Monthly-Specific Daily Global Solar Radiation Estimates Based On Sunshine Hours In Wa, Ghana

Emmanuel A. Sarsah, Felix A. Uba

Abstract: Daily mean global solar radiation data are required for solar energy system design evaluation and performance studies is generally not available for a number of sites especially in remote locations. This study evaluates different empirical models based on Angstrom-Prescott model to estimate daily mean global solar radiation using month-specific correlations based on sunshine hours. Hourly solar radiation data measured at Wa Polytechnic weather station from 2010-2012 were used to perform the calculations using selected models. The following models were included: Angstrom-Prescott, Akinoglu and Ecevit, Samuel, Newland, Ampratwum and Dorvlo, KadirBakirchi and Almorox*et.al*. Statistical indices show that all models for each month show reasonably good agreement with measured data. The model by Ampratwum and Dorvlo in the form $H/H_o = a + b\log(n/N)$shows very good agreement for most monthly-specific correlations in the year. The models presented can be used to estimate daily and monthly mean global solar radiation in Wa Polytechnic site and in elsewhere with similar climatic conditions where radiation data are unavailable. The present work will help to advance the state of knowledge of global solar radiation to the point where it has applications in the estimation of daily mean global solar radiation.

Key Terms: Daily mean global solar radiation, empirical models, sunshine duration and *t*-statistics.

1 INTRODUCTION

Most solar energy applications such as the simulation of solar energy systems require, at the least, knowledge of daily values of global solar radiation on a horizontal surface. Thus, accurate estimation of daily values of global radiation data is essential for the design and long-term evaluation of solar energy conversion systems performances, such as in the design of a solar project, meteorological forecasting, solar heating, drying and architectural design.In the applications of solar energy listed above, the most important parameters that are often needed are the average solar irradiation and its components; measurements of which are not available at every location especially in developing countries due to cost, maintenance and calibration requirements of the measuring equipment [1]. One way of solving this is using appropriate correlations which are empirically established, that can be used to estimate global solar radiation from more readily available meteorological parameters such as sunshine hours.Several empirical models have been developed to calculate solar radiation from meteorological, geographical and climatological parameters such as relative humidity, ambient temperature, soil temperature, number of rainy days and evaporation [2], [3], [4], [5] ,[6], [7], [8]. In addition, other empirical models have been developed to calculate solar radiation from sunshine hours [9], [10], [11], [12]. The most commonly used parameter for estimating global solar radiation is sunshine duration.

- Sarsah Emmanuel is a lecturer in the Mechanical Engineering Department, Wa Polytechnic, Wa, Ghana. E-mail: emmanuelsarsah@gmail.com.
- Uba Felix is a lecturer in the Mechanical Engineering Department, Wa Polytechnic, Wa, Ghana. E-mail: felix_uba@yahoo.com

Among various correlations, the modified version of [13] model who proposed a linear relationship between the ratio of average daily global solar radiation to the corresponding value on a clear sky day and the ratio of average daily sunshine duration to the maximum possible sunshine duration and its derivatives have been used widely [1]. Consequently, bright sunshine data at locations can be used to estimate the values of the global solar radiation with the help of models listed above. In this study, the first aim was to evaluate models for the estimation of global solar radiation on a horizontal surface based on sunshine hoursfor every month and to recommend the most appropriate model for Wa Polytechnic weather station. The second aim was to perform a review of all the existing models for each month and we made a description of each model. We then compared the models using the statistical routine and recommended the most appropriate model for theevaluation of daily global solar radiation for every month. Our final aim was to recommend days of the year for evaluating the mean monthly daily global solar radiation for every month at Wa Polytechnic weather station and in elsewhere with similar climatic conditions.

2 CALCULATION PROCEDURE

[13] developed the earliest model used for estimating global solar radiation, in which sunshine duration data and clear sky radiation data were used:

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

where H is the monthly mean daily global solar radiation, $H_c$is the monthly mean clear sky daily global radiation for the location, $n$is the monthly mean daily bright sunshine duration, $N$is the daylength, $a$and $b$are empirical constants. A basic difficulty with equation (1) is that, there may be problems in calculating the clear sky radiation accurately. By replacing the clear sky radiation with extraterrestrial radiation, H_o, this model was modified to a more convenient form by [14]:

$$\frac{H}{H_o} = a + b\left(\frac{n}{N}\right) \quad (2)$$

H_o is calculated from the following equation [15]:

$$H_o = \frac{24 \times 3600}{\pi} \times G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \quad (3)$$

where G_{sc} is the solar constant (1367 W/m^2), ϕ is the latitude of the location, δ is the sun declination and ω_s is the sunset hour angle. Declination, sunset hour angle and daylengthcan be computed by the following equations [14] and [15]:

$$\delta = 23.45\sin\left(360 \times \frac{284 + d}{365}\right) \quad (4)$$

where d is the day of the year, $1 \le d \le 365$.

$$\omega_s = \cos^{-1}\left(-\tan\phi\tan\delta\right) \quad (5)$$

$$N = \frac{2}{15}\cos^{-1}\left(-\tan\phi\tan\delta\right) = \frac{2}{15}\omega_s \quad (6)$$

Further, seven different models have been selected from different previous studies for estimating daily global solar radiation. All models have been proposed for estimating themonthly mean daily global solar radiation, H based on the Angstrom-Prescott model. The regression models are listed in Table 1.

