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Evaluation of Meteosat-8 measurements using daily global solar radiation for two stations in Iraq

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Abstract
The use of solar radiation measurements on various solar systems design needs knowledge on its spatial and temporal variations. Such knowledge can be acquired by employing interpolation ground measured solar radiation collected by ground radiometric stations. More reliable information could be obtained by analyzing satellite images. The aim of this work is to evaluate the measurements of daily global solar radiation extracted from Meteosat-8 images using Heliosat-2 method. Ground measurements from two Iraqi stations were used in the evaluation processes. The results indicated that the mean RMSE and MAE for Baghdad were 0.621 kWh/m^2 and 0.024 kWh/m^2 and for Mosul were 0.458 kWh/m^2 and 0.012 kWh/m^2 respectively. These results are very satisfactory for monitoring the temporal and spatial variation of solar radiation for places which suffer from shortage of ground solar radiation measurements.

Keywords: Atmospheric radiation, Iraq, Solar radiation, Meteorology, Meteosat.

1. Introduction
Solar energy is one of the fields in the front line of research in renewable energy resources. Developments in the photovoltaic industry have transformed solar energy into a more viable solution in the last decade, and political and economic reasons are expected to increasingly lead consumers to solar energy for their needs in the future. Daily solar radiation reaching earth surface is very important for different applications of solar energy including assessment for heating and electricity generation, solar system design , and agriculture meteorology [1].
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, forth order polynomial and various distributions such as Wiebul and sine wave for estimating global solar radiation for different locations in Iraq [2-4]. On the other hand, researchers around the world investigated empirical and statistical models [5-7] which consist a simple regression between satellite measurements and corresponding measurements at the earth's surface. The first attempt to estimate solar radiation from satellite images in the world was conducted by the United States Department Commerce [8-9]. Other research were carried by Remund et al, [10] and Cano [11]. The first method of Heliosat was proposed by Beyer et al, [12]. Then modified later by several researchers among them [13-14]. Heliosat method was developed to generate solar radiation maps from Meteosat-8 images. The main procedure of Heliosat is that the solar radiation for an area is statistically calculated using cloud cover and the albedo of the same area. In this research daily solar radiation measured at two Iraqi stations were used to evaluate data extracted from Meteosat-8 images for the same locations.

2. Heliosat method

The Heliosat-2 method is described in details by [15-17]. Figure 1 illustrates the procedure used in this work for evaluating of Meteosat-8 satellite measurements using ground measurements of the two Iraqi radiometric stations; Baghdad (33.33^o N, 44.39^o E) and Mosul (36.33^o N, 43.11^o E).

The summery of Heliosat-2 can be explain by the following steps; recording the ground albedo maps for each month, computing the cloud index, calculating the clear sky index, and finally estimating the daily global solar radiation.

The monthly albedo (ρ_g) maps obtain from the daily albedo values is calculated for each pixel of Meteosat-8 images (ρ^t) . The cloud index is standard measure of cloud cover and can be computed as follows:

$$n^t(i,j) = \frac{[\rho^{rt}(i,j) - \rho_g^t(i,j)]}{[\rho^t cloud(i,j) - \rho_g^t(i,j)]} \tag{1}$$

where $n^t(i,j)$ is the cloud index for the time (t) and pixel (i,j), $\rho^t cloud(i,j)$ is the apparent albedo of the brightest clouds, and $\rho^{rt}(i,j)$ is the reflectance.

Clear sky index (K_{ch}) is calculated according to different levels of cloud index:

$K_{ch} = 1.2$ $\quad$ $if\ n^t < -0.2$

$K_{cf} = 1 - n$ $\quad$ $if\ -0.2 < n^t < 0.8$

$K_{ch} = 2.0667 - 3.6667 n^t + 1.667$ $\quad$ $if\ 0.8 < n^t < 11$

The global solar radiation (G_d) is computed as follows:

$$G_d = k_{ch} G_{ch} \tag{2}$$

where G_{ch} is the clear sky global solar radiation and can be calculated through ESRA clear sky model [18-19].

