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ESTIMATION OF AVERAGE MONTHLY TOTAL SOLAR RADIATION ON A HORIZONTAL SURFACE FOR THE CENTRAL ANATOLIA REGION: EXAMPLE OF SIVAS PROVINCE

Summary

In this study, in order to determine the solar energy potential in the Central Anatolia Region, the total solar radiation on the horizontal plane was evaluated with trigonometric functions (Models). During 1999-2019 in the region, monthly average values of total daily solar radiation coming to the horizontal plane was calculated with six different models. It was also compared with the values measured in the same time interval. Model 1 (Angstrom-Prescott-Page), Model 2 (Soler, Rietveld), Model 3 (Kılıc and Ozturk), Model 4 (Akinoglu and Ecevit), Model 5 (Bahel) and Model 6 (Louche) were used in the calculations. Regression coefficients were calculated for these models and the coefficients were used in the estimation of total solar radiation (SR). From these models, Model 2 and Model 3 regression values for many provinces in the Central Anatolia Region (CAR) are higher than other models. Model 3 (Kılıc and Ozturk) with a determination coefficient (R^2) of 0.986 showed the best predictive performance among the models examined. This model was compared to other models and the mean error of deviation (MBE) was found to be -0.060 and the root mean square error (RMSE) 0.707. However, considering the total SR, annual sunshine duration (SD) and average temperature, Model 4 (Akinoglu and Ecevit) showed the best predictive performance which indicates that it will be a suitable model for Sivas Province.

Key words: *solar radiation, Sivas, sunshine duration, solar energy, regression*

1. Introduction

Increasing population, changes in living standards, and the industrialization process have caused energy consumption to increase continuously and has thus led humanity to seek new energy sources. In the face of the exhaustibility of traditional energy sources, pricing and environmental problems, renewable energy sources offer great advantages [1]. In response to the environmental impacts and increasing costs of fossil energy resources, countries have turned to alternative energy resources to meet their energy demands, with an increase in geopolitical risks [1]. The world's most important and largest energy source is the Sun. This is caused by the fusion process in which hydrogen gas in the Sun turns into helium. The intensity of SR is constant and is 1370 W/m^2. However, it varies between 0 and 1100 W/m^2 values on earth [2].

The radiation energy of the Sun is the main energy source that affects physical formations on earth and in the atmosphere. The flow of matter and energy in the world is possible thanks to solar energy (SE) [3]. In addition, all energy resources have occurred directly or indirectly due to solar energy. Wind, sea wave, temperature difference and biomass energies are transformed forms of SE [4,5].

The Sun has the largest share among all known energy sources and has begun to be discovered in many countries in the world in electrical energy production. SE is seen and subsidized by many countries as an opportunity to meet energy consumption with domestic resources. It seems that electricity generation from SE will continue to increase in importance in the coming years [2]. However, there are difficulties in converting this energy source into a usable energy type suitable for human activities [6]. SE is the oldest known primary energy source. It has clean and renewable energy characteristics [7]. In addition, the fact that most of the pollution caused by traditional energy generation does not occur in SE production makes this type of energy a clean and environmentally friendly energy [8-10]. SR data are required in the design of solar systems [11,12].

Solar energy is used in water heaters, grain dryers, solar cookers, cooling and heating systems of buildings, and photovoltaic batteries [13-15]. Electric energy is produced with the help of solar cells called photovoltaic batteries from sunlight. Although solar cells have sufficient technology to meet electricity needs, the biggest obstacle in using this method is the high cost of the batteries [16,17]. Turkey is located between 36°-42° north latitude and 26°-45° east longitude. It is located north of the Equator and east of Greenwich. It is a country with four seasons. Since it is located in the temperate zone, it has sufficient SE potential [18-22]. Most models developed for SR prediction rely on current climatic parameters such as SD, minimum and maximum temperatures, cloudiness, and relative humidity [23-25].

In Turkey, the daily SD is approximately 7.2 hours. The SE potential of the region should be determined in order for it to benefit more from new energy resources [26]. This constitutes an important input for engineers, architects, agriculturalists and meteorologists working in the field of SE structures [27]. Working on solar cells started in Turkey and the first heat pump working with solar cells was established in the Aegean University's SE Laboratory [28].

Solar energy generation systems are attracting increasing attention of society day by day [29]. In recent years, electricity energy unit prices have been falling with the decrease in SE production costs. Although SE is not widely used in Turkey, significant progress has been made in this regard [30].

Turkey's geographical location and climatic conditions put it in an advantageous position in terms of exploiting solar energy. At the same time, the fact that the land conditions are suitable in many places adds to the advantages. 2.6% of Turkey's annual electricity production comes from SE. If it can use its full potential, it has the potential to meet eight times the electricity needs of the country [1].

Turkey's annual hours of sunshine are about 2,640 hours (a total of 7.2 hours per day), while an annual SR of approximately 1311 kWh/m^2-year (daily total of 3.6 kWh/m^2) has been established.

The SE potential has been calculated as approximately 380109 kWh/year. If SR is perpendicular to the earth's atmosphere, a portion of this value, which is 1367 W/m^2, is absorbed in the atmosphere and reaches the earth with a value of about 1000 W/m^2. On an annual basis, these values in Turkey vary between 1100 kWh/m^2-year and 1300 kWh/m^2-year. The absorption of sunlight on cloudy, slightly cloudy and summer days can be seen in Fig. 1 [31].

