ANALYSIS OF SUNSHINE HOURS AND GLOBAL SOLAR RADIATION FOR MARDIN OF TURKEY

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Abstract

Having a strategic area, the energy industry has a critical importance in development policy of a country. Demands of renewable energy have increased in recent years due to energy price, global warming and climatic change. Therefore, the concerns about solar energy, one of the most important clean energy sources, have risen in the last decades. In this study, the empirical solar correlations developed in Turkey and some other countries were investigated for the province of Mardin, Turkey. The compatibility of solar radiation models inspected in terms of statistics was tested by determining the nearest model according to measured data. In addition to climate data which is specific to this region, prediction of Angstroms model was developed to estimate global solar radiation in Mardin. These models, since the mathematical models with the highest compatibility represent the measured data statistically well, it is understood that it can easily be used for daily global solar radiation on horizontal surfaces. The data of the model were obtained from Solar Energy Potential Atlas (GEPA) of Electrical Power Resources Survey Administration (EIE). Angstrom-type model parameters were developed to forecast sunshine average and to compute empirical coefficients for Mardin. Monthly predicted global solar radiation mean values were compared with observed values using statistical parameter coefficient of regression analysis (R^2), mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), mean absolute percentage error (MAPE), t-statistic (t-sat) and the percent error (e) method developed in order to test the compliance of the models. The best developing ideal model was found to be quadric $H/H_0=-1,3049\ (S/S_0)^2+2,2791(S/S_0)-0,4143$ and R^2 0,9492 determined in terms of utilizing the solar radiation potential in Mardin, Turkey

Key words: solar models, solar energy, statistical parameters

1. Introduction

The primary physical reason of the events occurring in the atmosphere is radiation from the sun. Energy sources constitute the basis of civilization, we have today [1]. Solar power is the most important energy source effecting physical occurrences in the systems of earth and atmosphere. The solar power, the origin of a great majority of natural energy sources, is directly utilized with the purposes to obtain energy for heating and electricity. Since it has the property to be a clean source of energy, solar power is a strong alternative to the fossil fuels. Radiation energy pouring down the earth a year is approximately 160 times more than that of fossil fuels determined so far. Moreover, it is nearly 15000 times more than the energy that fossil, nuclear and hydroelectric plants can generate a year [2].

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The radiation value of the solar power out of the atmosphere is about 1370 W/m2. The distribution of solar power on earth displays significant differences due to the shape of the globe, thus the solar power received by earth is on average at 0-1100 W/m2 levels. 46% of solar radiation exists in the spectrum infrared area as energy, and 45% exist in the visible light area and the rest exists in ultraviolet area [3].

Today, in a controlled way, solar power is used in air conditioning of houses and workplaces, in cooking, in obtaining hot water and in heating swimming pools, in agricultural technology, in greenhouse heating and in drying agricultural crops, in industry, solar ovens, solar bakers, cookers, in obtaining drinking water and salt out of marine water, in solar pumps, solar cells, solar pools, in heat pipe applications, in transportation and communication devices, in signalling and automation, in electric generating [4,5].

It is quite important that solar radiation data of an area be known for the efficiency and design of photovoltaic (PV) systems running on solar power, flat plate collectors and other solar power collecting systems. Sunshine duration in the world is calculated in meteorology stations and with the obtained correlations it is possible to estimate monthly mean daily global radiation. So as to estimate solar radiation amount, a number of empirical model have been developed. These models have been obtained employing different parameters such as sunshine duration, cloudiness and environmental temperature.

Düzen and Aydın (2012) conducted a comparison from various statistical aspects with models resulting from solar radiation data and Angströ-Presscott linear regression of solar radiation pouring down the horizontal surface from 7 stations in Van province in Turkey [6]. Yang et al (2013) collected data at various tilts and azimuths to perform the analysis in Singapore [7]. Yaniktepe and Genc (2015); investigated solar radiation models on the horizontal surface to establish solar photovoltaic (PV) source for hydrogen generation [8]. Sabzpooshani and Mohammadi (2014); set up new empirical models for predicting the monthly mean diffuse solar radiation on a horizontal surface for city of Isfahan situated in the central part of Iran [9]. Mecibah et al (2014); developed 11 empirical models correlating the monthly mean daily global solar radiation on a horizontal surface with monthly mean sunshine records and air temperature data for six Algerian cities [10]. Besharat et al (2013); used the geographical and meteorological data of Yazd city, Iran for computing the monthly average daily global solar radiation on a horizontal surface [11].

