Algerian Journal of Environmental Science and Technology
March edition. Vol.7. Nº1. (2021)
ISSN : 2437-1114
www.aljest.org

The appropriate model for estimating global horizontal solar radiation for desert areas (Case study: Adrar, Algeria)

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ARTICLE INFO

Article History :

Received **: 05/06/2019**
Accepted **: 26/12/2019**

***Key Words*:**

Solar Radiation;
Measurement;
Empirical Models;
Statistical Analysis;
Global Performance Indicator

ABSTRACT/RESUME

Abstract: *In this paper, 50 typical models are chosen from the literature correlating the monthly average daily global radiation on horizontal surface to select an appropriate model for desert areas of Algeria (Case of study: Adrar). Meteorological data was monitored during to 2013-2017 for the city of Adrar (27.88°N, -0.27°E) at the Research Unit in Renewable Energies in Saharan Medium (URER.MS) Adrar. The maximum and minimum monthly average daily global radiations on the horizontal surface were observed in the whole year which reached 29.22 $MJ.m^{-2}.day^{-1}$and 14.94 $MJ.m^{-2}.day^{-1}$respectively. To select the relevant model among all the proposed models in the literature review, statistical parameters were used to analyze and evaluate the models and choose which one the most appropriate to the Adrar region. To demonstrate the performance comparison of the models, statistical formulas are used in this study such as: the mean percentage error (MPE), mean bias error (MBE), root mean square error (RMSE), maximum absolute relative error (erMAX), t-statistics (ts), mean absolute error (MAE), coefficient of determination (R^2) and mean absolute relative error (MARE) test indicators. To strengthen this study we added another specific global performance indicator (GPI), which is considered as an important dependent and useful parameter. The purpose of this comparison is to seek a convenient and accurate model based on the available meteorological data, which through it can estimate the behavior of the global solar radiation in the Adrar region.*

I. Introduction

Solar radiation is the most important renewable energy provenance for many solar applications [39]. For the best exploitation of solar energy, it is needed to value the availability of solar radiation of the interest zone. Bakirci [11] has shown the information importance of solar radiation to evaluate solar devices in exploitation sites. In addition, this information is helpful to produce a long period meteorological prediction of solar energy systems.
Solar radiation is estimated by the processing of satellite images or using pyranometer in meteorological stations [14]. However, because several barriers posed due to lack of required equipment and high cost of process and maintenance of this measurement equipment, the solar radiation data are generally not readily attainable in most countries [24]. Estimation of solar radiation utilizing empirical models is the most adopted technique to evaluate solar energy in the interest zone before setting up solar based equipment. Furthermore, some researchers have developed monthly average global solar radiation models using various approaches including artificial neural networks, classical empirical regression, time-series regression

techniques and autoregressive moving average. The employ of empirical correlation for estimating monthly average daily global solar radiation on horizontal surface had been carried out by Angstrom [45] in 1924. This equation is the best known and it is widely utilized because it's linked to the monthly average daily radiation and clear day radiation in a given site with an average part of possible sunshine hours. In 1940, Angstrom equation has been adapted by Prescott [27], in which he focuses only on the extraterrestrial radiation on the horizontal surface rather than on clear day radiation.
After this period, to estimate the monthly mean daily radiation using available meteorological, geographical and climatologically parameters many models had been suggested and developed through those models (Angstrom-Prescott) such as sunshine hours, air temperature, latitude, precipitation, relative humidity, and cloudiness. The common parameter most used for estimating global solar radiation in literature is the sunshine duration [2]. In the same context, many studies have been done by different authors, in the review literature a comparison of various existing models is used for the assessment of the monthly mean diffuse solar radiation has been carried out for the northern region of India by Jamil and Akhtar [4]. Another analytical conducted study of 101 global solar radiation models, for different regions of the world by Despotovic et al [11] to provide an evaluation, which could be helpful in the chosen of the appropriate and accurate model.
Due to unavailable data of global solar radiation of the most locations in Algeria, Chegaar and Chibani [15] have developed two models for estimating monthly mean daily global radiation on a horizontal surface to four Algerian sites. Mecibah et al [30] have applied 11 models for estimating monthly mean daily global radiation on horizontal surface for six different Algerian areas. A statistical comparison of 10 models has been carried out by Koussa et al [28] for estimating monthly mean daily global solar radiation for three different cities in Algeria (Ghardaia, Adrar and Bouzareah).
The main objective of the current work is to choose a model of global solar radiation appropriate to the Sahara region among 50 proposed models, based on a comparison between different empirical models developed and reported in the literature to assess the monthly mean global solar radiation. The study has been carried out for desert areas in Algeria in Adrar city (27.88°N, -0.27°E and 263m) in the southwest region of Algeria. Continuous measurements during five years (2013-2017) for global solar radiations were carried out and have been reported in the form of monthly mean values.