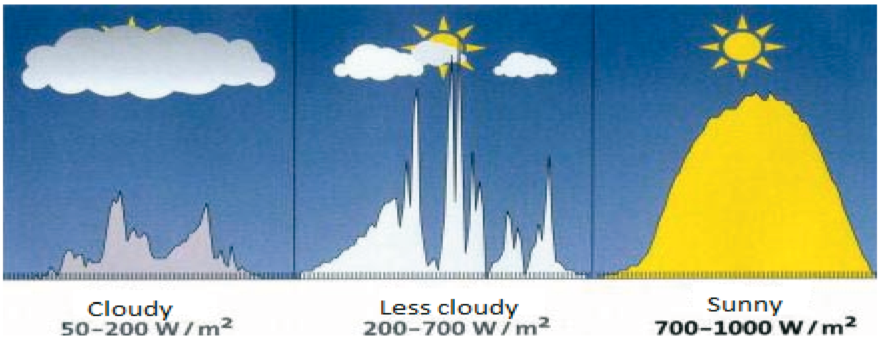

Fig. 1 Absorption of sunlight on cloudy, slightly cloudy and summer days

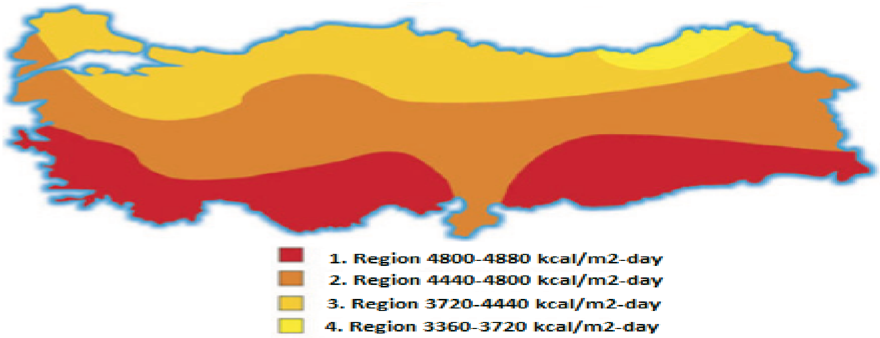

Fig. 2 Map of SE potential in Turkey[32,33]

The southeastern Anatolia region of Turkey has the highest solar field. This region is followed by the Mediterranean region. The annual sun energy coming to this region is 1460 kW/m^2 and the total annual SD is 2993 hours. The Black Sea region is the region with the least SE potential in Turkey. According to these data, total annual SE received in Turkey is about 1015 kWh.

Table 1 Distribution by months of SE total potential of Turkey [34]

Months	Monthly total solar energy (kWh/m^2-month)	Hours of Sunshine (hour/month)
January	51,75	103
February	63,27	115
March	96,65	165
April	122,23	197
May	153,86	273
June	168,75	325
July	175,38	365
August	158,4	343
September	123,28	280
October	89,9	214
November	60,82	157
December	46,87	103
Total	**1.311**	**2.640**
Average	**3.6 kWh/m^2-day**	**7.2 h/day**

Distribution by region of SD and SE potential of Turkey is given in Table 2.

Table 2 Distribution by months of SE total potential of Turkey [34]

Regions	Total solar energy (kWh/m^2-year)	Hours of sunshine (hours/year)
Southeastern Anatolia	1.460	2.993
Mediterranean	1.390	2.956
Eastern Anatolia	1.365	2.664
Central Anatolia	1.314	2.628
Aegean	1.304	2.738
Marmara	1.168	2.409
Black Sea	1.120	1.971

Accordingly, while most SE can be produced in Turkey in June, it can also be produced in December. Among the regions, the south-eastern Anatolia and Mediterranean regions are the first in terms of SE potential. In SE production, about 1100 kWh/m^2-year energy can be produced, and the total amount of SD is 2640 hours. Accordingly, the total annual amount of SE taken in Turkey is about 1015 kW hours [34]. However, studies have found that these values are lower than Turkey's real potential. Measurements of the Sun's radiation in Turkey, particularly by the State Meteorology Affairs General Directorate, the Republic of Turkey Ministry of Energy and Natural Resources, are provided by a few universities for research purposes. However, in recent years, SE measurements for energy purposes have been taken in order to measure SE values more consistently [34]. Models related to SR are frequently used in the analysis and design of SE systems. There are many studies in the literature similar to the subject of this study.

In this study, measurements were taken for the provinces of CAR and compared with the radiation models commonly used in the literature. Various models (linear, second and third order equations) were developed and their prediction accuracies were evaluated using various parameters.

2. Materials and methods

In this study, all SR coming to the CAR was calculated by using some model equations available in the literature and the results were compared with various methods. For this, SR measurement data coming to the horizontal plane for the years 1999-2019 were obtained from the Meteorology Directorate. By using some models in the literature, the total daily GSR values in the horizontal plane in Sivas Province were estimated. In addition, 8-48 Eppley Black and White model pyranometers were used for GSR measurement (Diffuse Pyranometer) [35]. Most of the prediction methods in the literature include the daily total extra-atmospheric GSR value (Q_o).

Fig. 3 Provinces of CAR

Calculation methods of monthly average total SR for the horizontal surface

The aim was to determine the appropriate model in estimating the monthly average SR coming to the horizontal plane for the provinces in CAR. In predicting SR, Page is a widely used model and is shown in the figure below:

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right), \tag{1}$$

where H is the monthly average daily SR, H_o is the monthly average daily out-of-atmosphere radiation, S_o the monthly average day length, S is the monthly average SD, and a and b are test coefficients. The monthly average daily out-of-atmosphere radiation in the horizontal plane was calculated by the following equation: [36]

$$H_o = \frac{24}{\pi} I_{gs} f \left(\cos\lambda \cos\delta \sin\omega_s + \frac{\pi}{180}\omega_s \sin\lambda \sin\delta\right) \tag{2}$$

I_{gs} = Solar constant (1367 W/m^2)
f = Offset factor
λ = Latitude of the region (°)
δ = Declination angle (°)
ω_s = Average sunrise-sunset hour angle for a given month (°).

The offset factor can be calculated by using the declination angle and sunrise-sundown hour angle formula:

$$f = 1 + 0.033\cos\left(\frac{360n}{365}\right), \tag{3}$$

$$\delta = 23.45\sin\left(\frac{360}{365}(284+n)\right), \tag{4}$$

$$\omega_s = \cos^{-1}(-\tan\lambda \tan\delta), \tag{5}$$

where n shows the day which represents the month. For a month that is given, the average day length (S_o) can be calculated with the equation below:

$$S_o = \frac{2}{15}\omega_s\,. \tag{6}$$

The a and b regression coefficients in equation (1) were calculated depending on the SR values measured for various regions. Linear and quadratic equations depending on the obtained SD for some provinces in Turkey are given below:

Model-1: The coefficients in the commonly used Angstrom-Prescott-Page model are given as below [37]

$$\frac{H}{H_o} = 0.23 + 0.48\left(\frac{S}{S_o}\right). \tag{7}$$

Model-2: Soler found the correlations given in Table 3 by applying the Rietveld model to 100 stations in Europe [38]

