Estimation of Global Solar Radiation using Solar PV and Its Comparison with Sunshine Duration Using Quadratic and Gaussian Fits

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Abstract: Solar energy is the prime energy source of hydrologic parameter such as evapotranspiration and aerodynamic parameter like wind. Knowledge of daily global solar radiation is important to estimate all solar energy related parameters. In this study, mean daily global solar radiation at Haramaya University (HU) and Dire Dawa (DD) meteorological stations were estimated using sunshine duration data, which were recorded using Campbell-Stock Heliograph as the input of Angstrom-Prescott model. These values were further used to calculate the half hourly power intensity of solar radiation by applying Collares-Pereira and Rabl's model. A 14 cm by 14 cm 12 V solar module was used to take indirect measurements of the solar radiation at the interval of 30 minutes from sunrise to sunset throughout the course of the study period. Readings were made in terms of voltage using a multi-meter, from which power intensities were calculated. Finally, comparisons were made between the estimated values of the half hourly power intensity of the solar radiation and the corresponding measured values to examine the degree of variability between the measured and estimated values of solar radiations using quadratic and Gaussian fits. The estimated values of the half hourly power intensity of the solar radiation agreed closely with the corresponding measured values within the error range of 15% when Gaussian fit was used but only within the error range of 10% when the quadratic fit was used. Gaussian fit reflected the actual solar radiation better than the quadratic fit despite the larger difference between the estimated and measured values. It could be concluded that satisfactory estimates of mean daily global solar radiation were obtained at both locations by using solar modules in the absence of pyranometers, and the errors could be minimized by selecting the appropriate mathematical function.

Keywords: Campbell-Stock Heliograph, Solar Module; Angstrom-Prescott model; Half hourly power intensity; Collares-Pereira; Rabl's model.

1. Introduction

Solar radiation at the outer edge of the atmosphere can be predicted with high precision as it depends essentially on astronomical geometric parameters. At the earth's surface, prediction is more difficult because of the interaction of the solar beam with the atmosphere aerosols, varying cloud cover, and variability of the reflecting surfaces. There are four basic types of measuring instruments for radiation components, namely, sunshine recorder, pyrheliometers, pyranometers and pyrgeometers. The first one delivers information on sunshine duration. The second delivers information on shortwave radiation normal to the surface. The third measures the hemispherical shortwave beam, diffuse and global radiation. The last measures long wave terrestrial radiation. Differences within the data recorded by these instruments, apart from insufficient maintenance and calibration, are due to the differences in what they measure.

Photovoltaic (PV) cells not only use the direct component of light, but also produce electricity even when the sky is overcast. To determine the PV electricity generation potential for a particular site, it is important to assess the average total solar radiation received over a year. Irradiance has the greatest impact on PV power. Beyond irradiance, module temperature, angle of incidence (AOI) and atmospheric mass (AM) also affect a module's or an array's power and production (del-Cueto, 2007; Myers, 2009; King et al., 1997). Module temperature is, in turn, influenced by ambient temperature, cloud patterns, and wind speed.

In most developing countries, there are no properly recorded radiation data. What are usually available are sunshine duration data obtained by a sunshine recorder. Ethiopia is one such country, which lacks properly recorded solar radiation data and, like many other countries, what is available is sunshine duration data. However, given the number of sunshine hours and local atmospheric conditions, sunshine duration data with the help of empirical model can be used to estimate daily average solar radiation (Duffie and Beckman, 1991).

The physical quantity of sunshine duration (n) is routinely observed at most weather stations. For climatological purposes, derived terms such as daily sunshine hours are used with percentage quantities, such as relative daily sunshine duration, n/N, where N may be related to the extraterrestrial or to the maximum sunshine duration. According to World Meteorological Organization (WMO, 2003), sunshine duration during a given period is defined as the sum of those sub-periods for which the direct solar irradiance exceeds 120 Wm-2. In order to homogenize the data of the worldwide network for sunshine duration, a special design of the Campbell-Stokes Sunshine Recorder, the so-called Interim Reference Sunshine Recorder (IRSR) was recommended (Adam, 2012). The requirements of sunshine recorders vary depending on site, season and according to the dominant cloud formation. The dominant

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ISSN 1992-0407

cloud formation can be mainly described by three ranges of relative daily sunshine duration (n/N) such as "cloudy sky" ($0 \leq n/N < 0.30$), "scattered clouds" ($0.30 \leq n/N < 0.70$) and "fair weather" ($0.70 \leq n/N \leq 1.00$) (WMO, 2006; Adam, 2012).

