Development of empirical models for estimation diffuse solar radiation exergy in Turkey

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Abstract: In this study, exergy of diffuse solar radiation is estimated using empirical models. Long-term meteorological data (1983–2005) consisting of monthly mean diffuse solar radiation for seven selected stations were available from NASA Langley Research Centre. Empirical models were developed by correlating diffuse solar radiation exergy in terms of relative sunshine period. The performance ranking of the models is carried out by using the global performance indicator (GPI) method. The maximum diffuse solar radiation exergy value (53 MJ/m^2 year) belongs to Adana for selected provinces. Quadratic type is the best predictive method for Bursa, Ankara, Adana, Gaziantep provinces located in Turkey, and Igdir and Trabzon regions are excellently predicted by cubic type. Linear type is then used for the best prediction of the Izmir city of Turkey. Consequently, the empirical models obtained in this study can successfully predict diffuse solar radiation exergy.

Keywords: diffuse solar radiation, exergy; empirical models; clearness index; sunshine period; Turkey.

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1 Introduction

In any geographic location, solar radiation data is the most important requirement in solar energy applications. However, solar radiation measuring devices for all locations may not be economical. Therefore, it has been shown that it is a suitable method to predict solar radiation by mathematical models (Lorenzo, 1994; Bouzid and Ghellai, 2015; Bailek et al., 2018). The global solar radiation on horizontal surfaces is sum of the beam and diffuse components. Among these components, the amount of diffuse solar radiation is always uncertain because it is often influenced by environmental parameters. So, the prediction of diffuse solar radiation an important subject. Khorasanizadeh et al. (2014) found that 20% of the annual global solar energy is diffuse solar radiation.

Diffuse solar radiation measurement are not available in different parts of the world. By using global solar radiation and meteorological data, diffuse solar radiation can be found by regression analysis. Recently, extensive studies have been conducted to estimate diffuse solar radiation using data available for different locations in the world. Various authors have formed regression equations to predict diffuse solar radiation using the clearness index (Bailek et al., 2018; Tasdemiroglu and Sever, 1991; Li et al., 2011; Khorasanizadeh and Mohammadi, 2016; Anis et al., 2019; Jamil and Akhtar, 2017a, 2017b; Jamil and Siddiqui, 2017; Arslanoglu, 2016b) or relative sunshine duration (Bailek et al., 2018; El-Sebaii et al., 2010; Jain, 1990; Khogali et al., 1983; Anis et al., 2019; Jamil and Siddiqui, 2017; Arslanoglu, 2016a), or combination of them (Bailek et al., 2018; Ahmad et al., 1991; Trabea, 1999; Kambezidis et al., 2017; Rensheng et al., 2004; Anis et al., 2019; Jamil and Akhtar, 2017c; Arslanoglu, 2016a).

As known, exergy is related to the work potential of the energy contained in a system at a specified state (Cengel and Boles, 2006), and it is a concept that explicitly shows the' usefulness (quality)' of energy and matter, in addition to 'what is consumed' in the course of energy transfer or conversion steps. The concept of 'energy' does not show these quality and consumption aspects, because it is a concept aimed at 'quantity'; this quantity, being subject to a conservation law, cannot be consumed according to the first law of thermodynamics. The concept of 'exergy' provides further understanding of 'how a system works', by pinpointing the subsystems where energy is degraded. An understanding of exergy consumption principles will lead us to a better understanding of resource and environment issues (Hepbasli and Alsuhaibani, 2014; Asada and Boelman, 2003).

Currently, the conversion of solar energy into useful energy, such as mechanical and electrical energy, does not play an important role in the energy budget of most countries. However, this energy conversion will become more important in the future because of its environmentally friendly standing. So, it is important to have these thermodynamic tools ready for action when the demand increases. Given a fixed environment, exergy is the fraction of the incoming energy that is fully convertible into mechanical or electrical energy. Mechanical and electrical energy are completely exergy; they are fully convertible into all other energy types.

Solar energy is not fully convertible because of its entropy content; therefore, its exergy content is less than 100%. Thus, the energetic conversion efficiency of a solar conversion device will not be 100%, even if there were an ideal, fully reversible conversion. The exergy content of solar radiation arriving on earth is between 50 and 80% of its energy flux, depending on the atmospheric conditions (Kabelac, 2005). For more than 20 years, several articles have been published that consider different approaches to solar radiation exergy (Kabelac, 2005; Petela, 2003, 2005; Candau, 2003; Zamfirescu and Dincer, 2009; Joshi et al., 2009).