Table 1. Regression models proposed in the literature

Model No.	Regression Equation	Model Type
1	$H/H_o = a + b(n/N)$	Linear [13], [14]
2	$H/H_o = a + b(n/N) + c(n/N)^2$	Quadratic [12]
3	$H/H_o = a + b(n/N) + c(n/N)^2 + d(n/N)^3$	Cubic [17]
4	$H/H_o = a + b(n/N) + c\log(n/N)$	Linear logarithmic [18]
5	$H/H_o = a + b\log(n/N)$	Logarithmic [19]
6	$H/H_o = a + b(n/N) + c\exp(n/N)$	Linear exponential [9]
7	$H/H_o = a + b\exp(n/N)$	Exponential [20]
8	$H/H_o = a(n/N)^b$	Exponent [9]

3 METHODOLOGY

Extraterrestrial radiation on a horizontal surface in daily periods were calculated numerically for each month using declination angle, latitude and sunset hour angle from thecalculation procedure "(3)","(4)","(5)","(6)". Available daily global solar radiation and sunshine duration hours were taken from the site of the meteorological station for Wa Polytechnic from 2010 to 2012. The meteorological data were collected hourly. From the hourly data set, daily statistics for each month were prepared for the global solar radiation and the other meteorological data. The geographical location of Wa Polytechnic is latitude 10.01°N, with an altitude of 322 m above sea level. Due to the limitation of space, monthly measurements and estimated values for three months in an interval of four months processed in preparation for the correlations are presented in Tables 2: (a), (b) and (c). The day of the year in tables(b) and (c) starts from 1st January.

Table 2(a) . Monthly Global Solar Radiation and other meteorological data for Wa Polytechnic (January)

	JANUARY					
Day	H (MJ/m^2)	Ho (MJ/m^2)	n (hours)	N (hours)	H/Ho	n/N
1	20.98	31.16	5.83	11.43	0.67	0.51
2	17.44	31.19	4.84	11.43	0.56	0.42
3	19.41	31.23	5.39	11.43	0.62	0.47
4	19.80	31.26	5.50	11.43	0.63	0.48
5	20.11	31.31	5.59	11.44	0.64	0.49
6	19.59	31.35	5.44	11.44	0.63	0.48
7	19.47	31.39	5.41	11.44	0.62	0.47
8	21.69	31.44	6.03	11.45	0.69	0.53
9	18.83	31.49	5.23	11.45	0.60	0.46
10	17.80	31.55	4.94	11.45	0.56	0.43
11	16.05	31.60	4.46	11.46	0.51	0.39
12	19.40	31.66	5.39	11.46	0.61	0.47
13	20.99	31.72	5.83	11.47	0.66	0.51
14	20.03	31.78	5.56	11.47	0.63	0.49
15	17.73	31.84	4.93	11.47	0.56	0.43
16	15.44	31.91	4.29	11.48	0.48	0.37
17	15.16	31.98	4.21	11.48	0.47	0.37
18	20.42	32.05	5.67	11.49	0.64	0.49
19	20.85	32.12	5.79	11.49	0.65	0.50
20	21.71	32.19	6.03	11.50	0.67	0.52
21	20.70	32.26	5.75	11.51	0.64	0.50
22	20.99	32.34	5.83	11.51	0.65	0.51
23	19.33	32.42	5.37	11.52	0.60	0.47
24	18.88	32.50	5.24	11.52	0.58	0.46
25	20.24	32.58	5.62	11.53	0.62	0.49
26	20.00	32.66	5.56	11.53	0.61	0.48
27	19.67	32.74	5.46	11.54	0.60	0.47
28	22.03	32.83	6.12	11.55	0.67	0.53
29	21.76	32.91	6.04	11.55	0.66	0.52
30	19.45	33.00	5.40	11.56	0.59	0.47
31	20.47	33.09	5.69	11.57	0.62	0.49

Table 2(b). Monthly Global Solar Radiation and other meteorological data for Wa Polytechnic (June)

Day	H (MJ/m²)	Ho (MJ/m²)	JUNE n (hours)	N (hours)	H/Ho	n/N
152	17.56	37.16	4.88	12.55	0.47	0.39
153	20.49	37.14	5.69	12.55	0.55	0.45
154	19.19	37.13	5.33	12.55	0.52	0.42
155	15.47	37.11	4.30	12.56	0.42	0.34
156	18.01	37.09	5.00	12.56	0.49	0.40
157	25.06	37.07	6.96	12.56	0.68	0.55
158	24.27	37.06	6.74	12.57	0.65	0.54
159	18.65	37.04	5.18	12.57	0.50	0.41
160	22.91	37.02	6.36	12.57	0.62	0.51
161	20.55	37.01	5.71	12.57	0.56	0.45
162	22.14	37.00	6.15	12.58	0.60	0.49
163	23.54	36.98	6.54	12.58	0.64	0.52
164	23.72	36.97	6.59	12.58	0.64	0.52
165	22.22	36.96	6.17	12.58	0.60	0.49
166	20.69	36.95	5.75	12.58	0.56	0.46
167	20.65	36.94	5.74	12.58	0.56	0.46
168	22.61	36.93	6.28	12.58	0.61	0.50
169	18.32	36.93	5.09	12.58	0.50	0.40
170	24.26	36.92	6.74	12.58	0.66	0.54
171	14.92	36.92	4.14	12.59	0.40	0.33
172	20.58	36.91	5.72	12.59	0.56	0.45
173	18.82	36.91	5.23	12.59	0.51	0.42
174	20.81	36.90	5.78	12.59	0.56	0.46
175	17.51	36.90	4.86	12.58	0.47	0.39
176	20.35	36.90	5.65	12.58	0.55	0.45
177	14.58	36.90	4.05	12.58	0.40	0.32
178	18.69	36.90	5.19	12.58	0.51	0.41
179	22.27	36.91	6.19	12.58	0.60	0.49
180	22.38	36.91	6.22	12.58	0.61	0.49
181	19.91	36.91	5.53	12.58	0.54	0.44