There are four main types of errors in sunshine duration registration with this type of instrument. The over-burning of the registration paper during intermittent sunshine results in overestimation of sunshine duration. The threshold sensitivity of the Campbell-Stokes Recorder of 120 W m^{-2} results in underestimation of sunshine duration. The analysis of the registration paper made by hand may cause additional errors in either direction. Finally, deteriorations of the performance of the glass sphere caused by weather phenomena like rain or hoarfrost or due to insufficient maintenance results in underestimation of sunshine duration.

In principle, the amount of solar radiation reaching the earth's surface could be calculated from the extraterrestrial radiation provided that losses in the atmosphere, which are caused by several processes such as absorption and scattering, are known (Iqbal, 1983; Pisimanis *et al*., 1987). Nevertheless, the best way of knowing the amount of global solar radiation at a site is to install measuring devices such as Pyranometers at many locations in a given region but this is a very costly exercise. For stations where no measured data are available, the common practice is to estimate global solar radiation from other measured meteorological parameters like surface pressure, relative humidity, sunshine duration, minimum and maximum temperatures and precipitation using empirical and physical models. The models' results may then be used for locations of similar meteorological and geographical characteristics for which solar radiation data are not available (EEPCO, 2007).

In this study, estimation of global solar radiation based on sunshine duration is made and compared with the value obtained from direct measurement of voltage output of solar PV at Haramaya University and Dire Dawa meteorological stations. The objective of this study was to estimate global solar radiation by direct measurement using solar PV and compare the result to solar radiation estimated from sunshine duration at the two locations, using two fitting methods.

2. Materials and Methods

2.1. Descriptions of the Study Areas

The study was carried out at Haramaya University (HU) and Dire Dawa (DD). Haramaya University is at an average altitude of 2043 m.a.s.l. and is located at a latitude of 90 0'N and longitude of 420 0'E. The place has a mean maximum temperature of 28.50C and mean minimum temperature of 12.60C. It is situated in the semi-arid tropical belt of eastern Ethiopia and is characterized by a sub-humid type of climate with an average annual rainfall of about 790 mm. Field experiment was also conducted at Dire Dawa, which has an average altitude of 1197 m.a.s.l. and is located at 90 6' N latitude and 480 8' E longitude. It lies in the semi-arid belt of Eastern Rift Valley and has annual average rainfall of 612 mm. The mean maximum and minimum temperatures at Dire Dawa are 31.35 and 18.05oC, respectively.

2.2. Data Collection

Sunshine duration data were obtained from the two meteorological stations (HU and DD) identified as HUMS and DDMS, respectively. Actual radiation measurements were conducted for a week at Haramaya University (13/06/12 -19/06/2012) and for another week at Dire Dawa (01/07/2012 -07/07/2012). At Haramaya University, data was collected at a specific location with the altitude of 2024 m above sea level.

A solar module of 14 cm by 14 cm of 12 V was used in this study to record the voltage of solar radiation at every half hour interval. The solar module was calibrated using 14 Ω and the same value was used to estimate the power. Voltage measurements were taken using a multi-meter every half hour from sunrise to sunset. Corresponding sunshine duration data were obtained from the two stations (i.e., HU and DD meteorological stations) to estimate the daily global solar radiation and the two values were compared.

2.3. Data Analysis and Mathematical Methodologies Used

Several empirical models exist to evaluate the daily global solar radiation, utilizing available meteorological and geographical parameters such as sunshine duration and latitude. In this study, the daily global solar radiation was estimated from sunshine duration using Angstrom-Prescott model (Prescott, 1940). The formula can be written as described by Medugu and Yakubu (2011):

$$H = H_o\left(a + b\frac{n}{N}\right) \quad (1)$$

H is daily global solar radiation and H_o is daily extraterrestrial radiation, both measured in kWh m^{-2}. H_o is calculated from several parameters as described by Medugu and Yakubu (2011):

$$H_o = \frac{24 \times 3600 \times Gsc}{\pi}\left(1 + 0.033 \times cos\left(\frac{2\pi n_d}{365}\right)\right) \times \left(cos(\phi)\, cos(\delta)\, sin(\omega_s) + \frac{\pi\omega_s}{180} sin(\phi)\sin(\delta)\right). \quad (2)$$

G_{sc} is the solar constant approximately equal to 1367 W m^{-2} (Antonio and Hedgus, 2005); n_d is day number of the year starting from January 1st as 1, ϕ is the latitude of the area and n is daily number of hours of bright sunshine.

