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A New Model to Predict the Global Solar Radiation GSR of Souk-Ahras City

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ABSTRACT

The value of the global solar radiation GSR reaching the earth is very important because it is an essential variable for different applications. Unfortunately, solar radiation measurements are not available, most of the time, in developing countries because of the lack of measurement means. Moreover, these measurements are difficult to obtain under complicated weather conditions. Thus, solar radiation evaluation models are used. In this study, a new semi-empirical model for the estimation and prediction of the global solar radiation of Souk Ahras area in Algeria is proposed. The model developed is based on meteorological data such as daily hourly temperatures and average relative humidity required from several stations and databases, over a period of four years. The values of the regression coefficients a, b and c calculated are 0.0142, -10.6206 and 57.8367 respectively. To set the modal valid, we have applied it to 10 Algerian cities and we calculated the H/H0 ratio for each site from our model. They have been then compared with the values from the (CDER). We can conclude that our new model gives a good estimate of the average daily global solar radiation (H) for the studied regions (error between 2.49% and 8.93%) and can also be used elsewhere in areas with the same climatic conditions.

1. INTRODUCTION

In Algeria, energy needs are totally dependent on fossil fuels. The entire economy of the country is based on the export of these products. Unfortunately, with the fall in oil prices in recent years and the tear sounded by scientists and world leaders (Paris agreement) for the protection of the environment and climate from the adverse effects of excessive use of energy conventional. Our country is forced to move towards other energy alternatives such as the use of renewable energies.

As a reaction and a contribution to the world policy for the preservation of the environment, the Algerian government has proposed several strategies for the reduction of the greenhouse effect. Hereby, we can clearly mention the Horizon 2030 project [1] that is all based on the partial substitution (total in the long term) of fossil energy by renewable energies, in particular solar energy given the enormous deposit that Algeria possesses. Several attractive projects have been set up and investors have been encouraged to invest in the technological promotion of renewable energies, for example the project SOLAR [2].

Therefore, information about local solar radiation is considered necessary and important for many applications, including architectural designs and solar energy systems. However, in many developing countries, data on solar energy, unfortunately, are not always available due to the lack of station measuring the parameters of incident solar radiation because of the cost of measuring equipment and their maintenance. Therefore, methods must be devised to estimate solar radiation. Based on meteorological data, many experimental models have been developed to calculate global solar radiation GSR using different climates (Figure 1). Parameters include extra-terrestrial radiation, sunshine hours, average temperature, relative humidity, altitude, longitude, latitude, clouds and radiation, which are measured.

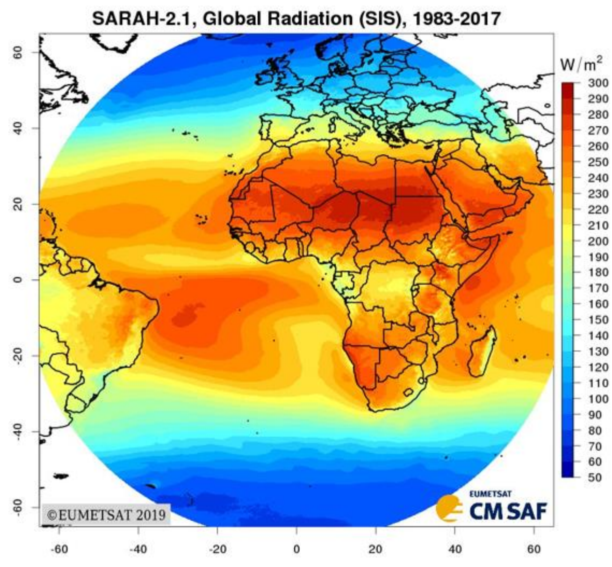

Figure 1. Global solar radiation by EUMETSAT 2019

2. GLOBAL RADIATION MODELING

Solar energy is one of the most important forms of renewable energy, which has become the center of interest of several countries in the world because of its enormous potential especially in the countries of the southern hemisphere as for the 'Algeria. In addition to being clean energy that does not pollute the environment, it is free and accessible to everyone. The aim of this research is to develop a modern method for calculating the amount of total radiation received every hour from sunrise to sunset based on a numerical calculation using mathematical relationships on a horizontal surface located in the Souk Ahras area, which is a city located in the extreme north east of the country, on the Tunisian border, its area is 812 km^2. Its location is as follows:

Geographical coordinates [3]:

- Latitude 36° 17′ 15″ north,
- Longitude 7° 57′ 15″ east,
- Altitude 653 m.

The climate of Souk Ahras is a Mediterranean hot-summer climate according to the Köppen-Geiger (Csa) classification [4].

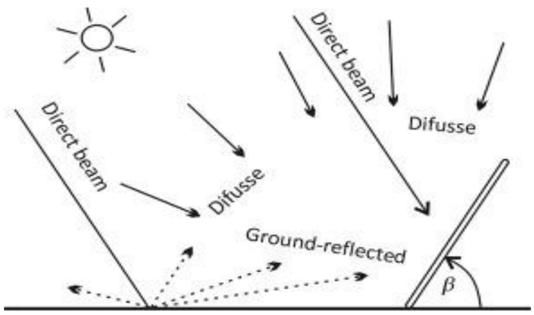

Figure 2. Solar of radiation components

The method used in our work, to calculate the global solar radiation, depends on a set of factors related to the geographical area of the place studied such as the angle of longitude, the width, the altitude, the relative humidity and the temperature.

The intensity of the external solar radiation decreases as it passes through the Earth's atmosphere [5]. The reason for the decrease in the intensity of the external solar radiation in the sixth month is the fact that the Earth is located at the aphelion point relative to the Sun, which is the farthest point of the Earth from the Sun, or its height in the first and twelfth months, due to the fact that the Earth is located in Perigee, which is the closest point to the sun and reaches the Earth, three types of solar radiation represent 50% of solar radiation.

1. Direct Solar Radiation

It is the rays that reach directly from the sun to the earth, and it represents a large percentage on sunny days, about 27% [6]. On cloudy days, the sun is almost non-existent radiation, when the scattered solar radiation is the majority in this case [7].

