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Sunshine-based global radiation models: A review and case study

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ABSTRACT

Many empirical correlations and models have been developed to estimate solar radiation around the world. The most commonly used parameter for estimating global solar radiation is sunshine duration because it can be easily and reliably measured, and data are widely available. In this paper, we report the performance of 52 sunshine models for the estimation of the monthly mean global solar radiation on horizontal surfaces in Jouf, Saudi Arabia (29°47′N, 40°06′E, altitude 670 m). Some models are totally unsuitable for use in this region, and others vary in performance. The best models are identified.

1. Introduction

Knowledge of solar radiation data is necessary for many solar-energy applications, including the design and analysis of energy-conversion devices and architectural design. Unfortunately, solar radiation data are not easily available for many developing countries because of the cost of measuring equipment and the maintenance and calibration requirements. In situations for which solar radiation data are scarce, models are commonly used to estimate the data required for solar-energy applications. Therefore, it is important to elaborate methods of estimating solar radiation based on readily available meteorological data. Several empirical models have been developed to estimate global solar radiation (GSR) based on various meteorological and geographical parameters, such as sunshine duration, mean ambient temperature, maximum and minimum ambient temperature, relative humidity, latitude, longitude, altitude and extraterrestrial radiation [1–8].

The most commonly used parameter for estimating GSR is sunshine duration. Sunshine duration can be easily and reliably measured, and data are widely available. Most sunshine-based models for estimating average daily GSR on a monthly basis use a modified Angström-type equation [9–12]. The original Angström regression equation relates monthly average daily radiation to clear-day radiation at the location in question and to the average fraction of possible sunshine hours [9]:

$$\frac{H}{H_\circ} = a + b\left(\frac{S}{S_\circ}\right), \tag{1}$$

where H is the monthly average daily global radiation, $H_\circ$ is the monthly average daily extraterrestrial radiation, S is the monthly average daily hours of bright sunshine, $S_\circ$ is the maximum possible sunshine duration, and a and b are empirical coefficients that can be determined either experimentally or empirically using some well-known models. Several types of regression models (linear, quadratic, third-degree, and logarithmic) have been proposed in the literature for estimating GSR based solely on the $S/S_\circ$ ratio.

The objective of the present study was to test the performance of 52 sunshine-based models against the global radiation measured in Jouf, Saudi Arabia (29°47′N, 40°06′E, altitude 670 m). We believe that Jouf has a clear sky; this may be attributable to the man-made lake nearby, and we also consider it to be a virgin area because it is far from any plants or factories [13] . The objective of our previous study regarding global radiation was to determine the most suitable model for predicting the measured GSR for the capital city Riyadh [14].

2. Models

The various models used to estimate the monthly average daily GSR on a horizontal surface exhibit different forms of dependence on the $S/S_\circ$ ratio. The models can be categorized according to this dependence as follows; see Al-Mostafa et al. [14] and references therein. The models are shown in Table 1.

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Table 1
The relative percentage error for each model for each month during the year in Jouf.