Petela (2003) presented the equation for the calculation for exergy of solar energy. Petela (2005) carried out exergy analysis for solar cylindrical-parabolic cooker (SPC). It is obtained that second law efficiency of the SPC is very low. Candau (2003) investigated the exergy of solar radiation and the results of exergy analysis are verified according to classical thermodynamics. A study was carried out by Zamfirescu and Dincer (2009) to calculate the exergy of solar radiation. Joshi et al. (2009) created a solar radiation exergy map and showed how important it is for solar energy systems.

1.1 Literature gap and statement

Öztürk et al. (2011) carried out exergy analysis of global solar radiation for the Akdeniz Region of Turkey. The highest and lowest calculated global solar radiation exergy values are ranged between 25.3 MJ/m^2–day and 18.1 MJ/m^2–day. Kareem et al. (2019) investigated the solar radiation and its exergy value for Baghdad in Iraq. The model of Nayak and Tiwari was used to predict solar exergy. Uçkan (2017) analysed the exergy of global solar radiation for the period of 1993 to 2007 in Van, Turkey. The highest annual solar radiation exergy value is obtained for the year of 2000 with 19.68 MJ/m^2 and the lowest annual solar radiation exergy value is obtained for the year of 1993 with 16.50 MJ/m^2. Hepbasli and Alsuhaibani (2014) computed global solar radiation exergy in different climate areas of Turkey and Saudi Arabia. Exergy-to-energy ratio for Saudi Arabia and Izmir in Turkey were computed 0.933 and 0.935 for both approaches of Petela and Spanner, respectively. Exergy-energy ratio values found using Jefer's approach seem to be 2% higher than Petela and Spanner's approaches. Kurtgoz et al. (2017) computed global solar radiation exergy values are computed for the 81 cities in Turkey. In addition, enviroeconomic analysis was performed and its results were presented. Rahnama et al. (2019) presented the solar exergoe conomic and exergo environmental maps of photovoltaic systems for Iranian climatic conditions. Gürlek and Şahin (2018) calculated value of global solar radiation exergy for Sivas, Turkey. The exergy-to-energy ratio for Divriği, Gemerek and Sivas City Centre are found to be 0.937 for both Petela and Spanner's approaches and 0,953 for Jeter's approach. Ozturk (2004) developed thermodynamic model to obtain first and second law efficiencies of the solar cookers. Alta et al. (2010) utilised the solar radiation data of 152 geo-referenced locations to calculate global solar radiation exergy value for Turkey. The mean solar exergy value in Turkey was estimated at 13.5 ± 1.74 MJ/m^2-day and the annual exergy-to-energy ratio were obtained to be 0.93.

There are few studies in the literature that estimate global solar radiation exergy by various methods (Edalati et al., 2016; Jamil and Bellos, 2019; Arslanoglu, 2016b; Mohammed and Mengüç, 2018). Empirical models were developed to predict global solar radiation exergy. Also to evaluate the performance of the models and to select the best model, six statistical methods were utilised. Edalati et al. (2016) predicted global solar radiation exergy value by artificial neural network (ANN)-based model. Mohammed and Mengüç (2018) developed a new methodology is introduced for predicting the global solar radiation exergy. Jamil and Bellos (2019) calculated direct and diffuse radiation exergy value. In addition, empirical models were presented to estimate global solar radiation exergy. However, there are no studies in the literature that estimate diffuse solar radiation exergy by modelling with methods like regression analysis, or artificial intelligence. The aim of this study is to fill this gap by modelling diffuse solar radiation exergy with regression analysis method and to be beneficial to the solar energy industry. Then, linear, quadratic, cubic models based solely on the relative sunshine duration were established for diffuse solar radiation exergy estimation. Then, these models are evaluated most frequently used statistical methods and the best model is determined for each province by using the global performance indicator (GPI). In addition, it is proved that empirical equations can be used in the prediction of diffuse solar radiation exergy. One of the important points of this paper is that the empirical models are independent of the diffuse solar radiation.