Table 2(c). Monthly Global Solar Radiation and other meteorological data for Wa Polytechnic (November)

Day	H (MJ/m²)	Ho (MJ/m²)	NOVEMBER n (hours)	N (hours)	H/Ho	n/N
305	20.76	33.58	5.77	11.63	0.62	0.50
306	21.84	33.49	6.07	11.62	0.65	0.52
307	23.66	33.40	6.57	11.61	0.71	0.57
308	22.11	33.32	6.14	11.61	0.66	0.53
309	19.57	33.23	5.44	11.60	0.59	0.47
310	22.49	33.14	6.25	11.59	0.68	0.54
311	22.36	33.06	6.21	11.58	0.68	0.54
312	21.56	32.97	5.99	11.58	0.65	0.52
313	22.01	32.89	6.11	11.57	0.67	0.53
314	21.78	32.81	6.05	11.56	0.66	0.52
315	20.19	32.72	5.61	11.56	0.62	0.49
316	20.50	32.64	5.69	11.55	0.63	0.49
317	22.03	32.56	6.12	11.54	0.68	0.53
318	20.90	32.48	5.81	11.54	0.64	0.50
319	20.55	32.41	5.71	11.53	0.63	0.49
320	18.68	32.33	5.19	11.53	0.58	0.45
321	21.94	32.26	6.09	11.52	0.68	0.53
322	19.61	32.18	5.45	11.51	0.61	0.47
323	19.78	32.11	5.49	11.51	0.62	0.48
324	20.32	32.04	5.65	11.50	0.63	0.49
325	19.44	31.98	5.40	11.50	0.61	0.47
326	15.49	31.91	4.30	11.49	0.49	0.37
327	19.06	31.85	5.29	11.49	0.60	0.46
328	19.56	31.78	5.43	11.48	0.62	0.47
329	19.18	31.72	5.33	11.48	0.60	0.46
330	19.14	31.66	5.32	11.47	0.60	0.46
331	19.02	31.61	5.28	11.47	0.60	0.46
332	18.55	31.55	5.15	11.46	0.59	0.45
333	18.36	31.50	5.10	11.46	0.58	0.45
334	19.57	31.45	5.44	11.46	0.62	0.47

We then developed equations to estimate H/H_o for each month by applying regression analysis to the parameter n/N based on the model equations in Table 1. Eight model equations for each month were formed. The values of daily global solar radiation were estimated for each month. The corresponding measured values were compared with the estimated values using the above eight models for each month.

4 STATISTICAL ROUTINE

The performance of the eight model equations for each month was evaluated on the basis of the statistical error tests, (i.e. the mean bias error (MBE), mean percentage error (MPE), root mean square error (RMSE), and coefficient of determination,R^2.The equations were also tested whether they are statistically significant using *t*-statistics.

4.1 The Mean Bias Error

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(C_i - M_i) \quad (7)$$

where C_i and M_i are the forecast and actual values of solar radiation being forecast respectively, and N is the number of observations. This test provides information on long-term performance. A low MBEvalue is desired. A mean error value of zero can mean that the method forecasts the actual values perfectly or that the positive and negative errors cancel each other out. So, one drawback of this test is that it tends to understate the error in all cases.

4.2 The Mean Percentage Error

$$MPE(\%) = \frac{100}{N}\sum_{i=1}^{N}\left(\frac{C_i - M_i}{M_i}\right) \quad (8)$$

MPE quantifies the schematic component of the normalized difference for individual observations. It is subjected to the averaging of the positive and negative errors. A percentage error between −10% and +10% is considered acceptable.

4.3The Root Mean Square Error

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(C_i - M_i)^2\right]^{1/2} \quad (9)$$

The value of RMSE is always positive, representing zero in the ideal case. The normalized root mean square error gives information on the short term performance of the correlations by allowing a term by term comparison of the actual deviation between the predicted and measured values. The smaller the value, the better is the model's performance.

4.4 The Coefficient of Determination, R^2

The coefficient of determination, R^2gives some information about the goodness of fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points.

4.5*t*-statistics

$$t = \left[\frac{(N-1)(MBE)^2}{(RMSE)^2 - (MBE)^2} \right]^{1/2} \quad (10)$$

T-statistics is an indicator of adjustment between calculated and measured data allowing the data to be compared. It can be used to induce whether or not data measurements are statistically significant at a particular confidence level.

5 RESULTS AND DISCUSSION

The accuracy of eight model equations were determined using data measured at Wa Polytechnic weather station from 2010 to 2012. The regression coefficients *a* ,*b*,*c* and *d* are given for all eight models for each month in Tables 3: (a – l).

