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Models for the estimation of diffuse solar radiation for typical cities in Turkey

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ABSTRACT

In solar energy applications, diffuse solar radiation component is required. Solar radiation data particularly in terms of diffuse component are not readily affordable, because of high price of measurements as well as difficulties in their maintenance and calibration. In this study, new empirical models for predicting the monthly mean diffuse solar radiation on a horizontal surface for typical cities in Turkey are established. Therefore, fifteen empirical models from studies in the literature are used. Also, eighteen diffuse solar radiation models are developed using long term sunshine duration and global solar radiation data. The accuracy of the developed models is evaluated in terms of different statistical indicators. It is found that the best performance is achieved for the third-order polynomial model based on sunshine duration and clearness index.

1. Introduction

The studies on the new and renewable energy sources gained speed and were encouraged because energy resources used today have rapidly depleted and they have caused environmental pollution. Therefore, to use this clean energy source is extremely important in terms of environmental pollution and contribution to the energy economy. The solar energy has many advantages according to other energy kinds. Solar energy is one of the main renewable energy resources in nature and it has an important place in between other alternative energy sources.

Solar radiation arriving on earth is the most fundamental renewable energy source in nature. Solar energy occupies one of the most important places among various alternative energy sources. In the studies of solar energy, data on solar radiation and its components at a given location are very essential [1]. Interest in solar energy as an alternative energy source has increased the demand for solar-radiation and climatological information for use in system design and performance evaluation. The most important radiation parameters used in solar energy techniques are global, diffuse and direct radiation and, for most applications, the values of this radiation on horizontal and tilted surfaces are needed. The diffuse radiation has special areas of applications and a data base of systematically-measured diffuse radiation, given on a daily or hourly basis, is a requirement in most of the solar energy studies. Since the measurement of diffuse data is relatively more tedious and expensive, it is carried out at relatively few stations and must often be estimated from theoretical or empirical correlations [2]. Several empirical models have been developed to calculate diffuse solar radiation using various climatic parameters. These parameters include extraterrestrial radiation, sunshine hours, mean temperature, maximum temperature, soil temperature, relative humidity, number of rainy days, altitude, latitude, total precipitation, cloudiness and evaporation. The most commonly used parameter for estimating diffuse solar radiation is clearness index and sunshine duration. Sunshine duration can be easily and reliably measured and data are widely available [3].

The current observational networks on some countries are inadequacy. This inadequacy occurs in three basic ways: limited spatial coverage; limited length of record; and predominance of global radiation data, while few data are available for the diffuse component. Given global solar radiation measurements, the diffuse component, essential for most of the energy applications, can be obtained through various theoretical or empirical correlations [4].

The diffuse fraction under clear-sky conditions may be calculated theoretically from various climatic and location parameters.

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Nomenclature

D	number of days of the year starting from first of January
H	monthly average daily global radiation ($MJ\ m^{-2}$)
H_d	monthly average daily diffuse radiation ($MJ\ m^{-2}$)
H_o	monthly average daily extraterrestrial radiation ($MJ\ m^{-2}$)
I_{sc}	solar constant ($W\ m^{-2}$)
K	monthly average daily diffuse fraction or cloudiness index (H_d/H)
K_D	monthly average daily diffuse coefficient (H_d/H_o)
K_T	monthly average daily clearness index (H/H_o)
n	monthly average daily measured sunshine duration
N	monthly average daily maximum possible sunshine duration
n/N	monthly average relative sunshine duration or sunshine fraction
δ	solar declination (°)
φ	latitude of site (°)
ω_s	mean sunrise hour angle for the month (°)

However, methods are inadequate for calculating the diffuse fraction for cloudy skies. Therefore, simple correlations are developed to predict the diffuse radiation from measured climatic data at different locations [5]. On the other hand, although there has been a general and continuous improvement of the worldwide solar radiation measurement networks in recent years; the recording of solar radiation is still limited compared with other meteorological parameters, especially for the diffuse component [6].

