An estimation of global solar radiation at ground level using clear-sky radiation in Hebron city, Palestine

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ABSTRACT

Due to its geographical position in the solar belt, Palestine is blessed with an abundance of solar energy and has the opportunity to utilize this bounty of natural energy effectively, promoting a clean environment and developing renewable energy technologies in the region. The present approach proposes one equation specific for every month of the year to simulate the global solar radiation under clear-sky in Hebron city. Four-years measured daily global solar radiation data on horizontal surfaces were used for the model assessment. In order to indicate the performance of the model, the statistical test methods of mean bias error (MBE) and root mean square error (RMSE) are used. The results obtained indicate that the model predict the global solar radiation reasonably well.

Keywords: *Global solar radiation, Clearness index, Hebron, MBE, RMSE.*

1. Introduction

Knowledge of the local global solar radiation is required by most models that simulate crop growth, and is also essential for many applications, including evapotranspiration estimates, architectural design, and solar energy systems. Design of a solar energy conversion system requires precise knowledge regarding the availability of global solar radiation at the location of interest [1]. A prerequisite to the design of solar collector systems is the availability of solar irradiance data at the required location. It would be cost effective for solar collector system when the utility load and solar resource profiles are well matched. Due to high and reliable solar irradiance of about 5.4 kWh/m^2 day a domestic usage for solar energy in Palestine over the life time has the potential to produce a domestic hot water for about 330 sunny days per year using solar collectors [2].

There is no doubt that systematic long-term data measurements are regarded as the most effective and accurate method of setting up the solar irradiance database. In many parts of the world, however, the basic solar irradiance data for the surfaces of interest are not always readily obtainable. Conventionally, different mathematical models have been developed in the literature to predict the solar irradiance on various inclined-surfaces using horizontal data [3-4]. For places where measured data are not obtainable, theoretical and empirical models have been postulated to compute the solar radiation would also be an appropriate solution [5-6].

The technical literature proposes a series of empirical models to estimate the global, direct and diffuse solar radiation variation [7]. Although these models are simple from a mathematical point of view, and these are easy to use in practice, they have the disadvantage of a limited area of applicability, these being specific to a particular area. The existent empirical models have been developed based on the specific measured data specific to a geographic area (solar radiation, temperature, humidity, etc.). The present work proposes a new empirical model to estimate the global solar radiation on horizontal surfaces at Hebron city, Palestine. Specific equations for every month of the year are also proposed.

2. Global solar radiation data

Palestine has a high solar energy potential, where average solar energy is between 2.63 kWh/m^{2}day in December to 8.4 kWh/m^{2}day in June, and the daily average of solar radiation intensity on horizontal surface is 5.4 kWh/m^{2}day [8]. Hebron City is located in the southern part of west bank at latitude of 31°57' N, and its climate is hot in summer and cold in winter. Also, it receives a large quantity of solar radiation, especially in summer [9]. The global solar radiation data employed in this work were supplied by the Palestinian meteorological office. A radiometric station was established at the Hebron city (1000 m above sea level). The measurements are carried out in a continuous manner since January 2009 to December 2012, being recorded at a 10 minute interval, data for other periods were checked but unfortunately there were big gaps encountered. Data collection started before sunrise and finished after sunset and all measurements were referred to true solar-time.

3. Results and discussion

Solar radiation data is required to conduct feasibility studies for solar energy systems, but ground irradiance measurement sites are not always available, requiring the use of models to estimate irradiance in lieu of measurements [10]. Clear sky models are essential to estimating irradiance levels.

Clearness index, k_t is a parameter that provides information concerning the real solar radiation compared with the available solar radiation. The clearness index is defined as the ratio of the global radiation at ground level on a horizontal surface G_h and the extraterrestrial global irradiation [11]. In order to obtain more accurate values of the clearness index the extraterrestrial global radiation is calculated according to its dependence on the eccentricity of the earth orbit and the altitude angle. The clearness index is given by:

$$k_t = {G_h}/{I_o} \, \varepsilon \sin\alpha \tag{1}$$

where I_0 is the extraterrestrial radiation; ε is the eccentricity correction factor of the Earth's orbit; α is the altitude angle.

The clearness index functions was achieved for every month by modeling the hourly values; hence, a monthly exponential formula of the clearness index was obtained depending on the solar time and then the monthly mean values was calculated along the study period.
Figure 1 presents the diagrams for monthly mean values of the clearness index; the diagrams presented are plotted for every year considered in the study.

