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Typical solar radiation year for southeastern Anatolia

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Abstract

The typical solar radiation year for seven provinces located in the southeastern Anatolia region of Turkey is generated from daily global solar radiation measured at least for 14 years, using the Finkelstein–Schafer statistical method. The typical data of the daily global solar radiation for the locations considered are presented throughout a year in a tabular form. The data obtained are also analyzed. It is expected that the presented typical data for southeastern Anatolia region, which has the highest solar energy potential in Turkey, will be useful to the designers of solar energy systems.

Keywords: Global solar radiation; Test reference year; Southeastern Anatolia; Turkey

1. Introduction

Energy is essential to economic and social development and improved quality of life in Turkey, as in other countries. Turkey is an energy importing country. Because of its limited energy resources, more than the half of the energy requirement is supplied by imports [1]. Solar energy is being seriously considered for satisfying a significant part of energy demand in Turkey, as is in the world. In this respect, the importance of solar radiation data for design and efficient operation of solar energy systems has been acknowledged [2]. Although, in recent years, many individual studies have been carried out on this subject for different locations of Turkey [2–15], the studies have not been completed yet.

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Turkey, which has 81 administrative provinces, is divided into seven geographical regions, and one of them is southeastern Anatolia region which is generally called the Southeastern Anatolia Project (SAP, Turkish initials "GAP") Region (Fig. 1). The Southeastern Anatolia Project (SAP) is Turkey's largest and most multifaceted development project, and also, one of the largest development projects of its kind in the world [16]. The project area covers nine provinces (Adıyaman, Batman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa and Şırnak) of the Southeastern Anatolia Region, which is a relatively underdeveloped region in Turkey. The project covers such sectors as irrigation, hydroelectric power production, agriculture, urban, rural and agricultural infrastructure, transportation, industry, forestry, tourism, education and health. Its water resources program envisages the construction of 22 dams and 19 power plants and irrigation schemes on an area extending over 1.7 million hectares [17]. Parallel to this development, an

Table 1
Geographical data and weather database for locations considered in this study

Province	Longitude (°E)	Latitude (°N)	Elevation (m)	Daily global solar radiation	
				Period	Total years
Adıyaman	38.17	37.45	678	1981–2001	19
Batman	41.10	37.52	540	1986–2001	16
Diyarbakır	40.12	37.55	660	1983–2001	18
Gaziantep	37.22	37.05	855	1985–2001	17
Kilis	37.05	36.44	638	1985–1998	14
Siirt	41.56	37.56	875	1981–1998	17
Şanlıurfa	38.46	37.08	547	1983–2001	18

intensive investment activity is expected to be undertaken in the region. Modern buildings and many new industrial establishments, etc., demanding considerable extra energy, will be installed. Therefore, new, reliable and detailed weather data for solar energy systems would be required, because energy analysis and simulation is of great importance for the region.

An accurate knowledge of the solar radiation data at a particular geographical location is of vital importance for the development of solar energy devices and for estimates of their performances [18]. In this study, typical solar radiation data for seven provinces located in the southeastern part of Turkey were generated by using the daily global solar radiation recorded during the period 1981–2001. Şırnak and Mardin are not included in this study because of a lack of solar radiation measurements.

In Turkey, meteorological measurements are taken and the related records are kept by the Turkish State Meteorological Service (Turkish initials "DMİ"). Solar radiation is measured hourly. Meteorological stations are located in city centers and there is generally only one station in each city. In this study, the global solar radiation data were taken from the Turkish State Meteorological Service in computer diskettes for each location. There were missing and invalid measurements in the data and they were marked and coded as 99999 in the files. The missing and invalid measurements, accounting for approximately 0.36% of the whole database, were replaced with the values of preceding or subsequent days by interpolation. In the calculations, if more than 15 days' measurements were not available in a month, the year was excluded from the database. For example, the data for the year 1985 for Batman was not considered in the calculations due to missing values. Table 1 provides geographical information for locations and the periods of the data considered.

2. Generation of typical solar radiation year

The real recorded data from past weather observations are selected for generation of representative weather data. A representative database for the one-year duration is known as test reference year (TRY) or typical meteorological year (TMY). TMY or TRY consists of the months selected from the individual years and concatenated to form a complete year. Many attempts have been made to produce such weather databases for different locations around the world [19–25].

