MODELLING OF THE HOURLY HORIZONTAL SOLAR DIFFUSE RADIATION IN SANLIURFA, TURKEY

by

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Horizontal diffuse solar radiation has been calculated over various models by using the total radiation data obtained from the horizontal surface due to reasons such as lack of adequate measurements and expensive measuring instruments. In this study, the measurements were calculated using the obtained data between the years 2009 and 2016 from solar radiation measurement system with solar tracking system, which belongs to the Department of Mechanical Engineering, Sanliurfa Harran University, Turkey. Three horizontal solar diffuse radiation models have been proposed by using the relationship between the diffuse radiation ratio and the clarity index obtained by eight years' data. Horizontal solar diffuse radiation values were calculated and compared with the measurement data for Sanliurfa by using 15 models of diffuse radiation given in the literature and the results obtained from the models. The statistical errors of the proposed models and 15 different diffusive radiation models were calculated. As diffuse radiation varies with time, it is determined that modelling of Model 1 and Model 2 obtained from Sanliurfa data gives better results in terms of clarity index constraints. Furthermore, although the desired success cannot be achieved with Model 2 in terms of t_{stat}, it has been determined that the relevant model provides better results than many models when compared to statistical errors. With the improvements to be made on Model 2, a local estimation model is thought to give better results.

Key words: *solar radiation, diffuse radiation, horizontal solar diffuse radiation, modelling diffuse radiation, hourly diffuse radiatio*

Introduction

The total radiation collected on the horizontal surface is composed of diffuse and direct radiations. Total direct solar radiation measurement on the horizontal surface has been carried out by researchers for many years. However, the measurement of horizontal solar diffuse radiation is rarely performed or there are not enough examples in the literature. Diffuse radiation is generally determined by various calculation models in the literature. Those models are mainly based on the value of the clarity index. There are valuable studies giving diffuse radiation for different places in the literature according to the value of the clarity index. These empirical formulas are based on the relationship between the diffuse radiation ratio and the clarity index. The relationship between diffuse radiation rate and clarity index was first described by Liu and Jordan [1]. Researchers have derived a first-order linear model that can

