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Alternative Way to Estimate the Global Solar Radiation in Sabha City in Southern Libya

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Abstract

In Libya some climatic parameters without solar radiation data are measured at meteorological stations. In south of Libya where the most solar energy available, there is no recorder data any more. Because of equipment installation, repair costs, poor maintenance culture and recent events in Libya. This study aims to estimate the global solar radiation in the city of Sabha in southern Libya. Data used in this purpose is the average monthly daily values of sunshine hours for previous years (2000 - 2010). The data were obtained from the archive of the meteorological station at Sabha airport. A model based on the hours of sunshine is used to calculate the horizontal solar radiation in the city. Calculated values are compared with other measurement data from NASA website. The comparisons are made using standard statistical tests, namely root mean square error (RMSE), mean bias error (MBE) and the correlation coefficient R. Statistical analysis: the RMSE average value in all years is positive and small (0.42), which make it desirable. The MBE average value in all years has negative value (-0.10), which is under estimation. Finally, the correlation coefficient R, the correlation between the estimated values and the measured values from NASA is a positive correlation in all years, reaching (0.9) and the correlation strength is strong. It may almost reach complete correlation.

INTRODUCTION

Solar energy is an abundant and practically limitless source of energy. It is also dependable form of energy that is accessible to everyone, everywhere, unlike other sources of energy. The amount of energy that we receive from the sun surpasses our energy requirements by a significant margin. The utilization of renewable energy resources, such as solar energy, presents several economic, social, and environmental advantages. It holds tremendous potential for decreasing greenhouse gas (GHG) emissions, which in turn mitigates the environmental impact of electricity production (Mustafa A. Al-Refai, 2014).

The use of solar energy necessitates exhaustive insights on the accessibility of the magnitude of aggregate solar radiation impinging on the terrestrial surface. The sum total of solar radiation that is incident on the terrestrial surface is referred to as global solar radiation. The compendium of global solar radiation statistics is indispensable at multiple stages of the development, simulation, agricultural science, construction, and appraisal of any project involving solar energy (Falayi & Rabiu, 2011).

Solar radiation data constitutes a crucial input for solar energy applications, including photovoltaic, solar-thermal systems, and passive solar design. In particular, these data should be dependable and readily accessible to facilitate the design, optimization, and performance evaluation of solar technologies in specific locations. Regrettably, the measurement of solar radiation remains a challenge for many developing countries, as it is not readily available (El-Sebaii et al., 2010).

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In the Libyan case, insufficient and unreliable measuring instruments, a poor maintenance culture, and recent events that unfolded in Libya have drastically destabilized the country and left it in a state of turmoil. All these factors have led to poor data records. In the absence of direct measurements, theoretical models have become the desired tools to predict and estimate the global solar radiation of a place using some meteorological parameters such as temperature, sunshine hours, and relative humidity (Muhammad & Darma, n.d.).

There are several methodologies that have been put forth to calculate the total amount of solar radiation that reaches the surface of the Earth (Muhammad & Darma, n.d.). In this paper, a model based on the hours of sunshine will be used to calculate the horizontal solar radiation in Sebha city. The proposal is compared with other measurement data from the NASA website. The city is located in the southwest of Libya, with geographical coordinates: latitude: 27.05 north and longitude: 14.43 east, and its height above sea level is about 624 meters.

Data and Methodology

Data

To estimate of global solar radiation of Sebha city, we used data obtained from the meteorological station of the city. The city is located in the southwest of Libya. It is the largest city in the south, and is about 750 km away from the capital city of Libya, with geographical coordinates: latitude: 27.05 north and longitude: 14.43 east and its height above sea level is about 624 meters.

The meteorological data used in this study is period of time for 11 years (2000 – 2010). Data consisting average daily hours of bright sunshine, monthly mean minimum/maximum temperatures and relative humidity were taken from meteorological station at Sabha International Airport ("Archive of the Meteorological Station (2000-2010)," n.d.) as shown in table 1.

Table 1. The monthly average of meteorological data for Sebha city (2000-2010).

Months	n (hrs)	T max(°C)	T min(°C)	T aver(°C)	Rh %
Jan	8.58	20	6.24	13.12	50
Feb	9.09	22.56	8.19	15.38	42.45
Mar	9.57	28.43	12.33	20.38	31.72
Apr	9.46	33.45	17.64	25.54	26.91
May	10.23	36	21.42	28.71	25.64
Jun	11.36	39.43	24.03	31.73	24.73
Jul	12.10	39.70	25.02	32.36	26.27
Aug	11.62	39.45	24.92	32.19	27.45
Sep	10.31	38.65	23.54	31.09	30.45
Oct	9.16	33.07	18.70	25.89	34.55
Nov	8.82	27.02	12.45	19.74	40.73
Dec	8.52	21.47	7.49	14.48	48.91

A measurements data of global solar radiation was taken from NASA website for the same period of time (2000-2010). The purpose is to comparing between it and the calculated solar radiation from model.

