Modelling of Global Solar Radiation on Horizontal Surfaces for Mersin City

R. Kulcu, A. Suslu, C. Cihanalp, and D. Yilmaz

Abstract—**Turkey is rich in solar energy potential due to its geographical location. Turkey's average annual sunshine duration is 2737 hours and the solar energy potential is 1527 kWh / m^2 year. The major solar energy regions are South Eastern Anatolia Region and the Mediterranean regions in Turkey. In this context, Mersin province is located in the provinces of maximum solar radiation in Turkey.**

Calculations of all the factors affecting the solar radiation from the atmosphere to the earth; creates a huge workload and the results cannot be obtained with sufficient accuracy. Therefore calculating the solar radiation coming to the earth models have been developed. In this study, the models for the prediction of solar radiation for Mersin city were evaluated using measured solar radiation data. Statistical aspects compliance of studied models were tested and validated which models the closest predicting to measured value.

Index Terms—**Mersin, modelling of solar radiations, solar energy, solar radiation calculations.**

I. INTRODUCTION

Energy is essential input of socio-economic prosperity and forward-looking development of today's technology. Therefore, region and country based energy policies and alternative strategies are developing in order to provide adequate, reliable and least damaging to the environment. This matter has a different position and property in Turkey. Turkey is dependent on importation for energy at a rate exceeding 70%. This rate is increasing day by day. Therefore, government and the community have to apply some special policy and specify behavior pattern. Therefore, government and the community have to requires apply some special policies and behavior pattern [1]. While the gap between Turkey's energy production and consumption has been increasing from 1990 to 2004, in the later years of 2010 Turkey's energy production has provided just %28-30 of our consumption. While Turkey's energy production is 34,47 MTEP in 2012, energy demand is 121 MTEP level in the same year [1]. Renewable energy sources aren't imported therefore it's national and reliable energy sources. Also these energy sources aren't run out and not produce exhaust and greenhouse gases emissions unlike conventional energy sources. The potentials of Renewable energy sources of Turkey showed in Table I.

TABLE I: RENEWABLE ENERGY POTENTIALS OF TURKEY [2]

Renewable Energy Source	Specify	Natural Potentials	Technical Potentials	Economical Potentials
Solar Energy	Electricity (TWh/year)	977000	6105	305
	Thermal (MTEP/year)	80000	500	25
Hydro Energy	Electricity (TWh/year)	433	216	127.4
Wind Energy	Electricity (TWh/year)	400	110	50
Wave energy	Electricity (TWh/year)	150	18	-
Geothermal Energy	Thermal (MWt)	31500	7500	2843
Biomass	Classical (MTEP/year)	30	10	7
	Modern (MTEP/year)	90	40	25

The solar energy has the feature of widespread more easily as to the other renewable energy sources with reasons such as its potential, its ease of use, its hygiene, being renewable and being eco-friendly. The factor of that it has height of setup costs, low productivity, marginal capacity according to the other energy sources and that being solved some similar technological and economic difficulties will make the solar energy more eligible in the future. Turkey is involved in sunbelt by geographical position; the utilization potential from the solar energy is at a size which needs to be examined importantly for its all regions apart from Eastern Black Sea. According to Solar Energy Potential Atlas of Turkey prepared by General Directorate of Renewable Energy, that annual average sunshine duration is 2373 hours (7,5 hours daily) and that total solar energy coming annually is 1527 kWh/m²years (4,2 kWh/m²daily) had been determined. An atlas indicating the solar energy distribution of our country within the context of the project of Solar Energy Potential Atlas had been created. The general image of this atlas has been shown in Fig. 1 [3].
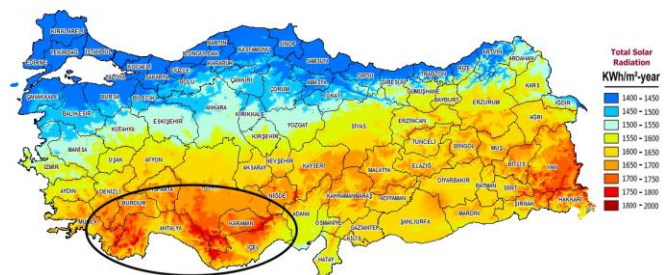

Fig. 1. Solar energy potential maps of Turkey.

In Turkey, it is benefited from the solar energy in the field of hot-water generating, power generation, greenhouse heating, drying of agricultural products and heating buildings.