The solar declination angle (δ) is calculated as:

$$\delta = 23.45\, sin\,(360\frac{284 + n_d}{365}). \quad (3)$$

The solar hour angle(ω_s) is given as:

$$os^{-1}\left(-tan\,(\phi)\,tan\,(\delta)\right). \quad (4)$$

The maximum possible daily hours of bright sunshine, N, is calculated using Eq. 5 (Zhou *et al*., 2005).

$$N = \frac{2}{15}\omega_s. \quad (5)$$

a and *b* is regression coefficients (Medugu and Yakubu, 2011), respectively given as:

$$a = -0.110 + 0.235\cos(\phi) + 0.323\frac{n}{N}. \quad (6)$$

$$b = 1.449 - 0.553\cos(\phi) - 0.694\frac{n}{N}. \quad (7)$$

In order to find the solar radiation intensity obtained on half hourly basis, first, the mean daily global solar radiation (*H*) was evaluated. Once the solar radiations of all hours of the day were computed, the daily total was obtained by summing the values of individual hours. Thereafter, the estimated half hourly power intensity $(I_{p,est})$ of solar radiation was calculated as (Collares-Pereira and Rabl, 1979):

$$I_{p,est} = r_t \times H. \quad (8)$$

Where r_t is the ratio of hourly total to daily total global radiation dependent on several parameters as shown in Eqn. 9.

$$r_t = \frac{\pi}{24}(x + y * \cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi}{180} * \omega_s * \cos\omega_s}. \quad (9)$$

The solar hour angle, ω, is calculated from (Scharmer and Greif, 2000)

$$\omega = (t_L - 12)15^0. \quad (10)$$

t_L is local solar time in hours. The *x* and *y* in equation (9) are dependent on ω_s and are expressed as shown in Eqns. 11 and 12, respectively.

$$x = 0.409 + 0.5016\sin\left(\omega_s - \frac{\pi}{3}\right). \quad (11)$$

$$y = 0.6609 - 0.4767\sin\left(\omega_s - \frac{\pi}{3}\right). \quad (12)$$

The sum of all r_t for all half hours adds up approximately to one. Hence, multiplying r_t for a specific time with estimated mean daily global solar radiation (*H*) gives estimated half hourly intensity of solar radiation. Solar power intensities were estimated from the electrical power obtained from measured voltages using

$$I_{p,meas} = \frac{P}{A}. \quad (13)$$

$$P = \frac{V^2}{R}. \quad (14)$$

$I_{p,meas}$ values were then compared with the corresponding values of the estimated half hourly power intensity of solar radiation. The graphs and area estimations were made using MATLAB, and finally, percent error estimations of both quadratic and Gaussian fits were made as:

$$\text{Percent Error} = \frac{\text{Estimated value} - \text{Measured value}}{\text{Measured value}} \times 100. \quad (15)$$

Finally, the percent errors were computed for each day using both fits to see how the powers estimated from sunshine duration varied from the power calculated using PV measured values.

3. Results and Discussion

3.1. Daily Sunshine Hours Obtained from the Two Experimental Sites

Daily sunshine hours obtained from each site were between 4 and 10.5 hours as shown in Table 1. The values of the two sites averaged over the week were 7.76±1.23 and 6.80±2.43 for Haramaya University Meteorological station (HUMS) and Dire Dawa University Meteorological station (DDMS), respectively. The low average sunshine duration recorded at DDMS could be due to more cloud cover during the week the measurements were taken. The cloud coverage of the atmosphere was more intense in July than in June. Note that measurements were taken during the month of June at HUMS and July at DDMS.

Table 1. Sunshine Duration of Each Day at Each Study Site.