3. Results and discussions

Figure 1 gives the general procedure for evaluating the Meteosat-8 measurements. Ground measurements of daily solar radiation for the year 2008 were used for the comparisons with the Meteosat-8 data. The ground data were obtained from the Iraqi Meteorological Office for two stations, namely Baghdad and Mosul.

Figures 2 and 3 show the results of these comparisons between for the two stations. It is seen that measured and estimated values of daily solar radiation are very comparable. Statistical analyses for these comparisons were carried out. Figure 4 and 5 illustrate the residual between measured and estimated daily solar radiation for both stations (Baghdad and Mosul) which indicated that the upper and lower control line for errors of estimation were ± 43% and ± 15% for Baghdad and Mosul respectively.

The correspondence between estimated and measured daily solar radiation is also illustrated by the scatter plots of Figure 6. It can be seen from this figure that the estimated values are in good agreement with the measured values for both stations and the correlation coefficients are significant at 0.01 levels. Finally from the results and presented measured and estimated values of solar radiation reaching earth surface, one can imagine the huge amount of solar radiation received by earth surfaces in Iraq which is about 4.52 KWh.m^2 day^{-1} or 1651 KWh.m^2 year^{-1}. About 61% of Iraqi area received solar radiation is higher than 4.25 KWh.m^2 day^{-1} and 39% ranged between 4.24 KWh.m^2 day^{-1} and 0.75 KWh.m^2 day^{-1} . The total area of Iraq is 438,320 km^2, thus the total solar radiation reaching the entire Iraqi area during the year is equal to 1.96 × 10^{13} KWh.m2 year^{-1}, and this huge amount of solar radiation could satisfy all Iraqi needs of energy.

Table 1 gives the statistical measures for validating estimated and measured values of solar radiation. It can be seen that the Maximum Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) are 1.544 and 0.186 $KWh.m^2$ for the entire data set respectively. The annual maximum RMSE and MAE values are 0.621 and 0.024 $KWh.m^2$ (13.7% and 0.5%) respectively for Baghdad station. However, combination of ozone, water vapour and aerosols content from total ozone mapping spectrometer (TOMS) satellite measurements, which play an effective role in evaluating the real values of solar radiation reaching earth surface and that which estimated using Meteosat-8 images. By comparing the results of the considered stations in present study

The results are summarized in Table 1. From this table it can be concluded that Mosul station showed lowest RMSE and MAE than those for Baghdad for both time scale (seasonally and yearly). For the two stations spring presented the highest RMSE and MAE and this due to the combined effect of the ozone, aerosols content and rain. The lowest RMSE and MAE shown in summer which have arid and semi arid climate characteristic for both stations (Baghdad and Mosul). The seasons which have ranged between the highest and lowest RMSE and MAE was winter which characterized with some rainy days and relatively high relative humidity and autumn season which have low ozone and some dusty days.

Table 1. Statistical measures of validation for estimated and measured solar radiation values

Year 2005	No. of observation	RMSE	MAE
Baghdad	365	0.621	0.024
Mosul	363	0.458	0.012
Average		0.539	0.018
Spring			
Baghdad	91	1.544	0.186
Mosul	90	0.654	0.149
Average		1.099	0.167
Autumn			
Baghdad	91	0.600	0.109
Mosul	91	0.445	0.106
Average		0.522	0.107
Summer			
Baghdad	91	0.413	0.103
Mosul	91	0.296	0.077
Average		0.354	0.090
Winter			
Baghdad	92	0.877	0.088
Mosul	91	0.375	0.019
Average		0.626	0.053