Design of systems that the solar energy is used and that the solar radiation coming to earth is known as a significant factor for determining its productivity. Datum of the solar radiation coming to earth (momentarily, hourly, daily) could be calculated by being measured with the solar radiation measuring device at meteorological stations or with assistance of mathematical correlations. Aim of the solar radiation calculations is to provide being calculated amount of the solar energy coming to a determinate coordinate between the desired dates. The amount of the solar energy coming to out of atmosphere could be calculated in high accuracy since there are very few factors affecting the radiation between sun and earth. Yet, being calculated of part reaching to earth of the radiation out of atmosphere is quite hard, and the models that make a prediction on calculations have been used. The models being developed show an alteration according to resource of datum which researcher used and coordinate that made measurement. Therefore, abilities of prediction have been on the wane in the case of that the same models are used and that coefficients used in the models are used at different geographical coordinates [4]. In this study, on conditions of Mersin the models have been semtinized to the end that relationships between the radiation coming to out of atmosphere and global monthly average daily radiation are determined and estimated. In the study, calculations have made by being six models taking part in literature, and it has been tried to state which model made more succeeded prediction by being compared datum obtained from the models with measured values. The models used within the context of the study as variable; have used values of sunshine duration, day length hour angle.

II. MATERIAL AND METHODS

Mersin City is located between 36-37 ° North latitude and 33-35 ° East longitude. Mersin City and around have temperate subtropical climate. Weather conditions is hot and too humidity in the summer months. Average weather temperature and humidity are 28 ℃ and 88%, respectively in summer months. In winter months average weather temperature is 16 ℃ and rainy. Mersin City is the hottest city of Turkey and Europe.

In this study target to modeling of global solar radiation on horizontal surfaces for Mersin City using extraterrestrial radiation on a horizontal surface were evaluated. Calculations performed in two stages. At stage one extraterrestrial radiation on a horizontal surface in Mersin City were calculated. At stage two six models predicted global solar radiation on horizontal surfaces for Mersin City were evaluated. Predicted values were compared with measured values (1968-2004) by Turkish State Meteorological Service.

A. Calculation of Extraterrestrial Radiation on a Horizontal Surface of Mersin City

H0 values were calculated using (1) and (2) [5], [6].

$$H_o = \left(\frac{24}{\pi}\right) I_{gs} f \left[\cos \lambda . \cos \delta . \sin w_s + \left(\frac{\pi}{180}\right). w_s . \sin \lambda . \sin \delta \right] \quad (1)$$

$$f = 1 + 0.033 \left(Cos \frac{360\, n}{365} \right) \quad (2)$$

Declination angle (δ) and hour angle (w_s) were calculated using following equations [5], [7]-[9].

$$\delta = 23.45\, Sin \left(360 \frac{n+284}{365} \right) \quad (3)$$

$$w_s = \cos^{-1}(-\tan \lambda . \tan \delta) \quad (4)$$

B. Calculating of Average Daily Solar Radiation on a Horizontal Surface in Mersin City

Modelling of global solar radiation on horizontal surfaces were performed using six models in the literature. These model's variables were S/S_0 and w_S. S_0 values were calculated using (5). Measured S values were used in the models [5].

$$s_0 = \frac{2}{15} \cos^{-1}(-\tan \lambda . \tan \delta) \quad (5)$$

C. Model in Literature

Model 1 (this model is modified Lewis model for Turkey Country) [10], [11];

$$\frac{H}{H_0} = 0.18 + 0.62 \left(\frac{S}{S_0} \right) \quad (6)$$

Model 2 [12];

$$\frac{H}{H_0} = 0.206 + 0.546 \left(\frac{S}{S_0} \right) \quad (7)$$

Model 3 [13];

$$\frac{H}{H_0} = 0.162802 + 0.780634 \left(\frac{S}{S_0} \right)^{0.276845} \quad (8)$$

Model 4 [14];

$$\frac{H}{H_0} = 0.006324^{(1/s)} \quad (9)$$

Model 5 (this model is modified Lewis model for Isparta City) [4];

$$\frac{H}{H_0} = 0.192888 \left(\frac{s}{s_0} \right) + 0.334576 \quad (10)$$

Model 6 (this model is developed for Turkey Country) [4];

$$\frac{H}{H_0} = \left[\frac{1.333962 \left(\frac{s}{s_0} \right)}{0.044188 . \omega_s} \right] + 0.002578 . \omega_s \quad (11)$$

D. Statistical Parameters for Determining Success of Models

MPE (Mean percentage error), MBE (Mean bias error) and

RMSE (Root mean square error) were used for statistical analyses of models. The lowest error parameters show that high level accuracy for models [15].