Table 3 Monthly Rietveld model relations

Months	Formula	Months	Formula
January	$\frac{H}{H_o} = 0.18 + 0.66\left(\frac{S}{S_o}\right)$	July	$\frac{H}{H_o} = 0.23 + 0.53\left(\frac{S}{S_o}\right)$
February	$\frac{H}{H_o} = 0.20 + 0.60\left(\frac{S}{S_o}\right)$	August	$\frac{H}{H_o} = 0.22 + 0.55\left(\frac{S}{S_o}\right)$
March	$\frac{H}{H_o} = 0.22 + 0.58\left(\frac{S}{S_o}\right)$	September	$\frac{H}{H_o} = 0.20 + 0.59\left(\frac{S}{S_o}\right)$
April	$\frac{H}{H_o} = 0.20 + 0.62\left(\frac{S}{S_o}\right)$	October	$\frac{H}{H_o} = 0.19 + 0.60\left(\frac{S}{S_o}\right)$
May	$\frac{H}{H_o} = 0.24 + 0.52\left(\frac{S}{S_o}\right)$	November	$\frac{H}{H_o} = 0.17 + 0.66\left(\frac{S}{S_o}\right)$
June	$\frac{H}{H_o} = 0.24 + 0.53\left(\frac{S}{S_o}\right)$	December	$\frac{H}{H_o} = 0.18 + 0.65\left(\frac{S}{S_o}\right)$

Model-3: Kılıc and Ozturk calculated a and b experimental coefficients in the Agstrom-Prescott-Page modal for Turkey [39]

$$\begin{aligned} a &= 0.103 + 0.000017Z + 0.198\cos(\lambda - \delta) \\ b &= 0.533 - 0.165\cos(\lambda - \delta) \end{aligned}, \tag{8}$$

where Z is the height value of the region.

Model-4: Akınoglu and Ecevit obtained the polynomial equation between H/H_o and S/S_o for Turkey [40]

$$\frac{H}{H_o} = 0.145 + 0.845\left(\frac{S}{S_o}\right) - 0.280\left(\frac{S}{S_o}\right)^2. \tag{9}$$

Model-5: Bahel proposed the following relation [41]

$$\frac{H}{H_o} = 0.175 + 0.552\left(\frac{S}{S_o}\right). \tag{10}$$

Model-6: Louche proposed the following relation [42]

$$\frac{H}{H_o} = 0.206 + 0.546\left(\frac{S}{S_o}\right). \tag{11}$$

Statistical evaluation

In this study, the following statistical expressions are used to statistically evaluate the Global SR forecast. R^2 is the indicator of the dependence of a variable on another variable and takes a value between $0 < R^2 < 1$. The closer this value is to one, the stronger the bond between variables:

$$R^2 = \frac{\sum_{i=1}^{n}(Q_i - Q_{ö})^2}{\sum_{i=1}^{n}(Q_{ö} - \bar{Q}_{ö})^2}. \tag{12}$$

RMSE is an indication of the deviation between the measured and calculated values and supplies information on the model being examined. The closer the RMSE is to zero, the higher the model's performance:

$$RMSE = \left[\frac{1}{n}\sum(Q_{iö} - Q_{ih})^2\right]^{0.5} \quad (\text{kWhm}^{-2} \cdot \text{year}^{-1}). \tag{13}$$

MBE provides information on the average bias error and the long-term performance of the model under study. The closer the MBE value is to zero, the more successful the model. If this value is positive, if it is negative above the calculated value, an estimate is made below the calculated value:

$$MBE = \frac{1}{n}\sum Q_{iö} - Q_{ih}\ (\text{kWhm}^{-2} \cdot \text{year}^{-1})\,. \tag{14}$$

The measurement system was installed in a region that receives sunlight during the day in Sivas Province. The signals received from the Eppley Black and White 8-48 model pyranometer were transmitted to the two channels of the highly accurate 16-Channel Data Logger and stored in mV per minute. The data in the Data Logger were recorded on a personal computer in mV and analysed using computer programs. The total daily SR was between 24.28 MJm^{-2} and 22.62 MJm^{-2} on summer days and 7.17 MJm^{-2} and 12.66 MJm^{-2} on winter days.

3. Results

The daily SR on a horizontal surface for CAR was calculated from some models available in the literature and the equations developed in this study, and the results were compared with various comparison methods. All SR measurement data coming to the horizontal plane in 1999-2019 were obtained from the General Directorate of State Meteorology Affairs. Statistical analysis of the calculation methods used to predict the monthly average of SR and insolation time was made by using the measured data as reference. In Table 4 and Table 5, R^2, MBE and RMSE values, calculated with different models, are given for monthly average daily SR data coming to the horizontal surface in CAR.

Table 4 SR results and measurement values obtained from models by months (CAR)

Z=891m	ANKARA	Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	6,19	5,70	5,58	5,46	5,47	5,07	5,57
February	8,40	8,46	8,84	8,59	8,57	7,78	8,41
March	13,79	12,59	13,72	12,99	13,20	11,93	12,73
April	17,60	16,30	17,72	17,07	17,22	15,59	16,58
May	20,86	20,48	21,84	21,15	21,79	19,98	21,07
June	24,21	23,46	25,31	23,76	24,86	23,25	24,37
July	23,49	24,50	26,07	24,43	25,71	24,53	25,60
August	20,96	22,23	23,94	22,12	23,33	22,26	23,23
September	17,25	18,11	19,88	17,98	19,08	18,07	18,88
October	11,86	11,98	12,87	11,94	12,74	11,65	12,31
November	6,31	7,61	8,06	7,50	7,93	7,16	7,67
December	5,77	5,18	5,18	5,03	4,95	4,60	5,05
R2		0,982	0,944	0,985	0,954	0,962	0,960
MBE		0,009	-1,026	-0,109	-0,679	0,402	-0,398
RMSE		0,891	1,572	0,735	1,299	1,169	1,207

Z=970m	AKSARAY	Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	7,96	8,27	9,16	7,82	8,80	8,06	8,50
February	11,27	9,12	9,51	8,97	9,48	8,56	9,17
March	14,96	13,19	14,30	13,29	13,95	12,64	13,43
April	17,61	16,97	18,51	17,47	18,01	16,37	17,35
May	21,08	21,53	22,96	21,91	22,88	21,19	22,27
June	23,35	25,61	27,69	25,42	26,77	25,71	26,81
July	23,46	25,79	27,50	25,41	26,76	26,02	27,07
August	21,39	23,91	25,79	23,34	24,65	24,20	25,14
September	18,05	19,03	20,86	18,54	19,85	19,15	19,95
October	12,94	14,24	15,51	13,70	14,91	14,28	14,89
November	9,01	8,22	8,75	7,84	8,70	7,89	8,38
December	6,41	5,79	5,92	5,45	5,90	5,35	5,78
R2		0,93	0,81	0,94	0,88	0,90	0,86
MBE		0,35	1,58	0,14	1,10	0,16	0,94
RMSE		1,56	2,56	1,41	2,02	1,82	2,16

