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Evaluation of classical parametric models for estimating solar radiation in the Eastern Mediterranean region of Turkey

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ABSTRACT

Accurate information on global solar radiation is essential to design and operate the systems that are based on solar energy. However, global solar radiation measurement is very rare while the measurements of other meteorological parameters such as air temperature, relative humidity, sunshine duration and precipitation are common in meteorological stations all around the world. Therefore, modelling global solar radiation is an important issue to fill the gaps in database and to estimate global solar radiation in places where global solar radiation measurement is not available. There are many different approaches in the literature for modelling global solar radiation.

Two new methodologies are presented in this paper to develop parametric models for estimation of daily global solar radiation based on sunshine duration and relative humidity as well as a review of fourteen different already exist parametric models which are based on air temperature, maximum temperature, minimum temperature, precipitation, sunshine duration and relative humidity. The proposed models improve the estimation results of the other fourteen models with average mean absolute error (MAE) of 0.947 MJ/m^2 for Adana station, 1.086 MJ/m^2 for Göksun station, 1.074 MJ/m^2 for Tarsus station and 1.060 MJ/m^2 for whole study area. Hence, the proposed models which significantly approximate to measurements from pyranometers can be useful for the modelling global solar radiation in Eastern Mediterranean Region.

1. Introduction

Global solar radiation is the total amount of solar energy received by the Earth's surface and the principal energy source for life in our planet. Therefore, records of observed solar radiation are required in different fields such as energy planning, climate monitoring and agriculture management. Generally, the best source of solar radiation data comes from on-ground measurements with high-quality and correctly maintained pyranometers. Solar energy maps which show the global solar radiation potential of the country can be useful to determine the most suitable locations to install solar systems and reduce the costs of feasibility studies for such projects [1]. However, due to cost and operational maintenance requirements, it is neither always possible to obtain spherical solar radiation data in such a way, nor to establish pyranometers with sufficient time to make a recording. For these reasons, solar energy planners seek different approaches to obtain long-term accurate solar radiation records. Among these methods, parametric models are widely used in literature because of their simplicity. These parametric techniques model the atmospheric transmittance using other commonly measured meteorological variables that are related to solar radiation [2]. Once trained in a location with a pyranometer, solar radiation can be estimated in stations without pyranometers with the only need of the other input variables, the calculation of the extraterrestrial irradiation and in some cases the calculation of maximum possible sunshine duration [3].

The first parametric model was proposed by Angström [4] using the relation between the measured value of sunshine duration and daily potential sunshine duration under clear-sky conditions. Other researchers, such as Swartman and Ogunlade [5] found an excellent agreement with the combination of sunshine duration and relative humidity to explain solar irradiation. The sunshine duration provides information about the cloud cover and the power of solar irradiance that is why models that use sunshine duration as independent variable significantly improve the errors [6]. In this line and for this study, two different models are developed using quadratic and cubic adjustments of the later model. Besides, other models are proposed in the past to estimate solar radiation with another more commonly measured variables such as sunshine duration, temperature, rainfall and humid-

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ity. Initially, Hargreaves [7] and later Bristow and Campbell [8] developed models to estimate daily global radiation from daily range of temperatures; being high values of this range typical of clear-sky days and low values of cloudy and overcast atmospheres. Many researchers made variations of the previous models adjusting them to the peculiarities of the climate where it is validated. Some of these models were included in this study, Angström-Prescott model which is most widely used equation in the literature, Hargreaves-derived models: Hunt et al. [9], Annandale et al. [10], Mahmood and Hubbar [11] and Chen et al. [12] and Bristow and Campbell-derived models: Donatelli and Campbell [13], Goodin et al. [14], Meza and Varas [15], Weiss et al. [16], Abraha and Savage [17] and Antonanzas-Torres et al. [18].

Most of the studies in solar radiation modelling focus on the estimation with a single method. Nevertheless, in this article it is performed an evaluation of sixteen different approaches for modelling global solar radiation, which are compared with on-ground measurements in three locations in Turkey. In this wise it is possible to quantify the differences between these models. Initially, it is performed, a review of sixteen different parametric models in which two new models are proposed. Both local and general parametric models are built out of different meteorological variables such as sunshine duration, temperatures, relative humidity and rainfall and then benchmarked.

The results provide valuable information regarding the remarkable differences between models based on different parameters, which could be considered as a factor in solar energy planning in Eastern Mediterranean Region.

