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Experimental Model of Prediction Solar Radiation in Southwestern of Iran, Yasuj

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Abstract

Various experimental models have been proposed for predicting solar radiation. These models have been defined to base on location and special conditions of each world's cities. In this paper, radiation magnitude bases on available models calculated and compared with actual data of Yasuj city. Current data of solar radiation have been measured by Pyranometer CMP21. Results show that models of Tahran & Sari 1, Hottel, Yahghubi & Jafarpour and Daneshyar have had good agreement with the mean solar radiation without meteorological data. Although new coefficient based on angstrom derived to predict irradiation accurately (less than 6% error). Whiles base on atmospheric data, models of Benghanem et al. 3 & 4 with only 8% error can proposes for various years in this area.

Keywords: Solar radiation, Radiation predicting models, Yasuj city

1. Introduction

Solar energy is a considerable renewal source that available in most locations of earth by means of radiation. This radiation amount in each part of the earth depends on

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meteorological, geographic, continental and extraterrestrial factors. Due to differ of effective parameters in each location and each time, the absorbed solar radiation should measure experimentally. The proper device to measure radiation is the pyranometer in ground station. However, lack of measuring devices in the entire of earth is a limitation of available accurate data. Experimental models are another helpful method in absent of measuring devices. Irradiation in the earth depends on two divisions, extraterrestrial and atmospheric. In the common, radiation out of aerosphere is constant, although in the atmosphere depends on various parameters. Badescu et al. (2012) [1] categorized effective parameters to Astronomical, Geographical, Meteorological (surface), Meteorological (column integrated) and Quantities related to atmospheric turbidity. In this paper, reviewed models selected from three classifications.

1) Models base on Angstrom such as ASHRAE used Astronomical and Geographical parameters.

2) Models of Gariepy, Sabbagh, Onyango, Maghrabi, El-Sebaii et al., Benghanem et al., and Hargreaves et al. used Astronomical, Geographical and Meteorological (column integrated).

3) Ashjaee also used quantities related to atmospheric turbidity in his model.

In this study, solar irradiation in Yasuj city with 30.55°, 51.33° Location and 1.88 (km) height of sea level investigates. Available models compares with measured data and Angstrom coefficients for this area are proposed. The data were saved by CM121 device type Shadow Ring (KIPP & ZONEN Inc.).

2. Experimental Model

Average irradiation in extraterrestrial obtained as follow [2]:

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$$H_0 = \frac{24 \times 3600}{\pi} I_{sc} \left(1 + 0.033 \cos \frac{360D}{365}\right)(\cos\varphi \cos\delta \sin\omega_s + \frac{2\pi\omega_s}{360} \sin\varphi \sin\delta), \quad (1)$$

Where, I_{sc} = 1353 (W/m^2) is the solar constant. δ is the solar declination angle and ω_s is the hour angle are as:

$$\delta = 23.45 \sin\left[\frac{360(D+284)}{365}\right], \quad (2)$$

$$\omega_s = \cos^{-1}\left[-\tan\varphi \tan\delta\right]. \quad (3)$$

Average hour of day in a month can calculated from:

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

2.1. Models base on Angstrom

These models established on adaption of experimental data with Angstrom correlation. Angstrom model derived base on H daily global irradiation at earth's surface (MJ/m^2/day), H_0 is the extraterrestrial average irradiation (MJ/m^2/day), S is hours (h) and S_0 is the average hours of day (h).

$$\frac{H}{H_0} = a + b\frac{s}{s_0}, \quad (5)$$

Where, a and b are the constants and obtain from the solar irradiation data. Proposed models for different locations show in Table 1.