Z=755m	ÇANKIRI	Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	6,60	5,46	5,24	5,23	5,10	4,79	5,29
February	9,79	8,27	8,59	8,41	8,29	7,55	8,19
March	14,07	12,12	13,15	12,59	12,62	11,39	12,21
April	18,15	15,39	16,54	16,33	16,10	14,54	15,54
May	22,61	18,98	20,21	19,97	20,11	18,26	19,37
June	24,73	21,68	23,34	22,37	23,07	21,20	22,34
July	23,81	22,45	23,81	22,83	23,83	22,18	23,27
August	21,66	20,65	22,12	20,85	21,89	20,44	21,43
September	17,05	16,66	18,08	16,76	17,70	16,39	17,23
October	12,54	11,36	12,08	11,39	12,04	10,94	11,60
November	6,45	7,01	7,22	6,93	7,14	6,47	6,99
December	5,36	4,79	4,64	4,65	4,37	4,16	4,61
R2		0,924	0,969	0,941	0,950	0,843	0,925
MBE		1,504	0,652	1,211	0,882	2,045	1,232
RMSE		1,887	1,192	1,462	1,355	2,391	1,657

Z=801m	ESKİŞEHİR	Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	7,54	5,87	5,81	5,61	5,71	5,26	5,75
February	11,58	8,76	9,21	8,86	8,97	8,12	8,75
March	16,26	12,59	13,72	12,99	13,20	11,93	12,73
April	18,29	16,17	17,56	16,97	17,06	15,44	16,43
May	24,79	20,75	22,13	21,36	22,08	20,29	21,38
June	27,21	23,60	25,46	23,87	24,99	23,41	24,53
July	25,98	24,63	26,22	24,53	25,82	24,68	25,76
August	24,03	22,76	24,55	22,54	23,77	22,87	23,83
September	18,91	17,75	19,43	17,67	18,75	17,65	18,47
October	13,27	11,77	12,61	11,76	12,51	11,41	12,07
November	9,48	7,53	7,94	7,42	7,82	7,06	7,57
December	7,43	5,10	5,07	4,95	4,84	4,51	4,96
R2		0,872	0,940	0,851	0,900	0,768	0,869
MBE		2,291	1,254	2,186	1,602	2,676	1,876
RMSE		2,489	1,701	2,328	1,903	2,902	2,186

Table 5 SR results and measurement values obtained from models according to months(CAR)

Z=801m KARAMAN		Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	7,70	5,87	5,81	5,61	5,71	5,26	5,75
February	12,14	8,46	8,84	8,59	8,57	7,78	8,41
March	16,36	12,12	13,15	12,59	12,62	11,39	12,21
April	18,62	16,30	17,72	17,07	17,22	15,59	16,58
May	22,91	20,07	21,40	20,82	21,35	19,51	20,61
June	24,99	24,01	25,91	24,19	25,37	23,88	24,99
July	24,46	25,59	27,28	25,28	26,60	25,78	26,84
August	23,37	23,55	25,46	23,17	24,40	23,78	24,74
September	19,01	18,47	20,33	18,28	19,40	18,48	19,30
October	13,32	12,08	13,00	12,04	12,86	11,77	12,42
November	7,30	7,70	8,18	7,58	8,04	7,26	7,77
December	6,89	5,33	5,39	5,18	5,18	4,78	5,22
R2		0,953	0,878	0,955	0,924	0,920	0,899
MBE		1,460	0,384	1,390	0,814	1,817	1,019
RMSE		2,141	1,958	1,926	1,933	2,593	2,158

Z=1053m KAYSERİ		Hpredicted (MJ /m2-day)					
Months	*Hö(MJ/m2-day)*	Model1	Model2	Model3	Model4	Model5	Model6
January	7,86	8,17	9,06	7,72	8,70	7,06	8,40
February	11,17	9,02	9,41	8,87	9,38	8,46	9,07
March	14,85	13,09	14,20	13,19	13,85	12,54	13,33
April	17,51	16,87	18,41	17,37	17,01	16,27	17,25
May	21,01	21,43	22,86	21,81	22,78	21,09	22,17
June	23,24	25,51	27,59	25,32	26,67	25,61	26,71
July	23,36	25,69	27,40	25,31	26,66	25,02	26,07
August	21,28	23,81	25,69	23,24	24,55	24,10	25,04
September	17,04	18,03	20,76	18,44	19,75	19,05	19,85
October	12,83	14,14	15,41	13,60	14,81	14,18	14,79
November	8,01	8,12	8,65	7,74	8,60	7,79	8,28
December	6,31	5,69	5,82	5,35	5,80	5,25	5,68
R^2		0,919	0,801	0,932	0,870	0,901	0,853
MBE		0,336	1,570	0,130	1,087	0,149	0,928
RMSE		1,545	2,550	1,401	2,012	1,808	2,147

Z=751m KIRIKKALE		Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	6,92	5,95	5,92	5,69	5,83	5,36	5,85
February	9,26	8,86	9,34	8,95	9,10	8,23	8,86
March	13,09	12,59	13,72	12,99	13,20	11,93	12,73
April	17,01	16,17	17,56	16,97	17,06	15,44	16,43
May	20,42	20,07	21,40	20,82	21,35	19,51	20,61
June	24,02	22,91	24,70	23,33	24,33	22,62	23,74
July	23,39	23,95	25,47	24,00	25,23	23,90	24,98
August	20,85	22,10	23,79	22,01	23,22	22,11	23,08
September	16,72	17,38	18,98	17,37	18,41	17,23	18,06
October	11,61	11,77	12,61	11,76	12,51	11,41	12,07
November	6,54	7,61	8,06	7,50	7,93	7,16	7,67
December	5,77	5,10	5,07	4,95	4,84	4,51	4,96
R2		0,985	0,949	0,986	0,960	0,967	0,970
MBE		0,096	-0,916	-0,060	-0,616	0,516	-0,287
RMSE		0,782	1,443	0,707	1,212	1,088	1,053