2. Diffused Solar Radiation

This radiation comes from different parts of the sky due to the presence of clouds, water vapor, the ozone layer. The amount of this radiation is 10% in this case when the sky is clear and 100% when the sky is cloudy [7, 8].

3. Reflected Solar Radiation

The amount of radiation reflected from the ground and reaching the surface of the solar panels depends on the ground reflection, which is known as albedo. The Albedo (reflectivity) is the energy reflection factor of a surface subjected to solar radiation. This coefficient is dimensionless and represents the ability of a surface to reflect solar radiation. A= Reflected solar flux / incident solar flux, and its value ranges between 0.2 for the usual case and 0.7 when there is snow, and this amount constitutes 13% of the total incoming solar radiation [7, 8]. The Figure 2 shows the types of solar radiation connecting to a tilted solar panel roof.

In general, the amount and intensity of solar radiation are affected by all the previous types by several factors, including: the state of the sky in terms of its clarity and in the case of clouds, the four seasons, the height above sea level, the position of the sun in the sky, the angle of inclination of the sun and the thickness of the atmosphere in addition to the solar angles.

3. REVIEW OF EXISTING GLOBAL RADIATION MODELS

The Site and Data source Souk-Ahras city

Description of the site and data source Souk Ahras is a semi-continental and humid region located in eastern Algeria, about 640 km east of the capital (Figure 3). The measured data on solar radiation used in this study were collected over a period of 4 years (2017-2020) by a radiometric station of the Renewable Energy Development Center presented in (Figure 4) with high resolution, installed on the roof of the solar radiation laboratory, based on the weather conditions of the day which are described by several parameters, namely: pressure, temperature, humidity, wind direction and speed, precipitation, cloudy conditions and fog, etc., at the surface and at altitude of the given location in addition to measurements of global solar radiation (GSR) on horizontal surface, solar direct normal irradiance (DNI) and diffuse solar radiation (DSR) on the horizontal plane.

N°	Name of Model	Analytic Model	N°	Name of Model	Analytic Model
01	Glover and McCulloch (1958) [9]	$\frac{H}{H_0} = 0.29\, cos\, \emptyset + 0.52 \frac{S}{S_0}$	**02**	Page (1961) [10]	$\frac{H}{H_0} = 0.23 + 0.48 \left(\frac{S}{S_0}\right)$
03	Swartman and Ogunlade (1967) [11]	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c(RH)$	**04**	Iqbal (1979) [12]	$\frac{H_d}{H} = 0.791 - 0.635\left(\frac{S}{S_0}\right)$ $\frac{H_d}{H} = 0.163 - 0.478\left(\frac{S}{S_0}\right) - 0.655\left(\frac{S}{S_0}\right)^2$
05	Kholagi et al. (1983) [13]	$\frac{H}{H_0} = 0.191 + 0.571\left(\frac{S}{S_0}\right)$ $\frac{H}{H_0} = 0.297 + 0.432\left(\frac{S}{S_0}\right)$ $\frac{H}{H_0} = 0.262 + 0.454\left(\frac{S}{S_0}\right)$	**06**	Benson et al. (1984) [14]	$\frac{H}{H_0} = 0.18 + 0.60\left(\frac{S}{S_0}\right)$for Jan, Mar and Oct $\frac{H}{H_0} = 0.24 + 0.53\left(\frac{S}{S_0}\right)$for Apr and Sep