HUMS	Date	13/06/12	14/06/12	15/06/12	16/06/12	17/06/12	18/06/12	19/06/12
	Hours	9.7	7.4	6.0	8.6	6.7	8.2	7.7
DDMS	Date	1/7/2012	2/7/2012	3/7/2012	4/7/2012	5/7/2012	6/7/2012	7/7/2012
	Hours	5.6	4.0	9.0	8.0	4.4	10.5	6.1

As indicated in Table 1, on four of the seven days DD experienced more cloud cover and thus had sunshine durations of about six hours or less. On the other hand, HU had sunshine durations in excess of six hours for most days of the week.

3.2. Estimation of Mean Daily Global Solar Radiation using Sunshine Durations

Summaries of the values of mean daily global solar radiation using sunshine duration for HUMS are given in Table 2. Intensity obtained using PV measurement were also shown for comparison on the last column. Table 3 shows corresponding values calculated for DDMS. The high values obtained at HU are understandable since the data were for June when the intensity of solar radiation is relatively higher since the sun is nearly overhead during this time of the year. Based on n/N values (WMO, 2006; Adam, 2012) of Tables 2 and 3, HUMS had only one fair weather ($n/N > 0.7$) day while DDMS had two. During the remaining days HUMS had fairly scattered clouds ($0.30 < n/N < 0.7$) with more days having n/N values closer to fair weather day value. DDMS also experienced scattered clouds with clouds more intense than that of HUMS since the n/N values for some of the days were closer to the lower value (0.30) than to the higher one (0.7). The values obtained at HUMS site were higher than that of DDMS values as indicated by the values of the average of the week. The low value at DDMS is due to the low values of sunshine durations. Besides, DDMS experienced higher variability (as indicated by the standard deviation (> 0.8)) compared to that of HUMS, which is close to 0.4. The measure of standard deviation is also a good indicator of cloudy and sunny days at DDMS compared to HUMS, which had days with closer weather conditions.

The ratio of measured power to calculated power ($I_{p,meas}/H$) based on the values of Tables 2 and 3 show 0.89 and 0.80, respectively. The fact that DDMS showed lower value indicates that the PV was more influenced by temperature at DDMS than at HUMS. Temperature adversely affects the performance of PV (del-Cueto, 2007; Myers, 2009; King *et al.*, 1997). Thus, the higher temperature at DDMS than at HUMS may have contributed to the lower performance of PV at the former.

Table 2. Estimation of Mean Daily Global Solar Radiation at HUMS.

Date	n	n_d	Δ	ω_s	N	n/N	a	B	H_o	H (kWm^{-2})	$I_{p.msd}$(kWm^2)
13/06/12	9.7	165	23.27	93.91	12.52	0.77	0.37	0.37	10.18	6.67	6.03
14/06/12	7.4	166	23.31	93.91	12.52	0.59	0.31	0.49	10.18	6.15	5.72
15/06/12	6.0	167	23.35	93.92	12.52	0.48	0.28	0.57	10.18	5.60	5.24
16/06/12	8.6	168	23.39	93.93	12.52	0.69	0.34	0.43	10.18	6.48	5.72
17/06/12	6.7	169	23.41	93.93	12.52	0.53	0.29	0.53	10.17	5.89	4.89
18/06/12	8.2	170	23.43	93.94	12.52	0.65	0.33	0.45	10.17	6.38	5.58
19/06/12	7.7	171	23.44	93.94	12.53	0.61	0.32	0.48	10.17	6.24	5.52
Average of the week										6.20±0.36	5.53±0.37

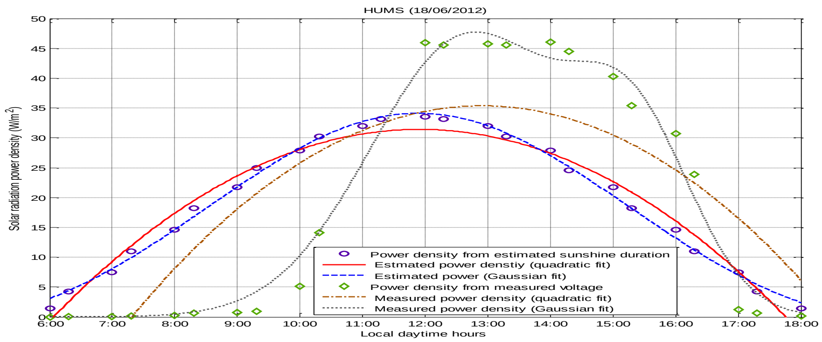
Table 3. Estimation of Mean Daily Global Solar Radiation at DDMS.

