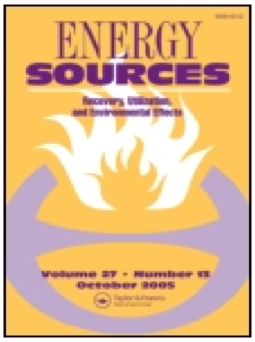

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Comparison of Total Horizontal Solar Radiation Measurements with Some Existing Models for Turkey

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Three models developed for calculating the monthly average daily total horizontal solar radiation anywhere in Turkey have been comparatively studied with monthly averages of the values measured via pyranometer in 11 stations. Comparison study has been done according to the values of mean quadratic error, mean absolute error, and correlation coefficient. In the statistical tests, it has been seen that the most successful model belongs to one developed by Ogelman et al. It has been established that new models could be investigated on a basis of the data collected through 11 stations.

Keywords solar radiation, total horizontal radiation, pyranometer, correlation models, Turkey

Introduction

In Turkey, horizontal solar radiation measurements are conducted by the Turkish State Meteorological Service (DMI), the Scientific and Technical Research Council of Turkey, the Electrical Works Research Directorate (EIEI), and by some universities' stations. Some researchers using these measurement values investigated relations in the form of the Angstrom equation for horizontal solar radiation. Kilic and Ozturk (1983) developed correlations of total and direct horizontal solar radiation by making use of measurements conducted via metallic actinographs in DMI stations. Ogelman et al. (1984) fitted a curve in quadratic form to the pyranometer measurements of 2 cities possessing diverse geographical and climatological features and maintained that the equations could be valid for Turkey. Aksoy (1997) analyzed the pyranometer measurements made in 5 DMI stations and proposed another correlation in quadratic form for Turkey on a basis of these measurements. Sahin et al. (2001) studied the monthly clearness index values of Turkey. Simple models of solar radiation data for the northwestern part of Turkey have been studied by Sen and Tan (2001). Some other researchers (Tiris et al., 1996; Kaygusuz and

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Ayhan, 1999; Togrul and Onat, 1999) developed the correlations valid for a single city center in Turkey.

In recent studies (Ertekin and Yaldiz, 1999; Kaygusuz, 1999; Togrul and Onat, 2000), the comparison of estimated and measured values of solar radiation in a single city center has been done. In this study, models developed for calculating the monthly average daily total horizontal solar radiation anywhere in Turkey have been comparatively analyzed with monthly averages of the values gathered through pyranometers in 11 stations located in 9 cities.

Existing Models

Best-known models developed for calculating the monthly average daily total horizontal solar radiation anywhere in Turkey have been given as follows:

Kilic and Ozturk's model (1983)

$$\frac{H}{H_0} = 0.103 + 0.000017Z + 0.198\cos(\phi - \delta) + [0.533 - 0.165\cos(\phi - \delta)]\frac{s}{S}, \qquad (1)$$

Ogelman et al.'s model (1984)

$$\frac{H}{H_0} = 0.195 + 0.676\frac{s}{S} - 0.142\left(\frac{s}{S}\right)^2, \qquad (2)$$

Aksoy's model (1997)

$$\frac{H}{H_0} = 0.148 + 0.668\frac{s}{S} - 0.079\left(\frac{s}{S}\right)^2. \qquad (3)$$

In these equations, H is the monthly average daily total radiation, H_0 is the monthly average daily extraterrestrial radiation, s is the monthly average daily hours of bright sunshine, S is the monthly average day length, Z is the altitude, ϕ is the latitude, and δ is the solar declination.

To determine the H_0 and S values, the following equations were used (Duffy and Beckman, 1974).