2 Modelling

Many empirical equations are nowadays to predict the diffuse solar radiation from measured bright sunshine hours, monthly average daily global solar radiation (H) and calculated day length. The linear, quadratic, cubic, models (Table 1) (Angström, 1924; Prescott, 1940; Akinoglu and Ecevit, 1990; Bahel et al., 1987) are the most commonly used models for prediction of diffuse solar radiation. The value of diffuse solar radiation exergy is obtained on a horizontal surface 'H_{de}' to change the diffuse solar radiation 'H_d'. The relative sunshine duration is expressed as the ratio of the observed bright sunshine hours (*n*) to the day length (*N*); *a*, *b*, *c* and *d* are the constants.

Table 1 Regression models used in this study.

Models	*Regression equations*	*Regression equations used in the present study*
Linear	$\frac{H_d}{H} = \alpha + b(n/N)$	$\frac{H_{de}}{H} = \alpha' + b'(n/N)$
Quadratic	$\frac{H_d}{H} = \alpha + b(n/N) + c({}^{n}/N)^2$	$\frac{H_{de}}{H} = \alpha' + b'(n/N) + c'({}^{n}/N)^2$
Cubic	$\frac{H_d}{H} = \alpha + b(n/N) + c({}^{n}/N)^2 + d({}^{n}/N)^3$	$\frac{H_{de}}{H} = \alpha' + b'(n/N) + c'({}^{n}/N)^2 + d'({}^{n}/N)^3$

The day length (*N*) can be computed as follows (Yigit and Atmaca, 2010):

$$N = \frac{2}{15} W_s \tag{1}$$

where the mean sunrise hour angle (w_s) can be defined by:

$$W_s = \cos^{-1}\left[-\tan(\delta)\tan(\varphi)\right] \tag{2}$$

where φ is the latitude of the site, δ is the solar declination that can be computed by (Yigit and Atmaca, 2010):

$$\delta = 23.45 \sin\left[\frac{360(D+284)}{365}\right] \tag{3}$$

where *D* is the number of day of the year, starting from first of January. There are several approaches to calculating solar radiation exergy (Kabelac, 2005; Petela, 2003, 2005; Candau, 2003; Zamfirescu and Dincer, 2009; Onyegegbu and Morhenne, 1993). The definition of the solar radiation exergy (H_e) with beam (H_{be}) and diffuse (H_{de}) parts is used in this study as follows (Onyegegbu and Morhenne, 1993):

$$H_{be} = H_b \left[1 \frac{4T_0}{3T_s}\right] \tag{4}$$

$$H_{de} = H_d \left[1 \frac{4T_0}{3T_s^*}\right] \tag{5}$$

$$H_e = H_b \left[1 \frac{4T_0}{3T_s} \right] + H_d \left[1 \frac{4T_0}{3T_s^*} \right] \quad (6)$$

$$\frac{T_s}{T_s^*} = 0.9562 + 0.2777 \ln \frac{1}{K} + 0.0511 \kappa \quad (7)$$

where κ, the dilution factor of diffuse radiation, less than 0.1 (Eskin, 1999). T_0 and T_s are the mean monthly air temperature and solar radiation temperature (6,000 K), respectively (Alta et al., 2010). H_b and H_d are the monthly average daily beam and diffuse radiation, respectively. The important point of this study is that the diffuse solar radiation exergy can be calculated without the use of diffuse solar radiation, mean monthly air and solar radiation temperature data in equation (8).

$$\frac{H_{de}}{H} + \frac{H_d \left[1 - \frac{4T_0}{3T_s^*} \right]}{H} = f\left(a', b', c', d', n, N\right) \quad (8)$$

Meteorological data has been obtained from seven stations (Bursa, Izmir, Ankara, Adana, Gaziantep, Trabzon, Igdir) in Turkey. The sites used in this study are shown in Figure 1. Also, the measured data (training data) of diffuse solar radiation for these cities is provided NASA satellite.

Figure 1 Location of the sites in turkey used in the present study

Detailed information about the data series and the measuring stations are given in Table 2. The constants (a', b', c' and d') in the empirical equations are presented in Table 3.