II. Data and methodology

II.1. Databases employed

Figure 1, presents the used experimental equipment. Where the global radiation data G ($MJ.m^{-2}.day^{-1}$) were observed and recorded using high-quality meteorological equipment station named (NEAL) [12-13], installed in the Research Unit in Renewable Energies in Saharan Medium (URER.MS) ADRAR.

Figure 1.*Meteorological station installed in URERMS Adrar*

The measured values from the data logger were available instantaneously with sampling time of one-minute solar radiation (in W/m2) on horizontal flat surface. The average experimentally results obtained of global solar radiation (G) for five years (2013-2017) are presented in figure 2, with the calculated values of extraterrestrial radiation (G_0). Mean global solar radiation is highest in June with a value of 29.40 $MJ.m^{-2}.day^{-1}$ and has a minimum value of 14.81 $MJ.m^{-2}.day^{-1}$in the month of December. The annual mean global solar radiation values for Adrar are observed as 22.20 $MJ.m^{-2}.day^{-1}$ [21].

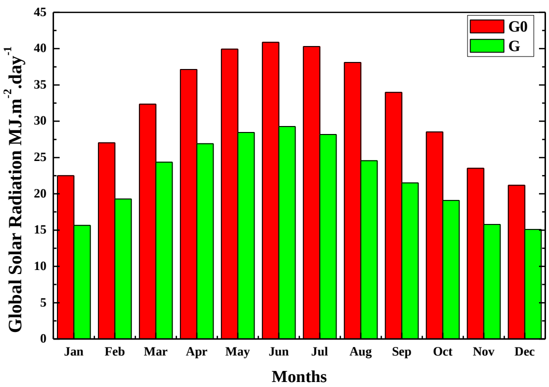

Figure 2. *Monthly average daily global solar radiation for five years (2013-2017) in Adrar city*

The values of the monthly average daily extraterrestrial irradiation (G_0) is computed from the following equation [51].

Algerian Journal of Environmental Science and Technology
March edition. Vol.7. N°1. (2021)
ISSN : 2437-1114
www.aljest.org

$$G_0 = \frac{24}{\pi} I_{sc} \left(1 + 0.033\cos\left(NJ\frac{360}{365}\right)\right)\left(\cos\emptyset \cos\delta \sin\omega_s + \frac{\pi}{180}\omega_s \sin\emptyset \sin\delta\right) \quad \textbf{(1)}$$

Where I_{sc} is the solar constant, ø is the latitude, NJ is the day of the year starting from 1 January, δ is the solar declination, and ω_s is the sunset hour angle.
The solar declination (δ) and the mean sunrise hour angle (ω_s) using the following equations (2) and (3).

$$\delta = 23.45^0 \sin\left(\frac{360(284+NJ)}{365}\right) \quad \textbf{(2)}$$

$$\omega_s = -\tan\emptyset \tan\delta \quad \textbf{(3)}$$

The daily maximum possible sunshine duration S_o is computed using the following equation [8]:

$$S_0 = \frac{2}{15}\omega_s \quad \textbf{(4)}$$

II.2. Selection of models

After realized an extensive review of the models used to estimate the global solar radiation in the literature, 50 models seem to be suitable for use in desert areas. The 50 selected global solar radiation assessment models are presented in Table 1.

Table 1. *The selected models from the literature review*

No	Model	Author
1	$\frac{G}{G_0} = 0.22 + 0.42\frac{S}{S_0}$	Hinrichsen [23]
2	$\frac{G}{G_0} = 0.367 + 0.367\frac{S}{S_0}$	Chegaar and Chibani [15]
3	$\frac{G}{G_0} = 0.233 + 0.591\frac{S}{S_0}$	Chegaar and Chibani [15]
4	$\frac{G}{G_0} = 0.10 + 1.02\frac{S}{S_0} - 0.44\left(\frac{S}{S_0}\right)^2$	Rietveld [42]
5	$\frac{G}{G_0} = 0.14 + 0.57\frac{S}{S_0}$	Lewis [29]
6	$\frac{G}{G_0} = 0.444 + 0.017\frac{S}{S_0} + 0.271\left(\frac{S}{S_0}\right)^2$	El-Sebaii and Trabea [18]
7	$\frac{G}{G_0} = 0.913 - 1.204\frac{S}{S_0} + 1.074\left(\frac{S}{S_0}\right)^2$	El-Sebaii and Trabea [20]
8	$\frac{G}{G_0} = 3.383 - 6.780\frac{S}{S_0} + 4.201\left(\frac{S}{S_0}\right)^2$	El-Sebaii and Trabea [20]
9	$\frac{G}{G_0} = 0.280 + 0.493\frac{S}{S_0}$	Hay [22]
10	$\frac{G}{G_0} = 0.1332 + 0.6471\frac{S}{S_0}$	Jin et al [25]
11	$\frac{G}{G_0} = 0.524 + 0.197\frac{S}{S_0}$	El-Metwally [17]
12	$\frac{G}{G_0} = 0.151 + 0.640\frac{S}{S_0}$	El-Metwally [17]
13	$\frac{G}{G_0} = 0.1840 + 0.6792\frac{S}{S_0} - 0.1228 + \left(\frac{S}{S_0}\right)^2$	Almorox and Hontoria [7]
14	$\frac{G}{G_0} = 0.241 + 0.502\frac{S}{S_0}$	Falayi et al [25]
15	$\frac{G}{G_0} = 0.219 + 0.553\frac{S}{S_0}$	Falayi et al [33]
16	$\frac{G}{G_0} = 0.1541 + 1.1714\frac{S}{S_0} - 0.705\left(\frac{S}{S_0}\right)^2$	Aksoy [6]
17	$\frac{G}{G_0} = 0.1 + 0.874\frac{S}{S_0} - 0.255\left(\frac{S}{S_0}\right)^2$	Said [44]

