attention in Iraq.

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