Measurements and Estimation of Monthly Solar Irradiance on a Horizontal Surface in the city of Agadir

Bouachrine Brahim[1], Kourchi Mustafa[2], Ajaamoum Mohamed[3], Bouhouch Lahoussine[4]

[1,2,3,4]Faculty of Science, IbnZohr University, Agadir-Morocco

ABSTRACT

In this study, the monthly average daily global solar radiation on a horizontal surface was estimated by an empirical model based on the knowledge of the monthly average sunshine duration for a period from July /2011 to Jun / 2012 in the city of Agadir. Analyses of calculated and measured results by elements of analysis: the correlation coefficient (*R*), root mean square (*RMS*), root mean square error (*RMSE*) and a coefficient of determination (*Rd*) have given respectively the values, 0.9497, 0.0609, 1.2581 and 0.9018. Thus, our model developed to predict the monthly average global solar irradiation received on horizontal surfaces shows good agreements with the measured values.

Keywords: Global irradiation, the Angstrom-Prescott model, Hour angle, Celestial declination, prediction model

1. INTRODUCTION

Besides the negative impact of energy sources based on the burning of fossil fuels, on our environment (global warming), such sources are expected to be depleted in a near future. Searching for alternative sources of energy is one of the most challenges of the 21st century. Concerning Morocco, diversifying our energy sources will allow us to reduce dependence on foreign energy. The availability of renewable energies sources (hydro, wind, photovoltaic, solar thermal, biomass…) is a promising way to lift the energy sector not only in Morocco but throughout the world [1-4].

Because of its cleanliness and its availability, solar energy can secure a part of our energy needs in the future [5]. Solar energy from the sun is free. However, we must take into account the cost of installation and maintenance. In fact an installation of solar unit is based on a study of feasibility and profitability. This later varies according to geographical location, climatic factors and density of solar flux ... The knowledge of the solar flux density is then essential for determining the size and the performance of the solar unit [6]. Hence, it is useful to take measurements of solar radiation from that place of the plant. Because of the lack of station, the data of solar radiation are not always available. That is the case in many regions around the world. Consequently a model that will allow us to estimate the solar radiation is necessary.

Various basic models [7-14] have been developed by several researchers to estimate solar radiation, according to climatic parameters such as temperature maximum and minimum air, sunshine duration, humidity, cloud cover and wind speed.

Agadir region (30.40° N, 9.6° W) in Morocco is sunny throughout the year and has a favorable benefit from solar energy, but the distribution of solar radiation is unknown. A study of the evolution of the solar flux density is required. It is in this context that the objective of this work, in which we present an empirical model that, will allow us to estimate the monthly distribution of solar radiation.

2. MATERIALS AND METHOD

Meteorological measurements were performed in the High Institute of Technology in Agadir, over the period scaling from July /2011 to Jun / 2012. The daily variation of some parameters such as global solar radiation, diffuse solar radiation, temperature, humidity and wind speed were recorded. The station is programmed to record measurements every 1 hour. The data were averaged to obtain the average monthly values. In this study, a non-linear correlation has been developed to estimate the global solar radiation on a horizontal surface in the city of Agadir. We propose the following polynomial model (1):

$$G_m = G_0^2 \left[a_1 + b_1 \left(\frac{S}{S_{maxm}} \right)^2 \right] \qquad (1)$$

Where:

a_1 and b_1 are constants determined by the method of least squares, $(MJ/m^2.day)^{-1}$.
G_m: Monthly average daily global solar radiation on horizontal surface$(MJ/m^2.day)$
G_0: Monthly average daily Extraterrestrial solar radiation $(MJ/m^2.day)$.
S: Monthly average of daily sunshine duration
S_{maxm}: the Maximum Monthly average of daily day length
Our model will be analyzed and compared to the Angstrom-Prescott model [15].

Several empirical models have been developed to calculate global solar radiation, but the first correlation is based on the method of Angstrom (1924), in which the sunshine duration data and the monthly average clear sky daily global radiation for the location data were used. Among The difficulties of this method is to calculate the the monthly clear sky radiation. Prescott (1940) has replaced this term with extraterrestrial radiation. The Angstrom-Prescott model $G'_m$is the most commonly used as given by

$$G'_m = a G_0 + b G_0 \left(\frac{S}{S_{maxm}} \right) \qquad (2)$$

Extraterrestrial radiation G_0 for the average day of the month on a horizontal surface can be calculated for each month using the following equation [16]:

$$G_0 = \frac{24}{\pi} I_0 d_r (\cos \theta_Z) \qquad (3)$$

I_0= 1353 $W.m^{-2}$: the solar constant.
$\pi = ar\cos(-1)$ Constant

d_r is relative distance between Earth and Sun[17]:

$$d_r = (1 + 0{,}0033 * \cos(2\pi * j / 365) \qquad (4)$$

j the Julian day ranging from 1 (1 January) to 365 or 366 (31 December).
δ :Celestial declination[radians] given as follow:

$$\delta = 23{,}45 * \pi * \sin(2\pi(284 + j)/365)/180 \qquad (5)$$

θ_Z =Zenith angle of the sun[18]

$$\cos \theta_Z = (\cos \varphi \cos \delta \sin \omega + \frac{2\pi w}{360} \sin \varphi \sin \delta) \qquad (6)$$