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predict diffuse radiation with a statistical study for 98 different areas of latitude with long-term diffuse and total radiation measurements. Bugler *et al.* [2] derived a model for estimating horizontal solar diffuse radiation from the interaction of the clarity index and the diffuse radiation ratio according to the solar heights for the 5-year data of the horizontal surfaces in Melbourne (Australia). Orgill and Hollands [3] used a 4-year diffuse radiation and total radiation measurement data for locations between the latitudes 43 and 53 in Toron, Canada, to derive a model that can predict diffuse radiation according to the clear index at different boundary conditions. Davies *et al.* [4] compared 12 different computational models, which can calculate the horizontal solar radiation components, with the measurement data of seven countries. The researchers analyzed the performance of total, diffuse, and direct solar radiation estimation models with a total of 15 stations as four stations in Australia, four in Europe, three in Canada and four stations in America. Reindl *et al.* [5] studied 22000 hours of data obtained from five different locations in the North American region for diffuse radiation rate, clarity index, solar height, temperature and relative humidity. Researchers found that as the variable number of the measurement data of the estimated location of the diffuse solar radiation increases, the error parameters will eventually be decreased. Stone [6] stated that *t*-statistic is an important parameter in the evaluation of solar radiation models and the use of the mean absolute error squared and the mean absolute errors separately would cause an incorrect selection. They also stated that the t-statistic has the advantage of allowing the person who tested the computational model to determine whether the estimates were correct or not and that it is statistically significant at a certain confidence level. Chandrasekaran and Kumar [7] proposed a local model for estimating diffuse radiation using the relationship between diffuse radiation ratio and clarity index with the 5-year horizontal total and diffuse radiation measurements collected in Madras, India. When they compared the proposed local model with the models in the literature in statistical terms, it was stated that the modelling of tropical data would minimize the estimation errors. Boland *et al.* [8] included the solar clock in the relationship between the clarity index and the diffuse radiation rate to estimate horizontal solar diffuse radiation. They concluded that the proposed model for Australia should be improved for any location outside of Australia. Using the total and diffuse radiation data for places in the northern Mediterranean sub-region, Miguel *et al.* [9] developed a local diffuse radiation model and compared this model with other models in the literature. As a result, they suggested that the best model between the models for each latitude varies with the proposed correlation for locations in the northern Mediterranean sub-region. Ulgen and Hepbasli [10] developed two models that calculate diffuse radiation using 5-year radiation data obtained from Izmir, Turkey, region. They stated that the developed models have good predictive ability for the climatic conditions similar to Izmir. In another study, horizontal solar diffuse radiation and the average monthly value of total radiation days were measured by El-Sebaii *et al.* [11] and the insolation hours were also analyzed for the four regions reflecting the northern and southern weather conditions in Egypt. The researchers suggested some models based on diffuse radiation, clarity index and insolation hours and examined these models statistically. The researchers have determined that all three models can be used with long-term measurements and with different correlations for diffuse radiation estimates. Karatasou *et al.* [12] examined the relationship between diffuse radiation rate and clear index for Athens, Greece. Similar to the studies in the literature, they modeled the existing data and compared these models with the models in the literature. Paliatsos *et al.* [13] used linear and quadratic modelling to calculate the diffuse radiation for the seasons and the whole year using the 10-year diffuse radiation ratio and clarity index data for Athens, Greece. Soares *et al.* [14] determined the horizontal solar diffuse radiation calculation by the neural network prediction technique using the four-year horizontal total solar diffuse radiation data collected from the city of Sao Paulo, Brazil. They compared the diffuse radiation measurements of 2002 with the neural network estimation technique and determined that neural network performance is improved by long-term data. In addition, this model was compared to another model in the literature for the city of Sao Paulo. Jin *et al.* [15] developed a model for horizontal solar diffuse radiation using horizontal total and diffuse radiation data from 78 meteorological stations across the country of China with reference to the Liu Jordan method. At the end of the study, the researchers determined that solar radiation was much more in Western and northern China. Notton *et al.* [16] proposed a model in which the changes in the measurement data of diffuse solar radiation according to the total solar radiation are taken into account using horizontal solar diffuse radiation data measured for Ajaccio in the Mediterranean region of France. Jacovides *et al.* [17] performed a local modelling using 4-year clarity index and diffuse radiation rate data for Athalassa, Cyprus. The researchers compared ten modelling in the literature with their modelling and examined the errors in statistical terms. Boland *et al.* [18] compared horizontal solar diffuse radiation forecasting models developed for Europe with the model produced by local data. They found that models in the literature for Australia were insufficient to predict horizontal solar diffuse radiation. Robaa [19] compared their produced model statistically with the 14-year solar irradiation data in Egypt which is based on the Robaa model, the Angstrom Prescott model for estimating horizontal solar diffuse radiation based on the relationship between sunshine duration and horizontal solar radiation, and eight horizontal solar diffuse radiation models in the literature and they found that the best model was the model they created. Jiang *et al.* [20] proposed nine models that predict diffuse radiation with the clarity index and sunshine duration using the data obtained from the ten year weather station in Beijing, China, such as daylight, diffuse solar irradiation and the duration of the sunlight and analyzed these models statistically. Bakirci [21] developed correlations with Ashrae clear sky calculations giving the average open sky hour total solar radiation for Erzurum. The researcher used the average error, RMSE and *t*-statistics methods to examine the performance of the correlations developed. Janjai *et al.* [22] proposed four separate models based on the relationship between 12-year diffuse radiation rate and clarity index for four latitudes in Thailand. Local models were found to be better in terms of performance compared to other models in the literature. Ridley *et al.* [23] developed a more comprehensive modelling for Australia, which varied from the clarity index ranges. The researchers found that this model showed a better performance compared to the other models in the literature for Australia. Torres *et al.* [24] compared 17 different models predicting hourly diffuse radiation with each other and found that the closest trend with experimental data could be provided by only two models. Dervishi and Mahdavi [25] compared eight models predicting the diffuse radiation rate with data from the measurement database for Vienna, Austria, and identified three models with the best performance. They also found that changing the coefficients of the models to represent Vienna, improves the estimation performance. Kuo *et al.* [26] examined four models with five predictive variables, including hourly clarity index, solar height, real sun time, daily clarity index and total solar radiation in Taiwan, and compared these models with the literature. Muneer *et al.* [27] proposed a horizontal solar diffuse radiation model based on the relationship between diffuse radiation rate and clarity index taken from NASA solar radiation measurements for ten locations in the UK between 50° and 59° latitudes and compared this model with 11 models in the literature. Behar *et al.* [28] tested 22 solar radiation models in which instant direct radiation and total radiation could be determined anywhere in the world. The researchers evaluated the long and short term performance of classified solar radiation models. In this traditional analysis, they did the validation study on the basis of absolute relative error and mean absolute error squared without considering the characteristic of linearity and modelling. Muneer *et al.* [29] proposed 14 diffuse radiation models based on the relationship between diffuse radiation rate and clarity index taken from the NASA measurement data for 14 locations between 13° and 59° latitudes. Kotti *et al.* [30] compared four diffusive radiation correction models to eliminate diffuse radiation calculation errors affecting direct radiation calculation. Li *et al.* [31] evaluated the change in solar radiation components using statistical parameters by using direct, diffuse and total solar radiation measurement data obtained from Hong Kong between 2008 and 2012.