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Table 1: Models base on Angstrom

Models	*a*	*b*
Page [3]	0.23	0.48
Ogelman et al. [4]	0.195	0.676 – 0.142 (s/s_0)
Akinoglu [5]	0.145	0.845 – 0.280 (s/s_0)
Lewis [6]	0.14	0.57
Ahmad and Ulfat [7]	0.324	0.405
Ahmad and Ulfat [7]	0.1874	0.8592 – 0.4764 (s/s_0)
Tahran and Sari [8]	-1.1126 (s/s_0) + 0.4516 $(s/s_0)^2$	0.845 – 0.280 (s/s_0)
Benghanem et al. [9]	0.3824	0.2786

2.2. Modified Angstrom models

These models derived with modifying Angstrom correlation. Models of Ampratwum, Eq. (6), [10] is available as follow:

$$\frac{H}{H_0} = 0.6376 + 0.2490 \log\left(\frac{s}{s_0}\right). \qquad (6)$$

2.3. Models with geographic factors

Height (z) in Gopinathan's models [11] proposed for estimating radiation.

$$\frac{H}{H_0} = -0.309 + 0.539\cos\varphi - 0.0693(z) + 0.290\left(\frac{s}{s_0}\right) + \left(1.527 + 1.027\cos\varphi - 0.0926(z) - 0.359\left(\frac{s}{s_0}\right)\right)\left(\frac{s}{s_0}\right). \qquad (7)$$

Kilic and Ozturk [12] in the proposed model employed height and latitude.

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$$\frac{H}{H_0} = 0.103 + 0.017(z) + 0.198\cos(\varphi-\delta) + \left[0.533 - 0.165\cos(\varphi-\delta)\right]\frac{s}{s_0} \cdot \qquad (8)$$

Model of Hottel [13] used for clear sky with visibility about 5 to 23 (Km).

$$\frac{H}{H_0} = (\tau_b + \tau_d)\cos(\theta_z), \qquad (9)$$

$$\tau_b = a_0 + a_1 \exp\left(\frac{-K}{Cos\theta_z}\right), \qquad (10)$$

$$\tau_d = 0.274 + 0.2939\,\tau_b, \qquad (11)$$

Where, cos θ_z = sinδ sinφ + cosφ cosδ cosω, ω, a_0, a_1 and k for standard atmospheric condition obtain as Eqs. (12-15).

$$\omega = \frac{360}{24}(12-t), \qquad (12)$$

$$a_0 = r_0[0.4237 - 0.0082(6-z)^2], \qquad (13)$$

$$a_1 = r_1[0.5055 + 0.00595(605-z)^2], \qquad (14)$$

$$K = r_k[0.271 + 0.01855(2.5-z)^2], \qquad (15)$$

Where, t is the hours of before and after the noon, r_0, r_1 and r_k are 0.97, 0.99 and 1.02, respectively.

2.4. Models affected by meteorological conditions

In this category, parameters T (°C) Temperature and P rain amount had been used by Gariepy [14].

$$\frac{H}{H_0} = 0.3791 - 0.0041T + 0.0176P + \left[0.4810 + 0.0043T + 0.0097P\right]\frac{s}{s_0} \cdot \qquad (16)$$

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EL-Sebaii et al. [15] also used the models base on meteorological conditions and Angstrom.

$$\frac{H}{H_0} = -1.92 + 2.60\left(\frac{s}{s_0}\right) + 0.006T, \quad (17)$$

$$\frac{H}{H_0} = -1.62 + 2.24\left(\frac{s}{s_0}\right) + 0.332R, \quad (18)$$

$$\frac{H}{H_0} = -0.08 + 0.21(T_{max} - T_{min})^{0.5} - 0.012\left(1 - \frac{s}{s_0}\right), \quad (19)$$

Where, R is the relative humidity. Benghanem et al. also presented another models with temperature and humidity.

$$\frac{H}{H_0} = 0.6369 + 0.037\left(\frac{T}{T_{max}}\right), \quad (20)$$

$$\frac{H}{H_0} = 0.7556 - 0.1353\left(\frac{R}{R_{max}}\right)\cdot \quad (21)$$

Onyango [16] applied relative humidity and T_{max} in his model and proposed estimation model base on extraterrestrial radiation.

$$H = H_0 \exp\left[\varphi\left(\frac{s}{s_0} - \frac{R}{15} - \frac{1}{T_{max}}\right)\right], \quad (22)$$

$$H_0 = (1.7 - 0.458\varphi) \times \left(\frac{20s_0}{1 + 0.1\varphi} + w_{i,j}\cos\varphi\right) \times 4.1858 \times 10^4, \quad (23)$$

$w_{i,j}$ for each month are respectively as follow: $w_{i,j}$ = 1.7, 1.6, 0.93, 0.765, 0.63, 0.58, 0.575, 0.682, 0.78, 0.87, 0.947 and 1.13. Hargreaves and Samani [17], [18] proposed estimation model for arid and semi-arid, territorial, and coastal zones. Where, A_{HG} is 0.17, 0.16 and 0.17, respectively.