Table 2 Information for selected provinces in the study

Location	*Longitude (East)*	*Latitude (North)*	*Elevation (m)*	*Diffuse solar radiation(training data)*	*Meteorological data (Global radiation, sunshine hours, etc.)*
Bursa	29.01	40.23	100	1983–2005	1968–2012
Izmir	27.18	38.4	29	1983–2005	1982–2006
Ankara	32.86	39.97	891	1983–2005	1967–2011
Adana	35.29	36.98	20	1983–2005	1968–2015
Gaziantep	37.46	36.94	700	1983–2005	1968–2010
Trabzon	39.76	40.99	39	1983–2005	1969–2005
Igdir	44.05	39.92	856	1983–2005	1968–2010

Table 3 Regression constants for provinces of Turkey

Location	*Model*	α'	b'	c'	d'
Bursa	Linear	0.5528	–0.3667		
	Quadratic	0.5397	–0.3094	–0.0573	
	Cubic	0.2194	1.8689	–4.7264	3.1692
Izmir	Linear	0.4756	–0.3162		
	Quadratic	0.4899	–0.3632	0.0364	
	Cubic	0.2808	0.6826	–1.6523	0.8835
Ankara	Linear	0.4855	–0.3105		
	Quadratic	0.4865	–0.3147	0.0047	
	Cubic	0.6732	–1.6085	2.7186	–1.7593
Adana	Linear	0.5078	–0.3183		
	Quadratic	0.3424	0.2421	–0.4573	
	Cubic	–0.1543	2.7821	–4.7024	2.3187
Gaziantep	Linear	0.5742	–0.4468		
	Quadratic	0.3932	0.2437	–0.6081	
	Cubic	0.8993	–2.6791	4.7753	–3.1814
Trabzon	Linear	0.5259	–0.2702		
	Quadratic	0.4918	–0.0744	–0.2707	
	Cubic	0.8449	–3.0991	8.1685	–7.6512
Igdir	Linear	0.4647	–0.2410		
	Quadratic	0.4087	0.0211	–0.2738	
	Cubic	0.5934	–1.3741	2.9104	–2.2534

3 Evaluation of statistical methods

There are many statistical methods that determine the performance of empirical models in the literature. The statistical methods used in this study are as follows; the coefficient of determination (R^2), the mean absolute percent error (MAPE), the mean absolute bias error (MABE), the root mean square error (RMSE), and the t-statistic method (t_{sta}). R^2, MAPE, MABE, and RMSE and t_{sta} can be calculated from the following equations (Teke and Basak, 2014; Bakirci, 2009; Ulgen and Hepbasli, 2009).

$$R^2 = \frac{\sum_{i=1}^{k}\left(H_{p,de} - H_{p,de,avg}\right)\cdot\left(H_{de} - H_{de,avg}\right)}{\sqrt{\left[\sum_{i=1}^{k}\left(H_{p,de} - H_{p,de,avg}\right)^2\right]\left[\sum_{i=1}^{k}\left(H_{de} - H_{de,avg}\right)^2\right]}} \tag{9}$$

$$MAPE = \frac{1}{k}\sum_{i=1}^{k}\left(\left|\frac{H_{p,de} - H_{de}}{H_{de}}\right| \times 100\right)(\%) \tag{10}$$

$$MABE = \frac{1}{k}\sum_{i=1}^{k}\left|H_{p,de} - H_{de}\right| \qquad \left(\frac{MJ}{m^2 - day}\right) \tag{11}$$

$$RMSE = \left[\frac{1}{k}\sum_{i=1}^{k}\left(H_{p,de} - H_{de}\right)^2\right]^{1/2} \qquad \left(\frac{MJ}{m^2 - day}\right) \tag{12}$$

$$t_{sta}\sqrt{\left[\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}\right]} \tag{13}$$

The coefficient of determination (R^2) values close to 1 show a good performance of the empirical model (Behar et al., 2015). The optimum result of MAPE and MABE is zero. A small RMSE value indicates that the model is performing well. Small t values are indicative of high performance of the model. Detailed information about these statistical methods is given in Arslanoglu (2016b).