07	Ogelman et al. (1984) [15]	$\frac{H}{H_0} = 0.195 - 0.676\left(\frac{S}{S_0}\right) - 0.142\left(\frac{S}{S_0}\right)^2$	**08**	Bahel et al. (1986) [16]	$\frac{H}{H_0} = 0.175 + 0.552\left(\frac{S}{S_0}\right)$
09	Bahel et al. (1987) [17]	$\frac{H}{H_0} = 0.16 - 0.87\left(\frac{S}{S_0}\right) - 0.61\left(\frac{S}{S_0}\right)^2 + 0.34\left(\frac{S}{S_0}\right)^3$	**10**	Gopinathan (1988) [18]	$\frac{H}{H_0} = \left(-0.309 + 0.539\cos\emptyset - 0.0693Z + 0.290\left(\frac{S}{S_0}\right)\right) + \left(1.527 - 1.027\cos\emptyset + 0.0926Z - 0.359\left(\frac{S}{S_0}\right)\right)\left(\frac{S}{S_0}\right)$
11	Newland (1989) [19]	$\frac{H}{H_0} = 0.34 + 0.40\left(\frac{S}{S_0}\right) + 0.17\log\left(\frac{S}{S_0}\right)$	**12**	Alsaad (1990) [20]	$\frac{H}{H_0} = 0.174 + 0.615\left(\frac{S}{S_0}\right)$
13	Akinoğlu and Ecevit (1990) [21]	$\frac{H}{H_0} = 0.145 - 0.845\left(\frac{S}{S_0}\right) - 0.280\left(\frac{S}{S_0}\right)^2$	**14**	Samuel (1991) [22]	$\frac{H}{H_0} = -0.14 + 2.52\left(\frac{S}{S_0}\right) - 3.71\left(\frac{S}{S_0}\right)^2 + 2.24\left(\frac{S}{S_0}\right)^3$
15	Lewis (1992) [23]	$\frac{H}{H_0} = 0.14 + 0.57\left(\frac{S}{S_0}\right)$ $\frac{H}{H_0} = 0.81 - 3.34\left(\frac{S}{S_0}\right) + 7.38\left(\frac{S}{S_0}\right)^2 - 4.51\left(\frac{S}{S_0}\right)^3$	**16**	Aksoy (1997) [24]	$\frac{H}{H_0} = 0.148 + 0.668\left(\frac{S}{S_0}\right) - 0.079\left(\frac{S}{S_0}\right)^2$
17	Ampratwum and Dorvlo (1999) [25]	$\frac{H}{H_0} = 0.6376 + 0.2490\log\left(\frac{S}{S_0}\right)$	**18**	Chegaar and Chibani (2001) [26]	$\frac{H}{H_0} = 0.309 + 0.368\left(\frac{S}{S_0}\right)$ For Algiers and Oran $\frac{H}{H_0} = 0.367 + 0.367\left(\frac{S}{S_0}\right)$ For Beni Abbas $\frac{H}{H_0} = 0.233 + 0.591\left(\frac{S}{S_0}\right)$ For Tamanrasset
19	Akpabio and Etuk (2003) [27]	$\frac{H}{H_0} = 0.23 + 0.38\left(\frac{S}{S_0}\right)^2$	**20**	Ahmad and Ulfat (2004) [28]	$\frac{H}{H_0} = 0.324 + 0.405\left(\frac{S}{S_0}\right)$ $\frac{H}{H_0} = 0.348 + 0.320\left(\frac{S}{S_0}\right) - 0.070\left(\frac{S}{S_0}\right)^2$
21	Chen et al. (2004) [29]	$\frac{H}{H_0} = a(T_{max} - T_{min})^{0.5} + b$	**22**	Bakirci (2007) [30]	$\frac{H}{H_0} = 0.6307 - 0.7251\left(\frac{S}{S_0}\right) + 1.2089\left(\frac{S}{S_0}\right)^2 - 0.4633\left(\frac{S}{S_0}\right)^3$
23	Bakirci (2009) [31]	$\frac{H_c}{H_0} = 0.6716 + 0.0760\left(\frac{S}{S_0}\right)$ $c\frac{H_c}{H_0} = 0.5622 + 0.5444\left(\frac{S}{S_0}\right) - 0.4490\left(\frac{S}{S_0}\right)^2$	**24**	Olayinka (2011) [32]	$\frac{H}{H_0} = a_1 + a_2T_{max} + a_3\sigma$
25	Adaramola (2012) [33]	$\frac{H}{H_0} = a_1 + a_2T_m$ $\frac{H}{H_0} = a_1 + a_2\frac{T_{min}}{T_{max}}$	**26**	Adhikari et al. (2013) [34]	$\frac{H}{H_0} = a + b\frac{S}{S_0} + c\frac{T_{avg}}{T_{max}} + d\ln(RH)$
27	Li et al. (2013) [35]	$\frac{H}{H_0} = a_1(1 + a_2RH)\Delta T$	**28**	Hassan et al. (2016) [36]	$\frac{H}{H_0} = a_1 + a_2\Delta T^{0.5}$
29	Jahani et al. (2017) [37]	$\frac{H}{H_0} = a_1 + a_2\Delta T + a_3\Delta T^2 + a_4\Delta T^3$	**30**	Fan et al. (2018) [38]	$\frac{H}{H_0} = a_1 + a_2\Delta T + a_3\Delta T^{0.25} + a_4\Delta T^{0.5}$ $\frac{H}{H_0} = a_1 + a_2\Delta T + a_3\Delta T^{0.25} + a_4\Delta T^{0.5} + a_5\frac{T_m}{H_0}$
31	Ekici and Teke (2018) [39]	$\frac{H}{H_0} = a_1\left[a_2\left(1 - e^{(\tau/RH)^{a_3}}\right) + a_4(\tau/RH)^{a_5} + a_6\cos(a_7\,\tau/RH) + a_8\cos\left(a_7\,T_{min}/\Delta T\right) + a_9\sin\left(a_7\,T_{min}/\Delta T\right)\right]$	**32**	Yildirim et al. (2018) [40]	$\frac{H}{H_0} = a_1 + a_2RH + a_3\sigma + a_4\sigma^2 + a_5\sigma^3$

The station consists of two parts:

• The stator consists of EKO MS-64 thermometers for measuring global solar radiation on a horizontal surface (shortwave sensitivity is 7.0 (mV / kW / m^2)) and on an inclined surface at the latitude of the site.

• A moving part capable of tracking the path of the sun from sunrise to sunset.

The last one consists of an EKO MS-101D thermometer with a short wave sensitivity of 6.71 (mV/kW/m^2), which is pointed at the sun disk to measure the DNI component.

Another thermometer EKO MS-64 with a short-wave sensitivity of 7.0 (mV / kW / m^2) used for measuring diffuse solar radiation on the horizontal plane. It is equipped with a shade bar to mask the radiation flux coming directly from the sun.

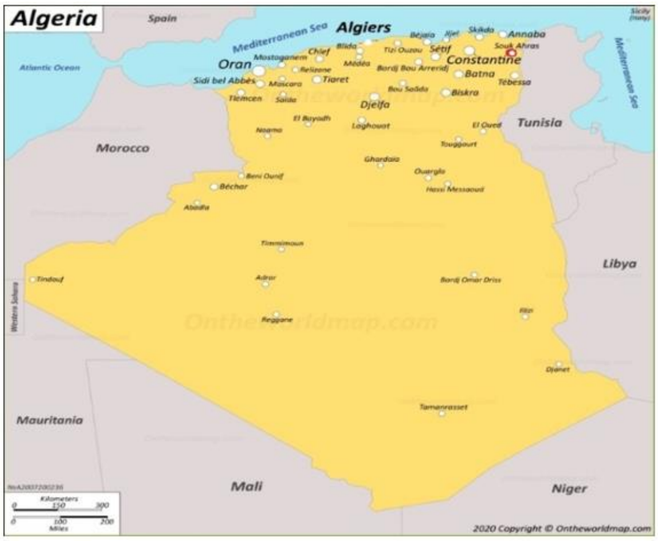

Figure 3. Souk Ahras site location

Figure 4. Radiometric station

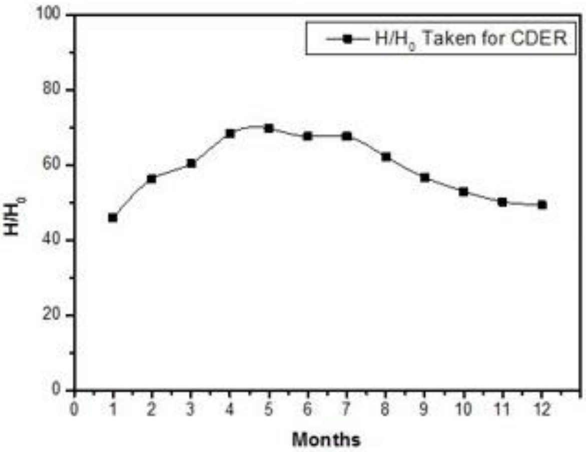

Figure 5. H/H$_0$ taken for CDER

All solar components are made with a five-minute interval for each component. (Figure 5) shows the variation of H / H$_0$ changes in terms of months measured in the Souk Ahras region. With H is the monthly average daily global irradiation on a horizontal surface (W/m^2 day) and H0 is the monthly average the daily extraterrestrial irradiation (W/m^2).