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$$H = H_0 \left[A_{HG} \left(T_{\max} - T_{\min} \right)^{1/2} \right], \tag{24}$$

Model of Bristow and Campbell [19], [20] considered temperature different of two continues days.

$$H = H_0 0.7 \left[1 - \exp\left(-(0.004 \ or \ 0.001) \Delta T^{2.4} \right) \right], \tag{25}$$

Which temperature different is ΔT (°C) = $T_{max(i)} - [T_{min(i)} + T_{min(i\text{-}1)}] / 2$. i is current day and i-1 is previous day. Sabbagh [21] submitted irradiation model as the function of climatological and geographic data: daily maximum temperature, relative humidity, latitude and longitude.

$$H = 1.53k \times \exp \varphi_{radian} \left(\frac{s}{s_0} - \frac{R^{1/3}}{100} - \frac{L}{T_{\max}} \right), \tag{26}$$

In this correlation H unit is (Cal/cm^2/day), latitude is in radian and k is a constant that obtains with:

$$K = \left[\lambda s_0 + \psi_{i,j} \cos(L) \right] 4.1815 \times 10^6, \tag{27}$$

$$\lambda = \frac{0.2}{1 + 0.1\varphi}. \tag{28}$$

In the Eq. (28), latitude is in degree and $\psi_{i,j}$ is season's constant. The season's constant draw out on Table 2, which i = 1 is for station located in general zone and i = 2 is for station near the sea. j = 1, 2 … 12 is number of month.

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Table 2: $\psi_{i,j}$ magnitude for Sabbagh's model

Months	ψ_1	ψ_2
Jan	1.28	1.48
Feb	1.38	1.77
Mar	1.54	2.05
Apr	1.77	2.15
May	2.05	2.05
Jun	2.3	2.05
Jul	2.48	2.1
Aug	2.41	2.17
Sep	2.36	2.14
Oct	1.73	1.96
Nov	1.18	1.6
Dec	1.17	1.43

2.5. Special models for Yasuj

Daneshyar in 1978 proposed the model for 24 cities of Iran base on experimental relation [22]. It achieved total instant irradiation in horizontal surface with:

$$H = 1.432 + 2.107(90-\theta_z) + 121.3CF + 950\left\{1-\exp\left[-0.75-(90-\theta_z)\right]\right\}(1-CF)Cos\theta_z. \tag{29}$$

Irradiation unit is (Cal.day/cm^2). He also used approximate relation for cloud factor $CF = 1 - (s / s_0)$. Behrang et al. [23] presented nonlinear estimation models for Shiraz city (210 (Km) far from Yasuj).

$$\frac{H}{H_0} = 0.5282 + 0.0959\left(\frac{s}{s_0}\right)^{0.4732}, \tag{30}$$

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$$\frac{H}{H_0} = 0.9916 + 0.3451\cos\left[0.8875(\frac{s}{s_0})\right]$$
$$-0.7006\sin\left\{0.8875(\frac{s}{s_0}) - 0.6971\cos\left[1.775(\frac{s}{s_0})\right]\right\} \quad (31)$$
$$+0.3684\sin\left[1.775(\frac{s}{s_0})\right].$$

Yahghubi & Jafarpour [24] also proposed estimation model base on Hottel's model for Shiraz city moreover their Angstrom model.

$$\frac{H}{H_0} = 0.23\cos\varphi + 0.54\frac{s}{s_0}, \quad (32)$$

$$H_0 = \left[(1+0.16)(\frac{s}{s_0}) + 0.55(1-\frac{s}{s_0})\right] I_{sc}\tau_b \cos\theta_z \cdot \quad (33)$$

And Ashjaee [25] in his model used only parameters independent the years.