18	$\frac{G}{G_0} = 0.2416 + 0.6411\frac{S}{S_0}$	Safari and Gasore [43]
19	$\frac{G}{G_0} = 0.29 + 0.42\frac{S}{S_0}$	Augustine and Nnabuchi [9]
20	$\frac{G}{G_0} = 0.148 + 0.668\frac{S}{S_0} - 0.079\left(\frac{S}{S_0}\right)^2$	Aksoy [6]
21	$\frac{G}{G_0} = -0.14 + 2.52\frac{S}{S_0} - 3.71\left(\frac{S}{S_0}\right)^2 + 2.24\left(\frac{S}{S_0}\right)^3$	Samuel [46]
22	$\frac{G}{G_0} = 0.1275 + 0.7251\frac{S}{S_0} - 0.229\left(\frac{S}{S_0}\right)^2 + 0.1837\left(\frac{S}{S_0}\right)^3$	Jin [25]
23	$\frac{G}{G_0} = 0.1401 + 0.6162\frac{S}{S_0} + 0.0351\left(\frac{S}{S_0}\right)^2$	Jin et al [26]
24	$\frac{G}{G_0} = 0.450 + 0.274\frac{S}{S_0}$	Olayinka [37]
25	$\frac{G}{G_0} = 0.219 + 0.638\frac{S}{S_0}$	Olayinka [37]
26	$\frac{G}{G_0} = 0.211 + 0.629\frac{S}{S_0}$	Olayinka [37]
27	$\frac{G}{G_0} = 0.320 + 0.308\frac{S}{S_0}$	Tijiani [49]
28	$\frac{G}{G_0} = 0.2861 + 0.2591\frac{S}{S_0} + 0.6171\left(\frac{S}{S_0}\right)^2 - 0.4834\left(\frac{S}{S_0}\right)^3$	Ulgen and Hepbasli [50]
29	$\frac{G}{G_0} = 0.2120 + 0.8502\frac{S}{S_0} - 0.3254\left(\frac{S}{S_0}\right)^2$	David and Ngwa [16]
30	$\frac{G}{G_0} = 0.2770 + 0.4270\frac{S}{S_0} + 0.5306\left(\frac{S}{S_0}\right)^2 - 0.5374\left(\frac{S}{S_0}\right)^3$	David and Ngwa [16]
31	$\frac{G}{G_0} = -0.6034 + 5.9653\frac{S}{S_0} - 11.3126\left(\frac{S}{S_0}\right)^2 + 7.3260\left(\frac{S}{S_0}\right)^3$	David and Ngwa [16]
32	$\frac{G}{G_0} = 0.1195 + 1.232\frac{S}{S_0} - 0.694\left(\frac{S}{S_0}\right)^2$	Gana and Akpootu [19]
33	$\frac{G}{G_0} = 0.2 + 0.5\frac{S}{S_0}$	Mulaudzi et al [31]
34	$\frac{G}{G_0} = 0.17 + 0.68\frac{S}{S_0}$	Yohanna [52]
35	$\frac{G}{G_0} = 0.22 + 0.46\frac{S}{S_0}$	Mulaudzi et al [31]
36	$\frac{G}{G_0} = 0.3 + 0.4\frac{S}{S_0}$	Mulaudzi et al [31]
37	$\frac{G}{G_0} = 0.7191 - 1.0673\frac{S}{S_0} + 1.1448\left(\frac{S}{S_0}\right)^2$	Singh [47]
38	$\frac{G}{G_0} = 0.119 + 1.234\frac{S}{S_0} - 0.695\left(\frac{S}{S_0}\right)^2$	Gana et al [20]
39	$\frac{G}{G_0} = 0.050 + 0.971\frac{S}{S_0} - 0.2\left(\frac{S}{S_0}\right)^2 + 0.001\left(\frac{S}{S_0}\right)^3$	Nwokoye and Okonkwo [1]
40	$\frac{G}{G_0} = 0.7191 - 1.0673\frac{S}{S_0} + 1.1448\left(\frac{S}{S_0}\right)^2$	Singh [47]
41	$\frac{G}{G_0} = 0.69 - 0.158\frac{S}{S_0}$	Ogolo [35]
42	$\frac{G}{G_0} = 0.348 + 0.320\frac{S}{S_0} + 0.07\left(\frac{S}{S_0}\right)^2$	Ahmad [4]
43	$\frac{G}{G_0} = 0.15 + 1.145\frac{S}{S_0} - 1.474\left(\frac{S}{S_0}\right)^2 + 0.963\left(\frac{S}{S_0}\right)^3$	Rensheng [41]
44	$\frac{G}{G_0} = 0.3465 + 0.352\frac{S}{S_0}$	Rehman [40]

