Empirical Models for Solar Radiation Estimation by Some Weather Data for Baghdad City

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ABSTRACT
The aim of this research is to developing equations to predict the relationship between global solar radiations with one or more combinations of the following weather parameters: clearness index, mean of daily temperature, ratio of maximum and minimum daily temperature, relative humidity and relative sunshine duration for Baghdad city for 22 years (1984-2005). Data of solar radiation and surface parameters were obtained from Meteorology NASA website. Using Angstrom model as a base, other equations regression were developed by modifying Angstrom formula. The correlation coefficient \( r \) and Root Mean Square Error (RMSE), Mean Bias Error (MBE) and Mean Absolute Bias Error (MABE) and Mean Percentage Error (MPE) Mean Absolute Percentage Error (MAPE) values were determined for each equation.

INTRODUCTION
The design of a solar energy conversion system requires precise knowledge regarding the availability of global solar radiation and its components at the location of interest. Since the solar radiation reaching the earth's surface depends upon climatic conditions of the place, a study of solar radiation under local climatic conditions is essential. [1]

Several researchers have determined the applicability of the Angstrom type regression model for estimating global solar irradiance. The best way of knowing the amount of global solar radiation at a site is to install pyranometers at many locations in the given region and look after their day-today maintenance and recording, which is a very costly exercise. The alternative approach is to correlate the global solar radiation with the meteorological parameters at the place where the data is collected. The resultant correlation may then be used for locations of similar meteorological and geographical characteristics at which solar data are not available. [2]

The extraterrestrial solar radiation on a horizontal surface \( G_0 \) is a function only of Latitude and independent of other location parameters. As the solar radiation passes through the earth's atmosphere, it is further modified by processes of scattering and absorption due to the presence...
of cloud and atmospheric particles. Hence, the daily global solar irradiation incident on a horizontal surface $G$ is very much location-specific and less than the extraterrestrial irradiation [3]. There are several correlations available for such estimation in developing countries [4-9]. The objective leading to this paper is to continue in the effort to develop predictive

**METHOD OF ANALYSIS**

The monthly means daily solar radiations, sunshine duration, temperature, relative humidity, were for period of 22 years (1983-2005) were obtained from solar radiation and surface Meteorology NASA for four selected locations in Iraq [10].

The data obtained to cover a period of 22 years (1984 - 2005) for Baghdad located at latitude 33.02N and longitude 46.14E. The monthly averages data processed in preparation for the correlations are presented in table 1.

| Table-1. Meteorology data and global solar radiation for Baghdad. |
|---------------------|-----------------|-----------------|-------------|-------------|-------------|
| Months              | $G/Go$          | $S/S_{\text{max}}$ | $T$         | $\theta$   | RH          |
| January             | 0.550186        | 0.4526           | 9.6348      | 0.2069      | 37          |
| February            | 0.596154        | 0.4929           | 11.4261     | 0.2008      | 38          |
| March               | 0.584507        | 0.4812           | 16.1048     | 0.2795      | 29.9        |
| April               | 0.533136        | 0.5362           | 22.9761     | 0.3705      | 22.3        |
| May                 | 0.581688        | 0.5678           | 29.1265     | 0.435       | 17.1        |
| June                | 0.65625         | 0.7028           | 33.3874     | 0.4823      | 16.2        |
| July                | 0.620567        | 0.7477           | 36.1696     | 0.4923      | 17.1        |
| August              | 0.643954        | 0.7764           | 35.7817     | 0.4799      | 19.4        |
| September           | 0.614618        | 0.733            | 31.9739     | 0.4558      | 27.2        |
| October             | 0.545953        | 0.578            | 26.1961     | 0.4429      | 42.3        |
| November            | 0.520979        | 0.439            | 17.8178     | 0.394       | 55.7        |
| December            | 0.529293        | 0.429            | 11.6291     | 0.2857      | 32.4        |

The simplest model used to estimate monthly average daily solar radiation on horizontal surface is the well-known Angstrom equation is given: [11]

$$G = G_o \left( a + b \left( \frac{S}{S_{\text{max}}} \right) \right)$$  \hspace{1cm} (1)