Date	n	n_d	Δ	ω_s	N	n/N	a	B	H_o	H(kWm^{-2})	I_{pmsd} (kWm^{-2})
1/7/2012	5.6	183	23.05	93.91	12.52	0.45	0.27	0.59	10.18	5.41	4.20
2/7/2012	4.0	184	22.97	93.89	12.52	0.32	0.23	0.68	10.19	4.51	3.52
3/7/2012	9.0	185	22.89	93.88	12.52	0.72	0.35	0.40	10.19	6.57	5.20
4/7/2012	8.0	186	22.80	93.86	12.51	0.64	0.33	0.46	10.19	6.34	5.50
5/7/2012	4.4	187	22.70	93.84	12.51	0.35	0.24	0.66	10.19	4.76	3.67
6/7/2012	10.5	188	22.59	93.82	12.51	0.84	0.39	0.32	10.20	6.75	5.61
7/7/2012	6.1	189	22.48	93.80	12.51	0.49	0.28	0.56	10.20	5.66	4.57
Average of the week										5.71 ± 0.88	4.61±0.85

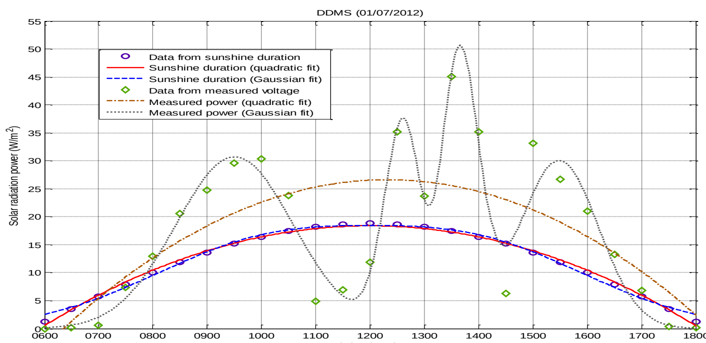
3.3. Degree of Variability between Estimated and Measured Values of Solar Radiation

The half hourly power intensity of solar radiation was calculated from PV measured solar radiation using Eqn. 13. From the observed result, the half hourly estimated and the intensity obtained from the measured voltages were shown with their corresponding cumulative sums (as samples, one each, for the two sites) in Fig. 1. Curve fits through the data points were made using Quadratic and Gaussian models.

As observed in the sample figures, Gaussian fits reflected the reality (presence of clouds) better than quadratic fits particularly when fitting data points obtained from voltage measurement. Unlike quadratic fit whose cumulative area has sufficient contribution during midday, Gaussian fits have subdued contribution especially when there were cloud covers during midday and early or late afternoon hours. This in turn may have undermined the total daily contribution and as a result power intensity obtained by voltage measurement was smaller than intensity estimated from sunshine duration. The results are reflected in Tables 4 and 5 for the two sites in which the cumulative power intensities of the Gaussian fits were always less than the corresponding quadratic fits.



(A)



(B)

Figure 1. Representative sample figures: (A) at HUMS on 18/06/2012 and (B) at DDMS on 01/07/2012) shown to illustrate how daily solar intensity varied with model type used to fit the curve.

Table 4. Summary of cumulative power density of daily solar radiation (kWhm^{-2}d^{-1}) at HUMS estimated using two models (Quadratic and Gaussian fits.