*The values are in kWh/m^2

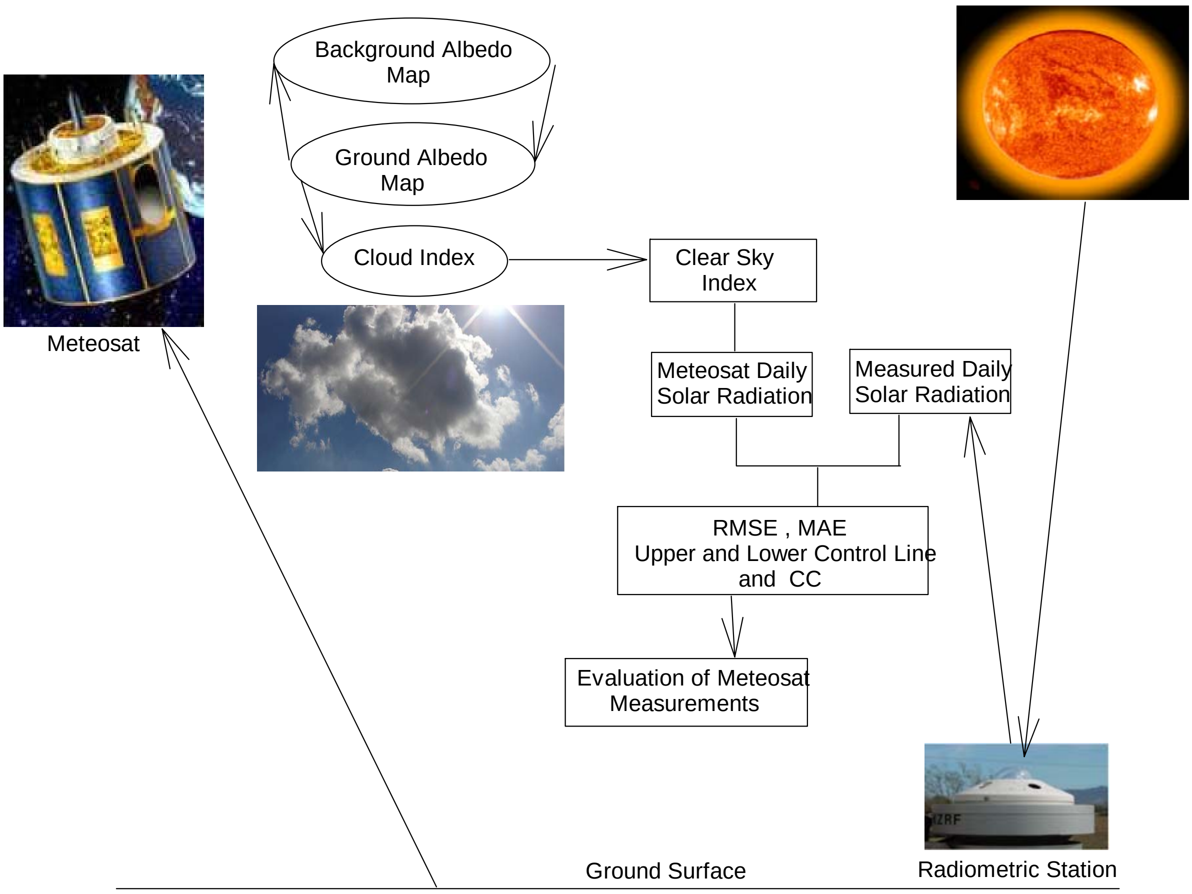

Figure1. General procedure evaluation of Meteosat measurements

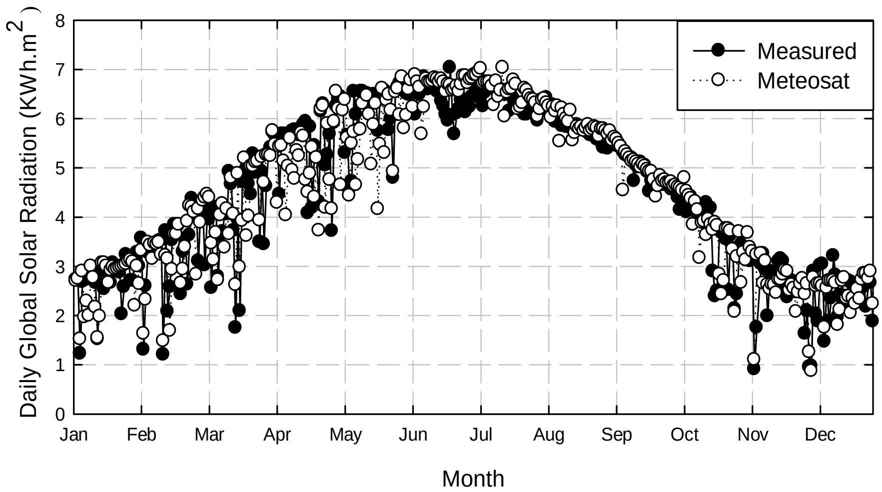

Figure 2. Annual variation of measured and estimated daily global solar radiation over Baghdad city