4. PROPOSED MODEL

In the literature, several types of models exist for the evaluation and prediction of global solar radiation, the difference between them is the parameters that come into play. These parameters depend on the characteristics and climatic specificities of the region considered. In our case we used the regression equation which depends of temperature and relative humidity. They are the two main parameters that influence the climate of Souk Ahras, this semi-empirical relationship is based on statistical methods applied to available data. Our objective is to find a, b and c that represent the determinants of the matrix for the first, second and third column, respectively, in the following form:

$$\frac{H}{H_0} = aT^2 + bRH + c \tag{1}$$

H_0 can be computed from the following equation [41]:

$$H_0 = \frac{24}{\pi} I_{sc} \left[\cos\emptyset \cos\delta \sin w_s + \frac{\pi}{180} w_s \sin\emptyset \sin\delta\right] \left[1 + 0.033 \cos\frac{360n}{365}\right] \tag{2}$$

where:

I_{sc} represents the solar constant (I_{sc}=1367 W/m^2), $\emptyset$ is the latitude of the site, δ presents the solar declination, w_s is themean sunrise hour angle for the given month and n is the number of days of the year starting from first January. The solar declination δ and the mean sunrise hour angle w_s can be calculated by Eqns. (3) and (4), respectively [41]:

$$\delta = 23.45 \sin\left(\frac{360(284+n)}{365}\right) \tag{3}$$

$$w_s = cos^{-1}(tan\emptyset \tan\delta) \tag{4}$$

$$S_0 = \frac{2}{15} w_s \tag{5}$$

We conducted a study for the year 2020, taking into consideration the average values of temperatures T and the percentages of the average values of relative humidity RH for each season (three months) of the year. These values are taken from Renewable Energy Development center (CDER) [42] and Global Surface Summary of Day (GSOD) [43].

We calculated the mean values for each day of the month of the Souk Ahras area, for example the month of October, by taking the mean of each day $T_j$with: $T_j = \frac{T_{max}-T_{min}}{2}$, for more precision. Then, we take the average of the temperaturevalues for the whole month $T_m$with $T_m = \sum_{j=1}^{=31} \frac{T_j}{31}$. We reproduce the same work for the months of November and December. After that, we calculate the midpoint of temperature T with $T = \sum_{m=1}^{m=3} \frac{T_m}{3}$ for the three months we have chosen. Hourly temperature values and relative humidity values for each day of the month are taken from GSOD. As for the value of the average solar radiation of the area H is taken from the data of the CDER. For the solar radiation on the ground H0is calculated from Eq. (2) for the three months considered.

The same work is done for the other chosen quarters, namely January, February, March and July, August and September (we chose three quarters in the year because we have three unknown determinants in our proposed model). Our results are shown in Table 1.

Table 1. Results for T, T², RH, H, H_0 and H/H_0

T [°C]	T2 [°C]	RH	H(W/m²)	H_0(W/m²)	H/H_0
9.8	96.04	0.697	8588	165.8	51.80
27.5	756.25	0.583	11081	177.60	62.4
9.1	82.81	0.845	8012	160.10	50.04

To solve our system of equations of order 3, we used Cramer's rules for a system of order 3. This method, which is valid when the system has a unique solution, allows to define our determinants as follows:

$$\begin{cases} \frac{2401}{25}a + \frac{697}{1000}b + c = \frac{259}{5} \\ \frac{3025}{4}a + \frac{583}{1000}b + c = \frac{312}{5} \\ \frac{8281}{100}a + \frac{169}{200}b + c = \frac{1251}{25} \end{cases} \tag{6}$$

$$a = 0.0142 \tag{7a}$$

$$b = -10.6206 \tag{7b}$$

$$c = 57.8367 \tag{7c}$$

Using the results our model will have the following form:

$$\frac{\boldsymbol{H}}{\boldsymbol{H_0}} = 0.0142\boldsymbol{T^2} - 10.6206\boldsymbol{RH} + 57.8367 \tag{8}$$

Table 2. Calculated H of the area of Souk Ahras for 2017

Month	T[°C]	T²[°C]²	RH	C	H/H_0
1.Jan	5.62	31.5844	0.705	57.8367	50.79768
2.Feb	10.3	106.09	0.735	57.8367	51.53704
3.Mar	12.46	155.2516	0.661	57.8367	53.02106
4.Apr	14.54	211.4116	0.662	57.8367	53.80791
5.May	19.09	364.4281	0.491	57.8367	57.79686
6.jun	26.2	686.44	0.474	57.8367	62.54998
7.Jul	29.55	873.2025	0.341	57.8367	66.61455
8.Aug	29.06	844.4836	0.369	57.8367	65.90937
9.Sep	22.55	508.5025	0.492	57.8367	59.8321
10.Oct	17.24	297.2176	0.61	57.8367	55.57862
11.Nov	11.64	135.4896	0.636	57.8367	53.00595
12.Dec	7.84	61.4656	0.754	57.8367	50.70158
Year 2017					