Model	Group	Relative percentage error (%)											
		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
4	1	−1.98	−3.99	−5.15	−0.31	5.83	−1.58	5.35	10.58	5.96	8.11	5.21	9.05
7	1	−0.45	−2.75	−3.82	1.09	7.08	−0.41	6.39	11.56	7.27	9.28	6.51	10.56
10	1	−2.61	−3.73	−5.27	−0.43	6.51	−0.95	6.74	12.39	6.44	9.18	5.69	9.03
12	1	−19.32	−20.44	−21.63	−17.63	−12.07	−18.23	−12.03	−7.46	−12.08	−9.95	−12.70	−9.83
13	1	3.28	1.31	0.02	5.13	11.73	3.91	11.34	16.93	11.84	14.20	11.05	15.02
19	1	−49.53	−46.60	−48.93	−46.32	−39.37	−43.62	−36.39	−31.64	−40.17	−36.35	−40.60	−40.79
21	1	−7.04	−9.33	−10.26	−5.68	−0.22	−7.21	−1.00	3.76	−0.02	1.76	−0.73	3.13
22	1	2.82	−0.28	−1.06	3.99	9.48	1.81	8.16	13.13	9.83	11.40	9.05	13.63
23	1	4.05	4.03	1.88	7.08	15.62	7.52	16.83	23.48	15.29	19.03	14.47	17.40
25	1	−4.04	−4.68	−6.39	−1.61	5.67	−1.73	6.29	12.09	5.50	8.52	4.76	7.79
27	1	−5.98	−6.09	−8.00	−3.30	4.32	−2.98	5.34	11.29	4.05	7.36	3.31	6.01
30	1	−15.85	−16.72	−18.09	−13.91	−7.82	−14.27	−7.53	−2.60	−7.90	−5.46	−8.55	−5.72
31	1	−6.91	−9.89	−10.52	−5.96	−1.15	−8.07	−2.49	1.92	−0.80	0.51	−1.50	2.74
32	1	16.80	16.59	14.25	20.08	29.49	20.42	30.70	38.06	29.16	33.23	28.25	31.63
33	1	11.70	13.86	10.60	16.24	27.49	18.57	30.57	38.83	26.67	32.17	25.77	27.71
34	1	11.80	13.01	10.16	15.79	26.14	17.30	28.44	36.22	25.51	30.37	24.63	27.10
35	1	−14.21	−13.05	−15.34	−11.02	−2.85	−9.65	−0.89	5.20	−3.38	0.51	−4.06	−2.30
39	1	−2.68	−5.33	−6.20	−1.41	4.05	−3.23	3.03	7.88	4.32	6.01	3.59	7.77
40	1	5.61	4.01	2.51	7.74	14.89	6.85	14.83	20.75	14.91	17.61	14.10	17.93
41	1	17.98	16.95	14.94	20.81	29.53	20.46	30.08	37.10	29.38	32.92	28.46	32.33
42	1	−2.68	−5.33	−6.20	−1.41	−0.31	−3.23	3.03	7.88	4.32	6.01	3.59	7.77
44	1	−5.73	−6.42	−8.08	−3.39	3.71	−3.55	4.26	9.93	3.56	6.48	2.82	5.84
45	1	−3.20	−3.74	−5.51	−0.69	6.76	−0.72	7.46	13.37	6.57	9.68	5.81	8.82
48	1	−4.09	−3.32	−5.65	−0.83	7.80	0.25	9.56	16.09	7.32	11.30	6.56	8.83
49	1	−1.35	−1.80	−3.66	1.26	8.95	1.32	9.75	15.83	8.73	11.98	7.96	10.97
50	1	−5.34	−4.88	−7.05	−2.30	5.92	−1.49	7.42	13.71	5.52	9.25	4.77	7.17
51	1	−2.17	−3.94	−5.20	−0.36	5.99	−1.44	5.69	11.03	6.06	8.37	5.31	9.02
52	1	−5.80	−6.97	−8.42	−3.74	2.89	−4.32	3.05	8.47	2.84	5.43	2.11	5.39
2	2	−7.25	−11.68	−11.52	−7.01	−4.20	−10.91	−8.23	−5.79	−3.29	−3.90	−3.97	1.39
5	2	−2.44	−3.98	−5.37	−0.54	6.16	−1.28	6.43	12.17	6.12	8.81	5.37	8.86
8	2	−0.76	−2.89	−4.05	0.85	7.06	−0.44	6.70	12.12	7.17	9.41	6.41	10.31
15	2	5.24	−0.15	0.24	5.35	7.99	0.43	2.61	4.77	9.19	7.93	8.42	14.82
26	2	−2.44	−3.70	−5.05	−0.21	6.13	−1.30	5.01	9.61	6.29	8.19	5.54	9.24
28	2	−5.56	−5.67	−7.51	−2.79	4.57	−2.75	4.79	10.13	4.42	7.26	3.68	6.56
29	2	−7.61	−7.11	−9.22	−4.59	3.40	−3.84	4.65	10.62	3.03	6.55	2.30	4.67
37	2	−59.74	−62.78	−62.29	−60.37	−59.96	−62.77	−61.96	−60.96	−59.43	−60.06	−59.71	−56.92
47	2	−2.97	−3.93	−5.48	−0.66	6.23	−1.21	6.14	11.48	6.20	8.76	5.45	8.79
1	3	−7.55	−11.15	−11.59	−7.08	−2.63	−9.44	−3.90	0.52	−2.25	−0.99	−2.94	1.45
3	3	−7.63	−11.56	−11.71	−7.20	−3.56	−10.31	−6.03	−2.35	−2.92	−2.55	−3.61	1.26
6	3	−1.67	−3.41	−4.59	0.28	6.22	−1.22	4.28	8.09	6.51	7.94	5.75	9.72
11	3	−1.56	−3.41	−4.53	0.34	6.19	−1.24	4.42	8.52	6.49	7.95	5.74	9.77
16	3	5.53	0.10	0.54	5.67	8.12	0.55	2.14	3.79	9.40	7.81	8.63	15.16
20	3	−3.93	−4.94	−6.41	−1.63	4.92	−2.42	4.09	8.73	5.00	7.11	4.26	7.72
24	3	−24.00	−26.84	−26.99	−23.26	−19.88	−25.49	−18.58	−11.38	−19.59	−17.92	−20.16	−16.26
36	3	−12.82	−13.49	−14.44	−10.07	−6.02	−12.60	−13.73	−15.98	−5.04	−6.90	−5.71	−1.54
38	3	40.12	37.00	35.18	42.08	51.80	41.17	54.83	65.78	51.51	56.58	50.43	55.42
9	4	−4.74	−3.80	−6.29	−1.50	7.61	0.08	10.53	17.94	6.94	11.63	6.19	8.12
14	4	3.92	−0.23	−0.51	4.57	8.90	1.27	6.15	10.21	9.58	10.10	8.80	14.13
17	4	2.81	2.45	0.39	5.52	13.94	5.96	15.70	22.77	13.56	17.52	12.76	15.65
18	4	3.83	0.86	0.05	5.16	10.66	2.91	9.01	13.77	11.06	12.48	10.27	14.92
43	4	−2.38	−5.06	−5.92	−1.12	4.35	−2.96	3.31	8.17	4.62	6.30	3.88	8.08
46	4	1.78	0.70	−0.83	4.23	11.13	3.35	10.32	15.36	11.22	13.46	10.44	14.13