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_{i,pred.} - H_{i,meas.}}{H_{i,meas.}}\right)\times 100 \qquad (12)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_{i,pred.} - H_{i,meas.}\right) \qquad (13)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(H_{i,pred.} - H_{i,meas.}\right)^2} \qquad (14)$$

III. RESULT AND DISCUSSIONS

Predicted and measured monthly H values of Mersin City were showed Fig. 2-Fig. 7. Model 1 developed by Tiris *et al.* [10] predicted higher values than measured *H* values for summer months. But Model 1 predicted more accuracy values for winter months (Fig. 2 and Fig. 3).
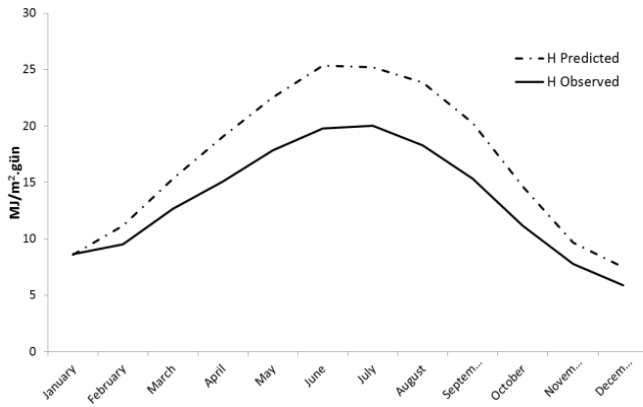

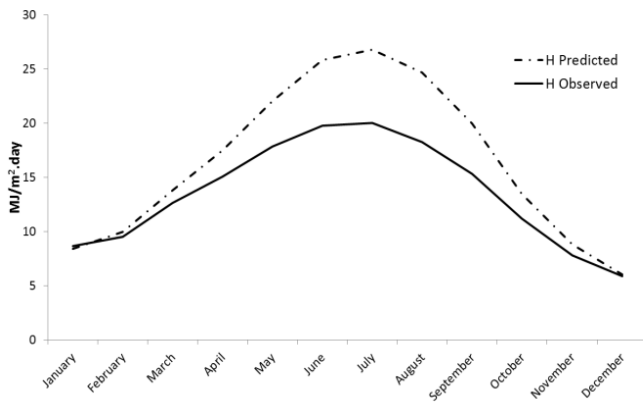Fig. 2. Measured and predicted values by Model 1.

Fig. 3. Measured and predicted values by Model 2.

The more accuracy values were predicted by Model 2 for winter months. In spring and autumn months Model 2 calculated more correctness values than Model 1. But accuracy of predicted values by Model 2 was high level in summer months (Fig. 3).

Model 3 similar to Model 2 and Model 1 predicted more correct values in winter than summer months (Fig. 4 and Fig. 5).
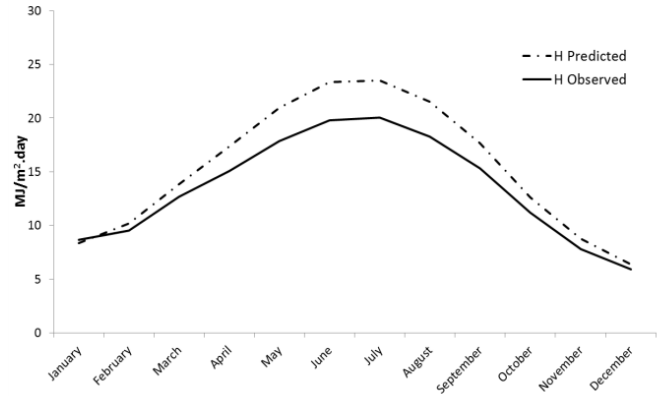

Fig. 4. Measured and predicted values by Model 3.

Distribution of predicted values by Model 4 were different from Model 3, 2, 1. Predicted values in November to in the middle of February were lower than measured *H* values but in the other months these values were higher than measured *H* values (Fig. 5).
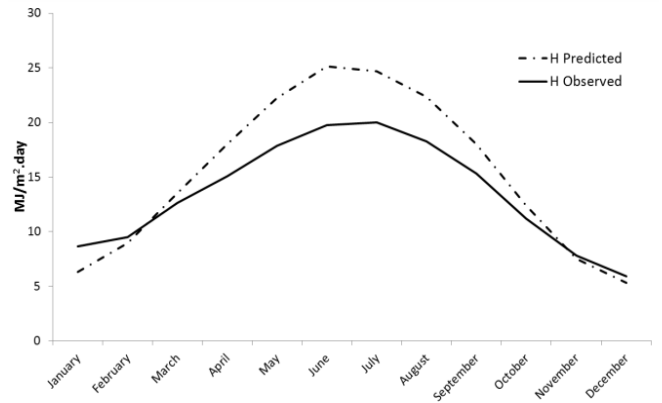

Fig. 5. Measured and predicted values by Model 4.