Z=1007m KIRŞEHİR		Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	8,64	6,20	6,26	5,92	6,18	5,64	6,13
February	11,97	8,96	9,46	9,04	9,23	8,35	8,97
March	15,30	12,70	13,86	13,09	13,35	12,06	12,87
April	18,03	16,30	17,72	17,07	17,22	15,59	16,58
May	21,98	20,34	21,69	21,04	21,64	19,82	20,92
June	26,92	23,46	25,31	23,76	24,86	23,25	24,37
July	25,06	24,63	26,22	24,53	25,82	24,68	25,76
August	23,42	22,63	24,40	22,44	23,66	22,72	23,68
September	19,33	18,11	19,88	17,98	19,08	18,07	18,88
October	13,74	12,39	13,39	12,31	13,19	12,13	12,78
November	7,99	8,21	8,91	8,07	8,68	7,85	8,35
December	8,04	5,72	5,93	5,55	5,73	5,22	5,66
R2		0,903	0,951	0,899	0,933	0,841	0,912
MBE		1,731	0,615	1,636	0,981	2,086	1,289
RMSE		2,021	1,439	1,915	1,560	2,406	1,789

Z=1029m KONYA		Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	8,01	6,42	6,57	6,12	6,50	5,90	6,38
February	10,85	9,01	9,35	8,92	9,31	8,41	9,03
March	16,06	13,89	15,14	13,95	14,76	13,43	14,22
April	19,08	17,79	19,56	18,20	18,93	17,31	18,28
May	22,38	22,24	23,72	22,52	23,58	22,01	23,08
June	25,72	24,93	26,95	24,94	26,19	24,94	26,04
July	26,60	26,11	27,85	25,70	27,01	26,38	27,43
August	24,51	24,47	26,43	23,84	25,08	24,84	25,78
September	19,92	19,14	20,97	18,68	19,95	19,25	20,05
October	14,27	13,22	14,22	12,85	14,02	13,09	13,73
November	8,95	8,27	8,78	7,93	8,75	7,93	8,42
December	6,74	5,81	5,89	5,48	5,87	5,33	5,77
R2		0,971	0,972	0,953	0,979	0,940	0,967
MBE		-0,982	0,198	-1,161	-0,262	-1,188	-0,404
RMSE		1,162	1,149	1,308	0,885	1,477	1,095

Z=1294m SİVAS		Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	7,17	5,87	5,81	5,61	5,71	5,26	5,75
February	9,71	8,46	8,84	8,59	8,57	7,78	8,41
March	12,66	12,12	13,15	12,59	12,62	11,39	12,21
April	17,25	16,30	17,72	17,07	17,22	15,59	16,58
May	19,76	20,07	21,40	20,82	21,35	19,51	20,61
June	24,12	24,01	25,91	24,19	25,37	23,88	24,99
July	24,28	25,59	27,28	25,28	26,60	25,78	26,84
August	22,62	23,55	25,46	23,17	24,40	23,78	24,74
September	20,14	18,47	20,33	18,28	19,40	18,48	19,30
October	12,38	12,08	13,00	12,04	12,86	11,77	12,42
November	8,10	7,70	8,18	7,58	8,04	7,26	7,77
December	5,93	5,33	5,39	5,18	5,18	4,78	5,22
R2		0,979	0,948	0,976	0,960	0,953	0,958
MBE		0,380	-0,696	0,310	-0,267	0,736	-0,061
RMSE		0,936	1,494	0,939	1,206	1,310	1,232

Z=1211m NİGDE		Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	9,42	7,02	7,39	6,68	7,29	6,58	7,06
February	13,40	9,74	10,47	9,75	10,24	9,25	9,87
March	17,13	13,52	14,85	13,78	14,32	13,00	13,79
April	21,37	17,34	19,08	17,92	18,43	16,79	17,76
May	24,84	21,16	22,58	21,68	22,50	20,76	21,85
June	29,07	24,70	26,67	24,72	25,99	24,67	25,78
July	29,87	25,72	27,43	25,38	26,71	25,94	27,00
August	26,65	23,55	25,46	23,17	24,40	23,78	24,74
September	21,97	19,20	21,23	18,89	20,01	19,32	20,12
October	15,51	13,12	14,32	12,96	13,92	12,96	13,60
November	9,80	8,56	9,39	8,39	9,08	8,25	8,74
December	8,78	6,41	6,90	6,23	6,66	6,02	6,45
R2		0,804	0,928	0,703	0,834	0,664	0,799
MBE		3,149	1,838	3,188	2,355	3,375	2,588
RMSE		3,273	1,983	3,286	2,458	3,495	2,701

Z=1301m YOZGAT		Hpredicted(MJ/m2-day)					
Months	Hö(MJ/m2-day)	Model1	Model2	Model3	Model4	Model5	Model6
January	6,89	6,36	6,48	6,07	6,41	5,83	6,31
February	8,59	9,05	9,59	9,13	9,36	8,46	9,09
March	12,59	12,82	14,00	13,19	13,49	12,19	13,00
April	16,94	16,69	18,23	17,39	17,68	16,04	17,02
May	19,63	20,48	21,84	21,15	21,79	19,98	21,07
June	24,79	23,60	25,46	23,87	24,99	23,41	24,53
July	23,61	24,63	26,22	24,53	25,82	24,68	25,76
August	21,86	23,02	24,86	22,75	23,99	23,17	24,13
September	16,55	18,11	19,88	17,98	19,08	18,07	18,88
October	11,41	12,39	13,39	12,31	13,19	12,13	12,78
November	6,80	8,04	8,67	7,90	8,47	7,66	8,16
December	5,79	5,80	6,04	5,63	5,84	5,31	5,75
R2		0,981	0,914	0,976	0,934	0,975	0,950
MBE		-0,462	-1,601	-0,536	-1,221	-0,123	-0,919
RMSE		0,917	1,927	0,932	1,545	0,948	1,350

When Table 4 and Table 5 are examined, Model 3 (Kılıc and Ozturk Angstrom-Prescott-Page; R^2= 0.986) showed the best performance for all daily SR on the horizontal surface for CAR. Model 3 was followed by Model 1 (Page; R^2 = 0.985), Model 4 (Akinoglu- Ecevit; R^2 = 0.979), Model 5 (Bahel; R^2 = 0.9753), Model 2 (Soler, Rietveld; R^2 = 0.972) and Model 6 (Louche; R^2 = 0.970). When Table 4 and Table 5 are analysed, Kırıkkale Province gives the highest R^2 (0.986) and the lowest MBE (0.06) and RMSE (0.707) values with Model 3. The annual total SD and average temperature is higher in Sivas (2902.5 hours/year) than Kırıkkale (2648 hours/year). Thus, no matter how high the R^2 is in Kırıkkale Province, the fact that the annual total SD and the average temperature in Sivas are much higher ensure the high SE performance of Sivas. Fig. 4 and Fig. 5 show, according to the models, the monthly average daily total SR coming to the horizontal plane for CAR and a comparison of the measurement and estimated values of the changes by months.