In this study, local models have been formed by using the relationship between horizontal solar diffuse radiation ratio and clarity index data obtained from solar radiation measurement system with solar tracking system in the Department of Mechanical Engineering, Sanliurfa Harran University between 2009 and 2016. The reliability of the local models using the eight year measurement data of the station was evaluated with statistical parameters and compared with the diffuse radiation models used in the literature. In the analyzes, it was determined that the models produced with local data gave better results than the models in the literature. As a result, instead of the models proposed in the literature, it was determined that the use of the models proposed in the study would yield more accurate results for the estimation of diffuse solar radiation for the city of Sanliurfa. In addition, it was desired to obtain a more sensitive result than the other studies in this study. For this reason, in the light of the models in the literature, a composition was formed with the k_t clarity index limitations. Here, in order to get closer to $k_t = 1$, limitations that were closer to $k_t = 0.9$, which were closer than $k_t = 0$ were preferred.

Model development

In this study, obtained hourly horizontal total solar radiation and horizontal diffuse solar radiation data from the solar radiation measurement system with solar tracking system which is located in the Department of Mechanical Engineering, Sanliurfa Harran University (Latitude 37° 9' N, Longitude, 38° 27' E, Altitude: 555 m, fig. 1) for eight years (2009-2016) were used. Figure 2 shows the solar radiation measurement system with solar tracking system.

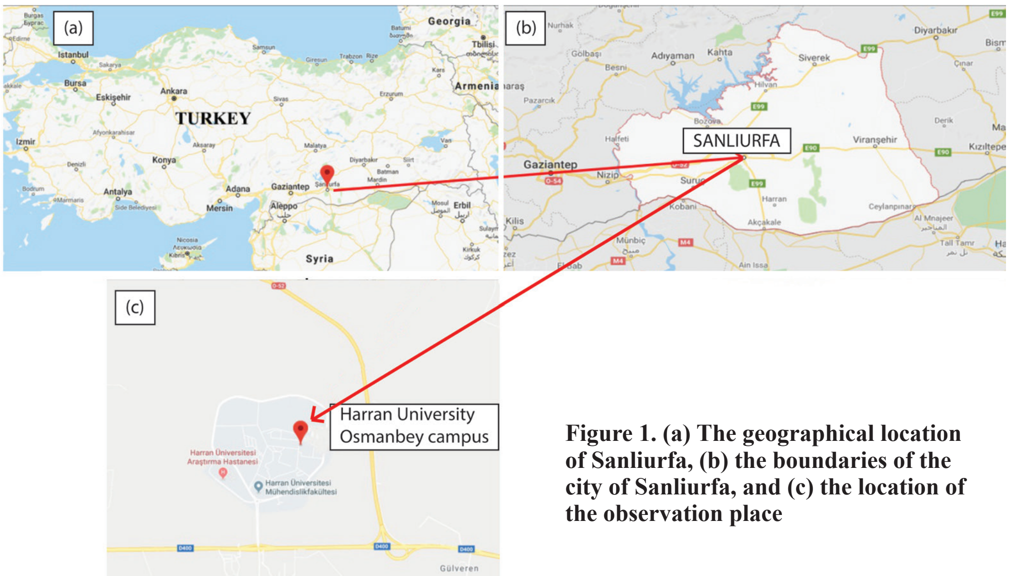

Figure 1. (a) The geographical location of Sanliurfa, (b) the boundaries of the city of Sanliurfa, and (c) the location of the observation place

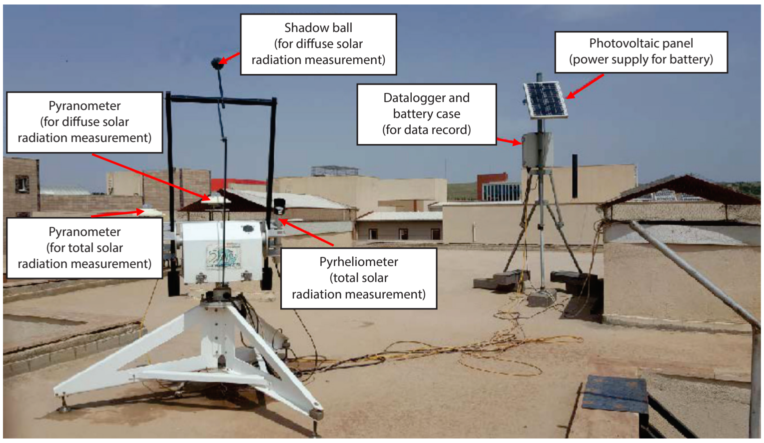

Figure 2. Solar radiation measurement system with solar tracking system

The devices used in the solar radiation measurement system with the sun tracking system given in fig. 2 and their characteristics are given in tab. 1.