Table 3. Calculated H of the area of Souk Ahras for 2018

Month	T[°C]	T²[°C]²	RH	C	H/H_0
1.Jan	9.9	98.01	0.901	57.8367	49.65928
2.Feb	10.11	102.2121	0.77	57.8367	51.11025
3.Mar	10.98	120.5604	0.668	57.8367	52.4541
4.Apr	15.24	232.2576	0.679	57.8367	53.92337
5.May	19.09	364.4281	0.739	57.8367	55.16296
6.jun	22.52	507.1504	0.569	57.8367	58.99511
7.Jul	28.37	804.8569	0.373	57.8367	65.30418
8.Aug	31.54	994.7716	0.62	57.8367	65.37768
9.Sep	22.68	514.3824	0.605	57.8367	58.71547
10.Oct	16.88	284.9344	0.718	57.8367	54.25718
11.Nov	11.61	134.7921	0.731	57.8367	51.98709
12.Dec	7.28	52.9984	0.765	57.8367	50.46452
Year 2018					

Table 4. Calculated H of the area of Souk Ahras for 2019

Month	T[°C]	T²[°C]²	RH	C	H/H_0
1.Jan	5.89	34.6921	0.81	57.8367	49.72664
2.Feb	7.96	63.3616	0.764	57.8367	50.6223
3.Mar	10.97	120.3409	0.722	57.8367	51.87747
4.Apr	12.91	166.6681	0.654	57.8367	53.25751
5.May	18.87	356.0769	0.673	57.8367	55.74533
6.jun	23.8	566.44	0.671	57.8367	58.75373
7.Jul	25.4	645.16	0.652	57.8367	60.07334
8.Aug	25.8	665.64	0.546	57.8367	61.48994
9.Sep	22.77	518.4729	0.712	57.8367	57.63715
10.Oct	18.77	352.3129	0.755	57.8367	54.82099
11.Nov	12.8	163.84	0.79	57.8367	51.77295
12.Dec	10.2	104.04	0.757	57.8367	51.27427
Year 2019					

Table 5. Calculated H of the area of Souk Ahras for 2020

month	T[°C]	T²[°C]²	RH	C	H/H_0
1.Jan	7.62	58.0644	0.394	57.8367	54.4767
2.Feb	10.8	116.64	0.435	57.8367	54.78303
3.Mar	14.15	200.2225	0.422	57.8367	56.19797
4.Apr	16.3	265.69	0.425	57.8367	57.09574
5.May	20.4	416.16	0.475	57.8367	58.70139
6.jun	23.7	561.69	0.478	57.8367	60.73605
7.Jul	27.02	730.0804	0.437	57.8367	63.56264
8.Aug	28.05	786.8025	0.422	57.8367	64.5274
9.Sep	24.5	600.25	0.755	57.8367	58.3417
10.Oct	17.56	308.3536	0.592	57.8367	55.92793
11.Nov	15.75	248.0625	0.65	57.8367	54.4558
12.Dec	7.6	57.76	0.677	57.8367	51.46675
Year 2020					

Now, we spread our calculations over a period of four years, 2017, 2018, 2019 and 2020. We used our proposed model (Eq. (8)) to find the values of H (monthly average daily global solar radiation on horizontal surface). The values of T and RH of Souk Ahras region, for each hour of each day of the month of the year, are taken from GSOD. The results are presented in Tables 2, 3, 4 and 5.

The following figures show us the evolution of the temperature T with H/H_0 ratio calculated by our new proposed model (Eq. (8)).

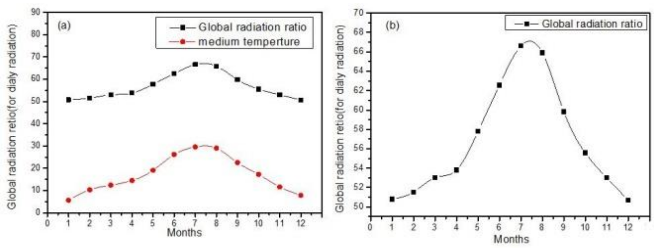

Figure 6. (a) the Variations of (H / H_0) and T temperature versus months of 2017, (b) The variation of H / H0 changes in terms of months of 2017

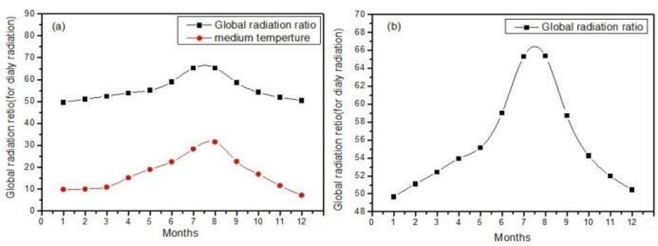

Figure 7. (a) the Variations of (H / H_0) and T temperature versus months of 2018, (b) The variation of H / H_0 changes in terms of months of 2018

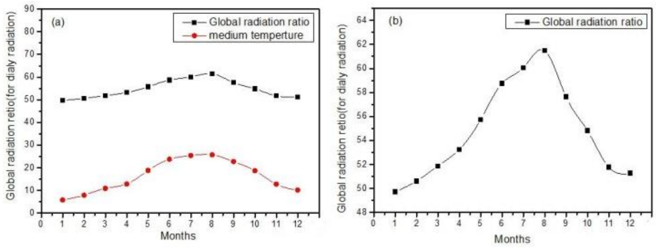

Figure 8. (a) The variations of (H / H0) and T temperature versus months of the year 2019, (b) The variation of H / H0 changes in terms of months of 2019

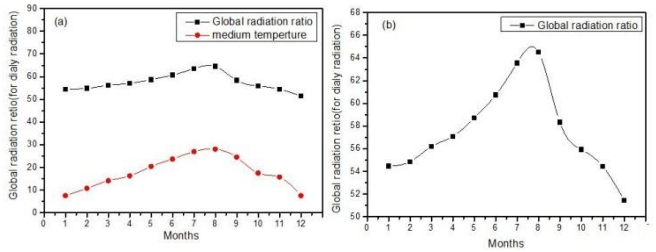

Figure 9. The variations of (H / H0) and T temperature versus months of 2020, (b) The variation of H / H0 changes in terms of months of 2020

As we can see in the Figures (6, 7, 8, 9), the range of H/H_0 calculated for each day of the month of the four years (2017-2020) follows that of the temperatures.