2. Materials and Method

Turkey is located between 36° - 42° North latitudes and 26°- 45° East Longitudes. She is a rich country in respect to renewable energy source potential. On average, 170 million MW energy comes to earth from the sun per second. If it is considered that the annual energy production of Turkey is 100 million MW, only the sun's one second energy to the earth is 1,700 times more than the energy production of Turkey. Utilizing sunshine duration and radiation exposure intensity data measured in 1966 – 1982 by means of devices in State Meteorological Affairs, General Directorate (DMI), it was found out that the total average annual sunshine duration of Turkey was 2640 hours and that radiation intensity was 1,311 kWh/m²-year according to a study carried out by EIE. The most sunny region of Turkey, as is shown in Table 3.1, is Southeastern Anatolian Region with 2993 hours and 1460 kWh/m^2 year [12,15]. One of the cities having the longest of sunshine duration of the region is Mardin (Figure 3.1)

Table 2.1 Distribution of Annual Total Solar Power Potential to Regions in Turkey Reference: EIE General Directorate

Region	Total Solar Energy (kWh/m^2-year)	Hours Of Sunshine (Hour/year)
Southeastern Anatolia	1460	2993
Mediterranean	1390	2956
East Anatolia	1365	2664
Central Anatolia	1314	2628
Aegean	1304	2738
Marmara	1168	2409
The Black Sea	1120	1971

Mardin with its 8891 m^2 area, and with its 1082 m altitude, is located between 36 55 – 38 51 North Latitudes and 39 56 – 42 54 East Longitude. The mountains covering 4.8% of Mardin Province landscape stretch east-west direction and they make up a very large mass of approximately 600 m high on the plane. It is situated on the Tigris Part of Southeastern Part of Anatolia. It borders with Syria. In its south, Syria, in its west Sanliurfa province, in its north Diyarbakir and Batman provinces, in its northeast Siirt province and in its east Sirnak province are located [13].