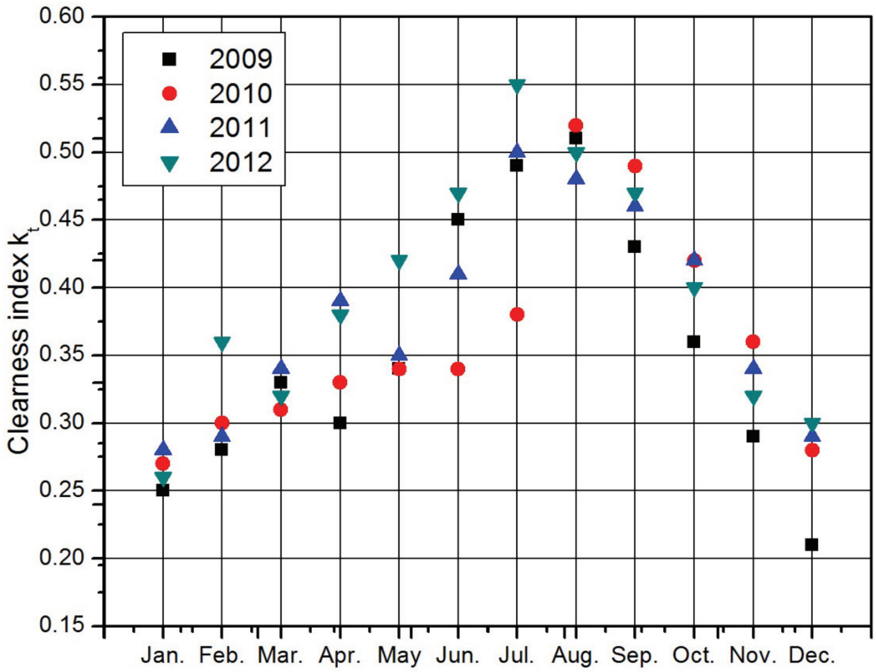

Figure 1 Monthly mean values of the clearness index.

Figure 1 presents seasonal variations of the clearness index with low values characterized in winter season and high values in summer season, however, spring and autumn are transition seasons. The higher monthly mean value of the clearness index for Hebron city was observed to be 0.55 in July 2012, whereas, the lowest value (0.21) was obtained in December 2009.

The proposed global radiation model estimates the solar radiation for clear sky conditions. Thus, the real data underlying the new model determination are data that comply with the WMO clear sky condition. Based on the selected clear sky days the estimation equations for the global solar radiation were determined specific for each month of the year.

The estimation equations for global solar radiation are original and specific to every month of the year; the expressions of these equations are presented in Table I. The estimation equations of the global radiation are expressed as functions depending on solar time, altitude angle and extraterrestrial radiation. The global radiation depends on the geographical characteristics of the area trough the altitudinal angle; local particularization and seasonal are realized through the solar time (a spring and autumn day have about 9 hours of sun and a maximum altitudinal angle of 45°; a summer day has 13 hours of sun and the maximum value for the altitudinal angle is 68°; for winter the maximum altitudinal angle is 22°).

Table I. Specific equations for global radiation estimation for each month.

Month	Equation
January	$G_h = I_o * \sin(\alpha) * (0.0452 * time_{solar} + 0.0870)$
February	$G_h = I_o * \sin(\alpha) * (0.0369 * time_{solar} + 0.3311)$
March	$G_h = I_o * \sin(\alpha) * (0.0296 * time_{solar} + 0.3104)$
April	$G_h = I_o * \sin(\alpha) * (0.0162 * time_{solar} + 0.4782)$
May	$G_h = I_o * \sin(\alpha) * (0.0262 * time_{solar} + 0.3634)$
June	$G_h = I_o * \sin(\alpha) * (0.0227 * time_{solar} + 0.5224)$
July	$G_h = I_o * \sin(\alpha) * (0.0362 * time_{solar} + 0.2952)$
August	$G_h = I_o * \sin(\alpha) * (0.0316 * time_{solar} + 0.2688)$
September	$G_h = I_o * \sin(\alpha) * (0.0331 * time_{solar} + 0.2531)$
October	$G_h = I_o * \sin(\alpha) * (0.0268 * time_{solar} + 0.3526)$
November	$G_h = I_o * \sin(\alpha) * (0.0263 * time_{solar} + 0.4155)$
December	$G_h = I_o * \sin(\alpha) * (0.0582 * time_{solar} + 0.0622)$

The estimated global radiation data from the equations in Table I and the real data are presented in Fig.2; the June and July months have been plotted separately in Fig.3.

