Study of the statistical indicators of global solar radiation in Algeria using the Angström model

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***Abstract*— This study was conducted to estimate the monthly global solar radiation in the Algerian territory using the Angström model, for seven sites in Algeria, namely: Algiers, Ain Bessem, Constantine , Oran, Djelfa, Mascara, and Tamanrasset. The models are based on global solar radiation in the horizontal surface as well as sunshine hours .**

To evaluate the results obtained by the different sites we calculated the following relative average algebraic differences: MAE, MBE and RMSE

The results show a remarkable agreement between the measured and computed values, especially in Tamanrasset site where the slope is of the order of 1.

Keywords*— *Solar radiation, Angström equation, modeling, Algeria

I. Introduction

The amount of solar radiation received throughout the Algerian territory exceeds 2000 hours per year [1] which represents a high average [2, 3] compared to the countries of the world. To exploit this energy as a source of photovoltaic systems or thermal photos [4-7], it is necessary to know the quantity of the solar radiation received by the different regions of the Algerian territory. The best source of this information is the data measured using the pyranometer.

The lack of means of measurement, the unavailability of meteorological stations all over, and the surface area of the studied regions, all these represent difficulties which obliged the researchers in the different countries of the world to develop models aiming to estimate global solar radiation at any site. In this work the model is presented based on the linear Angström equation. The equations developed by the researchers to estimate the amount of global solar radiation for different sites in the Algerian territory.

II. Statistical methods.

In this work, we are interested in these methods. They have been used for the development of solar radiation estimation models in Algeria. These methods use statistical relationships between radiation and insolation [8-12],we present a review of different models used.

A. Linear relationships

Linear relationships between daily and monthly solar radiation with sunstroke are considered the simplest and best models for estimating solar radiation on a horizontal plane in sites where measuring stations are available, they can be applied in sites with the same climate and measured values are unavailable.

The constants of these mathematical relations are coefficients, which are based on the climate of the studied area; they are well represented by the Angström model .

B. Applied model

For the evaluation of the global solar irradiation on the chosen sites in our work, we chose the Angström model.

- Angström model [13]: is the first model used, it is given by the relation :

$$\frac{G}{G_0} = a + b\left(\frac{S}{S_0}\right) \qquad (1)$$

G: The average monthly global radiation measured on a horizontal plane ($MJ.m^{-2}.j^{-1}$).

G_0: The monthly average global radiation outside the atmosphere on a horizontal plane ($MJ.m^{-2}.j^{-1}$). It is calculated by the equation [14]:

$$G_0=24/\pi(1+0.033\cos 360/365)(\cos\lambda\cos\delta\sin w)+2\pi/360(w\sin\lambda\sin\delta) \qquad (3)$$

where I_0 is the solar constant, is equal to 1367 Wm^{-2}, λ is the latitude of the place, w: the hour angle, δ is the declination, it is given by [15]:

$$\delta = 23.45\left[\sin\frac{360(284+n)}{365}\right] \qquad (4)$$

$$\omega = \cos^{-1}(-\tan\lambda \tan\delta) \quad (5)$$

n : The number of the day of the year from the first of January

S : The duration of the effective sunshine

S_0 : The maximum duration of sunshine or duration of the day, its expression is [16-18]:

$$S_0 = \frac{2}{15}\omega \quad (6)$$

C. Statistical indicators Statistical indicators

To determine the constants a and b of equations (2), (3) and (4), we calculated the rate (G/G_0) and (S/S_0) for each day and month for the different sites.

To evaluate the results obtained by the different models we calculated the following relative average algebraic differences:

- MAE (Mean Absolute Error): measures the average magnitude of errors in a series of forecasts, regardless of direction. It measures precision for continuous variables, its expression is given by [19]:

$$MAE = \sum_{1}^{N} \left| G_{i,m} - G_{i,c} \right| / N \quad (7)$$

MBE (Mean Bias Error): provides information on the long-term performance of expressions, offering information regarding more or underestimation of estimated data, given by [21-22] :

$$MBE = \sum_{1}^{N} (G_{i,m} - G_{i,c}) / N \quad (8)$$

- Root Mean Square Error (RMSE): provides information on short-term performance by comparing the difference between estimated and measured values. The smaller the value, the better the model, given by the relationship [20-21] :

$$RMSE = \left[\sum_{1}^{N} \left(\left| \left(G_{i,m} - G_{i,c} \right) \right| \right)^2 / N \right]^{\frac{1}{2}} \quad (9)$$

Where m is the number of measures considered.

III. STUDIED SITES

A. Geographical coordinates

For this study we have chosen seven sites: Algiers, Ain Bessem, Constantine , Oran, Djelfa, Mascara, and Tamanrasset and this given the availability of measured data of global radiation. Measured values of solar radiation have been provided of metronome data source in addition, they cover a considerable area of Algerian territory, recalling that:

- Algiers representing the north,
- Constantine representing the east,
- Oran and Mascara are sites in western Algeria,
- Djelfa and Ain Bessem represent southern Algeria
- Tamanrasset represents the south.