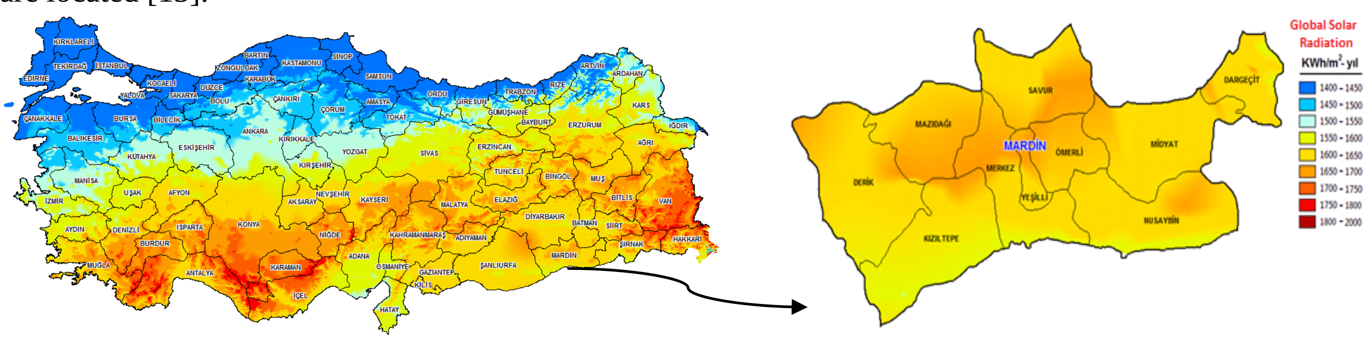


Figure 2.1 Solar Power Map of Turkey and Mardin Province

In the Southeastern part of Anatolia, terrestrial and Mediterranean climate is dominant; that is, the east of the province is under the effect of terrestrial climate, while in its west Mediterranean climate is more effective. Annual precipitation declines from north towards south. In the skirts of the Taurus Mountains and on high altitudes, while annual precipitation is 1200 – 1300 mm, it drops up till 300 mm in lower areas. Average evaporation in the region is between 1500 – 2500 mm; and annual average temperature changes between 12º-18º. Rate of humidity demonstrates great differences between summer and winter months. Annual humidity rate ranges from 42% (Sırnak) to 65% (Savur). There is a long and dry period not limited to summer months solely. Though rarely, but sometimes this period reaches even 10 months a year. The hottest month of the year is August, while the coldest month is February.

The high mountains in the North have a significant effect on climate of Mardin. High pressure area occurring during winter leads to cold winter months. On the one hand Mardin is under the effect of desert climate in the south, on the other hand the high mountains in the north which prevent the cool weather current entering in the area. Because of all these reasons, summers in the north of Mardin displays a typical terrestrial climate with boiling hot weather. However, the fact that cotton, hazelnuts and black olives are grown in some provincial towns such as Derik, Nusaybin and Savur shows that micro climate properties are lived in area.

Table 2.2 Mean values accruing within long years belonging to Mardin province (1954 – 2013)

MARDIN	January	February	March	April	May	June	July	August	September	October	November	December
Average Temperature (°C)	3.1	4.0	8.0	13.4	19.5	25.6	29.9	29.5	25.0	18.4	10.7	5.2
Average max. Temperature (°C)	5.8	7.2	11.6	17.2	23.8	30.5	34.9	34.6	29.9	22.8	14.2	8.0
Average min. Temperature (°C)	0.5	1.2	4.6	9.6	14.8	20.0	24.3	24.5	20.4	14.5	7.8	2.7
Average Sun Hours (hour)	4.2	5.0	5.6	7.1	9.4	12.1	12.2	11.3	10.1	7.4	5.5	4.2
Average Number of Rainy Days	11.4	10.7	11.4	10.6	7.4	1.6	0.5	0.2	0.8	5.1	7.6	10.8
Average Monthly Total Precipitation (kg/m^2)	117.0	107.3	97.8	82.4	43.2	4.7	1.3	0.2	1.8	32.9	70.1	110.8

According to meteorological data, precipitation is mostly observed in March. It was established that the highest annual temperature average is in July with 42,5ºC; on the other hand, the coldest month of the year is February with -14,0ºC. The highest humidity rate is measured in January with 76,1%. Annual shining duration in Mardin is more than 3000 hours, in some places duration can come close to 3250 hours. Throughout the year, daily sun-shining duration is between 8 – 9 hours. The temperature (at least +5ºC) needed for photosynthesis is present in Mardin from 294 – 332 days a year. This makes it possible for the farmers to receive crops 2-3 times a year [14].

2.1 Theory/calculation

In the general formula of model equations related to sun-shining duration, monthly mean daily total sunshine is represented by H, monthly mean outer atmosphere, solar radiation by Ho, sunshine duration by S, possible maximum monthly average daily sunshine duration by So. The equation related to this is as follows.

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right) \tag{2.1}$$

Here, a and b values called as Angström coefficient are regression constants. Daily outer solar radiation coming to horizontal surface (Ho), Solar constant (Gsc=1367 W/m^2), world orbit eccentric correction factor (*f*), declination (δ), latitude of the region ($\emptyset$) and sunset hour angle (ω_s) can be found as a function.

$$H_o = \left(\frac{24}{\pi}\right).Gsc\ .f.\left[\cos\emptyset.\cos\delta.\sin\omega_s + \left(\frac{\pi}{180}\right).\sin\emptyset.\sin\delta.\omega_s\right] \quad (2.2)$$

Day length in hours (S_o) changes according to different time periods in the year related to hour angle (ω_s).

$$S_o = \left(\frac{2}{15}\right).\omega_s = \left(\frac{2}{15}\right).arccos(-\tan\delta.\tan\emptyset) \quad (2.3)$$

So as to find monthly mean daily total solar radiation (H) value, various estimation models in many parts of Turkey and the world were developed. Many of the models developed were of a specific position since they possessed parameters of the region the calculation of which is desired to be carried out. Below, it is possible to find twenty authentic calculation models about different geographies of Turkey and the world in general.