Many empirical models are difficult to be assessed in terms of performance. Therefore, in this study, the GPI statistical method that combines the effects of many statistical methods under a single value is used. In order to obtain GPI, the values obtained from all statistical methods are rationalised on a scale of 0–1. These scaled values are subtracted from the median value of the respective scaled method. In order to find the GPI of the model, the differences obtained for each statistical method are summed after being multiplied by the appropriate weight factor. The GPI value is expressed mathematically as follows(Jamil and Bellos, 2019; Despotovic et al., 2015):

$$GPI = \sum_{j=1}^{5} \propto_j \left(\tilde{y}_j - \widetilde{y_{ji}}\right) \tag{14}$$

$\propto_j$ is –1 for R^2 and equals 1 for other methods. The $\tilde{y}_j$ value indicates the median of the scaled value of the statistical method j. $\widetilde{y_{ji}}$ shows the scaled value of the statistical method j for the i^{th} model. The model with the highest GPI indicates the best performance. Table 4 shows that results obtained from the statistical test methods showing the performance of the models.

4 Results and discussion

In this paper, the maximum work obtained from diffuse solar radiation was calculated. In addition, empirical equations have been formed to predict this maximum amount of work. Diffuse radiation (training data), diffuse solar radiation exergy values, and monthly air temperatures used in this study are shown in Table 5. The maximum diffuse solar radiation exergy value (53 MJ/m^2 year) belongs to Adana province. The reason for this is that the most diffuse solar radiation comes to Adana for selected provinces.

Figure 2 gives the diffuse solar radiation exergy values calculated from the test dataset (Eu Science Hub, 1999) and estimated from the models. The diffuse solar radiation exergy values calculated from the test data (data for the year 2016) are good agreement with these estimated from the models.

The scaled statistical method values for the obtained three models considered together and corresponding overall GPI are performed in Table 4. The GPI lies in the range of –3.138 to 2.2072. Ranking of the models is dependent on the GPI values. Maximum GPI value indicates the best quality of a model to estimate a value and is therefore ranked as 1 among the obtained models.

- Bursa: The best result ($R^2 = 0.984$ and $t_{sta} = 3.6132$) was derived from the cubic model. The optimal results of MAPE, RMSE, MABE, are obtained by quadratic equation as 9.9076, 0.5243, and 0.4493. The diffuse solar radiation exergy was obtained in the range of 2.097 to 6.57 throughout year. The maximum GPI of 0.4447 was derived for the quadratic model. Izmir: The highest result ($R^2 = 0.976$) was achieved from the cubic equation. The optimum results of the statistical methods are 0.4765 (MABE), 0.5623 (RMSE) and 11.3452 (MAPE) by the linear model, and 0.5416 (t_{sta}) by the cubic equation. The diffuse solar radiation exergy value was obtained in the range of 2.269 to 6.052 in a year. The maximum GPI of 2.2072 was obtained for the linear equation.
- Ankara: The optimum results of MABE, MAPE and t_{sta} were obtained by the quadratic equation as 0.7359, 14.2640 and 4.7133. Optimal results of RMSE (0.8735), R^2 (0.963) were derived from the cubic equation. The maximum and minimum diffuse solar radiation exergy values were derived at 6.485 and 2.194. The maximum GPI value of 0.9606 was obtained for the quadratic model.
- Adana: The best results of MABE, MAPE were calculated as 0.4509, 10.1307 from the quadratic model; However the optimum result of $t_{sta} = 0.9463$ was derived from the linear equation. The best result for RMSE = 0.5263, $R^2 = 0.87$ was obtained for the cubic equation. The diffuse solar radiation exergy values were found in the range of 2.356 to 6.69 throughout a year. A maximum GPI of 0.1802 was observed for the quadratic model.
- Gaziantep: The best results of MABE, MAPE were derived by the quadratic model as 0.5743, 11.0333. The best results of the RMSE (0.8312) and R^2 (0.972) were achieved from the cubic regression model. The optimum result of $t_{sta} = 2.6677$ was

obtained with the linear equation. The diffuse solar radiation exergy values were found in the range of 2.368 to 6.092 in a year. A best GPI of 1.4836 was obtained for the quadratic model.

- Trabzon: The optimal results of RMSE, t_{sta}, R^2 were found as 0.5327, 4.8528, and 0.85 from the cubic equation. The optimum result for MABE = 0.4467 was derived from the quadratic equation, and the minimum result for MAPE = 8.4603 from the linear equation. The diffuse solar radiation exergy value was found in range of 2.094 to 7.108 throughout a year. A best GPI of –0.2563 was obtained for the cubic model.
- Igdir: The best results of MABE, RMSE, MAPE, R^2 were derived from the cubic equation as 0.7493, 0.9551, 13.5920, and 0.807. A minimum tsta value 3.3529 was calculated using the linear equation. Maximum and minimum diffuse solar radiation exergy values were computed to be 6.619 and 2.163. A highest GPI of 1.0727 was obtained for the cubic model.