Table 1 represents the geographical coordinates of these sites.

TABLE I. GEOGRAPHICAL COORDINATES OF THE SITES CHOSEN FOR THE STUDY

Station	Latitude (deg)(N)	Altitude (m)	Longitude (deg)
Oran	35.38	99	0.37W
Djelfa	34.68	1126	3.25E
Ain Bessem	36.31	629	3.67E
Tamanrasset	22.47	1378	5.31E
Alger	36,43	450	2.83E
Constantine	36.17	687	6.37E
Mascara	35,26	518	0.06E

B. Metronome data

Metronome is a complete meteorological reference including a catalog of meteorological data and calculation methods for solar applications and system design at any desired location in the world. It is based on more than 23 years of experience in the development of meteorological databases for energy applications. It brings together more than 20 measurement stations around the world. The table below represents the overall solar irradiance of all selected sites.

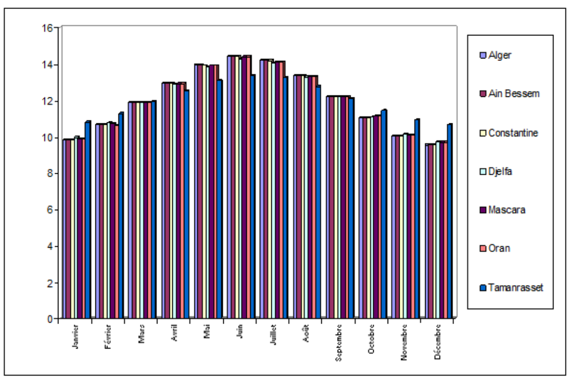
Table 2 summarizes the monthly average of measured values of global solar radiation.

TABLE II. MONTHLY AVERAGE OF MEASURED VALUES OF GLOBAL SOLAR RADIATION

Month	Alger	Ain Bessem	Const.	Djelfa	Mascara	Oran	Tam.
	Measured values of global radiation solar. G_m ($M.J.m^{-2}$)						
January	9,95	*11,15*	11,75	13,01	12,60	12,55	20,98
February	11,92	*13,95*	14,65	16,22	15,19	15,36	24,74
March	16,67	*19,6*	20,05	22,55	21,09	20,76	29,01
April	20,12	*23,19*	24,40	26,75	24,88	24,72	31,10
May	25,46	*27,24*	29,12	30,14	28,88	28,76	31,80
June	32,55	*32,65*	32,62	33,33	32,89	32,76	30,61
July	34,38	*33,42*	33,92	33,04	33,79	33,59	31,60
August	29,55	*29,7*	29,52	30,19	30,38	30,23	29,98
September	21,62	*22,6*	23,45	23,63	23,48	23,16	26,94
October	16,45	*17,52*	17,67	19,34	18,68	18,65	24,54
November	11,33	*12,68*	12,87	14,63	13,88	13,76	21,93
December	8,57	*9,83*	10,42	11,28	10,88	10,76	19,80

Figure 1 shows the distribution of the average effective sunshine duration for a six-year period from the seven selected sites. It is more than 8 hours a day during the winter months and more than 12 hours a day during the months of June to July. The sites are therefore very favorable to the use of solar energy.

Fig. 1. : Distribution of the effective sunshine duration at the sites



IV. DISCUSSION OF RESULTS

Using the different equations, the monthly average global solar irradiation was calculated and the different coefficients a and b were determined. Table 3 summarizes the expressions obtained for the different models as well as the statistical indicators of precision MAE, MBE and RMSE.

TABLE III. DEVELOPED MODELS AND VALUES OF MBE, MAE AND RMSE.

Site	Equation	MBE (%)	MAE (%)	RMSE (%)
Algiers	$G/G_0 = 0.061+0.947(S/S_0)$	-0.622	7.260	9.130
Ain Bessem	$G/G_0 = 0.447+0.427(S/S_0)$	-0.189	4.456	5.322
Constantine	$G/G_0 = 0.448+0.381(S/S_0)$	-0.075	3.694	4.429
Djelfa	$G/G_0 = 0.725+0.046(S/S_0)$	-0.147	3.511	4.203
Mascara	$G/G_0 = 0.396+0.525 (S/S_0)$	-0.111	3.571	4.066
Oran	$G/G_0 = 0.47+0.392(S/S_0)$	-0.062	3.905	4.429
Tamanrasset	$G/G_0 = 0.573+0.316(S/S_0)$	0.130	2.188	2.623

Figure 2 shows the relative errors between the measured values and those calculated by the different models. We can observe that different methods provide good estimates of global radiation.

The maximum error was 9.137% obtained in Algiers by RMSE.