Table 1. Devices used in measurements and their properties

Measuring device	Features
Kipp Zonen 2AP tracker	Model: 2 AP GD Voltage: 115/230 V-60/50 Hz Power: 50 VA
Pyrheliometer	Model: CH-1 Serial: No. 080005 Sensitivity = $9.76 \cdot 10^{-6}$ [VWm^{-2}]
Difusse pyranometer	Model: CMP11 Serial: No. 080086 Sensitivity = $8.89 \cdot 10^{-6}$ [VWm^{-2}]
Global pyranometer	Model: CMP11 Serial: No. 080085 Sensitivity = $8.59 \cdot 10^{-6}$ [VWm^{-2}]

Several models have been used in the literature using the hourly clarity index k_t, eq. (1), which is the main parameter in the calculation of diffuse radiation coming into the horizontal surface and the ratio of total hourly total radiation on the horizontal surface, I_{global}, and the total hourly non-atmospheric solar radiation, I_0. In the calculation models which use the local measurement data, the ratio of the hourly diffuse radiation on the horizontal surface, I_d, to the total hourly radiation on the horizontal surface, I_{global}, gives the diffusive radiation ratio, d, eq. (2):

$$k_t = \frac{I_{\text{global}}}{I_0} \tag{1}$$

$$d = \frac{I_d}{I_{\text{global}}} \tag{2}$$

The station where the measurements were taken and studies were carried out between 2009 and 2016 are shown in fig. 3. The solar radiation measuring device shown in fig. 2 takes measurements at intervals of 10 minutes for 24 hours a day for 365 days and gives the total value for the solar radiation components per hour. According to the solar height and the angle of rising, the inclination of the pyrheliometer device for the direct radiation measurements varies in 365 days and the inclination varies from the direction where the sun rises to the direction where the sun sets in a day. Since there is a small amount of moonlight, the measurements are close to zero However, the data required for the analysis are carried out according to the sunrise and sunset angles. In the study, direct radiation measurements were not used with a solar radiation measurement tracking device. Model 1 was developed in fig. 3, consisting of 27259 raw data, with the device was located according to sunrise and sunset, which is based on eight years, 365-day, hourly global and diffuse radiation measurement data according to the total day length.

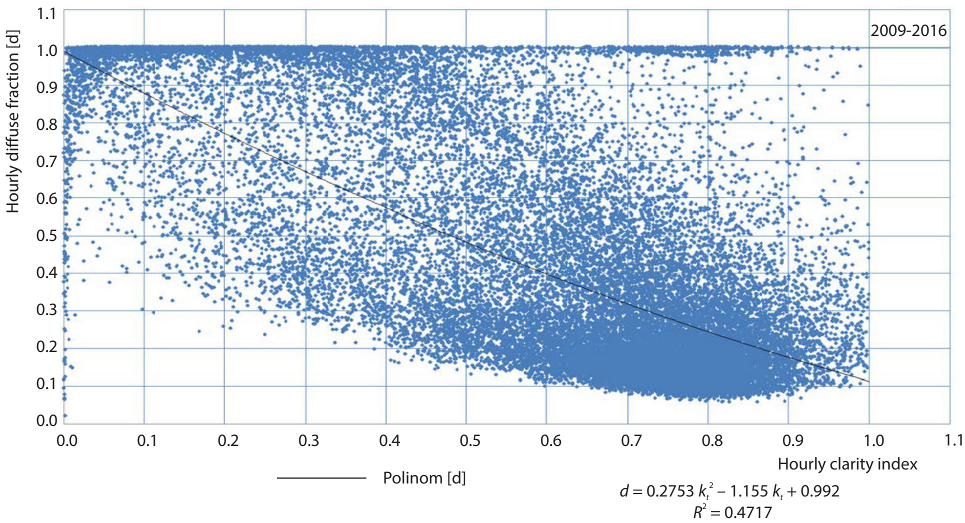

Figure 3. Variation of diffuse radiation rate according to the index of clarity between 2009 and 2016