In Fig.2 and Fig.3 it is clear that the proposed monthly equations estimate in a correct manner the global solar radiation for values greater than 100 W/m^2; the estimated values are not widely spread from the 1:1 line, especially for the interval 100-800 W/m^2. A larger scattering of the simulated values towards the real values are observed for high values of the global solar radiation.

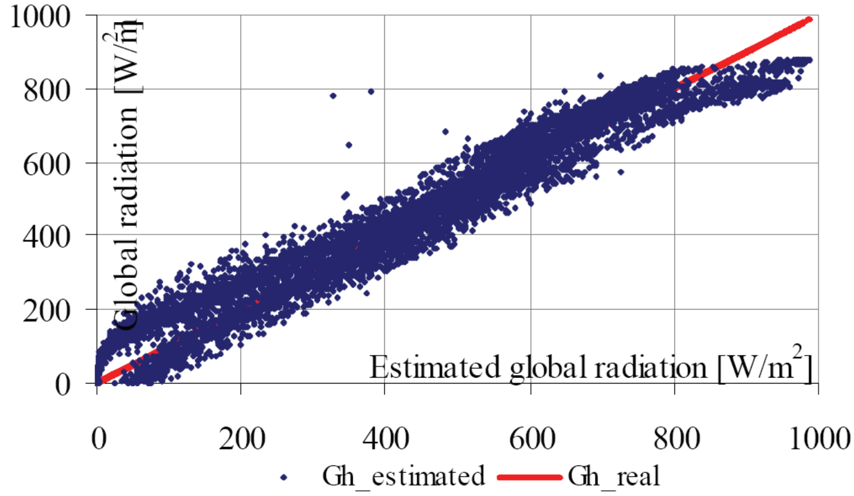

Figure 2. Real and estimated global solar radiation data for all days with clear sky conditions.

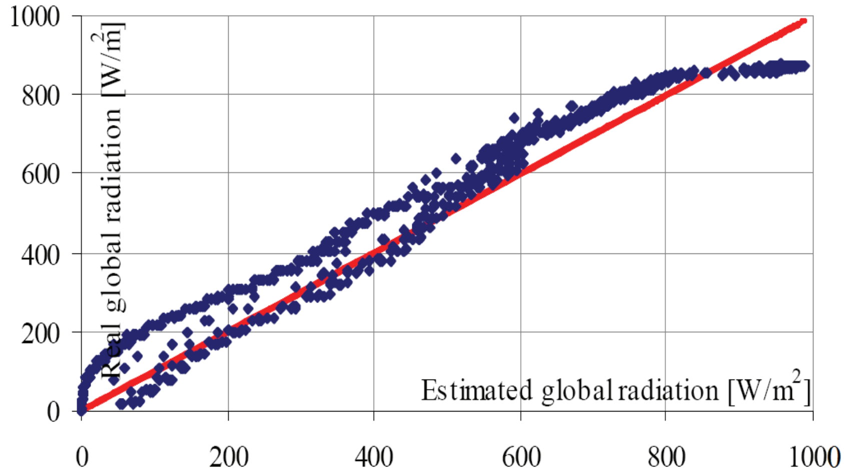

Figure 3. Real and estimated global solar radiation data for June and July months, days with clear sky conditions.

Figure 3 present the estimated and real global solar radiation for June and July months, points corresponding to higher values than 800 W/m^2 of global solar radiation values are situated below the 1:1 line that means the estimated values are smaller than the real values. The underestimation tendency is predominant for the summer days, when the altitudinal angle has high values.

In Figure 4, the estimated and real curves of the global solar radiation for clear sky days for January, March, June, July and October months are also presented.