Methodology

An estimation of the global solar radiation in Sabah city based on the meteorological parameters, we used a modified Angstrom model based on sunshine hours to calculate the horizontal solar radiation in equation (Mustafa A. Al-Refai, 2014). The original Angstrom-type regression equation was related monthly average daily radiation to clear day radiation at any station and average fraction of possible sunshine hours. The equation (Mustafa A. Al-Refai, 2014) has being modified to be relying on extraterrestrial radiation on horizontal surface rather than on clear day radiation (Angstrom, 1924), (Gana & Akpootu, 2013), (Page, 1964) & (Adeniji et al., 2019):

Journal of Earth Energy Engineering
Vol. 13 No. 1, June 2024, pp 1-5

$$\frac{H}{Ho} = a + b\ \frac{n}{N} \tag{1}$$

Some examples of how your references should be listed are given at the end of this template in the 'References' section, which will allow you to assemble your reference list according to the correct format and font size.

Where H is the monthly average daily global radiation on a horizontal surface ($MJ.m^{-2}.day^{-1}$), Ho is the daily extraterrestrial radiation on a horizontal surface ($MJ.m^{-2}.day^{-1}$), n is the monthly average daily hours of bright sunshine and N is the monthly average day length.

(a and b) values are known as angstrom empirical constant or regression coefficients. Their values have been obtained from the relationship given by (Tiwari, 1977) and confirmed by (Frere E. T., 1980) as:

$$a = -0.110 + 0.235 cos\emptyset + 0.323\left(\frac{n}{N}\right) \tag{2}$$

$$b = 1.449 - 0.553 cos\emptyset + 0.694\left(\frac{n}{N}\right) \tag{3}$$

The monthly average daily extraterrestrial irradiation Ho can be calculated from the equation below:

$$Ho = \frac{24}{\pi} Isc\left[1 + 0.033 COS\left(\frac{360\,D}{365}\right)\right]\left[cos\emptyset cos\delta sin\omega s + sin\emptyset sin\delta\left(\frac{2\pi\omega s}{360}\right)\right] \tag{4}$$

Where:

Isc: Solar constant =(1367 W/m^2).

D: The number of days of year starting from the first of January.

$\emptyset$: The latitude of the site.

δ : The solar declination , ωs: The mean sunrise hour angle for the give month, Which are calculated by the following equations (5) and (6).

$$\delta = 23.45 \sin\left(\frac{360(D+284)}{365}\right) \tag{5}$$

$$\omega s = cos^{-1}[-tan\delta tan\emptyset] \tag{6}$$

The length of a day, N is the number of hours the brightness of the sun during 24 hours on a given day. It is calculated by the following equation:

$$N = \frac{2}{15}\omega s \tag{7}$$

Stastical Analysis

The accuracy of the estimated values was tested by calculating the Root Mean Square Error RMSE(MJ.m^(-2).day^(-1)), Mean Bias Error MBE (MJ.m^(-2).day^(-1)) and the correlation coefficient R (El-Sebaii & Trabea, 2005) as showing in the following equations:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Hcul - Hmeas)^2} \tag{8}$$

$$MBE = \frac{[\Sigma(Hcul - Hmeas)]}{n} \tag{9}$$

$$r = \frac{n\Sigma(Hcul.Hmeas)(\Sigma Hcul)(\Sigma Hmeas)}{\sqrt{[n\Sigma Hmeas^2 - (\Sigma Hmeas)^2][n\Sigma Hcul^2 - (\Sigma Hcul)^2]}} \tag{10}$$

Where the:

r: correlation coefficient

Hcul: calculated solar radiation

Hmeas: measured solar radiation

n: sample size

In general, MBE provides information on the long term performance of the models. Positive MBE value means the average amount of overestimation contrary a negative MBE value indicates underestimation. RMSE provides information on the short term performance of the model. It is always positive and a low value of it is desirable.

Result and Discussion

Table 2 shows the calculated monthly average values of the basic parameters for Sebha city. They are the daily extraterrestrial radiation on a horizontal surface Ho ($MJ.m^{-2}.day^{-1}$), a and b regression coefficients, the solar declination δ, the mean sunrise hour angle for the give month ωs and the monthly average day length N using equations (4), (5) & (6). All these parameters are used to calculate the monthly average solar radiation in equation (1) for years (2000-2010) as results show in last column of table 2.