Finkelstein–Schafer (FS) statistics [26] are the common methodology for generating typical weather data [19–25]. According to these statistics [26], if a number, n, of observations of a variable X are available and have been sorted into an increasing order X_1, X_2,…,X_n, the cumulative frequency distribution function (CDF) of this variable is given by a function $S_n(X)$ which is defined as follows:

$$S_n(X) = \begin{cases} 0 & \text{for } X < X_1 \\ (k\text{-}0.5)/n & \text{for } X_k < X < X_{k+1} \\ 1 & \text{for } X > X_n \end{cases} \tag{1}$$

The FS by which comparison between the long-term CDF of each month and the CDF for each individual year of the month was done is given by the equation:

$$FS = (1/n)\sum_{i=1}^{n}\delta_i \tag{2}$$

where δ_i is the absolute difference between the long-term CDF of the month and 1 year CDF for the same month at X_i (i=1,2,…,n), n being the number of daily readings of the month.

δ_i and $F(X_i)$ are expressed with the following equations:

$$\delta_i = \max[|F(X_i) - (i-1)/n|, |F(X_i) - i/n|] \tag{3}$$

$$F(X_i) = 1 - \exp(-X_i/\bar{X}) \tag{4}$$

where X_i is an order sample value in a set of n observations sorted in an increasing order and $\bar{X}$ is the sample average.

Finally, the representative year for each month of the data set was determined on the basis that the representative year is that of the smallest value of FS, i.e.

$$\mathrm{TRY} = \min(\mathrm{FS}) \equiv \min(\delta_i). \tag{5}$$

By applying the above methodology for all the months in the database, the test reference year for daily global solar radiation data was formed for seven provinces of southeastern Anatolia region. Due to lack of wet-bulb temperature, relative humidity and wind speed data, the study could not be extended to include these parameters. However, detailed weather data such as new outdoor design conditions, heating and cooling degree-days and bin values for the southeastern Anatolia region were presented by Büyükalaca and Bulut [27] in a previous study.

Table 2 gives the test reference years with minimum FS for monthly mean global solar radiation for all locations considered in this study. As can be seen from the table, the minimum and maximum values of monthly mean of daily global solar radiation on a horizontal surface (I_{TRY}) in the GAP region are, respectively, 4.72 MJ/m^2 in December in Batman, and 28.18 MJ/m^2 in June in Diyarbakır, with an annual average value of 15.91 MJ/m^2.

Table 2
The test refence years with minimum (min) FS and monthly mean of daily global solar radiation (I_{TRY}) for southeastern Anatolia, Turkey

Province	Month	Year	Min FS	I_{TRY} (MJ/m^{2}day)
Adıyaman	January	1982	0.033	6.72
	February	1983	0.044	8.92
	March	1992	0.033	12.66
	April	1986	0.045	15.91
	May	1996	0.048	18.23
	June	1994	0.045	20.32
	July	1992	0.041	20.01
	August	1981	0.044	17.94
	September	1982	0.044	15.19
	October	1982	0.031	11.27
	November	1985	0.030	7.64
	December	1989	0.032	5.58
Batman	January	1995	0.056	5.67
	February	1990	0.033	8.84
	March	1995	0.034	12.39
	April	1996	0.031	16.09
	May	1991	0.037	19.49
	June	1987	0.031	21.71
	July	1997	0.037	20.48
	August	1987	0.033	19.03
	September	1987	0.037	16.42
	October	1990	0.033	11.30
	November	2001	0.035	7.81
	December	1988	0.050	4.72
Diyarbakır	January	1992	0.039	8.66
	February	1999	0.036	11.40
	March	2001	0.042	16.13
	April	1998	0.036	20.39
	May	1997	0.032	24.28
	June	1993	0.034	28.18
	July	1994	0.030	26.99
	August	2000	0.038	24.77
	September	1983	0.035	21.06
	October	1999	0.041	15.01
	November	1998	0.034	9.63
	December	2000	0.049	6.83
Gaziantep	January	1986	0.052	6.84
	February	1993	0.058	9.39
	March	1993	0.057	13.45
	April	1994	0.053	17.71
	May	1996	0.052	20.30
	June	1991	0.053	23.36
	July	1990	0.053	23.31
	August	1991	0.052	20.80
	September	1995	0.053	17.56
	October	1993	0.054	12.29
	November	1988	0.038	7.77
	December	1995	0.050	5.41

(continued on next page)

Table 2 (*continued*)