Since the measurement will be made according to the open day (it is the day when the direct radiation is at the maximum level in the sunbathing times during the day) method, it is necessary to eliminate the closed day (the days when the air is cloudy, ie the diffuse radiation is maximum) data firstly. However, because of the four seasons in Turkey, Sanliurfa province has Sun even on closed days. To extract open day data from all measurement data a residual classification was made. To classify residual data using the MINITAB program, the difference between the scattered radiation ratio corresponding to the clarity index and the value that should be corresponded was taken. Thus, the difficulty of determining that open day data is between 12 and 14 or 16 and 18 hours was eliminated by editing the MINITAB program with the residual classification method, and the maximum values obtained for those hours are measured and the received data was left. Thus, there were 17194 data to be modeled according to the open day method shown with the data of 27259 raw data. Modelling of the obtained data according to the relationship between the clarity index and the diffuse radiation rate after the elimination of the data collected between 2009 and 2016 according to the $t_{\text{stat.}}$ are shown in fig. 4.

For Model 2, no clarity index restrictions have been made. However, it has been reported in the literature that more precise calculations can be made using clarity index limita-

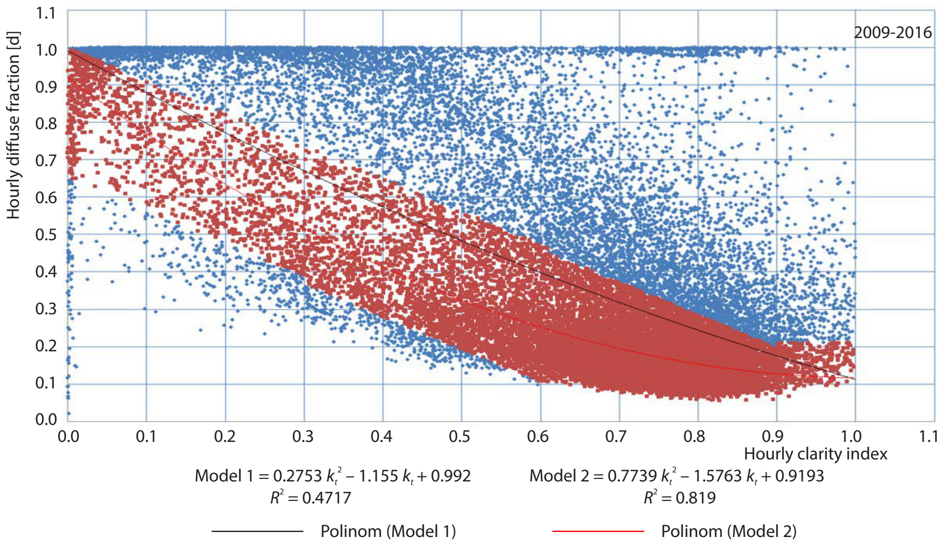

Figure 4. Modelling of the obtained data according to the relationship between the clarity index and the diffuse radiation rate after the elimination of the data collected between 2009 and 2016 according to the $t_{stat.}$ (*for color image see journal web site*)

tions. Therefore, for the data using Model 2 given in fig. 5, the Model 3 was developed according to the clarity index limitations. However, in the literature, these limitations were classified as 0.60 and after 0.80 or as $k_t < 0.2$, $0 < k_t < 0.2$. On the other hand, this study was intended to achieve a more precise result. For this reason, a composition was created in the light of the modellings in the literature with the limitations of the clarity index. Here, in order to get closer to $k_t = 0$, greater than zero limitation was preferred and $k_t = 0.9$ limitation which is closer to