2. Method

2.1. Parametric models based on temperature

Temperature-based models for estimating global solar radiation utilize the fact that thermal amplitude directly affects atmospheric transmissivity [19]. In order to model global solar radiation with temperature, there are several methods proposed in the literature. Hargraves and Samani developed a global solar radiation model which assumes there is a relation between global solar radiation and maximum-minimum temperature difference [7].

$$\frac{H}{H_0} = a(T_{max} - T_{\min})^{0,5} \tag{1}$$

where H is the daily global solar radiation on a horizontal surface, H_0 is the daily extraterrestrial radiation on a horizontal surface, T_{max} is daily maximum temperature and T_{min} is daily minimum temperature. The calculated coefficient is firstly determined as 0.17 then it is changed as 0.16 for hinterland and 0.19 for littoral zone.

Bristow and Campbell suggested an exponential function relationship between global solar radiation and daily temperature difference [8].

$$\frac{H}{H_0} = a[1-\exp(-b\Delta T^c)] \tag{2}$$

where ΔT is the difference between daily maximum and minimum air temperature, a, b and c are empirical coefficients.

Donatelli and Campbell suggested the following formula for modelling global solar radiation [13].

$$\frac{H}{H_0} = a\left[1-\exp\left(-b\frac{\Delta T^c}{T_m}\right)\right] \tag{3}$$

Hunt et al. added the coefficient 'b′ to Hargraves and Samani model [9].

$$H = a(T_{max} - T_{min})^{0.5}H_0 + b \tag{4}$$

Goodin et al. developed a model based on, Bristow and Campbell model and they used extraterrestrial radiation in both sides of the formula [14].

$$\frac{H}{H_0} = a\left[1 - \exp\left(-b\left(\frac{\Delta T^c}{H_0}\right)\right)\right] \tag{5}$$

Meza and Varas calibrated coefficients 'b' and 'c' in Bristow and Campbell model and they got less error with this model [15].

$$\frac{H}{H_0} = 0.75[1-\exp(-b\Delta T^2)] \tag{6}$$

Weiss et al. simplified Donatelli and Campbell model and determined the coefficient 'a' as 0.75 [16].

$$\frac{H}{H_0} = 0.75\left[1 - \exp\left(-b\frac{\Delta T^2}{H_0}\right)\right] \tag{7}$$

Annandale et al. modified Hargraves and Samani model by multiplying coefficient 'a' with a correction factor [10].

$$\frac{H}{H_0} = a(1 + 2.7x10^{-5}Z)(T_{max} - T_{\min})^{0,5} \tag{8}$$

where Z is the elevation of the site.

Mahmood and Hubbard modelled global solar radiation with maximum and minimum temperature and added the formulation below to the literature [11].

$$\frac{H}{H_0} = a(T_{max} - T_{\min})^{0,69}xH_0^{0.91} \tag{9}$$

Chen et al. suggested the model below for the modelling of global solar radiation [12].

$$\frac{H}{H_0} = a(T_{max} - T_{min})^{0.5} + b \tag{10}$$

Abraha and Savage modelled solar radiation with temperature difference by determining 'a' and 'c' coefficients of Donatelli and Campbell model [17].

$$\frac{H}{H_0} = 0.75\left[1 - \exp\left(-b\frac{\Delta T^2}{T_m}\right)\right] \tag{11}$$

2.2. Parametric models based on other meteorological parameters

Due to the lack of meteorological data which are commonly used as a predictor in the literature, solar radiation cannot be modelled effectively in many places in the world. Therefore, many researchers came up with alternative models that model global solar radiation with variable meteorological parameters such as relative humidity and rainfall. One of the oldest parameter used as a predictor to model global solar radiation is relative humidity.

Angström model is one of the widely used models for the estimation of global solar radiation in the literature. Angström offered to calculate global solar radiation with sunshine duration and clear sky hours first then Prescott used extraterrestrial solar radiation instead of clear sky data [4,18]. Angström method is most widely used model in the literature because of its simplicity. The model makes possible to calculate global solar radiation with just one single parameter which is sunshine duration. In many studies it is pointed that regression coefficients in the models are site dependent [19–24]. Even so the most widely used model to estimate global solar radiation in the literature is Angström- Prescott model which is based on sunshine duration [25–30].

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \tag{12}$$

As mentioned in the literature, the amount of global solar radiation which reaches the Earth's surface depends on the meteorological