Algerian Journal of Environmental Science and Technology
March edition. Vol.7. Nº1. (2021)
ISSN : 2437-1114
www.aljest.org

45	$\frac{G}{G_0} = 0.195 + 0.676\frac{S}{S_0} - 0.142\left(\frac{s}{s_0}\right)^2$	Ögelman [34]
46	$\frac{G}{G_0} = 0.231 + 0.463\frac{S}{S_0} - 0.044\left(\frac{s}{s_0}\right)^2$	Okonkwo and M.Sc [36]
47	$\frac{G}{G_0} = 0.0801589 + 0.7092\frac{S}{S_0}$	Ouali and Alkama [38]
48	$\frac{G}{G_0} = 0.22 + 0.43\frac{S}{S_0}$	Ouali and Alkama [38]
49	$\frac{G}{G_0} = 0.15 + 1.145\frac{S}{S_0} - 1.474\left(\frac{s}{s_0}\right)^2 + 0.963\left(\frac{s}{s_0}\right)^3$	Rensheng et al [41]
50	$\frac{G}{G_0} = 0.212 + 0.512\frac{S}{S_0}$	Adeala et al [3]

II.3. Statistical error analysis

The performance of each selected model was analyzed and evaluated in this section based on different statistical parameters [50-52]. The statistical parameters used in this evaluation are the most relevant and appropriate such as the root mean square error (RMSE), mean bias error (MBE), t-statistics (ts), maximum absolute relative error (erMAX), mean percentage error (MPE), mean absolute error (MAE), and mean absolute relative error (MARE) and coefficient of determination (R^2) test indicators. The mathematical formulae of the used statistical parameters are described below:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(G_{i,c} - G_{i,m})^2\right]^{\frac{1}{2}} \quad \textbf{(5)}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(G_{i,c} - G_{i,m}) \quad \textbf{(6)}$$

$$ts = \sqrt{\frac{(N-1)MBE^2}{RMSE^2 - MBE^2}} \quad \textbf{(7)}$$

$$erMax = max\left[\left|\frac{G_{i,m} - G_{i,c}}{G_{i,m}}\right|\right] \quad \textbf{(8)}$$

$$MPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{G_{i,m} - G_{i,c}}{G_{i,m}}\right) \times 100 \quad \textbf{(9)}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}(|G_{i,c} - G_{i,m}|) \quad \textbf{(10)}$$

$$MARE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{G_{i,m} - G_{i,c}}{G_{i,m}}\right| \quad \textbf{(11)}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(G_{i,c} - G_{i,m})^2}{\sum_{i=1}^{N}(G_{i,m} - G_{m,av})^2} \quad \textbf{(12)}$$

Where N is the total number of available data points, $G_{m,av}$ is the average of measured values of solar radiation ($MJ.m^{-2}.day^{-1}$), $G_{i,c}$ and $G_{i,m}$ are the estimated and measured monthly mean daily solar radiation ($MJ.m^{-2}.day^{-1}$) respectively.

Table 2. *Values of the statistical analysis based on the selected models*

Models	**MBE**	**RMSE**	**ts**	**MPE**	**Ermax**	**MAE**	**MARE**	**R²**	**GPI**	**Rank**
1	-4.584	4.775	16.427	20.215	0.246	4.584	0.202	0.132	-24.11	50
2	-1.212	1.383	8.718	5.069	0.084	1.212	0.051	0.927	3.24	23
3	0.188	**0.660**	1.422	-1.221	0.079	**0.533**	0.026	**0.983**	16.92	1
4	-2.149	2.304	12.368	9.293	0.132	2.149	0.093	0.798	-5.77	36
5	-3.334	3.544	13.321	14.599	0.211	3.334	0.146	0.522	-13.68	44
6	-2.115	2.279	11.955	9.114	0.136	2.115	0.091	0.802	-5.15	35
7	-1.738	1.932	9.877	7.391	0.124	1.738	0.074	0.858	-0.92	29
8	-0.505	2.365	1.049	1.759	0.244	2.039	0.090	0.787	11.37	8
9	-0.798	1.013	6.129	3.208	0.083	0.865	0.036	0.961	8.05	13
10	-1.590	1.879	7.602	6.761	0.142	1.608	0.069	0.866	2.02	24
11	-0.497	0.961	2.901	1.863	0.081	0.794	0.034	0.965	12.45	6
12	-1.199	1.515	6.207	5.005	0.123	1.275	0.055	0.913	5.55	17