The monthly average daily extraterrestrial radiation H_0 can be calculated by

$$H_0 = \frac{24 \times 3600 \times G_{SC}}{\pi}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{2\pi\omega_S}{360}\sin\phi\sin\delta\right), \qquad (4)$$

where G_{sc} is the solar constant (= 1367 W/m^2), n is the day of year starting from the first of January, and ω_S is sunrise hour angle. The declination δ is calculated using

$$\delta = 23.45\sin[360(284 + n)/365], \qquad (5)$$

and ω_S can be found from the following equation:

$$\omega_S = \cos^{-1}(-\tan\phi\tan\delta). \tag{6}$$

It also follows that the S is given by

$$S = \frac{2\omega_S}{15}. \tag{7}$$

Measurement Data and Comparison

Stations where horizontal solar radiation data collected via pyranometer will be studied and some other information regarding these stations are given in Table 1. It is seen that both DMI and EIEI stations are in Ankara and Antalya. In DMI stations the time interval of measurements for Ankara is 42 months and for the rest it is 36 months. The measurement data period in EIEI stations for Isparta is 24 months and for Izmir it is 73 months, for Adana, Ankara, Antalya, and Aydin it is 48, 56, 57, and 51 months, respectively. Detailed analysis of the data can be found in the other study (Güneş, 2001).

In order to compare the measurement values with existing models given in Equations (1)–(3), 3 statistical test values were used: mean quadratic error (MQE), mean absolute error (MAE), and correlation coefficients (R2). They are defined as follows:

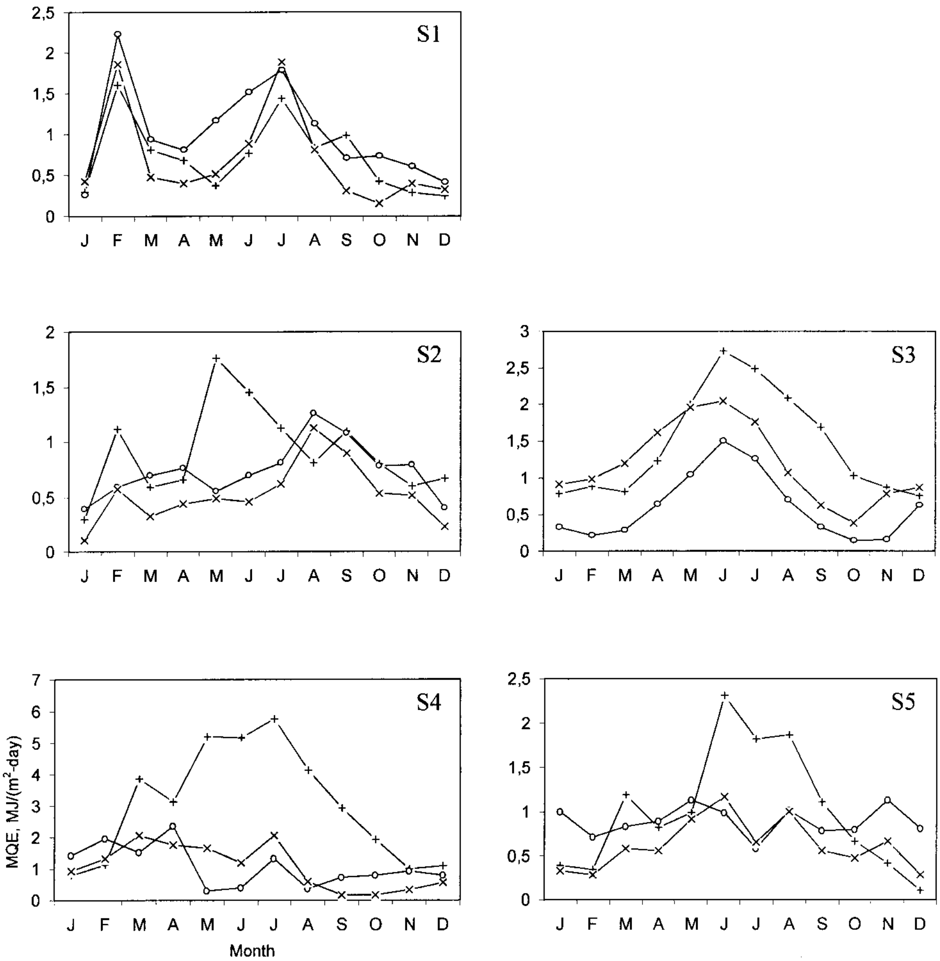
$$\mathrm{MQE_i} = \left(\frac{\Sigma\ (H_M - H_C)^2}{k_i}\right)^{1/2}, \tag{8}$$

$$\mathrm{MAE} = \frac{\Sigma\ |H_M - H_C|}{k}, \tag{9}$$

$$\mathrm{R2} = \frac{k\Sigma\ H_M H_C - (\Sigma\ H_M)(\Sigma\ H_C)}{\{[k\Sigma\ H_M^2 - (\Sigma\ H_M)^2][k\Sigma\ H_C^2 - (\Sigma\ H_C)^2]\}^{1/2}}, \tag{10}$$