Table 3(a). Regression coefficients for Wa Polytechnic site (January)

JANUARY					
Model Type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.022	1.246	-	-
Quadratic	2	-0.092	1.755	-0.563	-
Cubic	3	-0.755	6.219	-10.496	7.310
Linear logarithmic	4	-0.319	0.623	0.395	-
Logarithmic	5	1.031	1.283	-	-
Linear exponential	6	0.527	0.623	0.642	-
Exponential	7	-0.660	0.792	-	-
Exponent	8	1.260	0.966	-	-

Table3(b). Regression coefficients for Wa Polytechnic site (February)

FEBRUARY					
Model Type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.008	1.204	-	-
Quadratic	2	-0.008	1.204	-0.001	-
Cubic	3	0.076	0.582	1.691	-1.433
Linear logarithmic	4	-0.348	0.602	0.398	-
Logarithmic	5	0.915	1.001	-	-
Linear exponential	6	0.462	0.602	0.500	-
Exponential	7	-0.705	0.796	-	-
Exponent	8	1.202	0.978	-	-

Table 3(c). Regression coefficients for Wa Polytechnic site (March)

MARCH					
Model Type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.001	1.167	-	-
Quadratic	2	-0.001	1.194	-0.046	-
Cubic	3	0.021	0.588	2.104	-2.042
Linear logarithmic	4	-0.408	0.583	0.423	-
Logarithmic	5	0.753	0.524	-	-
Linear exponential	6	0.377	0.583	0.262	-
Exponential	7	-0.816	0.847	-	-
Exponent	8	1.169	1.002	-	-

Table 3(d). Regression coefficients for Wa Polytechnic site (April)

APRIL					
Model Type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.001	1.161	-	-
Quadratic	2	-0.051	1.378	-0.224	-
Cubic	3	0.052	0.710	1.191	-0.982
Linear logarithmic	4	-0.298	0.581	0.357	-
Logarithmic	5	0.966	1.260	-	-
Linear exponential	6	0.483	0.581	0.630	-
Exponential	7	-0.597	0.713	-	-
Exponent	8	1.165	1.004	-	-

Table 3(e). Regression coefficients for Wa Polytechnic site (May)

MAY					
Model Type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.009	1.176	-	-
Quadratic	2	-0.011	1.265	-0.095	-
Cubic	3	0.173	0.028	2.643	-1.992
Linear logarithmic	4	-0.306	0.588	0.369	-
Logarithmic	5	0.973	1.233	-	-
Linear exponential	6	0.491	0.588	0.617	-
Exponential	7	-0.621	0.738	-	-
Exponent	8	1.181	0.984	-	-

Table 3(f). Regression coefficients for Wa Polytechnic site (June)

JUNE					
Model Type	Model Number	*a*	*b*	*c*	*d*
Linear	1	-0.0002	1.225	-	-
Quadratic	2	-0.008	1.259	-0.039	-
Cubic	3	0.193	-0.166	3.278	-2.535
Linear logarithmic	4	-0.343	0.612	0.394	-
Logarithmic	5	0.976	1.212	-	-
Linear exponential	6	0.488	0.612	0.606	-
Exponential	7	-0.686	0.787	-	-
Exponent	8	1.225	1.001	-	-

Table 3(g). Regression coefficients for Wa Polytechnic site (July)

		JULY			
Model type	Model Number	*a*	*b*	*c*	*d*
Linear	1	-0.004	1.224	-	-
Quadratic	2	-0.007	1.243	-0.022	-
Cubic	3	-0.056	1.620	-0.971	0.774
Linear Logarithmic	4	0.472	0.612	0.563	-
Logarithmic	5	0.944	1.125	-	-
Linear Exponential	6	-0.359	0.612	0.402	-
Exponential	7	-0.718	0.805	-	-
Exponent	8	1.220	1.009	-	-

Table 3(h). Regression coefficients for Wa Polytechnic site (August)

		AUGUST			
Model type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.003	1.176	-	-
Quadratic	2	-0.003	1.207	- 0.039	
Cubic	3	0.029	0.948	0.634	-0.564
Linear Logarithmic	4	0.444	0.588	0.507	-
Logarithmic	5	0.886	1.013	-	-
Linear Exponential	6	-0.355	0.588	0.396	-
Exponential	7	- 0.712	0.792	-	-
Exponent	8	1.180	0.995	-	-

Table 3(i). Regression coefficients for Wa Polytechnic site (September)

		SEPTEMBER			
Model type	Model Number	*a*	*b*	*c*	*d*
Linear	1	- 0.003	1.181	-	-
Quadratic	2	0.003	1.153	0.032	-
Cubic	3	0.009	1.102	0.159	-0.099
Linear Logarithmic	4	0.457	0.590	0.534	
Logarithmic	5	0.917	1.069	-	-
Linear Exponential	6	-0.333	0.590	0.377	-
Exponential	7	- 0.663	0.754	-	-
Exponent	8	1.180	1.005	-	-

Table 3(j). Regression coefficients for Wa Polytechnic site (October)

		OCTOBER			
Model type	Model Number	*a*	*b*	*c*	*d*
Linear	1	- 0.001	1.214	-	-
Quadratic	2	0.019	1.121	0.101	-
Cubic	3	0.181	- 0.017	2.638	-1.817
Linear Logarithmic	4	0.494	0.6072	0.613	-
Logarithmic	5	0.990	1.227	-	-
Linear Exponential	6	-0.328	0.607	0.380	
Exponential	7	- 0.655	0.760	-	-
Exponent	8	1.210	0.998	-	-

Table 3(k). Regression coefficients for Wa Polytechnic site (November)