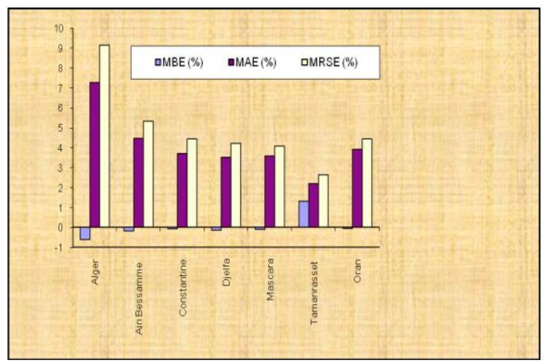


Fig. 2. Relative errors between measured and calculated values by Angström model

However, the best results are obtained by the model with an MAE (Fig 2 b) of 1.312% for Oran, while the great value of MAE was 5.041% for Constantine. The calculation results of the RMSE (Fig. 2 c) show that the best model is the linear model.

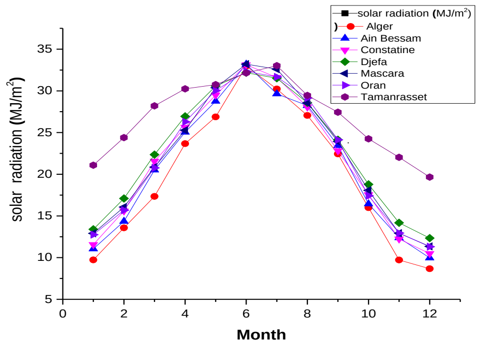


Fig. 3. Global solar irradiation

The maximum value of the global solar irradiation estimated by Angström model is obtained in the months of June and July for the different sites is :

Algiers : 32.97(MJ.m^{-2}),

Ain Bessem : 33.20 (MJ.m^{-2}),

Constantine : 33.13 (MJ.m^{-2}),

Djelfa : 32.18 (MJ.m^{-2}),

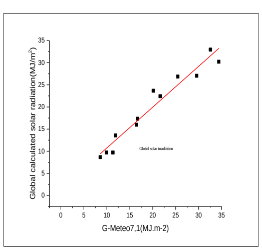
Mascara: 33.21 (MJ.m^{-2}),

Oran: 32.33 (MJ.m^{-2})

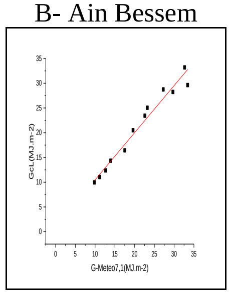
Tamanrasset: 33.02 (MJ.m^{-2}),

To know the coefficients of connection between the measured and calculated values of each site, the results are represented in the figure 4.

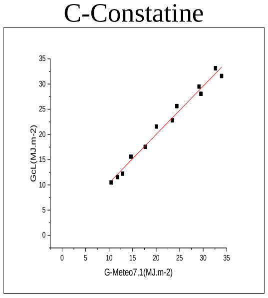
A-Algiers



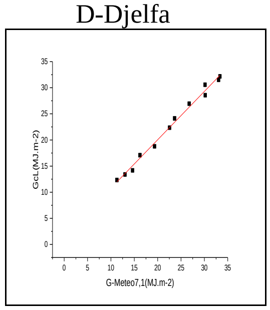
B- Ain Bessem



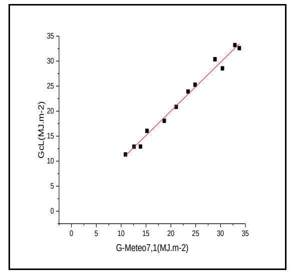
C-Constatine



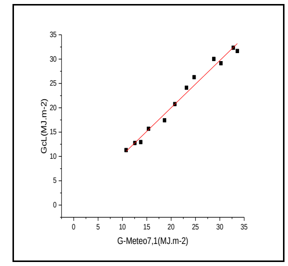
D-Djelfa



E-Mascra



F-Oran



G-Tammernsat

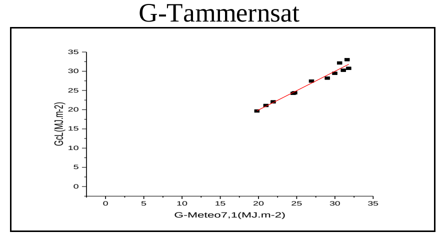


Fig. 4. Comparison between measured and calculated global solar irradiation

After comparing the measured and calculated solar radiation values of the seven regions, the order of the slope was found as follows:

Tamanrasset 1. Mascara and Oran 0.97 As Constantine and Ain Bassam 0.95. Algiers and Djelfa 0.92.

V. CONCLUSION

We have modeled the monthly averageglobal solar radiation received on a horizontal plane for different Algerian sites (Algiers, Ain-Bessam, Constantine, Djelfa, Mascara, Oran and Tamanrasset) using-based model the sunshine -based and the data G-Meteo7.1.

Three main findings are summarized as follows:

1)The linear variation is the best compared to the others. Our results for Oran and Constantine are respectivly 0.062 and 0.075.

2)The maximum value of the global solar irradiation estimated by Angström model is obtained in the months of June and July for the Mascara (33.21 (MJ.m^{-2})) and Tamanrasset(33.02 (MJ.m^{-2})).

3)A remarkable concordance between our calculated values of global solar radiation and the values measured by an Angström model, especially in Tamanrasset site where the slope is of the order of 1.

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