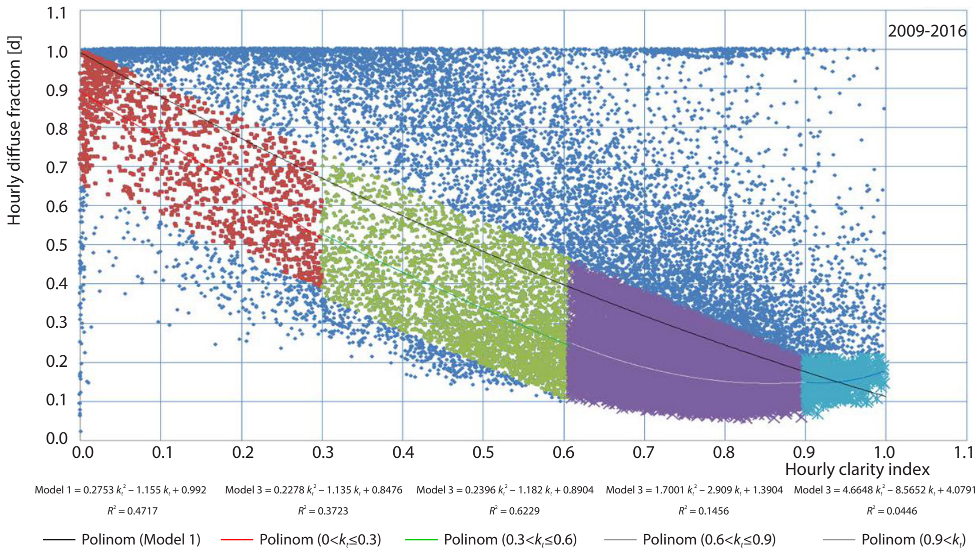

Figure 5. Modelling of the obtained data according to the relationship between the limitations of the clarity index and the diffuse radiation rate after the elimination of the data collected between 2009 and 2016 according to the t_{stat} (*for color image see journal web site*)

k_t = 1 was preferred. For the same data given in fig. 5, Model 3 is developed according to the $k_t$clarity index limitations.

Based on the relationship between the clarity index and the diffuse radiation rate in the literature, the solar tracking system based models which are purposed by several researchers (Liu and Jordan [1], Bugler *et al.* [2], Orgill and Hollands [3], Erbs *et al.* [32], Hawlader [33], Chandrasekaran and Kumar [7], Boland *et al.* [8], Miguel *et al.* [9], Karatasou *et al.* [12], Soares *et al.* [14], Jin *et al.* [15], Jacovides *et al.* [17], Boland *et al.* [18], and Ridley *et al.* [23]) and the Models 1, 2, and 3 which are developed by using the sun-tracking system based on the eight year clarity index and diffuse radiate on rate data of the solar radiation meter, fig. 2,were evaluated with statistical parameters.

The summary of the developed Model 1, Model 2, and Model 3 using local measurement data with the models in the literature (Liu and Jordan [1], Bugler *et al.* [2], Orgill and Hollands [3], Erbs *et al.* [32], Hawlader [33], Chandrasekaran and Kumar [7], Boland *et al.* [8], Miguel *et al.* [9], Karatasou *et al.* [12], Soares *et al.*[14], Jin *et al.* [15], Jacovides *et al.* [17], Boland *et al.* [18] and Ridley *et al.* [23]) which were produced using the relationship between diffuse radiation ratio and clarity index is shown in tab. 2.

Assessment of the model performance

There are many known statistical methods to compare the models used in the literature. In this study, the performance of solar radiation models was determined by using the statistical parameters [5, 21, 26] such as mean deviation error (MAE), mean absolute error percentage (MAPE %), mean error squares root (RMSE), *t*-test method (*t*-stat) and Bayes theory (BIC).

The MAE gives information about the long-term value of the correlation. The lower value is desirable and the ideal value is the closest to zero. The MAE is calculated:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left(I_{d_{\text{model}}} - I_{d_{\text{meas}}}\right) \tag{3}$$

The MAPE % is calculated as the absolute average value of the difference between the predicted model estimates and the measured value:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{(I_{d_{\text{model}}} - I_{d_{\text{meas}}})}{I_{d_{\text{meas}}}}\cdot 100 \tag{4}$$

The RMSE is used by calculating the error rate between the measured values and the model estimates as follows and the RMSE value to be zero indicates that the proposed model is excellent:

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(I_{d_{\text{model}}} - I_{d_{\text{meas}}}\right)^2\right]^{1/2} \tag{5}$$

The *t*-test method, which is calculated as follows, is a statistical analysis method that allows the comparison of the averages of the two data to decide whether the difference is random or statistically significant:

$$t_{\text{stat}} = \left[\frac{(n-1)MAE^2}{RMSE^2 - MAE^2}\right]^{1/2} \tag{6}$$