		NOVEMBER			
Model type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.085	1.106	-	-
Quadratic	2	- 0.166	2.158	-1.096	-
Cubic	3	- 1.617	11.653	- 21.595	14.621
Linear Logarithmic	4	0.545	0.553	0.606	-
Logarithmic	5	1.004	1.212	-	-
Linear Exponential	6	-0.201	0.553	0.341	-
Exponential	7	- 0.487	0.682	-	-
Exponent	8	1.170	0.871	-	-

Table 3(l). Regression coefficients for Wa Polytechnic site (December)

		DECEMBER			
Model type	Model Number	*a*	*b*	*c*	*d*
Linear	1	0.005	1.313	-	-
Quadratic	2	0.067	1.053	0.271	-
Cubic	3	0.880	-4.007	10.74	- 7.198
Linear Logarithmic	4	0.550	0.656	0.721	
Logarithmic	5	1.095	1.442	-	-
Linear Exponential	6	-0.337	0.656	0.406	
Exponential	7	-0.678	0.812	-	-
Exponent	8	1.310	0.991	-	-

The regression coefficients were obtained using curve fitting tool in MATLab. The values of the mean daily global solar radiation estimated using the above eight models were compared with the corresponding measured values. Statistical test of *MBE*, *MPE*, *RMSE*, R^2 and *t*-test were determined for all eight model equations for each month of the year. The applicability of the proposed correlations in predicting the daily mean global solar radiation is tested by estimating values for Wa Polytechniclocation used in the analysis. Estimated values for the eight models with measured data for the months January, June and November are shown in Tables 4: (a), (b) and (c).

Table 4(a). Comparison between measured and estimated values (H/Ho) of the correlation equations (January)

		MODEL VALUES FOR JANUARY							
Day	Measured H/Ho	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
1	0.673	0.657	0.657	0.656	0.658	0.656	0.657	0.658	0.658
2	0.559	0.550	0.551	0.552	0.550	0.553	0.551	0.549	0.550
3	0.622	0.610	0.611	0.610	0.609	0.612	0.611	0.609	0.610
4	0.633	0.621	0.622	0.621	0.621	0.623	0.622	0.621	0.622
5	0.642	0.631	0.631	0.630	0.630	0.632	0.631	0.630	0.631
6	0.625	0.615	0.615	0.615	0.614	0.617	0.616	0.614	0.615
7	0.620	0.611	0.612	0.611	0.610	0.613	0.612	0.610	0.611
8	0.690	0.678	0.676	0.676	0.679	0.673	0.676	0.680	0.678
9	0.598	0.591	0.592	0.592	0.591	0.594	0.593	0.590	0.591
10	0.564	0.560	0.561	0.562	0.559	0.563	0.561	0.559	0.560
11	0.508	0.507	0.506	0.506	0.507	0.505	0.506	0.508	0.506
12	0.613	0.608	0.609	0.609	0.607	0.610	0.609	0.607	0.608
13	0.662	0.656	0.655	0.655	0.656	0.654	0.655	0.656	0.656
14	0.630	0.626	0.627	0.626	0.626	0.628	0.627	0.626	0.627
15	0.557	0.557	0.558	0.559	0.556	0.560	0.558	0.556	0.557
16	0.484	0.488	0.485	0.485	0.489	0.482	0.485	0.490	0.487
17	0.474	0.479	0.476	0.475	0.481	0.472	0.475	0.482	0.478
18	0.637	0.637	0.637	0.637	0.637	0.638	0.637	0.637	0.637
19	0.649	0.650	0.649	0.649	0.650	0.649	0.649	0.650	0.650
20	0.674	0.675	0.674	0.674	0.676	0.671	0.673	0.677	0.676
21	0.642	0.645	0.644	0.644	0.645	0.644	0.645	0.645	0.645
22	0.649	0.653	0.653	0.652	0.653	0.652	0.653	0.654	0.653
23	0.596	0.603	0.604	0.604	0.602	0.606	0.604	0.602	0.603
24	0.581	0.589	0.590	0.590	0.588	0.592	0.591	0.588	0.589
25	0.621	0.630	0.630	0.629	0.629	0.631	0.630	0.629	0.630
26	0.612	0.622	0.623	0.622	0.622	0.624	0.623	0.621	0.622
27	0.601	0.612	0.613	0.612	0.611	0.614	0.613	0.611	0.612
28	0.671	0.682	0.680	0.681	0.684	0.677	0.680	0.685	0.682
29	0.661	0.674	0.672	0.673	0.675	0.670	0.672	0.676	0.674
30	0.589	0.604	0.605	0.605	0.604	0.607	0.606	0.603	0.604
31	0.619	0.634	0.635	0.634	0.634	0.635	0.635	0.634	0.635

Table 4(b). Comparison between measured and estimated values (H/Ho) of the correlation equations (June)