Table 1
Some geographical features of the stations

	Name	Code	Latitude (N)	Longitude (E)	Elevation (m)
DMI stations	Ankara	S1	39.6	32.5	890
	Antalya	S2	36.5	36.5	51
	Konya	S3	37.6	32.5	1031
	Samsun	S4	41.2	36.2	4
	Urfa	S5	37.1	38.8	549
EIEI stations	Adana	S6	36.6	35.3	20
	Ankara	S7	39.6	32.5	890
	Antalya	S8	36.5	36.5	51
	Aydin	S9	37.9	27.8	56
	Isparta	S10	37.4	30.5	997
	Izmir	S11	38.2	27.1	29



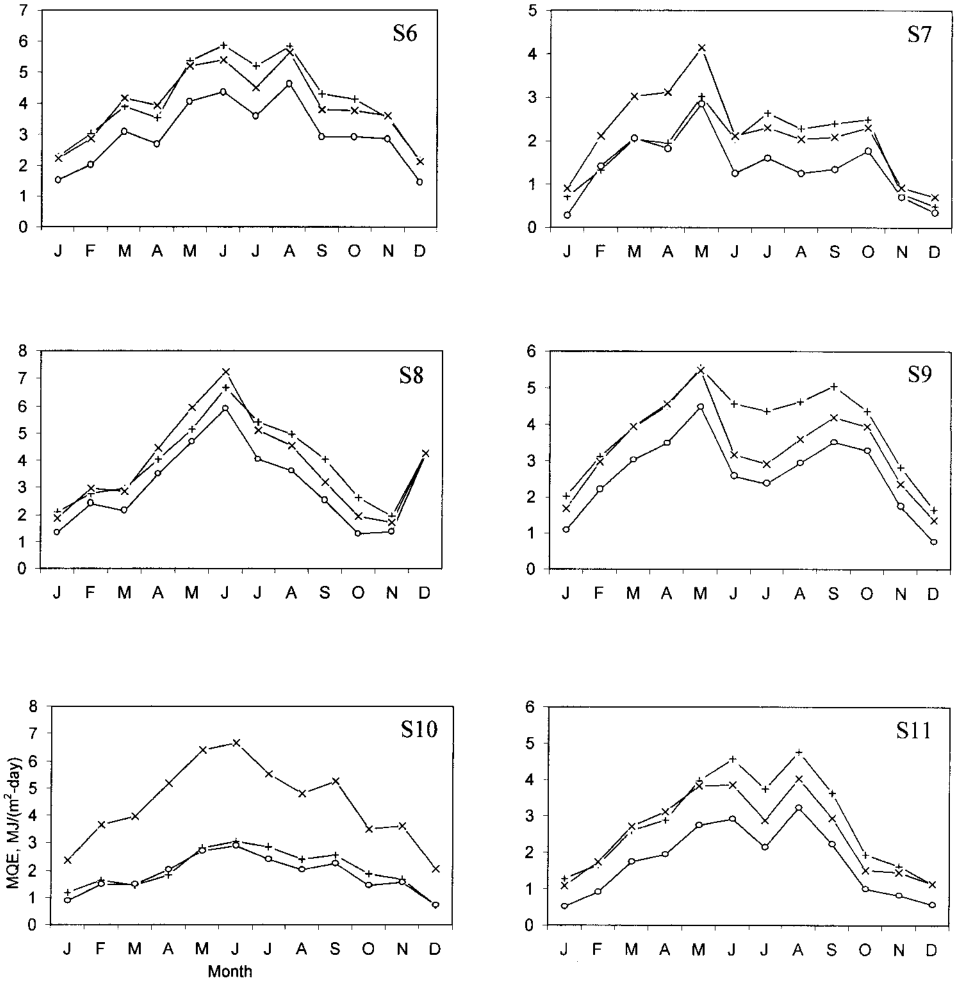
(a)

Figure 1. Monthly variation of MQE values of the models: (a) DMI stations (+: Equation (1); o: Equation (2); x: Equation (3)).

where H_m is the measured value, H_c is the calculated value, and k is the data number. Subscript i in Equation (8) shows the month.