Table 2.3 Input parameters for the estimation of monthly average daily global solar radiation in Mardin, Turkey (W/m^2)

Month	H_m	H_0	S	S_0	W_s	H_m/H_0	S/S_0
January	1910	5295,804	4,35	9,743011	73,07258	0,36066289	0,446473879
February	2520	6620,769	5,45	10,65433	79,90744	0,380620442	0,511529329
March	4070	8282,447	6,74	11,75424	88,15677	0,491400673	0,573410315
April	5080	9964,97	7,90	12,96758	97,25687	0,509785786	0,609211452
May	6230	11121,55	10,01	14,00314	105,0236	0,560173723	0,714839466
June	6830	11580,29	12,52	14,52642	108,9481	0,589795409	0,861878012
July	6620	11327,66	12,84	14,28952	107,1714	0,584410385	0,898560338
August	5920	10383,67	12,03	13,40017	100,5013	0,570125741	0,897749622
September	5040	8864,744	10,07	12,22532	91,6899	0,568544316	0,82370029
October	3800	7089,032	7,59	11,01299	82,59744	0,536039317	0,689185997
November	2410	5596,171	5,83	9,982757	74,87068	0,430651565	0,584007018
December	1800	4921,97	4,43	9,478185	71,08639	0,365707251	0,467389058

Some models available in the literature were investigated in order to determine daily mean global solar radiation in monthly basis coming to the horizontal surface in Mardin.

Table 2.4 List of All Models Compared

Model	**a**	**b**	**References**
1	0,307992	0,337410	Angström, Prescott, Page, Duffie and Beckman (1991)
2	0,217000	0,545300	Almorox and Hontoria (2005)
3	0,177000	0,692000	Jain (1990)
4	0,228000	0,527000	El-Metwally (2005)
5	0,174000	0,615000	Alsaad (1990)

2.2. Statistical Analysis

In literature, there are a number of statistical test methods so as to evaluate the performance of solar radiation estimation models. The most common ones among these are as follows: the calculations of relative error percentage (e), specificity coefficient (R^2), mean bias error (MBE), and t-statistics (t-sat).

2.2.1 Relative error percentage (e %)

Relative error is expressed as follows:

$$e = \left(\frac{mi - ci}{mi}\right) \times 100 \qquad (2.4)$$

Percentile bias between calculated and measured data is expressed with e, and its ideal value is equal to zero. While *ci* (calculated) in equation shows the calculated value, *mi* (measured) demonstrates the measured value.

2.2.2 Determination coefficient (R^2)

Determination coefficient shows at what rate a variable is relative to the other. It is used to determine the linear relation between calculated and measured values. The value of this coefficient change between 0 and 1 ($0 < R^2 < 1$) and the ideal value is the one that is close to 1

$$R^2 = \frac{\sum_{i=1}^{n}(ci - ca)x(mi - ma)}{\left[\sqrt{\sum_{i=1}^{n}(ci - ca)^2}\right]x\left[\sum_{i=1}^{n}(mi - ma)^2\right]} \qquad (2.5)$$

Here *ca* and *ma* are the mean of calculated and measured values respectively.

2.2.3 Mean percentile error (MPE %)

Monthly mean radiation value predicted out of models suggested and measured value bias are calculated with the help of equation below.

$$MPE = \frac{\sum_{i=1}^{n}\left(\frac{mi-ci}{mi}\right)}{n}\ x\ 100 \tag{2.6}$$

Here, value *n* is number of calculated and measured values.