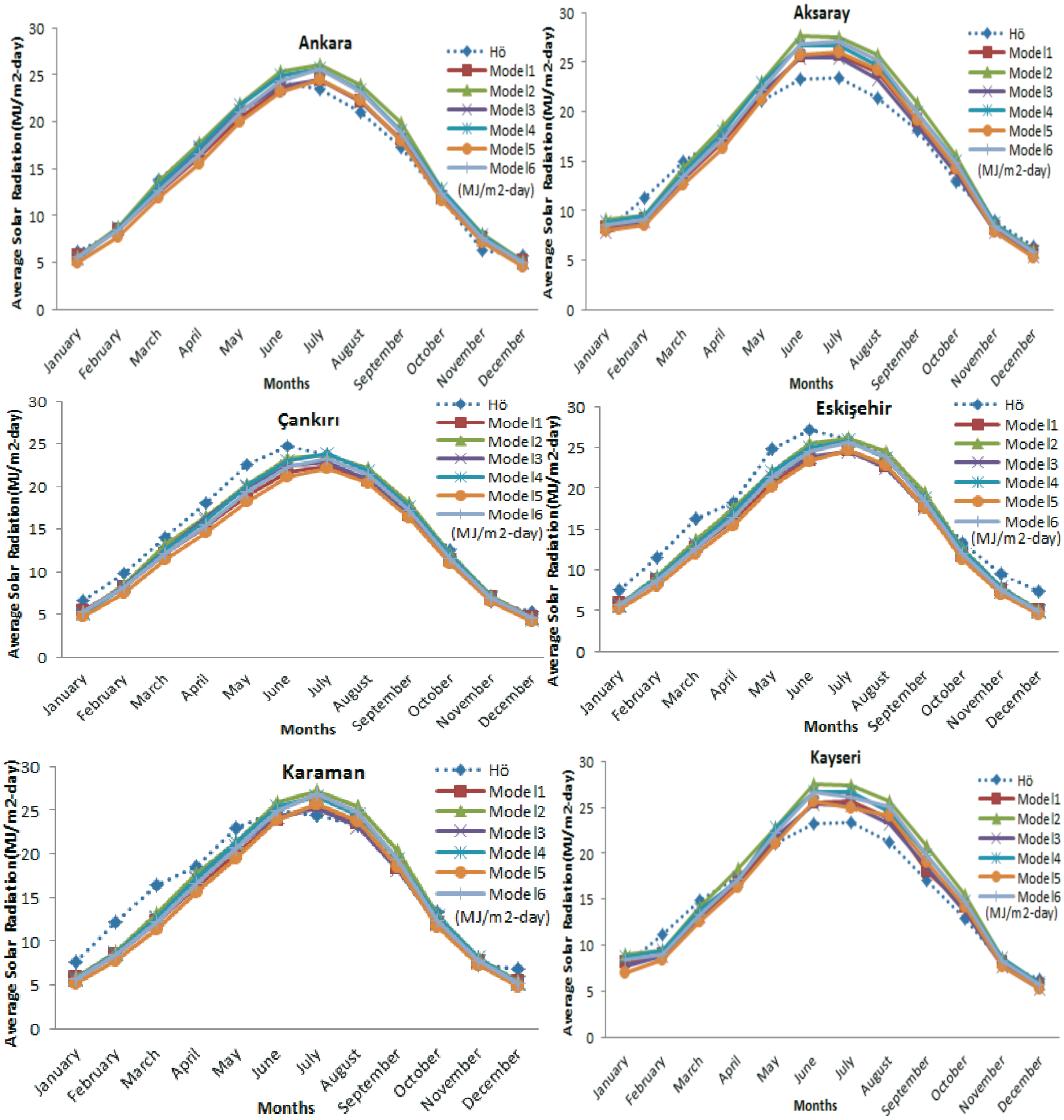

Fig. 4 Comparison of measurement and calculation data in CAR according to models

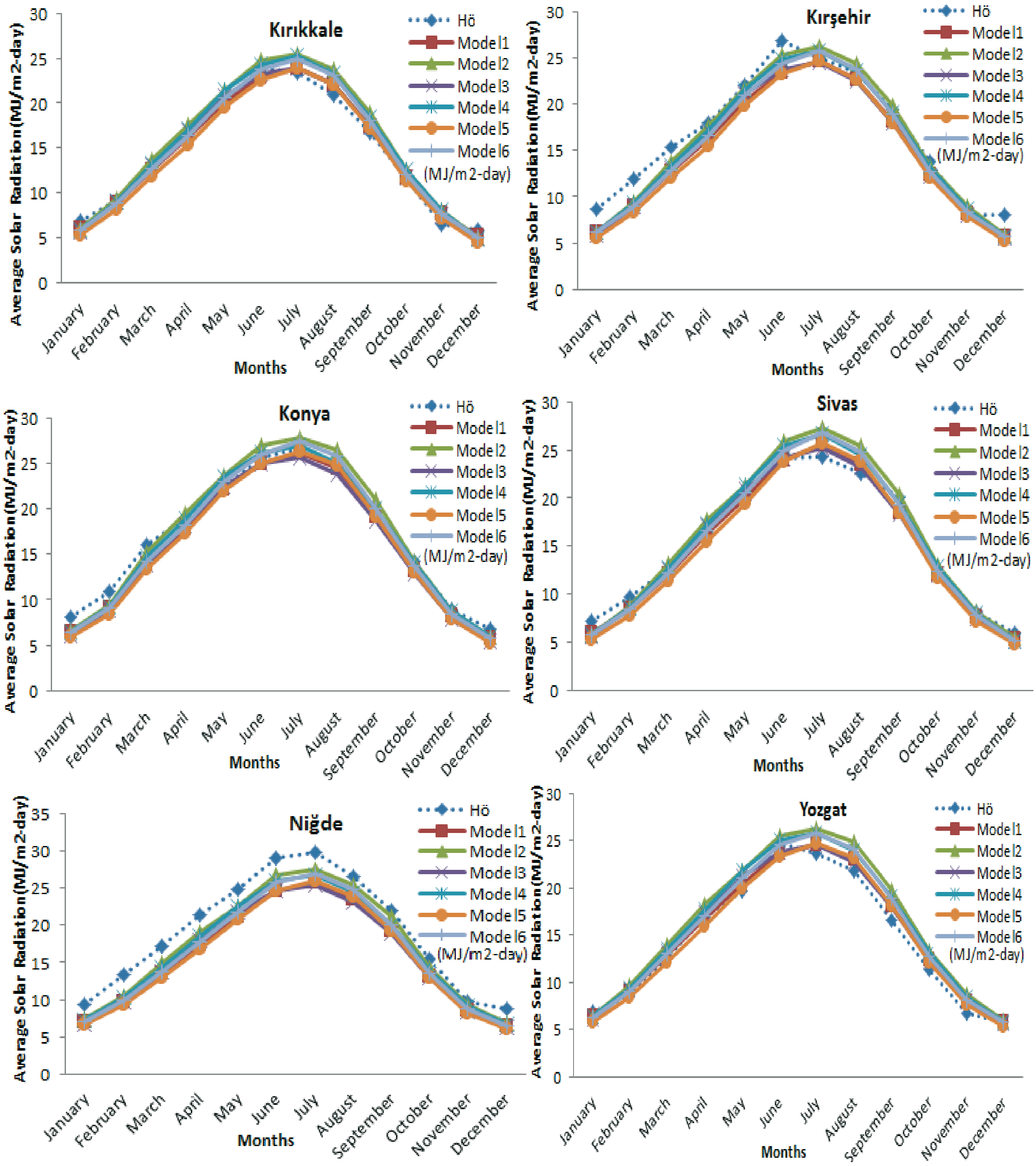

Fig. 5 Comparison of measurement and calculation data in CAR according to models

The estimated values seem to be in good agreement with the measured values. Table 4 and Table 5 show the statistical test results of MBE, RMSE and R^2 for the measuring stations. While the MBE values varied between -0.060 and 3.149, the optimal MBE value was 0.060. RMSE values ranged from 0.707 to 3.495. The optimal RMSE value was 0.707 obtained for the measurement station. R^2 values ranged from 0.703 to 0.986. For CAR, the highest R^2 value of 0.986 for all daily SR on the horizontal surface indicates that the estimating values are in good agreement with the measurement data. The R^2 was calculated as 0.83 according to the Yaman and Arslan model in their study on global SR in Mersin Province [43]. In another study conducted in Sivas Province, the estimation of sun radiation was calculated and R^2 was found to be close to 0.987. Among the models examined, the accuracy