Variation of MQE values according to months in DMI and EIEI stations are shown in Figure 1. It is observed that MQE changing in DMI stations are irregular and changing in EIEI stations are regular. When numerical values of the axis are analyzed, the MQE values of DMI stations apart from Samsun (S4) are lower than those of EIEI stations. In all the stations the curves have maximum values in summer months. The MQE values calculated through Equation (1) in 4 DMI stations are higher than the other 2 equations. The MQE values of Equation (2) in EIEI stations are lower than the other 2 equations.

The MAE values obtained from Equation (9) are shown in Figure 2. In DMI stations the MAE values calculated through Equation (3) and in EIEI stations the MAE values obtained for Equation (2) are smaller. The numerical values of EIEI stations are higher than values of DMI stations.



(b)

Figure 1. Monthly variation of MQE values of the models: (b) EIEI stations (+: Equation (1); o: Equation (2); x: Equation (3)).

Changing of the R2 values calculated via Equation (10) in DMI and EIEI stations are given in Figure 3. In DMI stations the highest R2 values are observed in Konya (S3) and the lowest R2 values are seen in Samsun (S4). In EIEI stations, on the other hand, in Isparta (S10) the highest and in Antalya (S8) the lowest R2 values are calculated. In DMI stations, the R2 values calculated for Equation (2) and in EIEI stations the R2 values calculated through Equation (1) possess the highest values.

Conclusion

According to the MQE values, the most compatible model with the measurement values of EIEI stations is the model belonging to Ogelman et al. (1984). In 3 of the DMI stations Aksoy's model and in 2 of the DMI stations Ogelman et al.'s model are better. In respect to the MAE values, Aksoy's model in DMI stations and Ogelman et al.'s model in EIEI

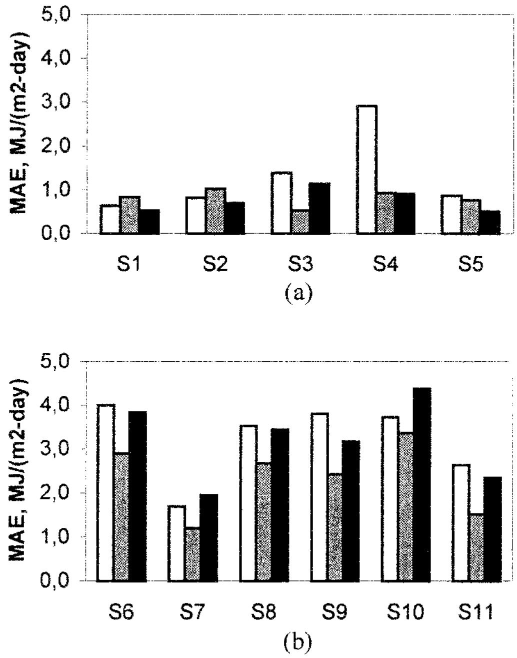


Figure 2. Comparison of the MAE values of the models: (a) DMI stations, (b) EIEI stations (□: Equation (1); ▒ Equation (2); ■: Equation (3)).