		MODEL VALUES FOR JUNE							
Day	Measured H/Ho	Model 1	Model 2	Model 3	Model. 4	Model 5	Model 6	Model 7	Model 8
152	0.472	0.476	0.476	0.475	0.476	0.479	0.477	0.475	0.476
153	0.552	0.555	0.555	0.555	0.554	0.560	0.558	0.553	0.555
154	0.517	0.520	0.520	0.519	0.519	0.525	0.523	0.518	0.520
155	0.417	0.419	0.418	0.418	0.421	0.412	0.415	0.423	0.419
156	0.486	0.488	0.487	0.487	0.487	0.492	0.490	0.487	0.488
157	0.676	0.679	0.678	0.676	0.681	0.665	0.672	0.684	0.678
158	0.655	0.657	0.656	0.656	0.659	0.648	0.653	0.660	0.657
159	0.504	0.505	0.504	0.504	0.504	0.510	0.507	0.503	0.505
160	0.619	0.620	0.619	0.620	0.620	0.618	0.619	0.620	0.620
161	0.555	0.556	0.556	0.556	0.555	0.561	0.558	0.554	0.556
162	0.598	0.599	0.598	0.599	0.598	0.600	0.599	0.598	0.599
163	0.636	0.637	0.636	0.636	0.637	0.632	0.634	0.638	0.637
164	0.642	0.641	0.641	0.641	0.642	0.636	0.639	0.643	0.641
165	0.601	0.601	0.600	0.601	0.600	0.601	0.601	0.600	0.601
166	0.560	0.559	0.559	0.560	0.558	0.564	0.561	0.557	0.559
167	0.559	0.558	0.558	0.558	0.557	0.563	0.560	0.556	0.558
168	0.612	0.611	0.611	0.612	0.611	0.610	0.611	0.611	0.611
169	0.496	0.495	0.495	0.494	0.494	0.500	0.497	0.494	0.495
170	0.657	0.656	0.655	0.655	0.657	0.647	0.652	0.659	0.656
171	0.404	0.403	0.402	0.403	0.406	0.391	0.397	0.408	0.403
172	0.558	0.556	0.556	0.556	0.555	0.561	0.558	0.554	0.556
173	0.510	0.509	0.508	0.508	0.508	0.514	0.511	0.507	0.508
174	0.564	0.562	0.562	0.563	0.561	0.567	0.564	0.560	0.562
175	0.474	0.473	0.473	0.472	0.473	0.476	0.474	0.473	0.473
176	0.551	0.550	0.550	0.550	0.549	0.555	0.552	0.548	0.550
177	0.395	0.394	0.393	0.395	0.397	0.379	0.387	0.400	0.394
178	0.506	0.505	0.505	0.505	0.504	0.510	0.508	0.503	0.505
179	0.603	0.602	0.602	0.603	0.602	0.602	0.602	0.601	0.602
180	0.606	0.605	0.605	0.606	0.605	0.605	0.605	0.605	0.605
181	0.539	0.538	0.538	0.538	0.537	0.544	0.541	0.536	0.538

Table 4(c). Comparison between measured and estimated values (H/Ho) of the correlation equations (November)

		MODEL VALUES FOR NOVEMBER							
Day	Measured H/Ho	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
305	0.618	0.634	0.635	0.634	0.634	0.635	0.633	0.633	0.634
306	0.652	0.663	0.662	0.661	0.662	0.662	0.663	0.663	0.663
307	0.708	0.711	0.705	0.711	0.708	0.704	0.712	0.714	0.711
308	0.664	0.670	0.669	0.669	0.670	0.669	0.671	0.671	0.671
309	0.589	0.604	0.605	0.606	0.605	0.605	0.603	0.603	0.603
310	0.679	0.681	0.679	0.680	0.680	0.679	0.682	0.682	0.682
311	0.676	0.678	0.676	0.676	0.677	0.676	0.678	0.679	0.678
312	0.654	0.657	0.657	0.656	0.657	0.657	0.657	0.657	0.658
313	0.669	0.670	0.669	0.668	0.669	0.668	0.670	0.670	0.670
314	0.664	0.664	0.664	0.662	0.664	0.663	0.664	0.664	0.664
315	0.617	0.622	0.623	0.623	0.623	0.624	0.621	0.621	0.622
316	0.628	0.630	0.632	0.631	0.631	0.632	0.630	0.630	0.631
317	0.676	0.671	0.670	0.670	0.671	0.670	0.672	0.672	0.672
318	0.643	0.642	0.643	0.641	0.642	0.643	0.641	0.641	0.642
319	0.634	0.633	0.634	0.633	0.633	0.634	0.632	0.632	0.633
320	0.578	0.583	0.584	0.586	0.584	0.584	0.583	0.583	0.583
321	0.680	0.670	0.669	0.669	0.670	0.669	0.670	0.671	0.671
322	0.609	0.608	0.610	0.611	0.609	0.610	0.608	0.608	0.608
323	0.616	0.613	0.615	0.615	0.614	0.615	0.613	0.612	0.613
324	0.634	0.628	0.629	0.629	0.629	0.630	0.628	0.627	0.628
325	0.608	0.605	0.606	0.607	0.606	0.606	0.604	0.604	0.604
326	0.485	0.499	0.489	0.486	0.493	0.487	0.502	0.505	0.496
327	0.598	0.595	0.596	0.598	0.596	0.596	0.595	0.594	0.595
328	0.615	0.608	0.610	0.611	0.609	0.610	0.608	0.608	0.608
329	0.605	0.599	0.600	0.601	0.600	0.600	0.598	0.598	0.598
330	0.605	0.598	0.599	0.601	0.599	0.600	0.597	0.597	0.598
331	0.602	0.595	0.596	0.598	0.596	0.596	0.594	0.594	0.595
332	0.588	0.582	0.583	0.586	0.583	0.583	0.582	0.582	0.582
333	0.583	0.577	0.578	0.581	0.578	0.578	0.577	0.577	0.577
334	0.622	0.610	0.612	0.612	0.611	0.612	0.610	0.609	0.610

It can be seen that the estimated values of the ratio H/H_o are in favourable agreement with the measured values of H/H_o for all the eight models for each month. All eight models therefore show good results. All eight models have very low values of *MBE*, *MPE*, *RMSE* and *t*-test and high values of R^2 as shown in Tables 5: (a) (b) and (c).