Ranking of the models make it convenient to choose the best empirical models. The best rank is obtained for quadratic model for the four site of selected seven sites. The present study used empirical models in order to estimate the exergy potential of diffuse solar radiation for different sites in Turkey. It is important to state that the diffuse solar radiation exergy potential is different from site to site because the percentage of the diffuse solar radiation is variable location to location .So; detailed analysis is carried out in order to obtain the exact potential of the diffuse solar radiation exergy for every location in Turkey. Jamil and Bellos (2019) also achieved this result in his study for India.

Figure 2 Diffuse radiation exergy for some provinces for Turkey

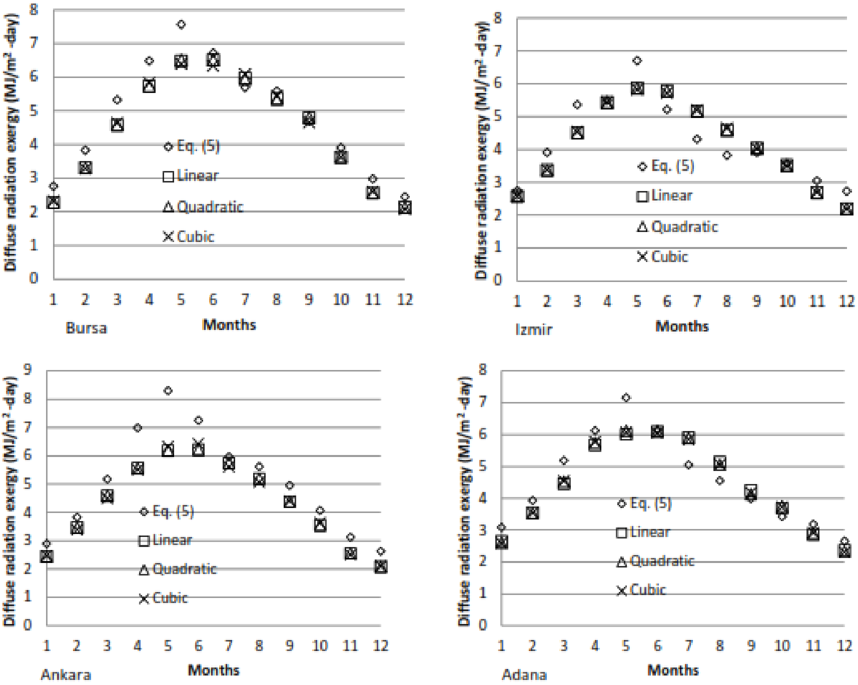

Figure 2 Diffuse radiation exergy for some provinces for Turkey (continued)