- Group 1 (linear models): Group 1 models have a similar form to the Angström-type regression equation. However, the empirical coefficients *a* and *b* differ depending on the results obtained for first-order regression analysis.
- Group 2 (second-order models): Some researchers have used a second-order polynomial equation in terms of the $S/S_\circ$ ratio to estimate the monthly average of the daily GSR on a horizontal surface.
- Group 3 (third-order models): In the group 3 models, the monthly average of the daily GSR is parameterized as a function of third-order dependence on the $S/S_\circ$ ratio.
- Group 4 (other models): This group contains all of the models that differ from groups 1–3. This includes exponential, non-linear and logarithmic functions of the $S/S_\circ$ ratio. The model of Gopinathan (model 46) [6], which is a function of latitude and altitude in addition to the $S/S_\circ$ ratio, is included in this group.

The following models were used in this study:
Model 1: [12]

$$\frac{H}{H_\circ} = 0.6307 - 0.7251\left(\frac{S}{S_\circ}\right) + 1.2089\left(\frac{S}{S_\circ}\right)^2 - 0.4633\left(\frac{S}{S_\circ}\right)^3 \quad (2)$$

Model 2: [15]

$$\frac{H}{H_\circ} = 0.1520 + 1.1334\left(\frac{S}{S_\circ}\right) - 1.1126\left(\frac{S}{S_\circ}\right)^2 + 0.4516\left(\frac{S}{S_\circ}\right)^3 \quad (3)$$

Model 3: [15]

$$\frac{H}{H_\circ} = 0.1874 + 0.8591\left(\frac{S}{S_\circ}\right) - 0.4764\left(\frac{S}{S_\circ}\right)^2 \quad (4)$$

Model 4: [16]