Table 5(a). Error values for the developed correlation models (January)

	JANUARY							
Statistical parameters	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
MBE	-0.0001	-0.0003	-0.0003	-0.0001	0.0000	0.0000	0.0000	0.0000
MPE	-0.0005	-0.0014	-0.0016	-0.0003	0.0000	0.0000	-0.0001	0.0000
RMSE	0.0005	0.0015	0.0017	0.0003	0.0000	0.0000	0.0001	0.0000
R^2	0.9710	0.9710	0.9720	0.9710	0.9700	0.9700	0.9690	0.9750
t-stat	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 5(b). Error values for the developed correlation models (June)

	JUNE							
Statistical parameters	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
MBE	0.0002	-0.0004	-0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
MPE	0.0010	-0.0023	-0.0008	0.0002	-0.0001	0.0001	0.0005	0.0001
RMSE	0.0009	0.0021	0.0007	0.0002	0.00006	0.00011	0.00050	0.00005
R^2	1.0000	1.0000	1.0000	0.9970	0.99300	0.99900	0.99800	1.00000
t-stat	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 5(c). Error values for the developed correlation models (November)

NOVEMBER								
Statistical parameters	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
MBE	0.0000	0.0000	0.0003	0.0001	0.0000	-0.0001	-0.0001	-0.0001
MPE	-0.0002	-0.0002	0.0015	0.0003	0.0000	-0.0004	-0.0003	-0.0005
RMSE	0.0002	0.0002	0.0016	0.0003	0.0000	0.0004	0.0004	0.0005
R^2	0.9728	0.9765	0.9782	0.9769	0.9769	0.9683	0.9683	0.9740
t-stat	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

It was found that the *MPEs* of all eight models were in the range of acceptable values between -0.0016% to zero for January, -0.0023% to 0.0005% for June and -0.0005% to 0.0015% for November. All models also have very low *RMSE* values that range from zero to 0.0017% for January, zero to 0.0001 for June and zero to 0.002 for November. Also the *MBE* values of all models are approximately equal to zero while the values of *t*-test were always equal to one. Similar trends were seen for all other months not shown here. The comparison between the different models according to the *t* values show that the calculated *t* values were less than the critical *t* values. These results show that all eight models have statistical significance. The R^2 values were also high (above 0.95) for all models. This means that the models obtained are reasonably compatible with the measured data. Following the analysis above, all eight models for each month are excellent indicators for predicting mean daily global solar radiation at Wa Polytechnic.Hence, the model equations are recommended for use to estimate the daily global solar radiation at Wa Polytechnic and other locations that have similar climate, latitude and altitude as WaPolytechnic. The measured H/H_o and calculated H/H_o values of the mean daily global solar radiation using the eight models are illustrated in Figs. 1: (a), (b) and (c) for January, June and November respectively.