Province	Month	Year	Min FS	I_{TRY} (MJ/m^{2}day)
Kilis	January	1992	0.042	9.14
	February	1993	0.062	12.10
	March	1997	0.067	16.38
	April	1987	0.068	20.52
	May	1997	0.069	23.62
	June	1987	0.064	26.56
	July	1994	0.068	26.68
	August	1997	0.064	24.06
	September	1991	0.064	19.77
	October	1990	0.068	14.86
	November	1989	0.060	9.85
	December	1988	0.054	6.60
Siirt	January	1986	0.051	7.81
	February	1997	0.051	11.45
	March	1989	0.047	15.35
	April	1981	0.049	18.75
	May	1983	0.055	22.42
	June	1987	0.048	26.39
	July	1981	0.040	26.20
	August	1988	0.039	23.88
	September	1983	0.040	19.96
	October	1992	0.051	13.68
	November	1982	0.038	9.69
	December	1981	0.033	7.58
Şanlıurfa	January	1993	0.038	8.48
	February	1993	0.034	11.02
	March	1997	0.053	16.48
	April	1998	0.037	20.02
	May	1997	0.041	23.89
	June	1999	0.043	27.19
	July	1998	0.038	25.98
	August	1992	0.036	23.34
	September	2001	0.035	19.78
	October	1990	0.040	14.63
	November	1998	0.052	9.93
	December	1992	0.032	6.69

Although typical solar radiation year are formed for each province considered, it is not practical to present all of them in this paper due to space limitations. Tables 3 and 4 show an example for typical solar radiation year for Gaziantep and Diyarbakır which are the biggest provinces in the region of GAP, respectively.

Variation of daily global solar radiation on a horizontal surface generated from test reference year and the all available long-term measured data for Gaziantep and Diyarbakır are shown in Figs. 2 and 3, respectively. It can be seen from figures that both data fluctuate significantly and are very random throughout the year.

Fig. 4 shows monthly mean of daily global solar radiation data (I_m) for seven locations considered in this study. As can be seen from the figure, although the

Table 3
Daily global solar radiation values obtained from test reference year data for Gaziantep

Day	Global solar radiation on a horizontal surface (MJ/m^2 day)											
	January	February	March	April	May	June	July	August	September	October	November	December
1	3.44	2.17	14.74	11.49	17.74	21.25	19.15	22.09	20.24	16.33	8.11	7.89
2	3.03	7.11	9.70	21.36	21.00	25.25	23.44	22.08	20.42	14.72	4.12	8.45
3	4.47	12.28	16.24	19.40	21.91	24.79	23.00	21.23	20.51	14.10	10.02	8.19
4	10.65	11.36	12.46	19.62	20.90	21.78	23.14	20.57	17.12	15.32	10.25	7.26
5	9.14	12.56	12.98	19.65	20.63	20.89	25.33	21.46	19.79	15.74	8.72	4.43
6	5.91	12.03	3.49	16.76	20.52	23.69	23.66	21.64	18.48	14.44	6.66	8.31
7	4.87	2.65	3.92	19.68	18.98	23.78	21.12	21.60	18.25	14.94	2.21	7.07
8	1.68	2.24	3.90	17.33	19.17	25.52	24.65	21.55	17.15	13.37	13.24	5.04
9	7.57	0.91	6.81	21.98	19.62	24.42	26.52	20.84	19.61	12.95	7.28	4.11
10	2.08	0.63	14.39	20.02	9.76	25.54	25.14	22.29	18.94	13.64	9.19	1.19
11	2.51	6.18	13.23	20.49	19.04	24.24	26.20	20.37	19.41	13.92	8.41	2.80
12	5.90	13.61	17.57	19.97	20.42	24.69	24.11	21.93	17.43	13.27	6.78	5.56
13	2.69	9.72	15.16	19.11	20.55	20.45	24.50	22.30	13.97	12.75	12.98	3.52
14	8.34	14.89	11.82	18.80	22.19	22.00	23.30	21.03	18.44	13.47	12.66	6.11
15	7.08	14.42	12.12	19.12	17.28	19.42	22.91	20.47	17.14	13.50	10.86	6.43
16	3.93	13.30	15.99	15.70	20.74	22.31	23.19	21.02	16.32	13.44	2.40	8.08
17	3.79	7.29	12.29	15.02	22.54	24.44	24.55	19.77	17.31	12.93	3.11	7.69
18	4.87	9.33	9.36	18.70	23.78	25.71	22.92	19.70	16.38	12.68	1.88	6.69
19	9.46	9.59	13.55	16.75	16.75	25.15	23.50	20.22	18.10	12.67	6.25	8.44
20	15.16	11.36	4.45	12.91	21.54	23.66	22.36	19.74	18.90	12.97	10.16	4.12
21	8.10	11.74	17.96	14.10	22.76	23.21	23.06	20.88	18.36	12.18	4.95	2.27
22	11.08	8.80	19.11	13.73	19.79	24.18	20.98	20.12	17.56	3.49	9.91	6.78
23	11.96	13.65	18.11	17.25	21.73	21.23	21.35	20.49	15.71	9.51	11.08	2.54
24	9.58	9.51	17.66	16.73	21.69	25.68	21.88	19.65	13.70	11.58	10.02	5.89
25	9.95	6.72	18.49	16.80	21.66	23.76	23.45	21.65	16.80	10.74	8.74	2.12
26	11.10	8.70	14.32	19.65	19.44	24.85	22.18	21.24	17.17	10.61	7.06	1.72
27	7.99	15.81	18.82	18.16	21.98	23.68	23.61	20.80	16.38	8.20	6.27	0.83
28	7.71	14.25	18.78	18.26	23.41	22.73	22.11	20.03	15.65	11.44	10.20	3.73
29	4.72	–	20.16	9.77	21.40	19.74	22.21	20.27	16.31	11.08	6.44	6.23
30	6.30	–	19.68	23.10	21.30	22.91	24.07	18.60	15.35	6.08	3.05	6.83
31	7.13	–	9.72	–	18.96	–	25.07	19.25	–	8.79	–	7.51