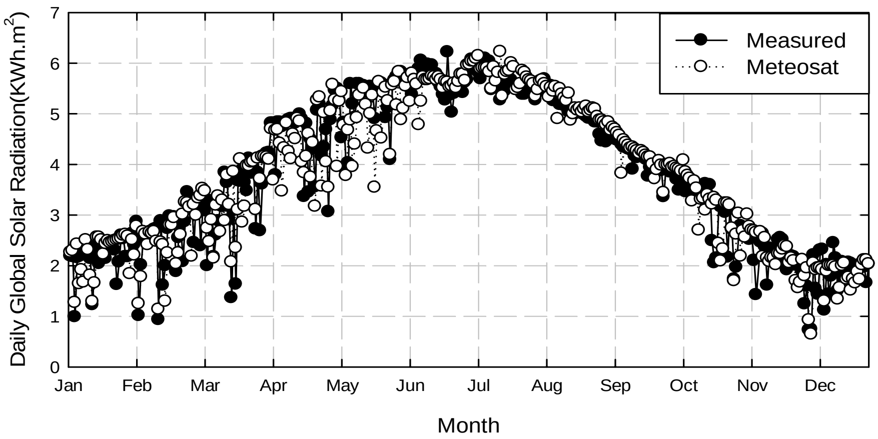

Figure 3. Annual variation of measured and estimated daily global solar radiation over Mosul city

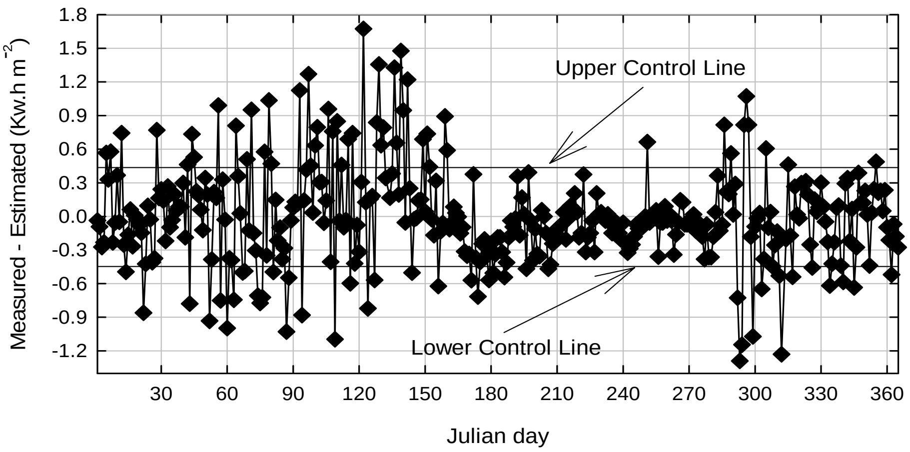

Figure 4. The residual between measured and estimated solar radiation with upper and lower control line for Baghdad city