13	-1.649	1.821	10.224	7.034	0.122	1.649	0.070	0.874	-0.78	28
14	-1.822	1.999	10.612	7.805	0.132	1.822	0.078	0.848	-2.16	30
15	-1.230	1.455	7.590	5.146	0.112	1.255	0.053	0.920	4.16	21
16	-1.969	2.297	7.982	8.499	0.171	1.978	0.085	0.799	-0.62	27
17	-2.087	2.252	11.822	9.008	0.140	2.087	0.090	0.807	-4.88	33
18	1.739	1.857	12.825	-8.193	0.155	1.739	0.082	0.869	8.29	12
19	-2.336	2.494	12.817	10.116	0.143	2.336	0.101	0.763	-7.29	39
20	-2.196	2.390	11.165	9.488	0.155	2.196	0.095	0.783	-4.89	34
21	-1.349	1.969	4.513	5.621	0.159	1.612	0.072	0.852	5.88	16
22	-1.420	1.795	6.211	5.993	0.142	1.500	0.065	0.877	4.21	20
23	-1.438	1.767	6.717	6.077	0.138	1.491	0.064	0.881	3.69	22
24	-0.914	1.163	6.093	3.732	0.085	0.961	0.040	0.949	7.41	14
25	0.935	1.151	6.675	-4.577	0.120	1.015	0.049	0.950	13.20	5
26	0.449	0.822	3.123	-2.394	0.098	0.718	0.035	0.974	15.74	4
27	-4.224	4.409	16.029	18.599	0.214	4.224	0.186	0.260	-21.56	48
28	-1.961	2.117	11.781	8.453	0.126	1.961	0.085	0.829	-4.11	32
29	-0.534	0.777	4.535	2.035	**0.064**	0.623	**0.026**	0.977	11.07	9
30	-0.639	0.927	4.570	2.526	0.086	0.723	0.030	0.967	10.36	10
31	0.455	3.827	0.574	-2.660	0.450	3.173	0.148	0.443	12.10	7
32	-1.312	1.625	6.569	5.549	0.132	1.354	0.058	0.900	4.55	19
33	-0.970	1.218	6.325	3.986	0.089	1.013	0.042	0.944	6.86	15
34	-0.734	0.945	5.925	2.924	0.065	0.774	0.032	0.966	8.66	11
35	-3.189	3.372	13.969	13.950	0.194	3.189	0.140	0.567	-13.44	43
36	0.430	0.919	2.541	-2.312	0.107	0.821	0.040	0.968	16.04	3
37	-3.565	3.744	14.955	15.640	0.205	3.565	0.156	0.466	-16.61	45
38	-2.524	2.682	13.328	10.961	0.149	2.524	0.110	0.726	-8.88	40
39	-3.039	3.349	10.349	13.229	0.219	3.039	0.132	0.573	-9.08	41
40	-1.298	1.612	6.513	5.485	0.131	1.341	0.057	0.901	4.68	18
41	**-0.083**	0.827	**0.487**	**0.002**	0.077	0.639	0.031	0.974	16.61	2
42	-3.039	3.349	10.349	13.229	0.219	3.039	0.132	0.573	-9.08	42
43	-1.589	1.750	10.397	6.760	0.111	1.589	0.068	0.883	-0.58	26
44	-2.527	2.768	10.728	10.944	0.180	2.527	0.109	0.708	-6.40	37
45	-2.252	2.411	12.530	9.743	0.130	2.252	0.097	0.779	-6.51	38
46	-1.769	1.930	10.998	7.576	0.122	1.769	0.076	0.858	-2.22	31
47	-3.940	4.119	15.728	17.325	0.216	3.940	0.173	0.354	-19.59	46
48	-4.034	4.213	15.932	17.749	0.218	4.034	0.178	0.324	-20.35	47
49	-1.712	2.062	7.140	7.310	0.156	1.741	0.075	0.838	1.69	25
50	-4.329	4.517	16.115	19.071	0.236	4.329	0.191	0.223	-22.29	49

Algerian Journal of Environmental Science and Technology
March edition. Vol.7. Nº1. (2021)
ISSN : 2437-1114
www.aljest.org

III. Results and discussion

The analysis of 50 considered models from the literature review has been performed using 8 statistical indicators to determine which model is suitable to assess the global solar radiation in the Sahara region south of Algeria. To obtain the best estimation, all statistical error indicators mast behave a minimal absolute value except the excluding the R^2, for which a value of 1 which represents the best correlation between the estimated and measured values and there is no correlation when R^2 around zero. According to the obtained results presented in Table 2, there is no model can satisfy all used statistical indicators, but some of them satisfy the 2 or 3 of these indicators. The performance is based on used indicators; only 3 models are candidates to represent the behavior of the global solar irradiance in the desert region according to the optimized values of the statistical indicators chosen in this study. The model 41 exhibit minimum values of MBE= -0.0834, MPE=0.0021, ts= 0.4865 but the other indicators still not good enough compared to the other models. Model 3 shows the best performance based on the indicators RMSE=0.6601, MAE=0.5332 and R^2=0.9834. However, the best values of erMAX and MARE have been achieved by the model 29 with 0.0635 and 0.0256 respectively. Therefore, it is difficult to choose the suitable model only based on the indicative values of statistical indicators. In this regard, global performance indicator (GPI) is used to allow choosing the appropriate model. The mathematical expression of GPI_i of the i^{th} model is defined as [10]:

$$GPI_i = \sum_{j=1}^{8} \alpha_j \left(\bar{z}_j - \bar{z}_{i,j}\right) \qquad \textbf{(13)}$$

Where α_j equals one for the seven indicators (MBE, RMSE, ts, MPE, Ermax, MAE and MARE) and R^2 equal to -1. The $\bar{z}_j$ is the median of scaled values of indicator j, $\bar{z}_{i,j}$ is the scaled value of indicator j for the i^{th} model.