Where,

- $G$ is the monthly mean horizontal daily total terrestrial solar radiation.
- $G_o$ is the monthly mean horizontal daily total extraterrestrial solar:

$$G_o = \frac{24 \times 3600}{\pi} G_{sc} \left( 1 + 0.033 \cos \frac{360n}{365} \right) \left( \cos \phi \cos \delta \sin w + \frac{2 \pi W_s}{360} \sin \phi \sin \delta \right)$$  \hspace{1cm} (2)

Where

- $G_{o}$: monthly mean daily extraterrestrial radiation MJ/m$^2$
- $G_{sc}$: solar constant = 1367 W/m$^2$
\( \delta \): Declination angle  
\( \phi \): Latitude of the station  
\( W_s = \) sunset hour angle for the typical day \( n \) of each month in degrees  
\( n = \) mean day of each months.  
\( S \): is the monthly mean of daily hours sunshine duration was divided by the number of hours of insolation \( (S_{\text{max}}) \). The values of \( S_{\text{max}} \) were computed from the following equations:

\[
S_{\text{max}} = \frac{2}{15} \cos^{-1} \left( -\tan \phi \tan \delta \right) \tag{3}
\]

\( S_{\text{max}} \) is the number of hour of insolation, \( \delta \) is the declination angle and is \( \phi \) the latitude of the station. Then the monthly average of daily global radiation \( G \) was normalized by dividing with the monthly average of daily extraterrestrial radiation \( G_0 \). Therefore, Clearness index \( K_T \) is defined as the ratio of the observed/measured horizontal terrestrial solar radiation \( (G) \), to the calculated/predicted horizontal extraterrestrial solar radiation \( (G_0) \).

**DATA ANALYSIS**

To estimate prediction of global solar radiation using meteorological parameters, multiple linear regression analysis were used \((K=G/G_0, S/S_{\text{max}}, \text{RH, } \theta, \text{ and } T)\) where \( K \) is the clearness index, \( S/S_{\text{max}} \) is the relative sunshine duration, \( \text{RH} \) is the relative humidity, \( \theta \) is the ratio of minimum to maximum daily temperature and \( T \) is the monthly average daily temperature (Table 1 and 2). The performance of the models were evaluated on the basis of the statistical measured like the RMSE (Root Mean square Error), MBE (Mean Bias Error), MABE (Mean Absolute Bias Error), MPE (Mean Percentage Error) and MAPE (Mean Absolute Percentage Error)[12].

\[
RMSE = \sqrt{\frac{1}{n} \sum \left( \frac{G_{\text{pre}} - G_{\text{obs}}}{G_{\text{obs}}} \right)^2} \tag{4}
\]

\[
MBE = \frac{1}{n} \sum \left( \frac{G_{\text{pre}} - G_{\text{obs}}}{G_{\text{obs}}} \right) \tag{5}
\]

\[
MABE = \frac{1}{n} \sum \left( \left| \frac{G_{\text{pre}} - G_{\text{obs}}}{G_{\text{obs}}} \right| \right) \tag{6}
\]

\[
MPE = \frac{1}{n} \sum \left( \frac{G_{\text{obs}} - G_{\text{pre}}}{G_{\text{obs}}} \times 100 \right) \tag{7}
\]

\[
MAPE = \frac{1}{n} \sum \left( \left| \frac{G_{\text{obs}} - G_{\text{pre}}}{G_{\text{obs}}} \times 100 \right| \right) \tag{8}
\]

The regression and correlation coefficients values are illustrated on Table 2. Figure 1 shows the comparison between measured and predicted values of the correlation equation.
RESULTS AND DISCUSSION

Monthly averaged data for the clearness index, the relative sunshine duration, the relative humidity, the ratio of minimum to maximum daily temperature and the monthly average daily temperature are analyzed for Baghdad city in Iraq. We have been get linear regression analysis from using equation (1) to four variables showed in Table 2. It is seen that the correlation coefficient r, correlation of determination R², MBE (w/m²), MABE (w/m²), RMSE (w/m²), MAPE (w/m²) and MPE (%) varies from one variable to another variable. correlation coefficients (0.827- 0.895) are high for all the variables. These results illustrate that, there are statistically significant relationships between the clearness index, relative sunshine duration, the relative humidity, the ratio of minimum to maximum daily temperature and the monthly average daily temperature. This is further clear by high values of coefficient of determination R² (0.684- 0.801) across the variables.