5. RESULTS AND ANALYSIS

To validate our model, we conducted a study for different sites in Algeria with different climates. Daily data, concerning the values of the average temperature T and the relative humidity RH, were collected for the year 2020, for several cities in Algeria. These data are taken from GSOD and CDER. The geographical characteristics of each city (latitude, longitude and elevation above sea level) are taken from the center of renewable energy development. For our calculations, we chose a typical day for each season, the 20th of February for winter (n=51), the 20th of April for spring (n=110) the 20th of July for summer (n=201) and the 20th of November for the fall (n = 324).

We calculated the extraterrestrial solar irradiance on a horizontal surface H_0 (W/m²) for each selected typical day. Then, we used our proposed new model for the calculation of the global solar radiation $H_{Calculated}$ for each zone, as shown in Table 6.

Table 6. The data of longitude, the sun declination, height, temperature; the average humidity, the ratio of global radiation to daily radiation form CDER DATABASES compared with our results which are obtained by our proposed model

State	Date	Day Number in the year	Ø[°]	Δ[°]	h(m)	T[°C]	RH	H_0(W/m²)	$\frac{H_{calculated}}{H_0}$	$\frac{H_{CDER}}{H_0}$	$H_{calculated}$ (W/m²)	H_{CDER}(W/m²)	$\Delta H/H_{Calculated}$	The average value of $\Delta H/H_{Calculated}$ (%)
	20/02/2020	51	7.95	-11.22	680	10.8	0.688	181.36	52.18	56.29	9463.36	10209	7.87	
Souk Ahras	20/04/2020	110	7.95	11.23	680	13,5	0.66	175.04	64.83	68.45	11348.88	11983	5.58	
	20/07/2020	201	7.95	20.82	680	27.3	0.472	171.44	68.42	67.64	10869.2	11597	6.69	6.49
	20/11/2020	324	7.95	-19.52	680	9,9	0.904	160.64	53.41	50.29	8580	8079	5.83	
	20/02/2020	51	-0.28	-11.22	263	18.4	0.233	181.9	60.16	56.15	10943.1	10215	6.65	
Adrar	20/04/2020	110	-0.28	11.23	263	23.8	0.545	175.95	60.09	64.23	10572.83	11303	6.9	
	20/07/2020	201	-0.28	20.82	263	39.2	0.125	138.47	78.32	76.65	10845.15	10615	2.12	4.71
	20/11/2020	324	-0.28	-1952	263	17.1	0.412	158.65	57.6	55.75	9138.24	8846	3.19	
	20/02/2020	51	0.12	-11.22	137	16.9	0.646	177.91	55.02	53.4	9788.6	9501	2.93	
	20/04/2020	110	0.12	11.23	137	21	0.455	186.17	59.36	60.14	11051.05	11197	1.32	
Mostaganim	20/07/2020	201	0.12	20.82	137	31.9	0.474	164.87	67.26	65.32	11087.5	10770	2.86	2.49
	20/11/2020	324	0.12	-19.52	137	15.3	0.832	174.09	52.32	44.09	7899.1	7674	2.85	
	20/02/2020	51	-0.6	-11.22	90	13.2	0.761	185.46	52.22	50.97	9684.72	9453	2.39	
	20/04/2020	110	-0.6	11.23	90	20.9	0.677	185.76	56.83	59.32	10556.74	11020	4.38	
Oran/Senia	20/07/2020	201	-0.6	20.82	90	26.5	0.666	163.58	60.72	65.29	9933.67	10681	7.52	5.72
	20/11/2020	324	-0.6	-19.52	90	14.6	0.725	175.98	53.16	43.39	8355.09	7636	8.6	
	20/02/2020	51	8.13	-11.22	813	11.6	0.527	184.89	58.7	56.35	10853.04	10420	4	
	20/04/2020	110	8.13	11.23	813	18.5	0.456	188.86	58.14	64.3	10980.32	12144	10.59	
Tebessa	20/07/2020	201	8.13	20.82	813	26.5	0.393	170.91	63.62	68.63	10873.29	11730	7.87	6.82
	20/11/2020	324	8.13	-19.52	813	9.7	0.844	164.82	50.2	52.63	8273.26	8675	4.84	
	20/02/2020	51	7.82	-11.22	4	11.3	0.764	176.81	51.52	52.35	9109.25	9259	1.64	
Annaba	20/04/2020	110	7.82	11.23	4	18.7	0.922	189.2	53	58.21	10027.6	11014	9.83	
	20/07/2020	201	7.82	20.82	4	24.4	0.739	170.71	58.44	62.21	9976.29	10621	6.46	6.85
	20/11/2020	324	7.82	-19.52	4	16.3	0.704	165.32	54.12	43.49	7947.11	7191	9.5	
	20/02/2020	51	5,52	-11.22	1378	16,9	0.446	180.65	57.17	64.09	10327.76	11579	12.11	
	20/04/2020	110	5.52	11.23	1378	26.6	0.207	178.69	65.88	69.86	11736.35	12484	6.37	
Tamanrasset	20/07/2020	201	5.52	20.82	1378	32.5	0.164	169.56	71.08	68.6	12052.32	11632	3.48	7.19
	20/11/2020	324	5.52	-19.52	1378	16.8	0.263	168.66	59.06	63.09	9961.05	10641	6.82	