The GPI represents the weighs of each statistical indicator equally and shows the deviation of the scaled values from the median. Its value would be negative for any model if most of the scaled statistical indicators for the model were lower than their corresponding median values, which means a poor estimation capability of the models. Similarly for an overall positive GPI, major of the scaled statistical indicators for that model are higher than their corresponding median values. The good comparison tool to assess a model that combines all the individual performance parameter is GPI indicator.

The compared values of the global solar radiation models ranking are done based on GPI. Table 2. Model 3 presents the best performance model with GPI equal to 16.92. Model 1 shows the last ranking with worst GPI equal to –24.11.

Figure 3, represents a comparison between the monthly average measured data for global solar radiation and model 3.

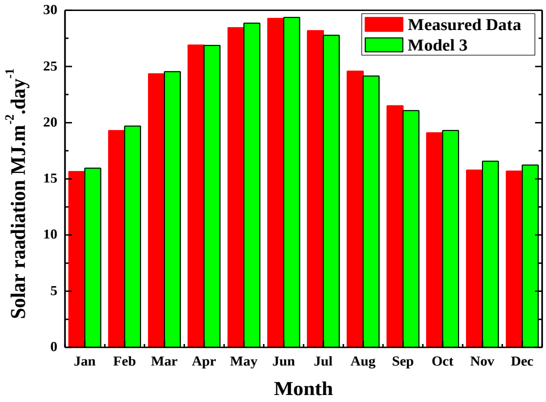

Figure 3.*Monthly average measured data and selected model 3 of global solar radiation*

IV. Conclusion

The objective of this study is the proposition and selected a mathematical model of the global solar radiation in the Sahara region, based on a comparison between 50 empirical models reported in the literature to assess of the monthly mean global solar radiation. The meteorological data in Adrar City located at (27.88°N,-0.27°E, and 263 m) are measured through during five years 2013-2017. A statistical evaluation of these 50 models is performed. The studied region is classified as a 'BWh' hot arid desertic climatic according to the most widely used climate classification systems (Köppen-Geiger climate classification system).

Some statistical indicators were used such as (mean bias error (MBE), root mean square error (RMSE), t-statistic (ts), mean percentage error (MPE), maximum absolute relative error (erMAX), mean absolute error (MAE), coefficient of determination (R^2) and Mean absolute relative error (MARE) test indicators.

Through the obtained results of statistical indicators, the conducted analysis showed an extensive distinction of indicators. Based on the values of statistical errors, no model satisfied all the statistical inducers used in this study (MBE, RMSE, ts, MPE, Ermax, MAE, MARE and R^2) and the best model cannot be chosen based on these inducers. The analyzing global performance indicator (GPI) was done that is helped to rank all models effectively and to decide which one the best accurate model.

The selected model corresponds to the best estimation accuracy of global solar radiation in the region of Adrar is the model presented by Chegaar and Chibani [15] equation (14) with a GPI =16.92.