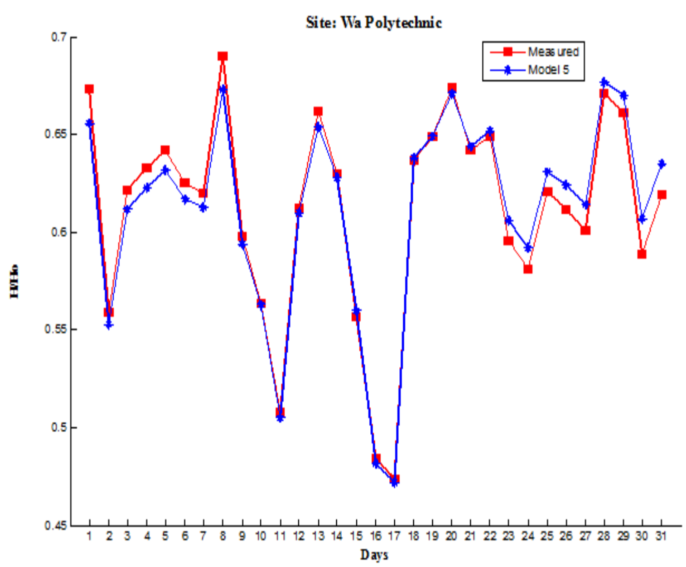

Fig. 1. Comparison of measured and estimated (H/Ho) for January

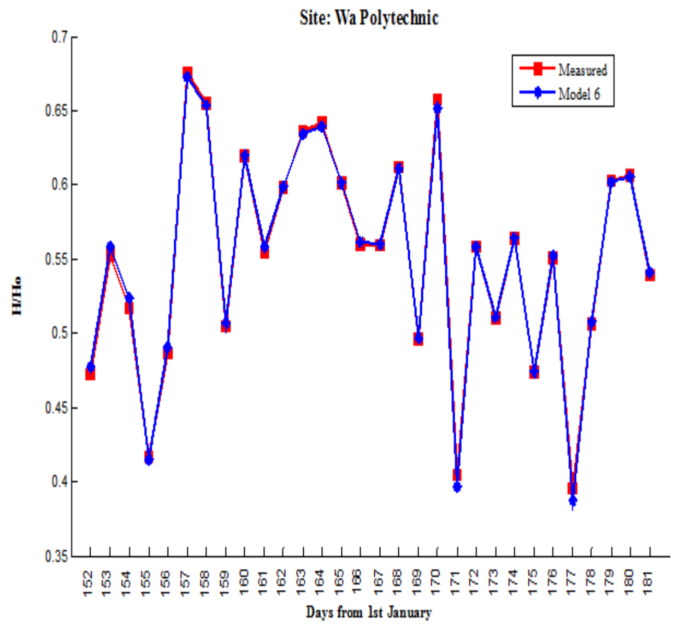

Fig. 2. Comparison of measured and estimated (H/Ho) for June

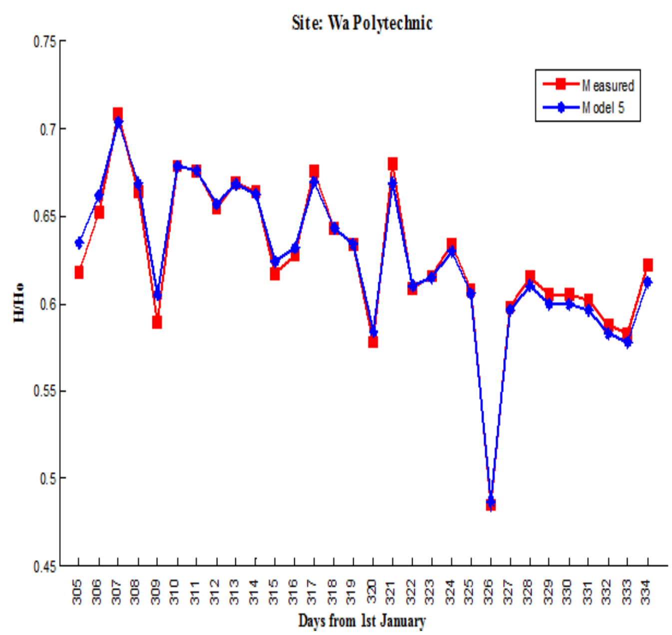

Fig. 3. Comparison of measured and estimated (H/Ho) for November

It is clear from Figs. 1(a), (b) and (c) that there is a good agreement between the estimated values and the measured data for all days of the month. Similar trends were observed for all other months. The above analysis also show that the global solar radiation can be related with the relative sunshine duration. For high accuracy, it is recommended that the following month-specific equations be used to estimate mean daily global solar radiation for Wa Polytechnic site based on statistical results:

$$Jan: H/H_o = 1.0311 + 1.2836\log(n/N) \quad (11)$$

$$Feb: H/H_o = 0.4617 + 0.6018(n/N) + 0.5003\log(n/N) \quad (12)$$

$$Mar: H/H_o = 0.7528 + 0.5244\log(n/N) \quad (13)$$

$$Apr: H/H_o = 0.9659 + 1.2600\log(n/N) \quad (14)$$

$$May: H/H_o = 0.9727 + 1.2331\log(n/N) \quad (15)$$

$$Jun: H/H_o = 0.4880 + 0.6124(n/N) + 0.6061\log(n/N) \quad (16)$$

$$Jul: H/H_o = 0.9440 + 1.1254\log(n/N) \quad (17)$$

$$Aug: H/H_o = 1.1800(n/N)^{0.9550} \quad (18)$$

$$Sep: H/H_o = 0.9167 + 1.0686\log(n/N) \quad (19)$$

$$Oct: H/H_o = -0.6546 + 0.7599\exp(n/N) \quad (20)$$

$$Nov: H/H_o = 1.0041 + 1.2116\log(n/N) \quad (21)$$

$$Dec: H/H_o = 0.8803 - 4.0068(n/N) + 10.7380(n/N)^2 - 7.1976(n/N)^3 \quad (22)$$

The above equations can be used to estimate the daily mean global solar radiation H for the given month for any day of the month. To find the average daily mean global solar radiation H for any month, H can be evaluated for each day of the month using the appropriate equation given above and the average found. To save time in calculations, the following days in Table 6, starting from 1st January, are recommended for the estimation of average global solar radiation for a particular month in Wa Polytechnic site and other locations that have similar climate, latitude and altitude as Wa Polytechnic site knowing the mean bright sunshine hours for that month:

Table 6. Recommended days for the estimation of mean monthly daily global radiation

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day	15	43	62	119	145	175	182	225	273	282	320	343

6 CONCLUSION

The objective of this study was to evaluate various models for the estimation of daily global solar radiation based on sunshine hours for every month and to recommend the most appropriate model for Wa Polytechnic meteorological station. Eight model equations were obtained for each month. The models were compared using the statistical routine. According to the results, all eight model equations for each month, which are based on Angstrom-Prescott model, are in favourable agreement with the measured values. [18] model in the form $H/H_o = a + b(n/N) + clog(n/N)$is recommended to estimate daily global solar radiation on a horizontal surface for the months of February and June. [9] exponential model $H/H_o = a + (n/N)^b$is recommended for use in August and his linear exponential model $H/H_o = a + b(n/N) + cexp(n/N)$ is recommended for use in October. For the month of December, the cubic model by [17] is recommended. The regression equation of the form $H/H_o = a + blog(n/N)$proposed by [19] is extremely recommended to estimate the mean daily global solar radiation for all other months for Wa Polytechnic site and in elsewhere with similar climatic conditions where radiation data are unavailable.

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