of Model 4 was found to be high. When the geographical distribution of solar power plants in Turkey is considered in terms of geographical factors such as provinces, districts, elevation and slope, most solar power plants in Turkey were installed in the Central Anatolia, Aegean and Mediterranean regions. SD, SR values, cloudiness duration, topographic conditions of the land and land use status were effective in these distributions. In addition, 94% of the installed power of existing solar power plants are located in rural areas. Although there are more urban areas in terms of the number of power plants, the fact that rural areas are suitable for large-scale power plant installations has led to such a result [44]. The total annual SD 2902.5 hours/year in the Province of Sivas is above average in Turkey. Fig. 6 shows the SE potential atlas of Sivas Province, and Fig. 7 shows the SD and global radiation values of Sivas Province. Fig. 8 shows the daily total global SR and daily average air temperature values of Sivas Province.

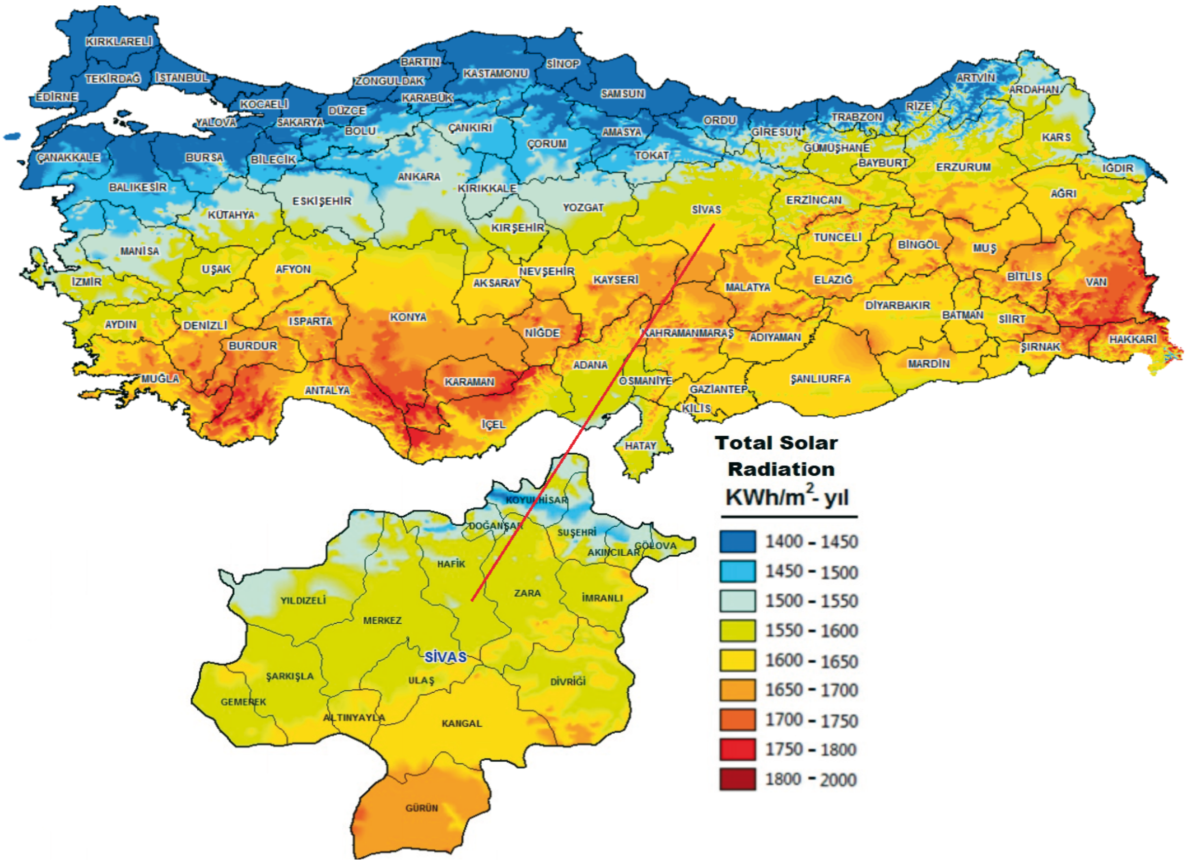

Fig. 6 SE potential atlas of Sivas Province [45]