Table- 2: Shows equation with regression and statistical indicators

<table>
<thead>
<tr>
<th>Equations</th>
<th>R</th>
<th>R²</th>
<th>RMSE</th>
<th>MBE</th>
<th>MABE</th>
<th>MPE</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation 9</td>
<td>0.827</td>
<td>0.684</td>
<td>0.042502</td>
<td>0.012269</td>
<td>0.62864</td>
<td>-0.13008</td>
<td>3.53660</td>
</tr>
<tr>
<td>Equation 10</td>
<td>0.678</td>
<td>0.406</td>
<td>0.078307</td>
<td>0.022605</td>
<td>0.83083</td>
<td>-0.23967</td>
<td>4.82835</td>
</tr>
<tr>
<td>Equation 11</td>
<td>0.468</td>
<td>0.219</td>
<td>0.227327</td>
<td>-0.15509</td>
<td>1.04646</td>
<td>-0.53883</td>
<td>5.861642</td>
</tr>
<tr>
<td>Equation 12</td>
<td>0.470</td>
<td>0.221</td>
<td>1.194443</td>
<td>-0.1547</td>
<td>1.0332</td>
<td>-0.34092</td>
<td>5.9485</td>
</tr>
<tr>
<td>Equation 13</td>
<td>0.840</td>
<td>0.706</td>
<td>4.134543</td>
<td>-3.86027</td>
<td>3.86026</td>
<td>23.49758</td>
<td>23.49758</td>
</tr>
<tr>
<td>Equation 14</td>
<td>0.886</td>
<td>0.785</td>
<td>0.740682</td>
<td>-0.05519</td>
<td>0.56641</td>
<td>-0.04532</td>
<td>2.925225</td>
</tr>
<tr>
<td>Equation 15</td>
<td>0.864</td>
<td>0.747</td>
<td>0.772309</td>
<td>-0.0607</td>
<td>0.62091</td>
<td>-0.12099</td>
<td>3.28811</td>
</tr>
<tr>
<td>Equation 16</td>
<td>0.886</td>
<td>0.785</td>
<td>0.746375</td>
<td>0.176237</td>
<td>0.61839</td>
<td>-1.29515</td>
<td>3.208371</td>
</tr>
<tr>
<td>Equation 17</td>
<td>0.869</td>
<td>0.756</td>
<td>0.744486</td>
<td>-17.5177</td>
<td>17.5177</td>
<td>-0.05337</td>
<td>3.207967</td>
</tr>
<tr>
<td>Equation 18</td>
<td>0.894</td>
<td>0.799</td>
<td>0.724523</td>
<td>-0.01409</td>
<td>0.51933</td>
<td>-0.13275</td>
<td>2.626675</td>
</tr>
<tr>
<td>Equation 19</td>
<td>0.895</td>
<td>0.801</td>
<td>0.73375</td>
<td>-0.02691</td>
<td>0.50191</td>
<td>-0.0572</td>
<td>2.536842</td>
</tr>
</tbody>
</table>

The correlation coefficient of 0.827 exists between the clearness index and relative sunshine duration also coefficient of determination of 0.8746 implies 87.46% of clearness index can be accounted using relative sunshine duration.

\[
\frac{G}{G_o} = 0.411 + \left(0.295 \times \frac{S}{S_{\text{max}}^+}\right) \tag{9}
\]

The correlation coefficient of 0.678 exists between the clearness index and monthly average daily temperature also coefficient of determination of 0.406 implies 40.6 % of clearness index can be accounted using monthly average daily temperature.

\[
\frac{G}{G_o} = 0.508 \times (0.00314 \times T) \tag{10}
\]

\[
\frac{G}{G_o} = 0.625 - (0.00159 \times RH) \tag{11}
\]

The correlation coefficient of 0.470 exists between the clearness index and relative humidity also coefficient of determination of 0.221 implies
22.1% of clearness index can be accounted using ratio of minimum to maximum daily temperature.

$$\frac{G}{G_0} = 0.505 - (0.201 * \theta)$$  \hspace{1cm} (12)

The correlation coefficient of 0.468 exists between the clearness index and relative humidity also coefficient determination of 0.219 implies 21.9% of clearness index can be accounted using relative humidity.