$$\frac{G}{G_0} = 0.233 + 0.591\frac{S}{S_0} \qquad \textbf{(14)}$$

V. References

1. Nwokoye, A.; Okonkwo, G. Testing the Predictive Efficiencies of Four Angstrom-Type Models for estimating Solar Radiation in Bida Nigeria. *IOSR Journal of Applied Physics 6* (2014) 15–17.
2. Achour, L.; Bouharkat, M.; Assas, O.; Behar, O. Hybrid model for estimating monthly global solar radiation for the Southern of Algeria: (Case study: Tamanrasset, Algeria). *Energy 135* (2017) 526–539.
3. Adeala, A.; Huan, Z.; Enweremadu, C. Evaluation of global solar radiation using multiple weather parameters as predictors for South Africa provinces. *Thermal Science 19* (2015) 495–509.
4. Ahmad, F. Empirical Models for the Correlation of Monthly Average Daily Global Solar Radiation with Hours of Sunshine on a Horizontal Surface at Karachi, Pakistan. *Turk J Phys 28* (2004) 301–307.
5. Ajayi, O.O.; Ohijeagbon, O.D.; Nwadialo, C.E.; Olasope, O. New model to estimate daily global solar radiation over Nigeria. *Sustainable Energy Technologies and Assessments 5* (2014) 28–36.
6. Aksoy, B. Estimated monthly average global radiation for Turkey and its comparison with observations. *Renewable Energy 10* (1997) 625–633.
7. Almorox, J.; Hontoria, C. Global solar radiation estimation using sunshine duration in Spain. *Energy Conversion and Management 45* (2004) 1529–1535.
8. Aoun, N.; Bouchouicha, K. Simple Correlation Models for Estimation of Horizontal Global Solar Radiation for Oran, Northwest Algeria. *International Journal of Engineering Research in Africa 32* (2017) 124–132.
9. Augustine, C.; Nnabuchi, M. Analysis of some meteorological data for some selected Cities in the Eastern and Southern zone of Nigeria. *African Journal of Environmental Science and Technology 4* (2007) 092–099.
10. Bailek, N.; Bouchouicha, K.; Al-Mostafa, Z.; El-Shimy, M.; Aoun, N.; Slimani, A.; Al-Shehri, S. A new empirical model for forecasting the diffuse solar radiation over Sahara in the Algerian Big South. *Renewable Energy 117* (2018) 530–537.
11. Bakirci, K. Models of solar radiation with hours of bright sunshine: A review. *Renewable and Sustainable Energy Reviews 13* (2009) 2580–2588.
12. Behar, O.; Khellaf, A.; Mohammedi, K. Comparison of solar radiation models and their validation under Algerian climate – The case of direct irradiance. *Energy Conversion and Management 98* (2015) 236–251.
13. Bouraiou, A.; Hamouda, M.; Chaker, A.; Mostefaoui, M.; Lachtar, S.; Sadok, M.; Boutasseta, N.; Othmani, M.; Issam, A. Analysis and evaluation of the impact of climatic conditions on the photovoltaic modules performance in the desert environment. *Energy Conversion and Management 106* (2015) 1345–1355.
14. Chaiyapinunt, S.; Ruttanasupa, P.; Ariyapoonpong, V.; Duanmeesook, K. A shadow-ring device for measuring diffuse solar radiation on a vertical surface in a tropical zone. *Solar Energy 136* (2016) 629–638.
15. Chegaar, M.; Chibani, A. Global solar radiation estimation in Algeria. *Energy Conversion and Management 42* (2001) 967–973.
16. David, A.; Ngwa, N.R. Global Solar Radiation of Some Regions of Cameroon Using the Linear Angstrom and Non-Linear Polynomial Relations (Part I) Model Development. *International Journal of Renewable Energy Research (IJRER) 3* (2013) 984–992.
17. El-Metwally, M. Sunshine and global solar radiation estimation at different sites in Egypt. *Journal of Atmospheric and Solar-Terrestrial Physics 67* (2005) 1331–1342.
18. El-Sebaii, A.A.; Trabea, A.A. Estimation of Global Solar Radiation on Horizontal Surfaces Over Egypt. *Egypt. J. Solids 28* (2005) 163–175.
19. Gana, N.N.; Akpootu, D.O. Angstrom Type Empirical Correlation for Estimating Global Solar Radiation in North-Eastern Nigeria. *The International Journal Of Engineering And Science* (2013) 2319–1813.
20. Gana, N.N.; Rai, J.K.; Momoh, M. Angstrom Constants for Estimating Solar Radiation in Sokoto, North-Western, Nigeria. *International Journal of Scientific & Engineering Research 5* (2014) 1636–1647.
21. Guermoui, M.; Rabehi, A.; Gairaa, K.; Benkaciali, S. Support vector regression methodology for estimating global solar radiation in Algeria. *The European Physical Journal Plus 133* (2018) 22.
22. Hay, J.E. Calculation of monthly mean solar radiation for horizontal and inclined surfaces. *Solar Energy 23* (1979) 301–307.
23. Hinrichsen, K. The Ångström formula with coefficients having a physical meaning. *Solar Energy 52* (1994) 491–495.
24. Jamil, B.; Akhtar, N. Comparison of empirical models to estimate monthly mean diffuse solar radiation from measured data: Case study for humid-subtropical climatic region of India. *Renewable and Sustainable Energy Reviews 77* (2017) 1326–1342.
25. Jin, Z.; Yezheng, W.; Gang, Y. General formula for estimation of monthly average daily global solar radiation in China. *Energy Conversion and Management 46* (2005) 257–268.
26. Jin, Z.; Yezheng, W.; Gang, Y. General formula for estimation of monthly average daily global solar radiation in China. *Energy Conversion and Management 46* (2005) 257–268.
27. Katiyar, A.K.; Pandey, C.K. A Review of Solar Radiation Models—Part I. *Journal of Renewable Energy 2013* (2013) 1–11.
28. Koussa, M.; Malek, A.; Haddadi, M. Statistical comparison of monthly mean hourly and daily diffuse and global solar irradiation models and a Simulink program development for various Algerian climates. *Energy Conversion and Management 50* (2009) 1227–1235.
29. Lewis, G. An empirical relation for estimating global

Algerian Journal of Environmental Science and Technology
March edition. Vol.7. Nº1. (2021)
ISSN : 2437-1114
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irradiation for Tennessee, U.S.A. *Energy Conversion and Management 33* (1992) 1097–1099.