Table 4
Daily global solar radiation values obtained from test reference year data for Diyarbakır

	Global solar radiation on a horizontal surface (MJ/m^{2}day)											
Day	January	February	March	April	May	June	July	August	September	October	November	December
1	2.26	12.52	14.73	20.37	17.84	28.23	31.34	27.90	23.41	18.11	13.22	7.05
2	5.35	12.06	14.66	14.77	20.24	24.16	30.21	27.59	19.17	18.28	13.36	10.00
3	9.91	10.54	16.47	6.64	23.74	27.16	30.30	28.91	22.85	16.22	12.48	9.61
4	9.93	14.03	18.00	20.42	23.76	27.41	30.08	25.98	23.29	17.58	12.54	9.98
5	8.81	6.65	18.36	24.54	28.83	26.86	30.12	20.44	21.69	15.62	13.02	10.55
6	6.07	12.65	18.66	24.88	28.19	28.07	28.34	21.40	18.70	15.06	12.08	10.10
7	2.97	1.39	14.31	23.68	28.25	17.51	28.63	25.21	19.32	13.64	12.14	10.20
8	11.04	2.79	5.07	23.89	28.73	25.62	28.46	25.35	23.40	16.60	12.36	9.62
9	10.05	7.61	15.41	25.03	27.58	27.63	26.65	25.52	22.56	14.13	11.60	10.15
10	9.85	14.92	21.68	19.18	27.38	27.29	26.59	25.26	23.71	17.47	8.23	10.43
11	10.29	14.68	21.70	18.85	26.75	29.44	24.16	26.67	22.60	8.16	11.03	9.77
12	10.07	14.72	15.95	21.06	28.21	29.06	26.80	24.97	21.11	19.92	11.54	7.29
13	7.21	13.88	5.07	25.58	27.15	29.84	26.23	24.87	23.33	19.40	5.85	1.05
14	7.59	13.18	4.23	24.51	27.90	28.53	23.70	25.27	24.02	18.21	7.75	2.08
15	3.81	12.06	6.08	20.19	27.65	29.12	26.83	25.51	21.99	15.51	7.28	9.17
16	9.00	12.13	12.26	22.79	25.82	29.23	27.28	26.94	21.15	16.55	10.22	4.97
17	11.23	4.67	22.84	8.74	8.22	28.41	26.79	25.83	19.49	14.39	4.33	0.85
18	2.78	5.80	21.68	21.55	13.19	26.27	24.54	25.21	18.43	10.45	8.87	3.74
19	9.65	12.32	20.16	20.51	19.75	25.74	27.59	25.74	18.47	15.81	9.04	0.80
20	3.84	17.02	19.12	20.58	20.49	27.98	27.00	22.48	20.04	15.40	11.06	1.48
21	11.10	18.77	20.71	26.37	27.18	31.24	28.34	22.37	20.62	15.23	11.01	6.36
22	12.71	4.60	15.68	14.27	19.25	31.81	28.10	23.09	21.29	15.89	8.34	10.89
23	12.03	16.95	10.02	13.84	27.46	29.90	23.75	23.96	22.04	13.29	9.76	3.84
24	12.14	17.33	16.13	26.66	17.30	29.69	24.62	23.73	14.78	4.35	10.12	2.85
25	9.50	5.80	23.32	24.29	16.92	30.47	25.79	22.67	21.28	13.90	9.95	2.97
26	12.50	14.06	15.79	6.48	28.02	29.10	24.44	20.31	22.48	16.60	5.16	10.64
27	13.24	6.96	18.24	20.93	26.66	29.10	26.12	24.09	20.25	15.54	7.94	7.91
28	12.32	19.09	20.17	21.88	28.82	29.59	25.52	24.36	20.71	11.29	8.15	8.93
29	10.49	–	16.80	24.79	29.86	30.41	26.33	26.62	19.72	15.26	1.98	9.87
30	5.10	–	19.96	24.31	21.76	30.48	25.17	26.30	19.76	14.98	8.53	5.32
31	5.65	–	16.91	–	29.64	–	26.77	23.46	–	12.37	–	3.38