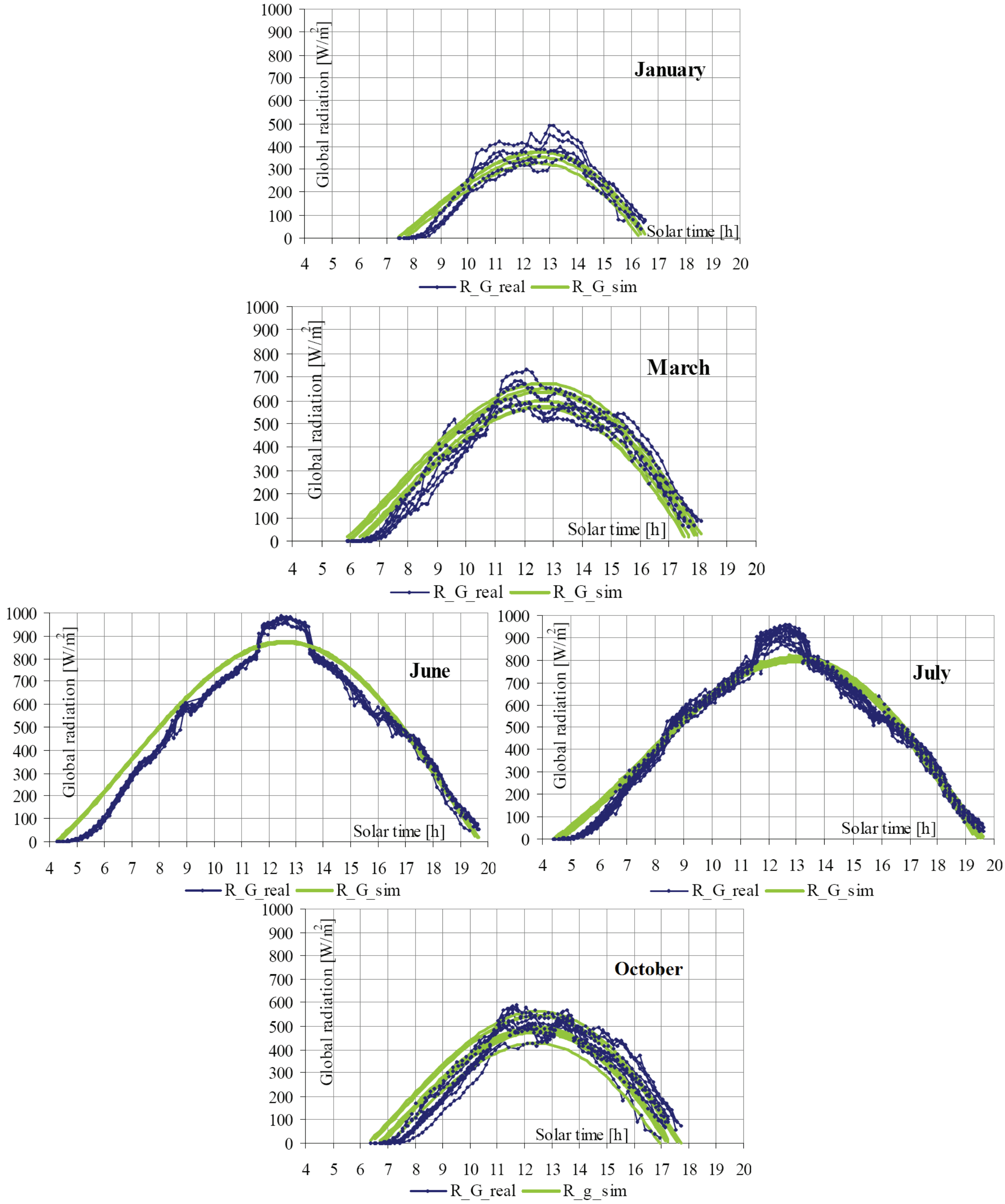

Figure 4. Real and simulated global radiation data of selected months.

From Figure 4 It can be observed that the global solar radiation curves simulated with the proposed equations in Table I provide an accurate estimation in comparison with the real radiation curves. The maximum value of global solar radiation is observed to be between 12 and 13 hours in June month. Also it is clear that the model predicts well the global solar radiation in the second half of the day and the maximum values with slightly underestimation.

Also by comparing the results of June and July months in Fig.3 and Fig.4, it is clear that global solar radiation with values higher than 800 W/m^2 is slightly underestimated. Overall, it can be concluded that the estimation model simulates satisfactory the real variation curves in the afternoon and sunset period, with a slightly overestimation in the sunrise period along the year.

4. Statistical performance

In order to evaluate the performance of the equations proposed to estimate the global solar radiation in Hebron city for the period (2009-2012) a statistical comparison is performed using the indicators Root Mean Square Error (RMSE) and Mean Bias Error (MBE) [12]. The test on RMSE provides information on the short-term performance of the model as it follows a term-by term comparison of the actual deviation between calculated and measured value [13]. The test of MBE provides information on the long term performance of the model studied. A positive MBE value gives the average amount of overestimation in calculated values and vice versa.

The monthly values of MBE and RMSE are calculated and presented in figures 5 and 6 respectively. The Mean Absolute Error (MAE) values provide an underestimation of the global solar radiation during the study period with higher values in summer months and lower values in winter months.

As seen in Fig. 5 in the year 2009 MAE values in summer months are higher than other years of the study period whereas, in winter months the underestimation of the global solar radiation is approximately equal during the study period. Also, MAE calculated for September 2010 was higher than the same month of the other years. As a comparison between the calculated and measured values of the global solar radiation, the RMSE presented in figure 6 provides higher values in months from June to August of 2009 than the other months of the study period. The lowest values of RMSE were obtained for January.