2.2.4 Mean absolute error percentage (MAPE%)

The mean percentage error value is calculated by means of the following equation as absolute mean value of the difference between measured value.

$$MAPE = \frac{\sum_{i=1}^{n}\left|\left(\frac{mi-ci}{mi}\right)\right|}{n}\ x\ 100 \tag{2.7}$$

2.2.5 Mean Bias Error (MBE)

It gives information about long term value of the correlation. Its lowest value is the desired value. Ideal value is the one which is close to zero. It is calculated via following equations.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(mi - ci) \tag{2.9}$$

2.2.6 Mean error squares root (RMSE)

This statistical data has importance in comparing model performance measured and predicted in the short term. Though it receives a positive value all the time, its ideal value is the one which is close to zero.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(ci-mi)^2} \tag{2.10}$$

2.2.7 t-test method (t-stat)

Comparing t-test one of the most extensively used hypothesis test and means of two groups, the difference between the two is decided logically whether the difference is coincidental or statistical. It becomes a crucial factor in determining the statistical significant between measured solar radiation values and predicted solar radiation values.

$$t - stat = \sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}} \tag{2.11}$$

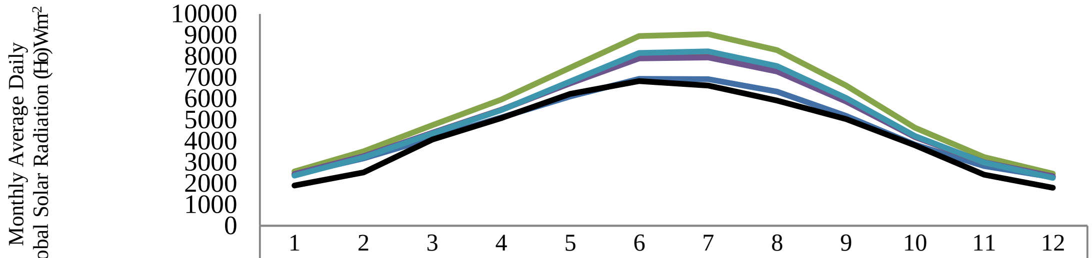
3.Results

The statistics of convenience of solar radiation values are calculated by means of the equation above.

Table 3.2. Statistical Analysis Of The Total Value Of Solar Radiation

	Model 1	Model 2	Model 3	Model 4	Model 5
	% e	% e	% e	% e	% e
January	-27,1649412	-27,67108	-34,74076168	-28,45561539	-24,37693168
February	-26,26413556	-30,29698048	-39,50335738	-30,72759667	-28,36686714
March	-2,048369533	-7,78997145	-16,76824432	-7,893062727	-7,172694914
April	-0,737613701	-7,732114094	-17,41683291	-7,702970551	-7,626587067
May	1,961487705	-8,323888828	-19,90368043	-7,952296565	-9,542137833
June	-1,526436325	-16,47803117	-31,13353766	-15,66887471	-19,37274638
July	-4,579805378	-20,97405692	-36,68541385	-20,04257891	-24,33293897
August	-7,152099206	-23,927551	-40,01169926	-22,97533684	-27,36067938
September	-3,055592679	-17,17006905	-31,3882804	-16,45355228	-19,704948
October	-0,837798605	-10,59135124	-21,99043782	-10,29060768	-11,53088382
November	-17,27388195	-24,33695141	-34,9427017	-24,40955573	-23,80410515
December	-27,34058217	-29,02868417	-36,83984317	-29,6977385	-26,178595
R^2	0,987704	0,977879	0,972148	0,978992	0,973409
MPE %	-9,66831	-18,6934	-30,1104	-18,5225	-19,1142
MAPE	9,995229	18,69339	30,1104	18,52248	19,11418
MBE	-258,705	-735,645	-1276,07	-718,842	-790,352
RMSE	347,9507	822,3378	1431,713	797,1244	913,5607
t-stat	3,687532	6,638856	6,519203	6,920726	5,721015

When radiation values and statistical values of the models chosen for estimation of solar radiation in Mardin province are compared, the closest values are found to be the empirical equation developed worldwide by Angström, Prescott, Page, Duffie and Beckman as model 1. Receiving the value of R^2, the model displays quite a good balance with the radiation data of Mardin province in respect to compliance.