The correlation coefficient of 0.840 exists between the clearness index, relative sunshine duration and relative humidity, also coefficient of determination of 0.706 implies 70.6% of clearness index can be accounted using relative sunshine duration and relative humidity.

$$\frac{G}{G_0} = 0.439 - (0.272 * \frac{S}{S_{\text{max}}}) - (0.000552 * RH)$$  \hspace{1cm} (13)

The correlation coefficient of 0.886 exists between the clearness index, relative sunshine duration and ratio of minimum to maximum daily
temperature, the coefficient of determination of 0.785 implies 78.5% of clearness index can be accounted by relative sunshine duration and ratio of minimum to maximum daily temperature.

\[
\frac{G}{G_0} = 0.409 - \left(\frac{0.445 S}{S_{max}}\right) - (0.226 \theta)
\]  
(14)

The correlation coefficient of 0.869 exists between the clearness index, relative sunshine duration and monthly average daily temperature, the coefficient of determination of 0.747 implies 74.7% of clearness index can be accounted by relative sunshine duration and monthly average daily temperature.

\[
\frac{G}{G_0} = 0.354 + \left(\frac{0.523 S}{S_{max}}\right) - (0.00319 T)
\]  
(15)

The equation (5) and (6) can be modified by incorporating extra parameters to the set of correlation equations for two variables. The correlation coefficient of 0.886 exists between the clearness index, relative sunshine duration, ratio of minimum to maximum daily temperature and relative humidity, the coefficient of determination of 0.785 implies 78.5% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature and relative humidity.

\[
\frac{G}{G_0} = 0.413 + \left(\frac{0.439 S}{S_{max}}\right) - (0.221 - \theta) - (0.000636 RH)
\]  
(16)

The correlation coefficient of 0.9718 exists between the clearness index, relative sunshine duration, relative humidity and the monthly average daily temperature, the coefficient of determination of 0.756 implies 75.6% of clearness index can be accounted by relative sunshine duration, monthly average of daily temperature and relative humidity.

\[
\frac{G}{G_0} = 0.413 + \left(\frac{0.377 S}{S_{max}}\right) - (0.00291 T) - (0.000359 RH)
\]  
(17)

The correlation coefficient of 0.894 exists between the clearness index, relative sunshine duration, the monthly average daily temperature and ratio of minimum to maximum daily temperature. The coefficient of determination of 0.799 implies 79.9% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature and monthly average of daily temperature.

\[
\frac{G}{G_0} = 0.480 + \left(\frac{0.297 S}{S_{max}}\right) - (0.436 \theta) + (0.00401 T)
\]  
(18)

The correlation coefficient of 0.946 exists between the clearness index, relative humidity, ratio of minimum to maximum daily temperature and the monthly average daily temperature. The coefficient of determination of 0.8957 implies 89.57% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature and monthly average of daily temperature.
The correlation coefficient of 0.895 exists between the clearness index, relative sunshine duration, ratio of minimum to maximum daily temperature, relative humidity, and the monthly average daily temperature. The coefficient of determination of 0.801 implies 80.1% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature, relative humidity and monthly average of daily temperature.

\[
\frac{G'}{G_0} = 0.484 + \left( 0.284 \times \frac{S}{S_{\text{max}}} \right) - (0.505 \times \theta) + (0.0002433 \times RH) + (0.498 \times T) \tag{19}
\]

Figure -2: (Eq. 13-17). Comparison between measured and predicted values of the correlation equation.

The monthly global solar radiation, relative sunshine duration, means temperature, ratio of minimum to maximum temperature and relative humidity have been employed in this study to develop several correlation equations. Four variables have been developed with different types of equations obtained. It was illustrated that equation (19) has the highest value of correlation coefficient and correlation of determination, which gives good results when considering statistical indicators that is, RMSE, MBE, MABE, MPE and MAPE. The equation could be
employed in estimation of global solar radiation of location that has the same geographical location information as Baghdad.

**REFERENCE**