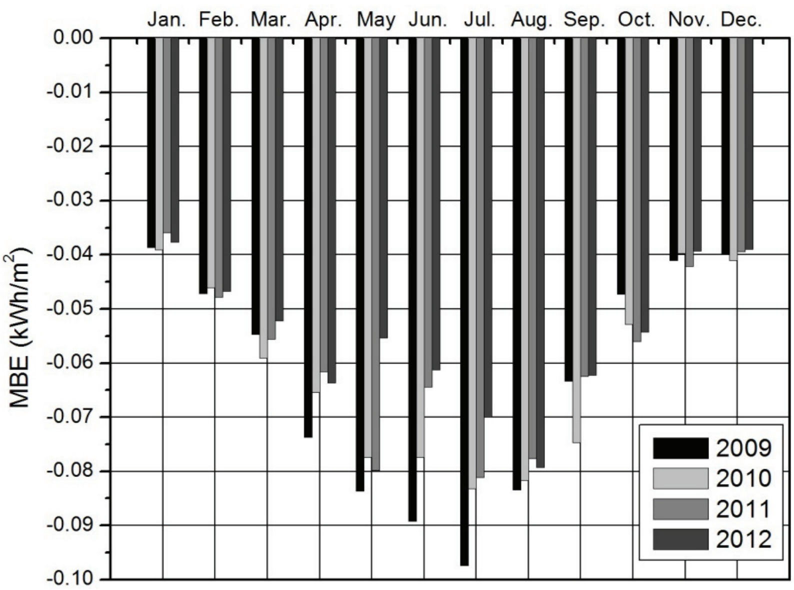

Figure 5. Monthly MBE values of global solar radiation.

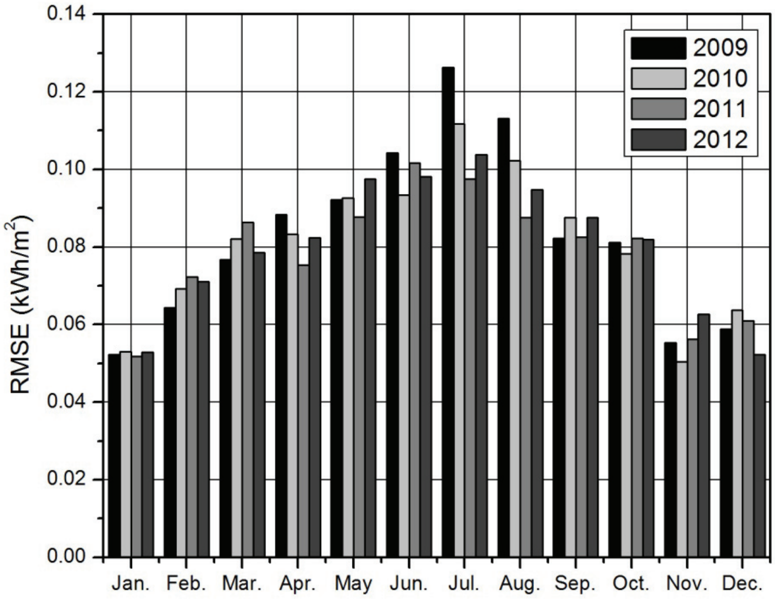

Figure 6. Monthly RMSE values of global solar radiation.

Overall, it can be concluded that the deviation values between the real and estimated global solar radiation are satisfactory results. The highest deviations have been obtained for the summer months, however, during the summer; the thermal inversion phenomenon manifests the greatest influence over the solar radiation due to increased temperature with altitude which causes more scattering of solar radiation, and meanwhile for the cold months the lowest values for the errors were obtained. The overestimation of the solar radiation in the sunrise period is due to the shadow caused by topography because the sun is at lower altitude angles. However, the underestimation of global solar radiation may caused by topographic (slope, aspect, sky-view factor, air mass) and atmospheric parameters (temperature and humidity) that did not took into account by the model.

5. Conclusion

The present work has the aim to help engineers and designers in evaluating the Hebron area potential for solar energy applications. An evaluation of the predicted solar-irradiance for Hebron horizontal surface using measured data for four years has been conducted in the present work. The proposed model was produced and implemented for Hebron city. The performances of the proposed model (characterized by 12 equations specific to every month) for estimating the global solar radiation for Hebron area have been confirmed based on the application of statistical indicators MBE and RMSE.

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