$\varphi = \frac{\pi}{180}$ *latitude: latitude of place (radian)
w Hour angle (radian) given as:

$$w = ar\cos(-\tan \varphi * \tan \delta) \qquad (7)$$

To evaluate the results obtained by the model presented in this study (1), we are using various statistical comparison methods such as a correlation coefficient (*R*), root mean square (*RMS*), root mean square error (*RMSE*) and coefficient of determination (*Rd*). The *R*, *RMS*, *RMSE* and *Rd* are defined as in the following equations:

A. The Correlation coefficient

The correlation coefficient, *R* is defined as

$$R = \frac{\sum_{i=1}^{N} \left(G(i) - \overline{G}\right)\left(G_{mes}(i) - \overline{G_{mes}}\right)}{\sqrt{\sum_{i=1}^{N} \left(G(i) - \overline{G}\right)^2} \sqrt{\sum_{i=1}^{N} \left(G_{mes}(i) - \overline{G_{mes}}\right)^2}} \quad (8)$$

The correlation coefficient is a number between -1 and 1 that indicates the strength of the linear relationship between two variables. If the coefficient is a positive number, the variables are directly related.

B. The root mean square

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{G_{mes}(i) - G(i)}{G_{mes}(i)}\right)^2} \quad (9)$$

The root mean square value of a quantity is the square root of the mean value of the squared values of the quantity taken over an interval

C. The Root Mean Square Error

$$RMSE = \sqrt{\sum_{1}^{N} \frac{\left(Gi_{mes} - Gi_{cal}\right)^2}{N}} \quad (10)$$

The Root Mean Square Error (*RMSE*) (also called the root mean square deviation, *RMSD*) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled.

D. The coefficient of determination

$$Rd = 1 - \frac{\sum_{i=1}^{N} \left(Gmes(i) - G(i)\right)^2}{\sum_{i=1}^{N} \left(Gmes(i) - \overline{Gmes}\right)^2} \quad (11)$$

Where:

$$\overline{G_{mes}} = \frac{\sum_{i=1}^{N} G_{mes}(i)}{N} \quad (12)$$

G_{mes}: Measured value
$\overline{G_{mes}}$: Mean measured global radiation
G :Estimated value
$\overline{G}$:Mean estimated global radiation
N : Number of observation

The reason why the Coefficient of Determination is a better measure lies in the fact that it tells us about the effect of the independent variable on the dependent variable.

3. RESULTANTS AND DISCUSSIONS

Table 1 summarizes the average values of monthly measurements of the parameters: Monthly average daily global radiation G_{mes} (MJ.m^{-2}/day), Monthly average daily extraterrestrial solar radiation G_0 (MJ.m^{-2}/day), Monthly average of daily sunshine duration S (hour), the Maximum Monthly average of daily day length S_{maxm}, over the period July /2011 - Jun / 2012.

We determined the coefficients *a* and *b* by the least squares method, was calculated using equation (13) and compared with the corresponding measured values. The results are illustrated in Figure 1.

$$G_m = G_0^2 \left[0.010416 + 0.0087755 \left(\frac{S}{S_{maxm}}\right)^2 \right] \quad (13)$$

Table1: Over the period July / 2011- Jun / 2012

Month-year	G_{mes} (MJ/m^2.day)	G_0 (MJ/m^2.day)	S (Hours)	S_{maxm} (Hours)	G_m (MJ/m^2.day)	G'_m (MJ/m^2.day)
July-2011	21,5175	29,3123	13,72	10,26	22.4200	22.8070
Aug-2011	19,6812	30,9738	13,03	10,94	21.9327	21.6721
Sept-2011	19,5173	32,0207	12,12	11,84	20.1106	19.5269
Oct-2011	15,8659	31,3726	11,19	12,76	16.8876	16.6468
Nov-2011	13,2214	29,6461	10,42	13,56	13.7101	14.0091
Dec-2011	12,3526	28,5466	10,07	13,94	12.2217	12.7836
Jun-2012	13,1489	29,1962	10,28	13,74	13.0702	13.4826
Feb-2012	17,3049	30,9129	10,95	13,04	15.8674	15.7919
Mar-2012	18,9921	32,0340	11,84	12,14	19.2589	18.7040
Apr-2012	23,9920	31,4988	12,77	11,18	21.6969	21.2176
May-2012	24,4685	29,8463	13,55	10,42	22.4966	22.6403
Jun-2012	22,1462	28,7643	13,92	10,05	22.5438	23.1299