2.6. New models base on Angstrom

The regression based on actual data had been derived to enhance accuracy. The polynomial has as follow:

$$\frac{H}{H_0} = \mathrm{a} + \mathrm{b}(\frac{s}{s_0}) + c(\frac{s}{s_0})^2 \cdot \quad (34)$$

The MAPE represents the mean absolute percentage deviation between calculated and measured values and the RMSE gives information on the short-term performance of the model. The MAPE and RMSE, respectively, are:

$$MAPE = \frac{1}{x}\sum_{i=1}^{x}\left|\frac{H_{i,c} - H_{i,m}}{H_{i,m}}\right| \times 100, \quad (35)$$

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$$RMSE = \sqrt{\frac{1}{x}\sum_{i=1}^{x}(H_{i,c} - H_{i,m})^2}. \qquad (36)$$

3. Irradiation Measurement Device

Irradiation measurement device (CMP21) can be mounted in all latitude. This device has three sensors for measuring various types of radiation.

1- RSR Pyranometer sensor: For measuring reflected solar radiation from the ground and without any shield. It is parallel with ground surface and downward locates (Figure 1).

2- DSR Pyranometer sensor: For measuring direct-beam radiation and without any shield. It is also parallel with ground surface and upward locates (Figure 1).

Measurement has been done with CMP21 type Pyranometer(KIPP & ZONEN Inc.).

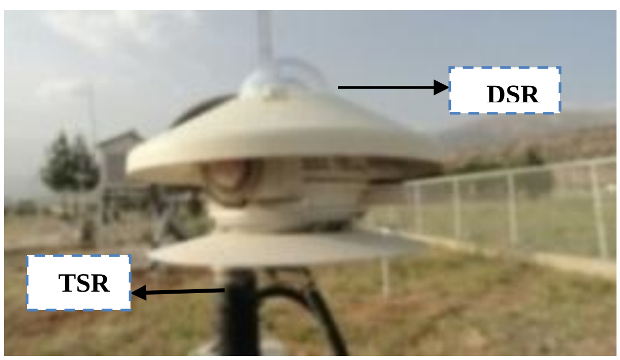

Figure 1: Irradiation measurement device (CMP21) RSR & DSR Sensors

4. Results

Models with geographic data can predict average irradiation. Mean irradiation base on these models for Yasuj city calculated, and its means differences show in Table 3. Furthermore, measured average irradiation meantime 2008 until 2013 illustrates in figure 2.

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As the Table 3, models of Tahran & Sari 1, Hottel, Yahghubi & Jafarpour and Daneshyar have only 6.4, 9.6, 9.9 and 10% different with average irradiation, respectively. These models were good approximation for Yasuj city. An addition, by dividing years to warm (April-September) and cold (October-March) seasons, precision of estimation models enhances. As models of Tahran & Sari 1 and Ashjaee have good prediction in warm seasons (1.9 and 5.2% difference); and in cold season, models of Daneshyar and Hottel have error about 7.4 and 7.7%. Also angstrom's model with respect to regression derived that has been better results for average irradiation (5.8%).

However, these models are only depending on geographic location with the same value in all years. While the actual amount of radiation was measured at the meteorological station of Yasuj by Pyranometer CM121 has had many changes over the years. Figure 2 shows the actual radiation has been measured by Yasuj station during the years 2008-2013. Variations of irradiation indicate that other parameters for better prediction are necessary.