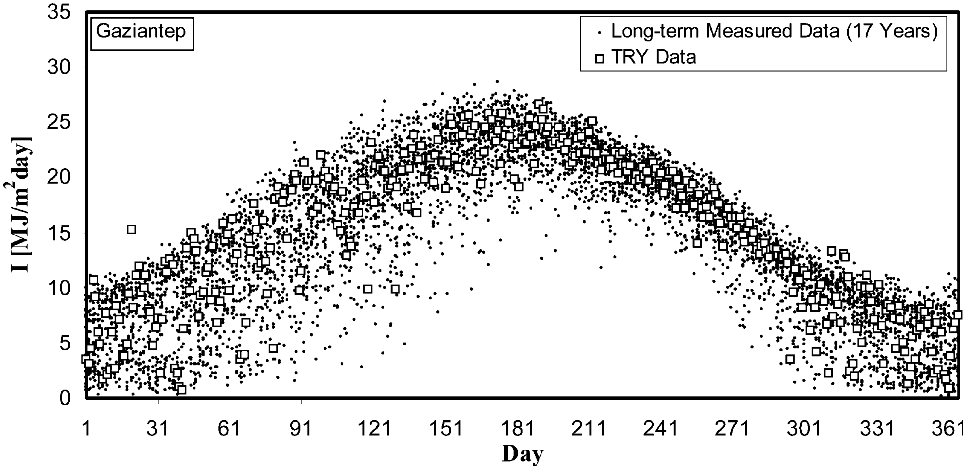

Fig. 2. Variation of daily global solar radiation for Gaziantep.

region has the highest solar energy potential in Turkey, there are remarkable differences between the solar data of locations. The reasons for the differences are cloud formation and lower sunshine duration in some locations. In Fig. 5, the I_{TRY} data is compared with long-term data set to show differences between I_{TRY} data and long-term data for Gaziantep and Diyarbakır. Comparisons were made on a monthly basis for daily global solar radiation. As indicated by the small bracketing of the scattering of the data, there is a reasonably good agreement on a monthly basis. It was seen that the I_{TRY} data is quite favorable on monthly basis.

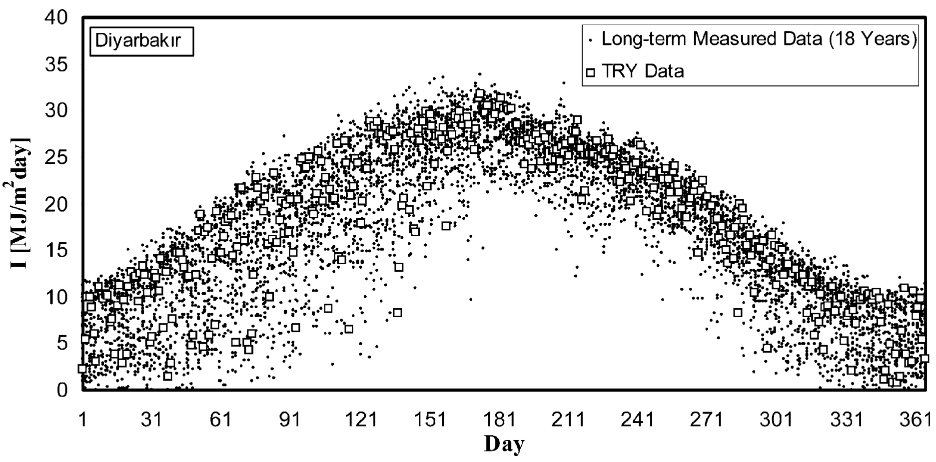

Fig. 3. Variation of daily global solar radiation for Diyarbakır.