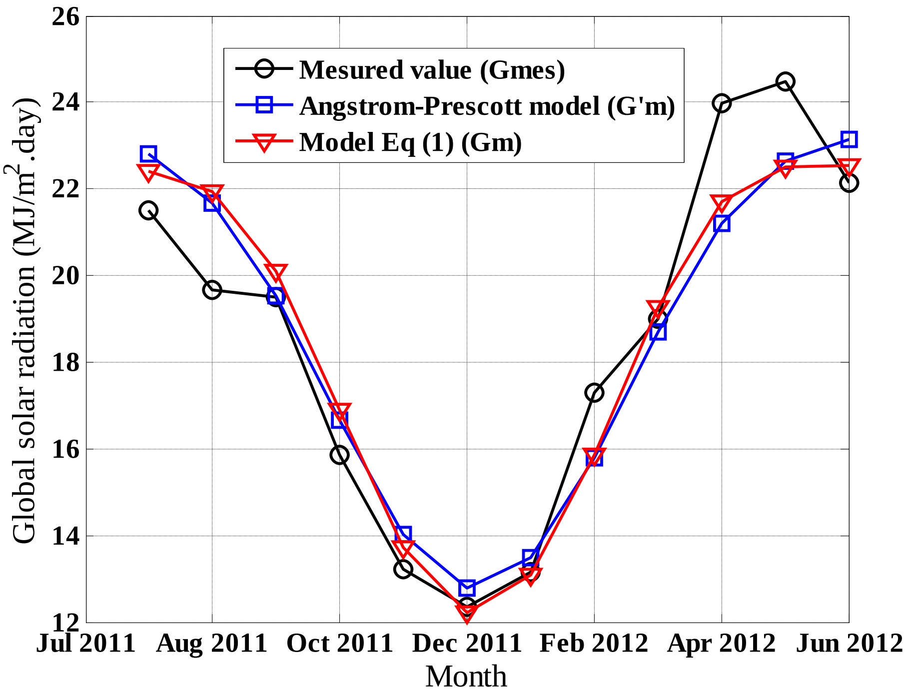

Figure.1: Representation of monthly average daily global solar radiation measured and Model proposed

The model performance was examined using elements of analysis; correlation coefficient (*R*), root mean square (*RMS*), root mean square error (*RMSE*) and Coefficient of determination (*Rd*). The values presented in the table 2 were respectively calculated indicating the validity of the model used to estimate the monthly mean of global solar radiation in good agreement with the results obtained with the model Angstrom.

Table 2: Validation of the models under different statistical tests

Statistical parameters		R	RMS	$RMSE$	R_d
Model (Eq. 1)	G_m	0.9497	0.0609	1.2581	0.9018
Angstrom-Prescott Model [16]	G'_m	0.9429	0.0648	1.3396	0.8887

As was seen in figure (2), estimated values are not too far from the solid line which presents good results.

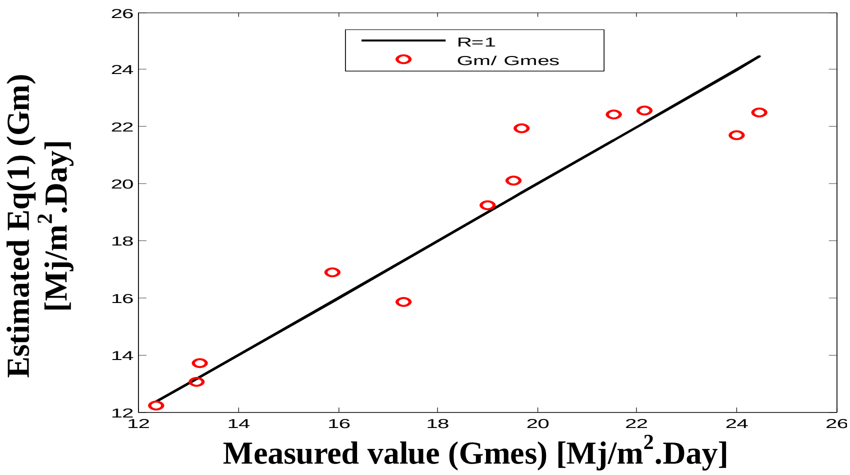

Figure. 2: The comparison of experimental and predict radiation

CONCLUSION

The monthly average daily global solar radiation on horizontal surface in the city of Agadir has been estimated. The module is based on the knowledge of monthly average of sunshine duration. This model shows good agreement between calculated and measured values of monthly mean of daily global solar radiation and can be used for sites where the climate is similar to that of Agadir.

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