	20/02/2020	51	5.42	-11.22	1038	6	0.505	177.6	52.79	60.1	9407.47	10675	13.47	
	20/04/2020	110	5.42	11.23	1038	17.2	0.422	188.61	56.68	66.08	11690.41	12464	6.61	
Setif	20/07/2020	201	5.42	20.82	1038	25.8	0.296	169.46	64.13	71.32	10867.46	12097	11.3	8.93
	20/11/2020	324	5.42	-19.52	1038	7,6	0.882	180.44	49.28	47.13	8892.08	8505	4.35	
	20/02/2020	51	3.82	-11.22	450	13.6	0.442	179.01	55.74	57.05	9978.01	10213	2.35	
Gherdaia	20/04/2020	110	3.82	11.23	450	22,8	0.466	187.94	60.26	62.05	11325.26	11662	2.97	
	20/07/2020	201	3.82	20.82	450	32.7	0.258	167.27	70.27	66.09	11754.06	11055	5.94	5.36
	20/11/2020	324	3.82	-19.52	450	15.6	0.486	171.11	56.12	50.38	9602.69	8622	10.21	
	20/02/2020	51	5.4	-11.22	141	14.2	0.481	180.66	55.58	54.73	10041.08	9888	1.52	
	20/04/2020	110	5.4	11.23	141	27.8	0.465	178.62	61.72	63.02	11579.9	11257	2.78	
Ouergla	20/07/2020	201	5.4	20.82	141	30.1	0.239	169.43	68.16	62.86	11548.34	10651	7.77	6.04
	20/11/2020	324	5.4	-19.52	141	16.1	0.541	168.87	56.12	49	9416.19	8276	12.1	

We compared our values of $(H_{Calculated}/H_0)$computed using the proposed model for each typical day of each season for each chosen city, with the values of (H_{CDER}/H_0) taken from the CDER database. We note that the smaller the value of$\Delta H/H_{Calculated}$, the more precise the value of H calculated according to the proposed model.

If we take the case of Souk Ahras (extreme east of the country), the value of $\Delta H/H_{Calculated}$ is 6.49%. The others are 4.71% for Adrar (south west of the Algeria), 2.49% for Mostaganem and 5.72% for Oran. For the cities of the Algerian Sahara, the value of $\Delta H/H_{Calculated}$ is between 5.36%-7.19% and it is 8.93% for Setif city. Given these values, it can be confirmed that the proposed model gives very satisfactory results for the evaluation of global solar radiation across the country of Algeria.

This model shows the global solar radiation reaching the Earth's surface affected by several factors. The most important of which are:

- The nature of gaseous envelope and the substances suspended in it.
- The angle at which the sun's rays reach the earth.
- The length of time during which the sun shines and this change according to the seasons.
- The nature of the region's climate.
- The temperature decreases during the short day and rises during the long day. It's also affected by latitude, which causes a difference in temperature.

From the Table 6 we draw graphs (H/H0 Calculated), (H/H0 Taken for CDER) as the following (Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18, Figure 19).

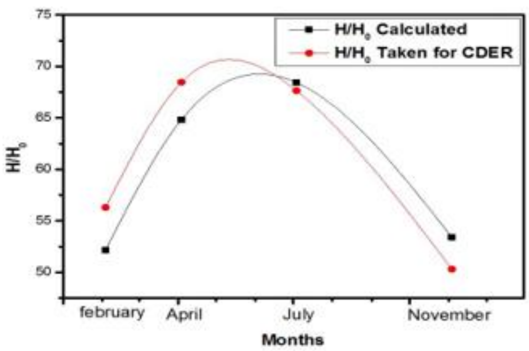

Figure 10. The variation of Hcal / H0 and HCDER / H0 in terms of months in Souk Ahras

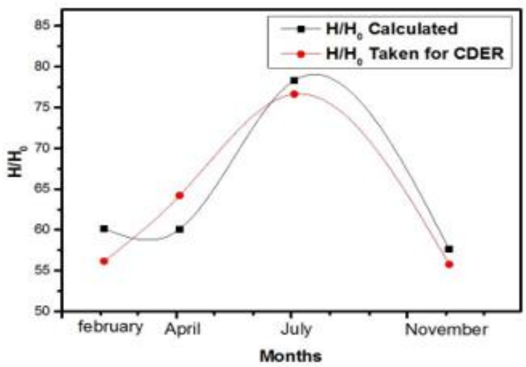

Figure 11. The variation of Hcal / H0 and HCDER / H0 in terms of months in Adrar

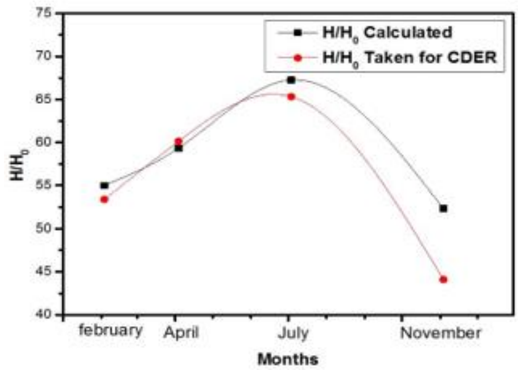

Figure 12. The variation of Hcal / H0 and HCDER / H0 in terms of months in Mostaganem

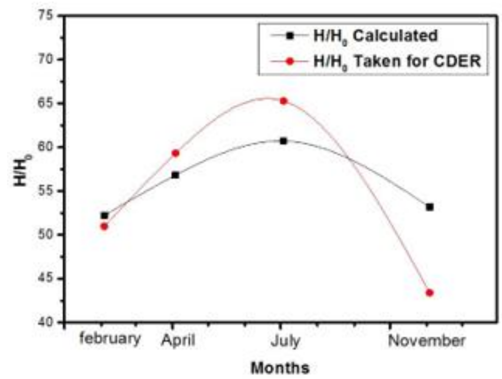

Figure 13. The variation of Hcal / H0 and HCDER / H0 in terms of months in Oran/Senia

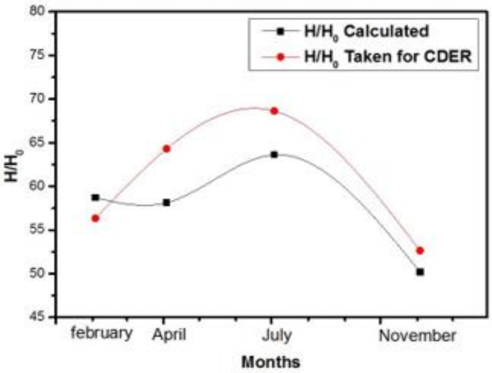

Figure 14. The variation of Hcal / H0 and HCDER / H0 in terms of months in Tebessa