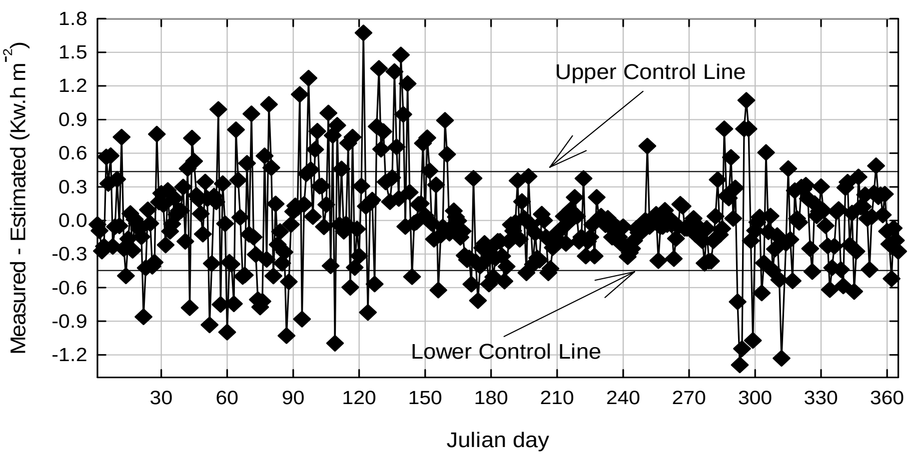

Figure 5. The residual between measured and estimated solar radiation with upper and lower control line for Mosul city

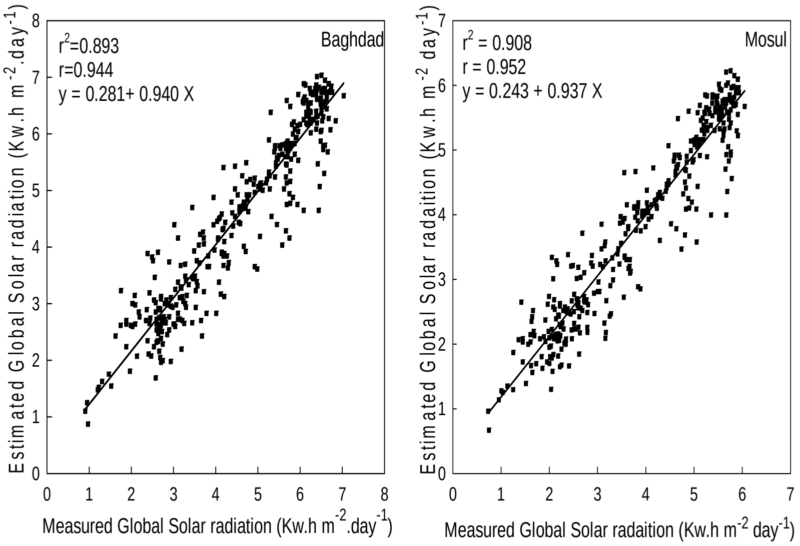

Figure 6. Scatter plots measured against estimated solar radiation (Kw .h m^{-2} day^{-1}) for Baghdad and Mosul stations respectively

4. Conclusion

In this work daily solar radiation values estimated from Meteosat-8 measurements were verified by using ground measurements for two stations (Baghdad and Mosul).

Results showed that the satellite and ground measurements of daily solar radiation are in a good agreement. Statistical analysis of these comparisons indicated that the daily solar radiation made by Meteosat-8 was very suitable for solar radiation measurements which can be used for regions which have a shortage on ground base solar radiation stations. The best results was obtained for Mosul station, where r^2, RMSE, MAE values were found to be 0.908, 0.458, 0.012 for Mosul station. Meteosat-8 data can further tested for other regions in Iraq as well.

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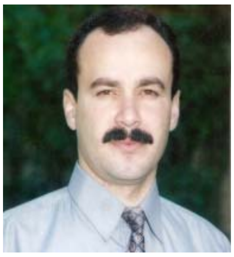

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