30. Mecibah, M.S.; Boukelia, T.E.; Tahtah, R.; Gairaa, K. Introducing the best model for estimation the monthly mean daily global solar radiation on a horizontal surface (Case study: Algeria). *Renewable and Sustainable Energy Reviews 36* (2014) 194–202.
31. Mulandzi ST; Sankarau V; Lysko MD. Solar radiation analysis and regression coefficients for the Vhembe Region, Limpopo Province, South Africa. *Journal of Energy in Southern Africa 24* (2013) 02–07.
32. Necaibia, A.; Bouraiou, A.; Ziane, A.; Sahouane, N.; Hassani, S.; Mostefaoui, M.; Dabou, R.; Mouhadjer, S. Analytical assessment of the outdoor performance and efficiency of grid-tied photovoltaic system under hot dry climate in the south of Algeria. *Energy Conversion and Management 171* (2018) 778–786.
33. O, F.E.; O, A.J.; B, R.A. Empirical models for the correlation of global solar radiation with meteorological data for Iseyin, Nigeria. *International Journal of Physical Sciences 3* (2008) 210–216.
34. Ögelman, H.; Ecevit, A.; Tasdemiroğlu, E. A new method for estimating solar radiation from bright sunshine data. *Solar Energy 33* (1984) 619–625.
35. Ogolo, E.O. Estimation of global solar radiation in Nigeria using a modified Angstrom model and the trend analysis of the allied meteorological components. *Indian Journal of Radio & Space Physics 43* (2014) 213–224.
36. Okonkwo, G.N.; M.Sc. Estimating global solar radiation from temperature data in minna location. *European Scientific Journal, ESJ 10* (2014) 254–264.
37. Olayinka, S. Estimation of global and diffuse solar radiations for selected cities in Nigeria. *International Journal of Energy and Environmental Engineering 2* (2011) 13–33.
38. Ouali, K.; Alkama, R. A new model of global solar radiation based on meteorological data in Bejaia City (Algeria). In *Energy Procedia*Elsevier, 2014, pp. 670–676.
39. Quej, V.H.; Almorox, J.; Arnaldo, J.A.; Saito, L. ANFIS, SVM and ANN soft-computing techniques to estimate daily global solar radiation in a warm sub-humid environment. *Journal of Atmospheric and Solar-Terrestrial Physics 155* (2017) 62–70.
40. Rehman, S. Solar radiation over Saudi Arabia and comparisons with empirical models. *Energy 23* (1998) 1077–1082.
41. Rensheng, C.; Shihua, L.; Ersi, K.; Jianping, Y.; Xibin, J. Estimating daily global radiation using two types of revised models in China. *Energy Conversion and Management 47* (2006) 865–878.
42. Rietveld, M.R. A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine. *Agricultural Meteorology 19* (1978) 243–252.
43. Safari, B.; Gasore, J. Estimation of Global Solar Radiation in Rwanda Using Empirical Models. *Asian Journal of Scientific Research 2* (2009) 68–75.
44. Said, R.; Mansor, M.; Abuain, T. Estimation of global and diffuse radiation at Tripoli. *Renewable Energy 14* (1998) 221–227.
45. Salima, G.; M. S. Chavula, G. Determining Angstrom Constants for Estimating Solar Radiation in Malawi. *International Journal of Geosciences 03* (2012) 391–397.
46. Samuel, T.D.M.A. Estimation of global radiation for Sri Lanka. *Solar Energy 47* (1991) 333–337.
47. Singh, O.P.; Srivastava, S.K.; Gaur, A. Empirical relationship to estimate global radiation from hours of sunshine. *Energy Conversion and Management 37* (1996) 501–504.
48. Stone, R.J. Improved statistical procedure for the evaluation of solar radiation estimation models. *Solar Energy 51* (1993) 289–291.
49. Tijjani, B. Comparison between First and Second Order Angstron Type Models for Sunshine Hours of Katsina, Nigeria. *Bayero Journal of Pure and Applied Sciences 4* (2012).
50. ULGEN, K.; HEPBASLI, A. Solar Radiation Models. Part 2: Comparison and Developing New Models. *Energy Sources 26* (2004) 521–530.
51. Yaniktepe, B.; Genc, Y.A. Establishing new model for predicting the global solar radiation on horizontal surface. *International Journal of Hydrogen Energy 40* (2015) 15278–15283.
52. Yohanna, J.K.; Itodo, I.N.; Umogbai, V.I. A model for determining the global solar radiation for Makurdi, Nigeria. *Renewable Energy 36* (2011) 1989–1992.

Please cite this Article as:
Babahadj A., Rahmani L., Necaibia A., Bouchouicha K., The appropriate model for estimating global horizontal solar radiation for desert areas (Case study: Adrar, Algeria), ***Algerian J. Env. Sc. Technology***, ***7***:**1 (2021) 1760-1768**