Table 2. The summary of the proposed models and models in the literature

	Restriction	Diffuse radiation ratio, d
[1]		$d = 0.384 - 0.416\ k_t$
[2]	$0 < k_t \leq 0.4$ $0.4 < k_t \leq 1$	$d = 0.94$ $d = (1.29 - 1.19\ k_t)/(1 - 0.334\ k_t)$
[3]	$k_t < 0.35$ $0.35 \leq kt \leq 0.7$ $k_t > 0.75$	$d = 1 - 0.249\ k_t$ $d = 1.557 - 1.84\ k_t$ $d = 0.177$
[32]	$k_t \leq 0.22$ $0.22 < k_t < 0.8$ $k_t > 0.8$	$d = 1 - 0.09\ k_t$ $d = 0.9511 - 0.16014\ k_t + 4.388 k_t^2 -$ $- 16.638\ k_t^3 + 12.336\ k_t^4$ $d = 0.165$
[33]	$k_t \leq 0.225$ $0.225 \leq k_t \leq 0.775$ $0.775 \leq k_t$	$d = 0.915$ $d = 1.135 - 0.9422\ k_t + 0.3878\ k_t^2$ $d = 0.215$
[7]	$k_t < 0.24$ $0.24 \leq k_t \leq 0.8$ $k_t > 0.8$	$d = 1.0086 - 0.178\ k_t$ $d = 0.9686 + 0.1325\ k_t + 1.4183\ k_t^2 +$ $+ 10.1862\ k_t^3 + 8.3733\ k_t^4$ $d = 0.197$
[8]		$d = -0.039 + 1.039/$ $1 + \exp(-8.769 + 7.325\ k_t + 0.377\,t)$
[9]	$k_t < 0.21$ $0.21 < k_t \leq 0.76$ $k_t > 0.76$	$d = 0.995 - 0.081\ k_t$ $d = 0.724 + 2.738\ k_t + 8.32\ k_t^2 + 4.967\ k_t^3$ $d = 0.18$
[10]	$k_t < 0.32$ $0.32 < k_t < 0.62$ $k_t > 0.62$	$d = I_t 0.68$ $d = I_t\ [0.0743 - 19.343\ k_t + 206.91\ k_t^2 -$ $- 719.72\ k_t^3 + 10.53.4\ k_t^4) - 562.69 k_t^5$ $d = I_t 0.30$
[12]	$0 < k_t \leq 0.78$ $k_t > 0.78$	$d = 0.9995 - 0.05\ k_t + 2.4156 + 1.4926\ k_t^3$ $d = 0.2$
[14]	$k_t \leq 0.17$ $0.17 \leq k_t \leq 0.75$ $k_t > 0.75$	$d = 1$ $d = 0.90 + 1.1\ k_t - 4.5\ k_t^2 + 0.01\ k_t^3 + 3.14\ k_t^4$ $d = 0.17$
[15]	$k_t < 0.2$ $0.2 \leq k_t \leq 0.75$ $k_t > 0.75$	$d = 0.987$ $d = 1.292 - 1.447\ k_t$ $d = 0.209$
[17]	$k_t \leq 0.1$ $0.1 \leq k_t \leq 0.8$ $k_t > 0.8$	$d = 0.987$ $d = 0.94 + 0.937\ k_t - 5.01\ k_t^2 + 3.13\ k_t^3$ $d = 0.177$
[18]		$d = 1 + (1/1 + e^{8.60\,k_t - 5})$
[23]	$0 \leq k_t \leq 0.3$ $0.3 \leq k_t \leq 0.78$ $k_t \geq 0.78$	$d = 1.02 - 0.254\ k_t + 0.0123\cos\theta$ $d = 1.40 - 1.749\ k_t + 0.177\cos\theta$ $d = 0.486\ k_t - 0.182\cos\theta$
Model 1		$d = 0.992 - 1.155\ k_t + 0.2753\ k_t^2$
Model 2		$d = 0.9193 - 1.15763\ k_t + 0.7739\ k_t^2$
Model 3	$0 < k_t \leq 0.3$ $0.3 < k_t \leq 0.6$ $0.6 < k_t \leq 0.9$ $0.9 < k_t$	$d = 0.8476 - 1.135\ k_t + 0.2278\ k_t^2$ $d = 0.8904 - 1.182\ k_t - 0.2396\ k_t^2$ $d = 1.3904 - 2.909\ k_t + 1.7001\ k_t^2$ $d = 4.0791 - 8.5652\ k_t + 4.6648\ k_t^2$

The BIC enables the evaluation of intuitive information with concrete implications. The BIC tries to cope with the prior probability, claiming that the preliminary probability can take any value between 0 and 1 without any evidence:

$$BIC = \{n \ln\}\left[\frac{1}{n}\sum_{i=1}^{n}\left(I_{d_{\text{model}}} - I_{d_{\text{meas}}}\right)^2\right] + k \ln n \qquad (7)$$