Table 3: Means difference predicting models with measured solar radiation in Yasuj city ($MJ/m^2/day$)

Models	Mape	Standard deviation Of MAPE
Page [3]	33.5	7.7
Kilik and Ozturk [12]	30.5	6.7
Ogelman et al. [4]	36.8	7.8
Gopinathan [11]	31.3	2.4
Akinoglu [5]	32.9	7.6
Benghanem et al. [9]	23.8	7.1
Lewis 1 [6]	33.7	7.7
Ampratwum [10]	19.0	6.8
Ahmad and Ulfat [7]	36.8	7.9
Tahran & Sari 1 [8]	6.4	5.4

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Tahran & Sari 2 [8]	17.0	6.7
Behrang et al. 1 [23]	16.3	6.6
Behrang et al. 2 [23]	19.2	6.8
Ashjaee [25]	16.9	13.4
Daneshyar [22]	10.0	6.4
Yahghubi & Jafarpour [24]	9.9	6.3
Hottel [13]	9.6	4.8
New model (a = 1, b = - 0.43, c = 0)	5.8	5.0
New model (a = 1,b = 0.6,c = -1)	7.8	5.8

Environmental factors, increased dust phenomenon in recent years are effective parameters on the rate of irradiation. In the other attempt, the meteorological associated models used to have more accurately estimation of irradiation. To do this, meteorological data was collected in the study area, and calculations were done. Table 4 shows the average error of prediction models with actual data. Among these models, Models of Benghanem et al. 3 & 4 with an average error of 8% offer a good estimate irradiation on the Yasuj city for each year.

Table 4: Percentage difference between the prediction's model with meteorological parameters associated and the measured values

Models	Mape
Bristow and Campbell (Eq. 25)	15.3
Hargreaves and Samani (Eq. 24)	11.2
Benghanem et al. 4 (Eq. 21)	8.0
Benghanem et al. 3 (Eq. 20)	7.9

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El-Sebaii et al. 3 (Eq. 19)	17.3
El-Sebaii et al. 2 (Eq. 18)	17.6
El-Sebaii et al. 1 (Eq. 17)	20.6
Onyango (Eq. 22)	17.9
Sabbagh (Eq. 26)	16.3
Gariepy (Eq. 16)	37.3

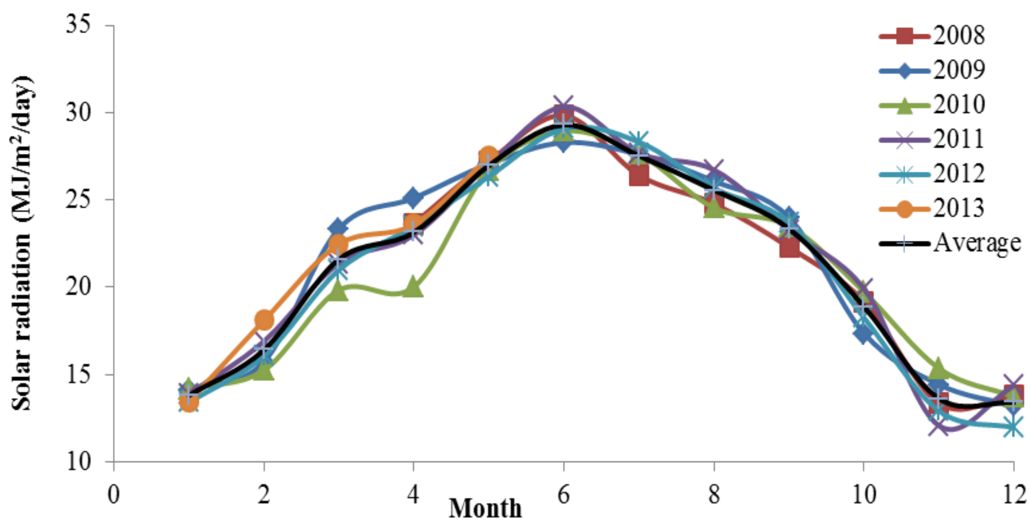

Figure 2: Measured irradiation during years 2008-2013 in Yasuj city

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Conclusion

A lot of models for the estimate solar radiations are present. For presenting the irradiation model for Yasuj city in southwestern Iran, available models were compared with the actual values that measured by irradiation measurement devices. The results shows existing models are not fully able to estimate irradiation in this area but models of Tahran & Sari 1, Hottel, Yaghubi & Jafarpour and Daneshyar have good agreement with the mean solar radiation without meteorological data. Also new coefficient based on angstrom derived to predict irradiation accurately

(less than 6% error). While with meteorological data, models of Benghanem et al. 3 & 4 with an average error of 8% can be used for the each year.

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