Researchers have developed many empirical equations to determine the relation between diffuse solar radiation and various climatological parameters [4–10]. El-Sebaii and Trebea [7] analysed the measured values of monthly average daily global and diffuse solar radiation on a horizontal surface, as well as the number of bright sunshine hours, for four Egyptian locations. All Egypt correlations were found to be able to predict the annual averages of horizontal diffuse radiation with excellent accuracy. Aras et al. [8] analysed the diffuse solar radiation models in the literature in detail, and developed new hybrid models estimate the monthly average daily diffuse solar radiation. The most accurate model was selected for guiding future projects. Elminir [4] carried out a study for the prediction of hourly and daily diffuse fraction using neural network, as compared to linear regression models. The obtained results indicated that the artificial neural network model was more suitable to predict diffuse fraction in hourly and daily scales than the regression models in the plain areas of Egypt. Naser [9] calculated the monthly average of daily diffuse solar radiation for a total of sixteen meteorological stations in Libya using some correlations in the literature. The data of bright sunshine hours and global solar radiation was obtained from fifteen meteorological stations during the period between 1981 and 1987. Sabzpooshani and Mohammadi [10] established new empirical models for predicting the monthly mean diffuse solar radiation on a horizontal surface for city of Isfahan situated in central part of Iran. The empirical models from previous studies were nominated and, diffuse fraction was calculated from function of the relative sunshine duration and clearness index. Also, the models suggested by the many investigators are used to estimate the diffuse fraction from the function of the clearness index and the relative sunshine duration [2,4,12–25].

In Turkey, few data are available for the diffuse component and, these data belong to a very limited period of record. The main aim of this study is to establish some empirical models for estimating the monthly average daily diffuse solar radiation, in the absence of measured diffuse radiation data for all the cities of Turkey. Therefore, new correlations are developed based on long term sunshine duration and global solar radiation data in typical cities of Turkey.

2. Data and methodology

Turkey has an important solar energy potential throughout the year. In this study, to establish diffuse solar radiation models for predicting monthly average horizontal diffuse solar radiation, the required data are obtained from Turkish State Meteorological Service. The monthly average daily values of data include long-term daily sunshine duration and global solar radiation on a horizontal surface for the period of 1975–2007. The calculations for the diffuse solar radiation models are conducted on the basis of these values.

Measured data of the monthly average global solar radiation and sunshine duration is taken from the eight stations of Adana, Ankara, Diyarbakir, Erzurum, Istanbul, Izmir, Samsun and Trabzon, in Turkey. These stations represent the geographical and climatic conditions of their regions. Table 1 gives the detailed information of the eight stations.

The monthly average daily diffuse solar radiation has been estimated using the empirical models including sunshine duration, global solar radiation and extraterrestrial solar radiation. The models used for predicting monthly average daily values of the diffuse solar radiation may be classified in three groups as follows:

I. Group: In this group, the monthly mean diffuse fraction (K) is the function of the monthly mean clearness index (K_T):

$$K = H_d/H = f(K_T) \tag{1}$$

II. Group: In this group, the monthly mean diffuse fraction is the function of the monthly mean relative sunshine duration (n/N):

$$K = H_d/H = f(n/N) \tag{2}$$

III. Group: In this group, the monthly mean diffuse fraction is the function of the monthly mean clearness index and the relative sunshine duration:

$$K = H_d/H = f(K_T, n/N) \tag{3}$$

Here, H is the monthly average daily global solar radiation, H_d is the monthly average daily diffuse solar radiation, n is the monthly average daily measured sunshine duration and N is the monthly average daily maximum possible sunshine duration [11].

Table 1
Information for the provinces considered in Turkey.

Location	Longitude (°E)	Latitude (°N)	Elevation (m)	Measured data	
				Period	Total years
Adana	35.18	36.59	20	1975–2007	33
Ankara	32.53	39.57	894	1975–2006	32
Diyarbakır	40.12	37.55	660	1975–2007	33
Erzurum	41.16	39.55	1869	1975–2007	33
İstanbul	29.05	40.58	39	1975–2006	32
İzmir	27.10	38.24	25	1975–2006	32
Samsun	36.20	41.17	44	1975–2006	32
Trabzon	39.43	41.00	30	1975–2005	31