When the performance of the models under the guidance of these statistical parameters is examined, it is seen that the Model 3, which is produced by the local parameters, performs better than the Bugler *et al.* [2], Jin *et al.* [15], Ridley *et al.* [23] models in MAE, MAPE %, RMSE evaluations, the Liu and Jordan [1], Bugler *et al.* [2], Ridley *et al.* [23] models in *t*-test (t-stat) evaluation and the Hawlader [33], Karatasou *et al.* [12], Bugler *et al.* [2], Boland *et al.* [8], Jin *et al.* [15], Ridley *et al.* [23] models in BIC statistic evaluation method. The performance success of Model 1 enabled the evaluation of a second model to be proposed. Based on this, Model 2 showed a better performance than the 15 models in the literature in MAE, MAPE %, RMSE, and BIC statistics evaluations. However, although the t_{stat} statistics parameter was better than the other models, it did not fall below the 1.96 level of confidence. For this reason, it was requested that a third model to be proposed would have achieved the success accomplished by Model 2 in other statistical parameters and the desired t_{stat} parameter without falling down from the level of

Table 3. Statistical performances of the developed models using the out of sample data between 2009 and 2016, Sanliurfa, Turkey ($t_{\text{crit.}}$= 1.96 at a level of confidence of 95% and n-1 degrees of freedom, n = 17195)

Models	*MAE*	*MAPE* [%]	*RMSE*	t_{stat}	$t_{\text{stat}} \leq t_{\text{crit.}}$	*BIC* × 104	R^2
Model 1	64.489	72.551	83.523	159.304	No.	41.780	0.472
Model 2	1.790	11.983	41.348	5.681	No.	39.382	0.819
Model 3	0.881	11.652	40.959	2.819	No.	39.350	0.703
[1]	–61.003	–52.871	76.439	173.650	No.	41.495	0.736
[2]	208.777	210.970	235.873	249.391	No.	45.370	0.317
[3]	45.608	57.591	68.568	116.797	No.	41.121	0.717
[32]	39.409	51.961	64.714	100.667	No.	40.923	0.693
[33]	53.606	64.656	71.320	149.414	No.	41.257	0.690
[7]	53.814	65.705	72.212	146.536	No.	41.300	0.710
[8]	57.938	69.398	128.564	66.192	No.	43.283	0.162
[9]	46.315	58.336	67.947	122.149	No.	41.090	0.702
[10]	–28.866	–20.751	70.701	58.645	No.	41.227	0.027
[12]	53.856	64.505	71.457	150.359	No.	41.263	0.727
[14]	26.446	39.199	50.541	80.508	No.	40.073	0.709
[15]	610.383	567.539	904.181	119.977	No.	49.990	0.595
[17]	47.987	58.936	67.150	133.949	No.	41.050	0.707
[18]	34.041	44.267	69.614	73.503	No.	41.174	0.705
[23]	76.325	88.214	93.252	186.789	No.	42.179	0.696

confidence. For this purpose, the Model 3 has been developed and it was successful in terms of all statistical evaluations. In this study, the values of the statistical parameters obtained for the models produced in the literature and locally produced models are given in tab. 3.

Conclusion

Since the 1900's, in the literature, empirical formulas have been produced for the calculation of horizontal solar diffuse radiation based on the relationship between diffuse radiation ratio and clarity index obtained from the stations of diffuse radiation measurement. However, as it is known that these empirical formulas in the literature are produced with the data of the studied region, the results of these models will not be the same in the radiation estimates of a different region. In addition, as shown in this study, horizontal solar diffuse radiation models in the literature have been proposed to update the previously proposed local models by suggesting new models in which varying radiation data are also taken into account in order to propose an accurate estimation model. According to the clarity index constraints obtained with diffuse radiation data for Sanliurfa, Model 3 shows better performance than Model 2 where there is no restriction of the Model 3 clarity index. Apart from the fact that both models are not suitable for t_{crit}, Model 2 provides better results than many models for MAE, MAPE %, RMSE, and BIC statistical errors. It is thought that better results can be obtained with the improvements on the models. As a result, it was determined that the models produced with local data gave better results than the models in the literature. In this context, instead of the models proposed in the literature, it was determined that the use of the models proposed in the study would yield more accurate results for the estimation of diffuse solar radiation in the region.

Nomenclature

d – diffuse radiation ratio
I_{global} – horizontal surface hourly total radiation, [Wm^{-2}]
I_0 – extraterrestrial total hourly radiation, [Wm^{-2}]
I_d – horizontal surface hourly diffuse radiation, [Wm^{-2}]
k_t – clearness index, clarity index
t_{stat} – t test metod

Subscripts

stat – statistical

Acronyms

BIC – bayesian information criterion
MAE – mean absolute error
MAPE – average relative error meas measurement
RMSE – square root of the mean square error

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