Table 2. Calculated values of basic parameters and solar radiation for Sebha city.

Months	Ho aver. ($MJ.m^{-2}.day^{-1}$)	a	b	Declination angle (δ)	Sunset hour angle (ωs)	Average day length (N)	H cul ($MJ.m^{-2}.day^{-1}$)
Jan	22.96	0.36	0.39	-20.89	78.77	10.50	15.53
Feb	27.23	0.36	0.38	-13.35	83.03	11.07	18.41
Mar	32.59	0.36	0.39	-2.39	88.77	11.84	21.9
Apr	37.24	0.34	0.43	9.51	94.92	12.65	24.29
May	39.89	0.34	0.42	18.85	100.03	13.34	26.27
Jun	40.75	0.36	0.38	23.13	102.57	13.68	27.67
Jul	40.20	0.38	0.33	21.15	101.38	13.52	28.11
Aug	38.07	0.38	0.33	13.32	96.95	12.93	26.69
Sep	34.07	0.37	0.36	1.99	91.02	12.14	23.34
Oct	28.74	0.36	0.39	9.87	84.90	11.32	19.43
Nov	23.91	0.36	0.38	-19.09	79.83	10.64	16.21
Dec	21.66	0.36	0.38	-23.15	77.42	10.32	14.65

The calculated monthly average solar radiation from the model in equation (1) for years (2000-2010) is compared with other measurement data in the same years (2000-2010) from NASA website, as shown in figure 1. The comparison shows good agreement between calculate values by mentioned equation and observed values from NASA. This agreement makes data from NASA is reliable for researchers in Libya, where is no recorder data recently especially in the south.

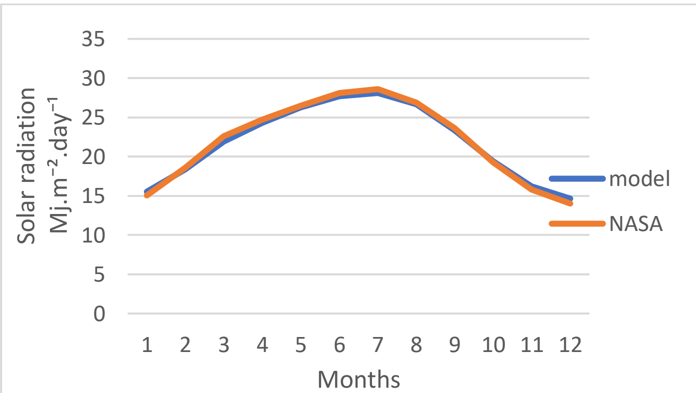

Figure 1: Comparison between Model and NASA of the monthly average solar radiation for Sebha city in (2000-2010).

In statistical analysis, the accuracy of the estimated values is tested using Root Mean Square Error RMSE ($MJ.\ m^{-2}.day^{-1}$), Mean Bias Error MBE ($MJ.\ m^{-2}.day^{-1}$) And Correlation Coefficient R. From the results in table 3, the RMSE average value in all years is positive and small (0.42), which make it desirable. As for the MBE average

Journal of Earth Energy Engineering
Vol. 13 No. 1, June 2024, pp 1-5

value in all years has negative value (-0.10), which is under estimation. Finally, the correlation coefficient R, the correlation between the estimated values and the measured values from NASA is a positive correlation in all years, reaching (0.9). That is sufficient evidence to conclude that there is a significant linear relationship between estimated and measurement values because the correlation coefficient is significantly different from zero.

Table3. Statistical Error Indicators.

Model	RMSE	MBE	R
Angstrom	0.42	-0.10	0.99

Conclusion

The calculated monthly average solar radiation from the model for years (2000-2010) was compared with other measurement data in the same years from NASA website. The comparisons were made using standard statistical tests, namely root mean square error (RMSE), mean bias error (MBE) and the correlation coefficient R. In statistical analysis; the RMSE average value in all years was positive and small (0.42), which make it desirable. As for the MBE average value in all years had negative value (-0.10), which is under estimation. Finally, the correlation coefficient R was a positive correlation in all years (0.9) and the correlation strength was strong and it may almost reach complete correlation. The comparison shows good agreement between calculate values by mentioned model and observed values from NASA. This agreement makes data from NASA is reliable for researchers in Libya, where is no recorder data recently especially in the south.

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