Model 5 used S/S_0 variable parameters for modeling and in this model have two constant value. Model 5 gave successfully predicted values except from July, August, September, December and January months for Mersin City. But predicted values by Model 5 were more close to measured values than before models (Fig. 6).

Model 6 used S/S_0, w_s and λ variable parameters for modeling. Model 6 calculated lower H values than measured values for January, February and March. But, it calculated more accuracy values for the other 9 months (Fig. 7).
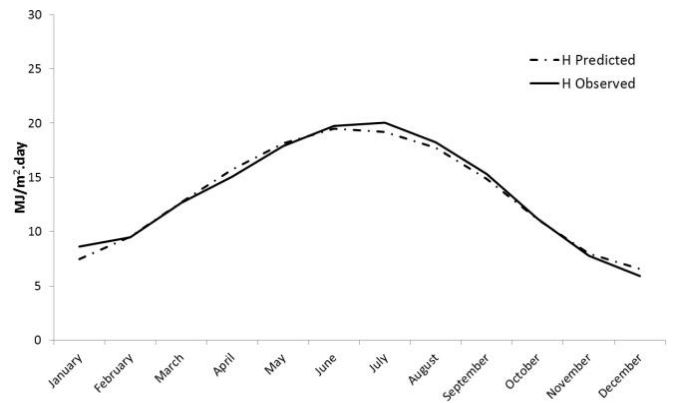

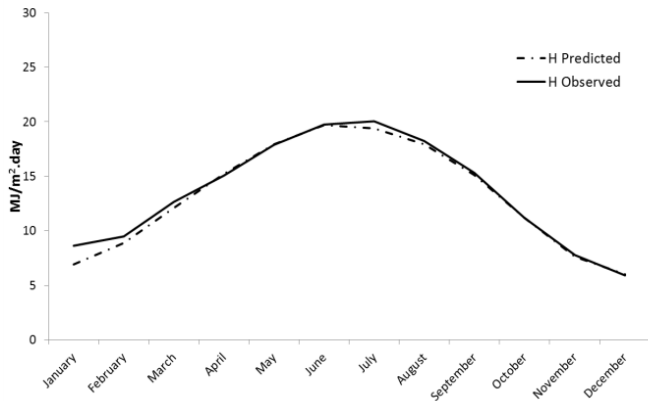Fig. 6. Measured and predicted values by Model 5.

Fig. 7. Measured and predicted values by Model 6.

Statistical analyses results were given in Table II. Absolute values of MPE and MBE parameters must be uses for assessment of the success of Model. Statistical analyses results showed that error values of Model 6 and Model 5 lower than other models.

TABLE II: STATISTICAL ANALYSES RESULT

Model Number	MPE Mean percentage error	MBE Mean bias error	RMSE Root mean square error
Model 1	22.1937	3.5925	4.6346
Model 2	17.9941	2.9347	3.8227
Model 3	12.3544	1.8783	2.2542
Model 4	4.6244	1.7345	3.7300
Model 5	3.3294	0.6092	0.9810
Model 6	-4.7622	-0.3251	0.8576

IV. SUMMARY

In this study modeling of global solar radiation on horizontal surfaces for Mersin City using extraterrestrial radiation on a horizontal surface were evaluated. Six different models were used for this aim. Statistical analyses showed that accuracy of Model 6 is higher than other models for prediction of global solar radiation on horizontal surfaces for Mersin City.

NOMENCLATURES

G_{sc}: Solar Constant 1367 W/m^2;

H: Average daily solar radiation on a horizontal surface (J/m^2.day);

H_0: Monthly average daily extraterrestrial radiation on a horizontal surface (J/m^2.day);

$H_{i,meas}$.: Measured H value;

$H_{i,pred}$.: Predicted H value;

MBE: Mean Bias Error;

MPE; Mean Percentage Error;

n: The number of the day of the year starting from the first of January;

$RMSE$: Root Mean Square Error;

w_s: Hour angle;

δ: The Solar Declination; angle;

λ: Latitude;

S: Sunshine length (h);

S_0: Day length (h).

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