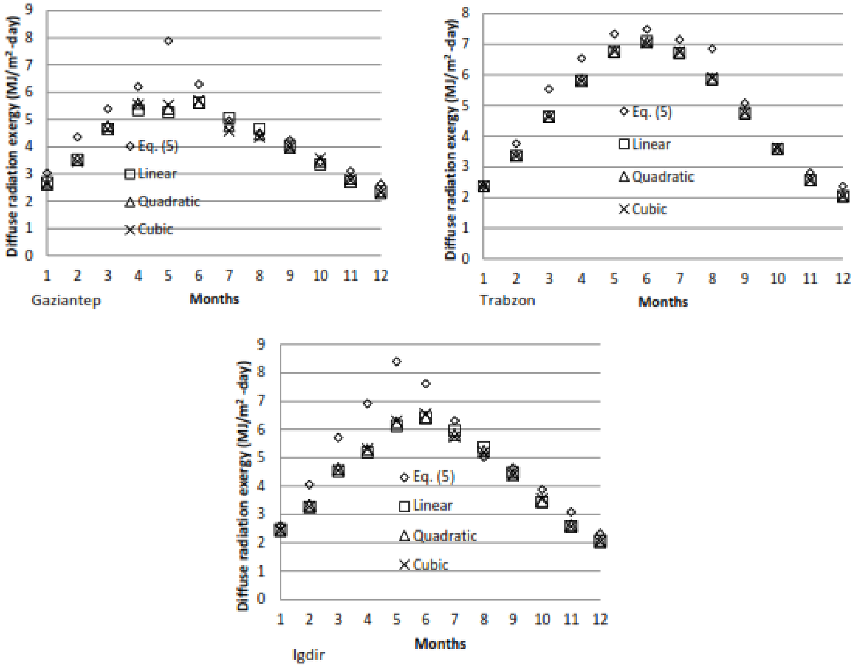

Table 4 Statistical indicators of the regression models for stations

Site/statistical indicator	*Models*		
	Linear	*Quadratic*	*Cubic*
Bursa			
MABE	0.4522	*0.4493*	0.4594
RMSE	0.5293	*0.5243*	0.5370
MAPE	9.9423	*9.9076*	9.9910
t_{sta}^{a}	3.6606	3.7495	*3.6132*
R^2	0.9698	0.9765	*0.9842*
GPI	*–0.0667*	*0.4447*	*–0.6219*
Rank	*2*	*1*	*3*
Izmir			
MABE	*0.4765*	0.4822	0.4817
RMSE	*0.5623*	0.5683	0.5731
MAPE	*11.3452*	11.4594	11.4930
t_{sta}^{a}	0.5715	0.5705	*0.5416*
R^2	0.9753	0.9751	*0.9762*
GPI	*2.2072*	*–0.0877*	*1.2949*
Rank	*1*	*3*	*2*

Note: The italic indicates the lowest values of MABE, RMSE, MAPE, t_{sta} and highest value of R^2.

Table 4 Statistical indicators of the regression models for stations (continued)

Site/statistical indicator	*Models*		
	Linear	*Quadratic*	*Cubic*
Ankara			
MABE	0.7364	*0.7359*	0.7365
RMSE	0.8996	0.8999	*0.8735*
MAPE	14.2758	*14.2640*	14.3695
t_{sta}^{a}	4.7266	*4.7133*	5.2021
R^2	0.9526	0.9522	*0.9634*
GPI	*0*	*0.9606*	*–0.0391*
Rank	*2*	*1*	*3*
Adana			
MABE	0.4821	*0.4509*	0.4536
RMSE	0.5645	0.5281	*0.5263*
MAPE	10.6024	*10.1307*	10.1749
t_{sta}^{a}	0.9463	0.9829	1.0245
R^2	0.8528	0.8676	*0.8765*
GPI	*–3.1384*	*0.1802*	*–0.3182*
Rank	*2*	*1*	*3*
Gaziantep			
MABE	0.6091	*0.5743*	0.5999
RMSE	0.9013	0.8525	*0.8312*
MAPE	11.5318	*11.0333*	11.6997
t_{sta}^{a}	*2.6677*	2.9658	3.2255
R^2	0.9465	0.9664	*0.9721*
GPI	*–1.1953*	*1.4836*	*0.1829*
Rank	*3*	*1*	*2*
Trabzon			
MABE	0.4470	*0.4467*	0.4480
RMSE	0.5368	0.5339	*0.5327*
MAPE	*8.4603*	8.4669	8.5229
t_{sta}^{a}	4.8959	4.9429	*4.8528*
R^2	0.8394	0.8432	*0.8543*
GPI	*–0.9655*	*–0.2908*	*–0.2563*
Rank	*3*	*2*	*1*
Igdir			
MABE	0.7813	0.7613	*0.7493*
RMSE	1.0188	0.9746	*0.9551*
MAPE	13.9657	13.7398	*13.5920*
t_{sta}^{a}	*3.3529*	3.6733	3.8011
R^2	0.7757	0.7987	*0.8076*
GPI	*–1.9273*	*0*	*1.0727*
Rank	*3*	*2*	*1*

Note: The italic indicates the lowest values of MABE, RMSE, MAPE, t_{sta} and highest value of R^2.