	1	2	3	4	5	6	7	8	9	10	11	12
Model 1	2429	3182	4153	5117	6108	6934	6923	6343	5194	3832	2826	2292
Model 2	2439	3283	4387	5473	6749	7955	8008	7337	5905	4202	2997	2323
Model 3	2574	3515	4752	5965	7470	8956	9049	8289	6622	4636	3252	2463
Model 4	2454	3294	4391	5471	6725	7900	7947	7280	5869	4191	2998	2335
Model 5	2376	3235	4362	5467	6824	8153	8231	7540	6033	4238	2984	2271
H Measured	1910	2520	4070	5080	6230	6830	6620	5920	5040	3800	2410	1800

Figure 3.1 Average daily total radiation values of Mardin model 1-5

When it is examined in terms of monthly values, while April shows the best compliance, January shows the worst. Monthly relative error percentage value shows the difference between 0,7376 and 27,164 according to months. This model is followed by the Model 4 developed by El-Metwally special to Egypt, and Model 2 developed by Almorox and Hontoria special to the whole of Spain, and Model 5 developed for Jordan and Model 3 developed by Jain special to Italy, respectively.

4. Conclusions

When the results of analyses are examined, it can easily be seen that the most appropriate model for Mardin province Quadratic model. This model is followed by Logarithmic, Exponential, Linear and Exponential Power models, respectively. When examined in detail, Quadratic model is seen to be a second degree equation. When this model is observed from the angle of measurement results and compliance, its R^2 is 0,994284. It is accepted by everybody from general perspectives in present literature since this rate is very close to the other.

Table 3.3 List of the Models Developed

References	a	b	c	R^2	
Linear	0,4946	0,1627	-	0,8613	$H/Ho = 0{,}4946\ S/So + 0{,}1627$
Quadratic	-1,3049	2,2791	-0,4143	0,9482	$H/Ho = -1{,}3049\ (S/So)^2 + 2{,}2791(S/So) - 0{,}4143$
Logarithmic	0,3348	0,6377	-	0,9044	$H/Ho = 0{,}3348 \ln S/So + 0{,}6377$
Exponential	0,6598	0,7115	-	0,8851	$H/Ho = 0{,}6598\ (S/So)^{0{,}7115}$
Exponential Power	0,2413	1,046	-	0,8344	$H/Ho = 0{,}2413\ exp^{1{,}046(S/So)}$

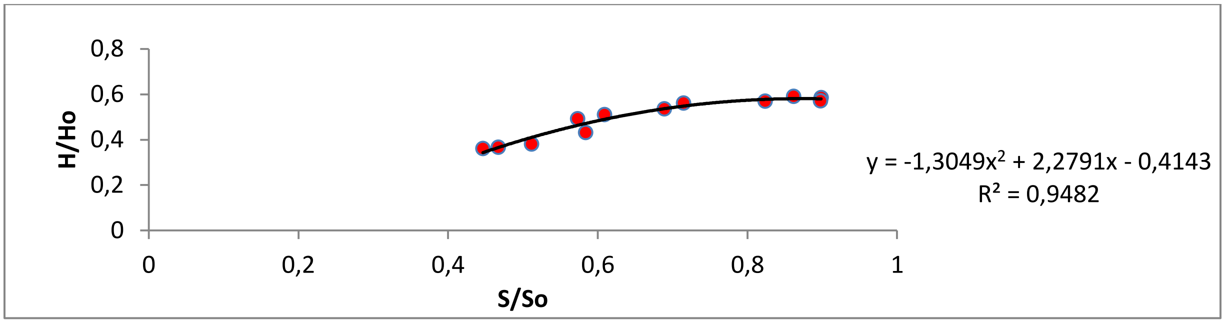
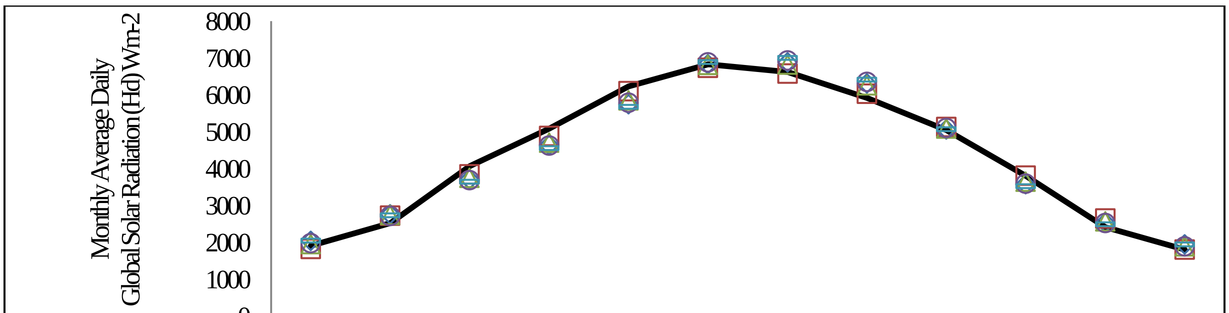