HUMS Calculated quantities	Date/Month/Year						
	13/6/2012	14/6/2012	15/6/2012	16/6/2012	17/6/2012	18/6/2012	19/6/2012
CEPQF (kWhm^{-2}d^{-1})	5.67	5.28	4.87	5.53	4.40	4.77	4.67
R^2	0.977	0.977	0.977	0.977	0.977	0.978	0.996
CEPGF (kWhm^{-2}d^{-1})	5.63	5.23	4.82	5.48	4.37	4.74	4.64
R^2	0.997	0.992	0.992	0.992	0.992	0.992	0.996
CEPQF-CEPGF	0.04	0.04	0.04	0.04	0.04	0.03	0.03
CMPQF (kWhm^{-2}d^{-1})	6.38	5.19	4.80	5.31	4.51	5.60	5.54
R^2	0.890	0.660	0.650	0.710	0.580	0.740	0.740
CMPGF (kWhm^{-2}d^{-1})	6.30	5.12	4.70	5.24	4.49	5.53	5.43
R^2	0.900	0.960	0.770	0.920	0.880	0.920	0.920
CMPQF-CMPGF	0.07	0.08	0.10	0.07	0.03	0.07	0.11
CEPGF –CMPGF	-0.67	0.12	0.12	0.25	-0.12	-0.78	-0.79
((CEPGF-CMPGF)/CMPGF)*100%	10.6	2.3	2.6	4.7	2.7	14.2	14.6
CEPQF –CMPQF	-0.70	0.08	0.06	0.22	-0.11	-0.83	-0.87
((CEPQF–CMPQF)/CMPQF)*100%	11.0	1.6	1.3	4.1	2.4	14.8	15.6

Note: CEPQF = Cumulative estimated power data quadratic fitted, CEPGF = Cumulative estimated power data Gaussian fitted, CMPQF = Cumulative measured power data quadratic fitted, CMPGF = Cumulative measured power data Gaussian fitted, R^2 = measure of fit .

As observed in Table 4, most of the differences between the quadratic and Gaussian fits were positive while differences between estimated and measured Gaussian fits could be either positive or negative. This implies that the sunshine duration underestimates the solar radiation intensity or the PV panel overestimates the value. PVs have the inherent problem of not accurately estimating solar radiation since they are temperature-dependent and have also low efficiency of only 10% (Rao and Parulekar, 2009).

Quadratic fits slightly overestimated the power density compared to the Gaussian fits for both estimated and measured values (CEPQF-CEPGF >0 and CMPQF – CMPGF >0). Percent differences computed both in terms of quadratic and Gaussian fitted values showed differences of up to 15%. Variability was higher when the sky was overcast since Gaussian fit reflected the reality during such times than quadratic fit and estimation by Gaussian fit was lower on overcast days.

While taking the voltage measurements of the solar module in this work, the values were generally very small on the multi-meter recording when the wind blew with a high speed and when the sky was covered with clouds as well as when a humid air blew at the moment of data recording. This showed the influences of the three atmospheric parameters on the performance of the solar module. However, since the differences between the measured and estimated values in most cases were less than 10% (average difference of approximately 7.25%) one can conclude that sunshine duration can give a good estimation of solar intensity and actual solar radiation intensity measurement can be made with PV as long as high accuracy (> 90%) is not expected.

Since the estimated power intensity of solar radiation in a given day depends on the sunshine duration, the underestimation of solar radiation might be due to errors in sunshine duration registration with the Campbell-Stokes recorder. The key component for Campbell-Stokes recorder is a glass bowl, which is working as a burning glass. It burns a track in a registration paper when the sun is shining with sufficient intensity. The threshold intensity normal to the solar beam for registration of sunshine by this measuring technique is about 120W m^{-2} (Duffie and Beckman, 1991), and it results in underestimation of sunshine duration. The analysis of the registration paper made by hand may cause additional errors. Deteriorations of the performance of the glass sphere caused by weather phenomena and lack of maintenance can also be a reason for the underestimation of sunshine duration. However, in this study, none of these factors seemed to have influenced the performances of the devices since the estimated power intensities were always higher than the measured values.

As shown in Table 4, the errors on the 16^{th} and 17^{th} of June were very small compared to the other dates. The weather conditions of those dates could be identified by calculating the mean daily clearness index of the solar radiation. Clearness index, ($K_T = H/H_0$) is the percentage deflection of the incoming global radiation by the sky and therefore indicates both the level of availability of solar radiation and changes in the atmospheric conditions in a given locality. According to Duffie and Beckman (1991) it depends on the location and time of the year considered. Below 0.3 indicates very overcast climates and above 0.6, very sunny climates. In the present work, $K_T = 0.64$ for June 16/2012, which implies a very sunny day whereas $K_T = 0.58$ for June 17/2012, is close to the theoretical value and represents a sunny day. Thus, the cumulative power intensity of solar radiation showed a fairly good agreement between estimated and measured values with an average error of 7.25%.