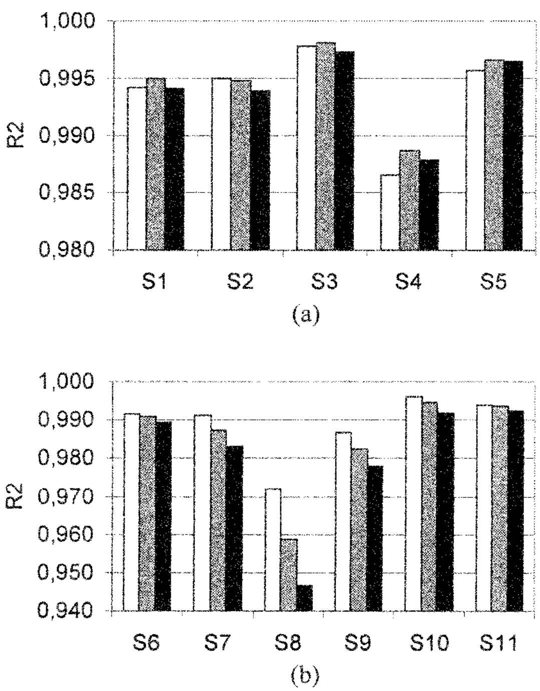


Figure 3. Comparison of the R2 values between models and measured values: (a) DMI stations, (b) EIEI stations (□: Equation (1); ▒ Equation (2); ■: Equation (3)).

stations is more compatible with measured data. The most compatible model with the measurement values regarding the R2 values in DMI stations is Ogelman et al.'s model, and in EIEI stations it is Kilic and Ozturk's model.

Ogelman et al.'s model appears to be the most successful in all statistical tests. But these researchers derived their model by making use of only 2 cities' measurement data. In later study, new models could be investigated on a basis of the data collected through 11 stations whose measurement data were analyzed in this study.

Acknowledgement

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Nomenclature

G_{sc}	solar constant (= 1367 W/m^2)
H	monthly average daily total radiation
H_0	monthly average daily extraterrestrial radiation
k	data number
n	day of year starting from the first of January
s	monthly average daily hours of bright sunshine
S	monthly average day length
Z	altitude
δ	solar declination
ϕ	latitude
ω_S	sunrise hour angle

Subscripts

c	calculated value
i	month of the year
m	measured value

Abbreviations

DMI	Turkish State Meteorological Service
EIEI	Electrical Works Research Directorate
MAE	mean absolute error
MQE	mean quadratic error
R2	correlation coefficients

References

Aksoy, B. 1997. Estimated monthly average global radiation for Turkey and its comparison with observations. *Renewable Energy* 10:625–633.

Duffy, J. A., and W. A. Beckman. 1974. *Solar Energy Thermal Processes*, chaps. 2–3. New York: John Wiley & Sons, pp. 8–60.

Ertekin, C., and O. Yaldiz. 1999. Comparison of some existing models for estimating global solar radiation for Antalya (Turkey). *Energy Convers. Mgmt.* 41:311–330.

Güneş, M. 2001. Analysis of daily total horizontal solar radiation measurements in Turkey. *Energy Sources* 23:563–570.

Kaygusuz, K. 1999. The comparison of measured and calculated solar radiations in Trabzon, Turkey. *Energy Sources* 21:347–353.

Kaygusuz, K., and T. Ayhan. 1999. Analysis of solar radiation data for Trabzon, Turkey. *Energy Convers. Mgmt.* 40:545–556.

Kilic, A., and A. Ozturk. 1983. *Solar Energy*, chap. 3. İstanbul: Kipas Press (in Turkish).

Ogelman, H., A. Ecevit, and E. Tasdemiroglu. 1984. A new method for estimating solar radiation from bright sunshine data. *Solar Energy* 33:619–625.

Sahin, A. D., M. Kadioglu, and Z. Sen. 2001. Monthly clearness index values of Turkey by harmonic analysis approach. *Energy Convers. Mgmt.* 42:933–940.

Sen, Z., and E. Tan. 2001. Simple models of solar radiation data for northwestern part of Turkey. *Energy Convers. Mgmt.* 42:587–598.

Tiris, M., C. Tiris, and I. E. Ture. 1996. Correlations of monthly-average daily global, diffuse and beam radiations with hours of bright sunshine in Gebze, Turkey. *Energy Convers. Mgmt.* 37:1417–1421.

Togrul, I. T., and E. Onat. 1999. A study for estimating solar radiation in Elazig using geographical and meteorological data. *Energy Convers. Mgmt.* 40:1577–1584.

Togrul, I. T., and E. Onat. 2000. A comparison of estimated and measured values of solar radiation in Elazig, Turkey. *Renewable Energy* 20:243–252.