Table 5 Diffuse solar exergy values for Turkey

	Months	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
Bursa	H_d (Mj/m^{2}day)	2.8812	3.9962	5.5443	7.2345	8.0282	8.1345	7.5243	6.6961	5.4729	4.3924	3.1682	2.5561
	H_{de} (Mj/m^{2}day)	2.3671	3.2822	4.5462	5.8823	6.5371	6.5734	6.0945	5.4234	4.4474	3.5821	2.5933	2.0972
	T_a (°C)	278.45	279.35	281.65	286.05	290.85	295.35	297.75	297.45	293.25	288.45	283.85	280.55
Izmir	H_d	3.0244	4.1435	5.4364	6.9485	7.4523	7.0246	6.4443	5.8323	4.8967	4.1456	3.2765	2.7722
	H_{de}	2.4793	3.3923	4.4463	5.6654	6.0524	5.6794	5.2044	4.7114	3.9676	3.3675	2.6744	2.2692
	T_a	281.95	282.55	284.95	289.05	294.05	298.85	301.15	300.75	296.75	292.05	287.25	283.65
Ankara	H_d	2.9163	3.9634	5.3642	7.1281	7.9565	7.9289	7.0565	6.4084	5.2299	4.2120	3.1325	2.6645
	H_{de}	2.4064	3.2642	4.4063	5.8322	6.4856	6.4351	5.7184	5.1943	4.2461	3.4426	2.5715	2.1944
	T_a	273.65	275.15	279.35	284.45	289.35	293.35	296.75	296.55	291.85	286.15	280.25	275.85
Adana	H_d	3.1684	4.2125	5.6884	7.3446	8.2447	7.7766	6.8046	6.1929	5.3282	4.2127	3.4246	2.8848
	H_{de}	2.5956	3.4486	4.6463	5.9845	6.6967	6.2916	5.4945	4.9988	4.3097	3.4199	2.7897	2.3560
	T_a	282.75	283.75	286.75	290.65	294.95	298.85	301.25	301.65	299.15	294.65	288.65	284.35
Gaziantep	H_d	3.1680	4.2127	5.6164	7.0564	7.4885	6.6678	5.9044	5.5447	4.6088	4.2129	3.3129	2.8876
	H_{de}	2.6097	3.4658	4.6068	5.7653	6.0924	5.3959	4.7692	4.4798	3.7368	3.4338	2.7148	2.3683
	T_a	276.25	277.45	281.45	286.35	291.85	297.25	300.95	300.65	295.95	289.35	282.55	278.05
Trabzon	H_d	2.8805	3.9645	5.5449	7.2723	8.3883	8.7485	8.3882	7.3878	5.7667	4.3290	3.1327	2.5567
	H_{de}	2.3636	3.2505	4.5466	5.9473	6.8393	7.1085	6.8013	5.9827	4.6815	3.5217	2.5607	2.0947
	T_a	280.65	280.55	281.65	285.05	289.05	293.35	296.15	296.35	293.25	289.55	285.85	282.75
Igdir	H_d	2.8567	3.7845	5.3612	7.1298	8.1356	7.9925	7.5612	6.4422	5.0789	4.0678	3.1698	2.6267
	H_{de}	2.3172	3.1216	4.4456	5.8134	6.6198	6.4821	6.1156	5.2138	4.1256	3.3189	2.5976	2.1637
	T_a	269.85	272.85	279.75	286.35	290.95	295.35	299.05	298.25	293.15	285.85	278.85	272.95

5 Conclusions

A maximum amount of work extracted from diffuse solar radiation is very important for the viability of solar power systems. Basically, diffuse solar radiation exergy is an indicator of the quality of diffuse solar radiation. Therefore, empirical equations have been formed to estimate diffuse solar radiation exergy. The results showed that the Adana city has the highest diffuse solar radiation exergy potential in Turkey.

The diffuse solar radiation exergy component of global solar radiation exergy is correlated with the relative sunshine duration. Statistical analyses have been employed to compare and determine the quality of models. Further, GPI was calculated and used to rank the models. The GPI lies among –3.138 to 2.2072 for empirical models. According to GPI, the models that best predict diffuse solar radiation exergy vary by site.

Quadratic type is the best predictive method for Bursa, Ankara, Adana, Gaziantep provinces located in Turkey, and Igdir and Trabzon regions are excellently predicted by cubic type. Linear type is then used for the best prediction of the Izmir city of Turkey. With these models, diffuse solar radiation exergy can be estimated without the need for diffuse solar radiation information. The empirical models providing the best results here can be reliably used to estimate diffuse solar radiation exergy in Turkey and in other locations with similar climatic conditions in the world. Finally, this study demonstrated that empirical models successfully predict diffuse solar radiation exergy.

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