The data obtained at Dire Dawa meteorology station are presented in Table 5. In the Table, the estimated solar radiation intensity from the sunshine duration showed errors ranging from 0.4 to 15% for Gaussian fit and between 0.5 to 7% for the quadratic fit. The fact is that the Gaussian fit is a more realistic fit reflecting sunny and cloudy times accurately while the quadratic fit showed less deviation from the curve fitted based on the data of the sunshine duration. Note that a sunshine duration fit is closer to the quadratic than the Gaussian, which may explain the fact that the percent error between estimated and measured quadratic fits was smaller than the ones between the Gaussian fits.

Table 5. Summary of cumulative power density of daily solar radiation ($kWhm^{-2}d^{-1}$) at DDMS estimated using two models (Quadratic and Gaussian fits).

DDMS	Date/Month/Year						
Calculated quantities	1/7/2012	2/7/2012	3/7/2012	4/7/2012	5/7/2012	6/7/2012	7/7/2012
CEPQF (kWhm-2d-1)	4.10	3.38	4.92	4.75	3.58	5.05	4.24
R2	0.977	0.977	0.977	0.977	0.977	0.977	0.977
CEPGF (kWhm-2d-1)	4.03	3.35	4.88	4.71	3.54	5.02	4.21
R2	0.997	0.997	0.997	0.997	0.997	0.997	0.997
CEPQF-CEPGF	0.08	0.02	0.04	0.03	0.04	0.04	0.03
CMPQF (kWhm-2d-1)	3.83	3.24	4.82	5.04	3.35	5.08	4.18
R2	0.450	0.639	0.868	0.830	0.525	0.642	0.682
CMPGF (kWhm-2d-1)	3.69	3.13	4.74	4.90	3.06	5.04	4.65
R2	0.960	0.836	0.908	0.951	0.711	0.722	0.815
CMPQF-CMPGF	0.14	0.11	0.08	0.14	0.29	0.04	-0.47
CEPGF –CMPGF	0.34	0.23	0.14	-0.19	0.48	-0.02	-0.44
((CEPGF–CMPGF)/CMPGF)*100%	9.2	7.2	2.9	3.8	15.8	0.4	9.5
CEPQF –CMPQF	0.27	0.14	0.09	-0.30	0.23	-0.02	0.06
((CEPQF–CMPQF)/CMPQF)*100%	7.0	4.3	1.9	5.9	6.7	0.5	1.5

Note: CEPQF = Cumulative estimated power data quadratic fitted, CEPGF = Cumulative estimated power data Gaussian fitted, CMPQF = Cumulative measured power data quadratic fitted, CMPGF = Cumulative measured power data Gaussian fitted, R^2*= measure of fit; DDMS = Dire Dawa Meteorological station.*

4. Conclusions

Comparisons have been made for half hourly power intensity of estimated and measured values of solar radiation at Haramaya University's Meteorological Station (HUMS) and Dire Dawa Meteorological Station (DDMS). Most of the measured values were consistent with the estimated ones throughout the day to within an error range of 15% in the worst cases. At HUMS, the intensity of solar radiation showed an error of about 15% and at DDMS the error was generally less than 10%. Although this study is specific to HU and DD, the solar module used for the study can be used to measure solar radiation at any time rather than predicting the solar radiation using sunshine duration alone. The results of this study indicated a fairly good agreement between estimation of cumulative power intensity of solar radiation and its corresponding measured values. Better results could have been obtained if temperature corrections were made for PV data. The Gaussian fits better reflected the daily solar radiation intensity but it also showed higher percent error at both sites. The quadratic fit showed better agreement with the estimated power when data points were closer to the normal distribution. Despite a very great simplification, the solar module appears to be well suited for measuring the solar radiation at any time since it is less expensive and more readily available than other devices. However, because of its low efficiency, it may not be suitable for calibration of sunshine recorder devices like Campbell-Stokes recorder.

The results of the study have demonstrated that even when materials that have lower accuracy such as solar modules are used for estimating global solar radiation, a better estimation could be obtained by selecting a better mathematical function to reduce the error. Since this study was conducted for a short duration, it is advisable to use data accumulated over long durations to make a conclusive recommendation.

5. References

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