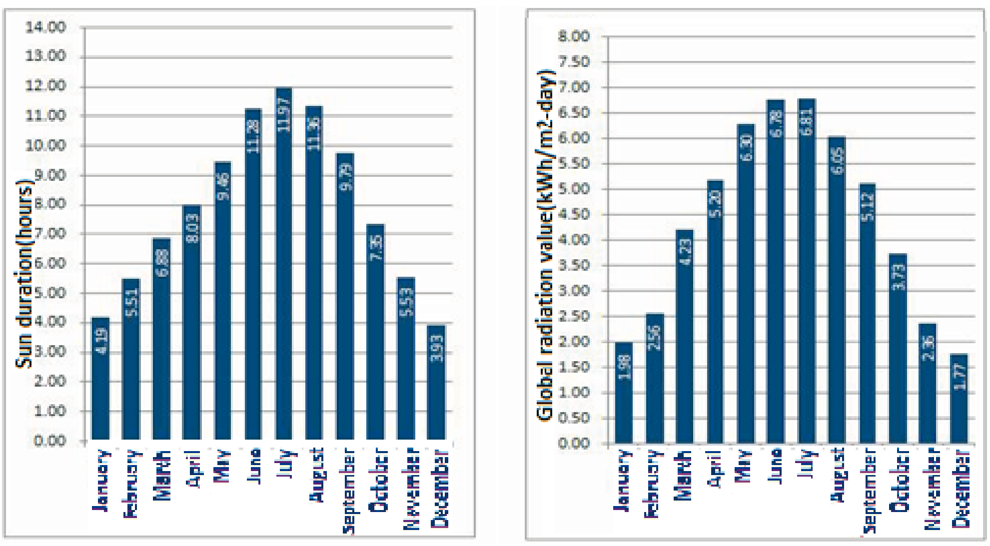

Fig. 7 SD and global radiation value for Sivas Province [45]

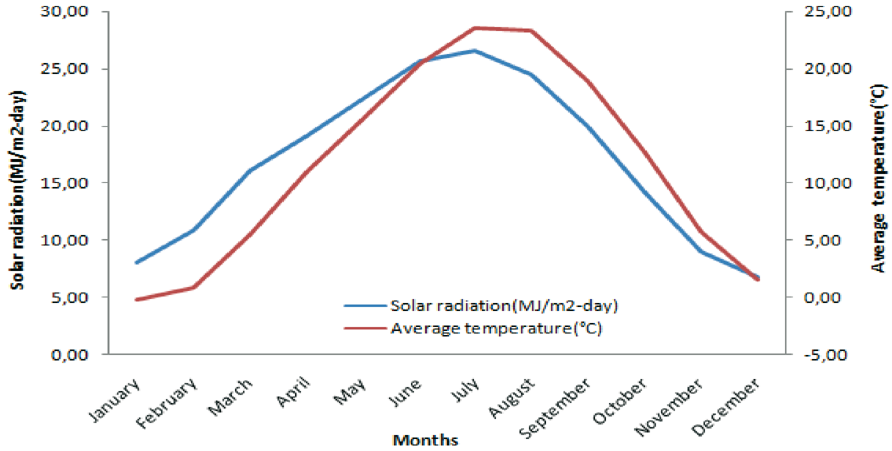

Fig. 8 Total daily global SR and daily average air temperature in Sivas Province

4. Conclusions

In this study, all SR coming to the horizontal plane for 12 provinces in CAR has been calculated with some models in the literature and compared with various methods. The study was created by establishing a relationship between the ratio of global SR to global SR outside the atmosphere and the ratio of SD to day length. Low performance was found compared to other regions. Therefore, various models were created by using regression analysis for CAR. The determination coefficients of these models were found to be the best R^2 (0.986) and the lowest MBE (0.06) and RMSE (0.707) values. The reason for the high performance of this model is that 20 years' long-term measurement data were used in the study. When Table 3 and Table 4 are examined, Kırıkkale Province gives the highest R^2 and the lowest MBE and RMSE values with Model 3. As a result, Model 3, whose coefficients were arranged by Kılıç and Öztürk, showed the best performance among the analysed and created models. The annual total SD and average temperature is higher in Sivas (2902.5 hours/year) than in Kırıkkale (2648 hours/year). The best performance of R^2, MBE and RMSE values for SE in Sivas Province are given by Model 4, whose coefficients were regulated by Akınoğlu and Ecevit. In models to be developed to achieve better results, a suggestion is made to increase the number of parameters that affect SR, to develop algorithms and to use long-term measurement data more widely. Studies in the literature are generally given as separate studies and have not been compared with other models. It was found that the models represented the measurement values well. These models will eliminate the need for data deficiency that will arise in applications and systems related to SE and will be useful for relevant engineers and practitioners.

On the other hand, in this study, it is thought that SE investors will contribute to the literature as they obtain information about the provinces of CAR. Values related to SR are not available for all provinces in the literature. Therefore, these models can be developed in other provinces. A complete and reliable database related to solar data should be established. There is great SE potential in Turkey. However, most of this potential is not used. Turkey will obtain many benefits when it can economically and strategically use its real potential in this regard. Efforts are underway to make effective use of SE in public institutions and organizations, universities, and associations established on the subject [45]. There is an annual solar electricity generation potential of about 380 109 kWh in Turkey which should be able to use this energy source fully and should also make good use of the opportunities arising from its geographical features. GSR can be estimated in regions where the measured temperature and SD data are available in Sivas. The predicted results are in agreement with the measurement data. For the widespread use of environmentally friendly, solar-based energy generation systems, there are high initial investment costs but no operating costs due to the lack of fuel costs. When the necessary long-term financing is provided, these technologies will develop, and the energy problem can be solved.

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