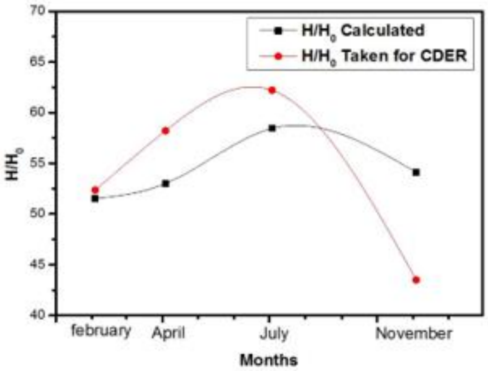

Figure 15. The variation of Hcal / H0 and HCDER / H0 in terms of months in Annaba

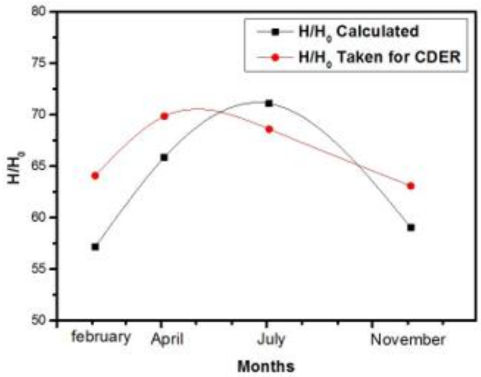

Figure 16. The variation of Hcal / H0 and HCDER / H0 in terms of months in Tamanrasset

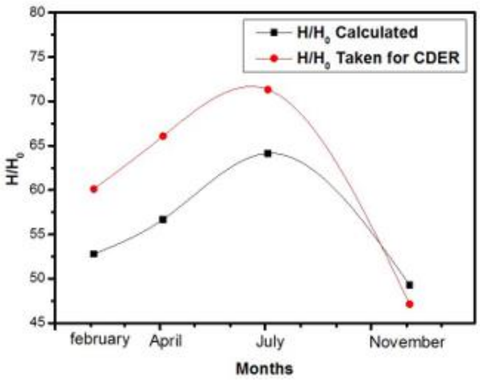

Figure 17. The variation of Hcal / H0 and HCDER / H0 in terms of months in Setif

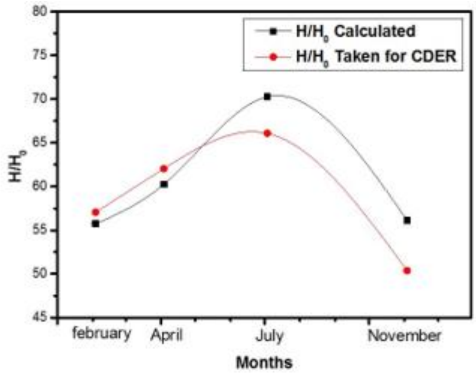

Figure 18. The variation of Hcal / H0 and HCDER / H0 in terms of months in Ghardaia

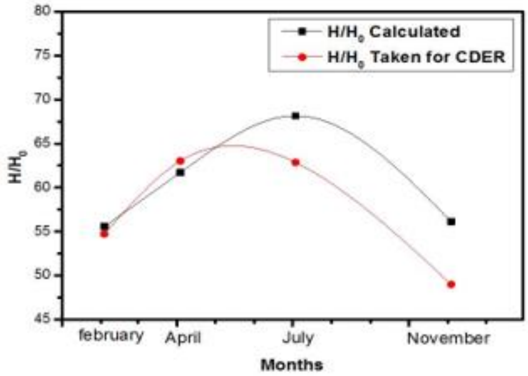

Figure 19. The variation of Hcal/ H0 and HCDER / H0 in terms of months in Ouergla

6. CONCLUSION

The future of the use of solar energy, which is a renewable and sustainable energy, requires accurate information about solar radiation and its components in any place on earth. That is why, the modeling of solar radiation for its evaluation or prediction is of great importance, especially in areas where there are no measured values. The main goal of this work is to propose a new model to estimate the global solar radiation for the region of Souk Ahras in Algeria especially that direct measurement data are difficult to obtain or even impossible to find because of the lack of means and stations for climatic and meteorological measurements in that area.

In this article, we presented a literature review on various existing models based on the regression equation and the duration of sunshine or on the temperature or even hybrid models based on several parameters for the calculation of global solar radiation for several regions in the world. We noticed that almost every model is proposed for a given area because of the diversity of climate, meteorological and geographical parameters.

The proposed model is made on data collection over four years (2017-2020). These data relate to the duration of sunshine, the daily temperature per hour of the air, the daily relative humidity and the geographical coordinates taken from the database (GOSD) and from (CDER). Based on the regression equation, we arrived at estimating the regression coefficients a, b and c specific to the Souk Ahras region. We made a comparison of the calculation result of the global solar radiation of several other sites in Algeria made from our model $H_{calculated}$) and those experimental proposed by the center for the development of renewable energies (H_{CDER}). We found that there is a good agreement between the results and that the proposed model has a very acceptable precision for the majority of the cities considered.

The model proposed in this study can be used anywhere in the world where climatic conditions are the same.

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NOMENCLATURE

H	the monthly average daily global solar irradiation on horizontal surface (W/m^2)
H_0	the extra-terrestrial solar radiance on a horizontal surface (W/m^2)
H_c	the monthly average clear sky daily global radiation (W/m^2)
H_d	the monthly mean daily diffuse solar irradiance on a horizontal surface (W/m^2)
I_{sc}	the solar constant (W/m^2)
δ	the solar declination (°)
N	the number of days of the year starting from first January
S	the monthly average daily bright sunshine duration (hours)
S_0	The day length (hours).
w_s	the sunset hour angle (°)
$\varnothing$	the latitude of location (°)
RH	the mean relative humidity (%)
T	Average temperature(°C)
ΔT	the temperature term difference (°C).