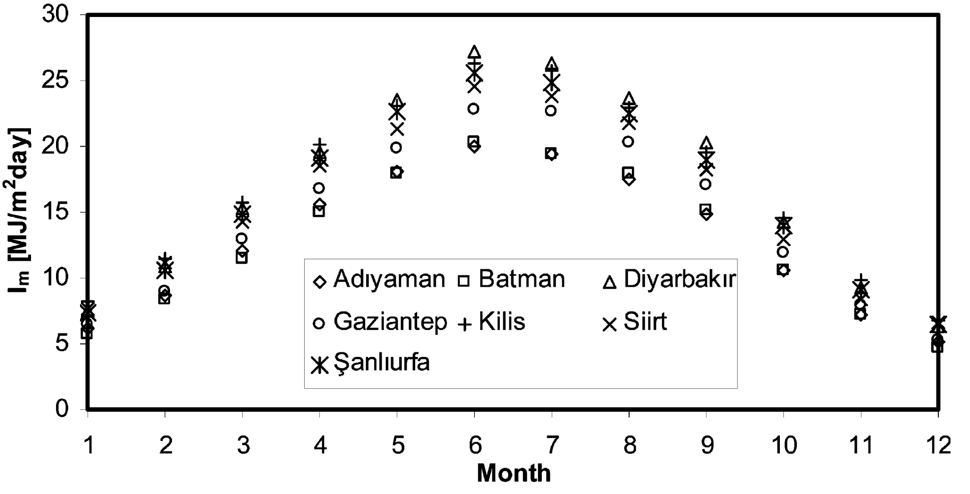

Fig. 4. Monthly mean of long-term daily global solar radiation for provinces of GAP region.

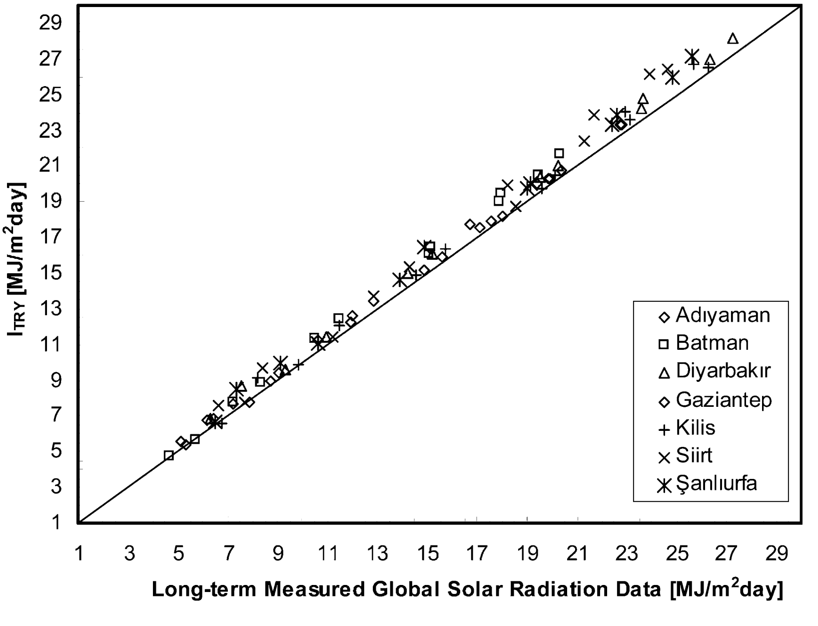

Fig. 5. Comparison of monthly averages of long-term global solar radiation data and TRY data for locations of southeastern Anatolia region.

3. Conclusion

Generation of typical solar radiation is very important for the calculations concerning many solar applications. In this study, test reference years for daily global solar radiation for seven provinces located in Southeastern Anatolia, Turkey are produced using at least 14 years' measured data. The daily global solar radiation on a horizontal surface for the region is presented throughout year in a tabular form. It is seen that both long-term measured and the typical data are very random throughout the year. It is found that there is good agreement between long-term data and typical data on a monthly basis.

It is expected that these typical solar radiation years will be useful to the designers of solar energy systems as well as those who need to have daily solar radiation data for southeastern Anatolia region of Turkey.

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