Figure 4.1. Correlation curve of quadratic model developed



	1	2	3	4	5	6	7	8	9	10	11	12
Lineer Model	2031	2752	3697	4624	5742	6821	6877	6300	5054	3570	2527	1939
Quadratic Model	1817	2715	3839	4881	6096	6724	6570	6023	5121	3804	2639	1801
Logaritmic Model	1947	2736	3740	4701	5842	6808	6818	6247	5077	3637	2561	1885
Exponential Model	1969	2711	3679	4621	5779	6874	6926	6345	5095	3589	2518	1890
Exponential Power Model	2038	2728	3641	4548	5668	6883	6997	6408	5063	3517	2487	1937
H Measured	1910	2520	4070	5080	6230	6830	6620	5920	5040	3800	2410	1800

Figure 4.2 Total radiation values of models developed for Mardin province, model A-E

This statistical data relative error percentage taking place among the other examined statistical data of the model's results and percentile MPE, MAPE, MBE, RMSE and t-stat values were figured out to be quite reasonable. When the monthly change compliance of Quadratic model was examined, while December provided the highest compliance, October, July, June, September, August, May, April, January, March, February, and November followed this month, respectively.

It is understood that the Mathematical model being able to meet appropriate solar radiation estimation in the best way in Mardin climate geography was Quadratic equation.

Table 4.1 Statistical analysis of models developed for Mardin province

	Linear Model	Quadratic Model	Logarithmic Model	Exponential Model	Exponential Power Model
	% e	% e	% e	% e	% e
January	-6,3391	4,8581	-1,9583	-3,0719	-6,7275
February	-9,2170	-7,7407	-8,5771	-7,5923	-8,2526
March	9,1762	5,6759	8,1198	9,6090	10,5447
April	8,9782	3,9096	7,4559	9,0323	10,4805
May	7,8393	2,1566	6,2239	7,2403	9,0157
June	0,1374	1,5450	0,3154	-0,6423	-0,7820
July	-3,8872	0,7514	-2,9908	-4,6268	-5,6891
August	-6,4198	-1,7444	-5,5183	-7,1794	-8,2453
September	-0,2740	-1,6005	-0,7425	-1,0922	-0,4562
October	6,057	-0,1094	4,2845	5,5521	7,4367
November	-4,8527	-9,5214	-6,2646	-4,4943	-3,2117
December	-7,7010	-0,0438	-4,7431	-5,0158	-7,5834
R^2	0,9753	0,9942	0,9830	0,9754	0,9657
MPE %	-0,5419	-0,1552	-0,3662	-0,1901	-0,2891
MAPE	5,9066	3,3047	4,7662	5,4291	6,5354
MBE	24,7826	16,5524	19,112	19,4287	26,1952
RMSE	281,5808	141,7101	233,7246	281,4875	333,0256
t-stat	0,2930	0,3900	0,2721	0,2294	0,2616

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