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Evaluation of empirical models for predicting monthly mean horizontal diffuse solar radiation

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ABSTRACT

In many solar applications knowing diffuse solar radiation on horizontal surface represents an important requirement. The measurement of diffuse radiation is quite expensive, and because of that solar radiation measurements are not easily available in many locations around the world. Therefore many empirical correlations have been developed by various researchers to predict diffuse radiation from available meteorological data. The main objective of this study is to assess and compare different diffuse solar models available in the literature. These empirical models have been derived for specific location using long term measurements for that location. There is no general formula to calculate the diffuse solar radiation at any location in the world. While there are several studies in which authors compare different diffuse models for specific location, there is no comprehensive study in which these models are compared on a global scale. In this study we used statistical analysis to evaluate performance of analyzed models using long term measurements at 267 different sites around the world. Ten statistical quantitative indicators are used to evaluate different diffuse solar radiation models. The results are also visually presented by means of Taylor diagrams, which give a clear picture of how close a particular model is to measured data and how it is relatively compared to other models.

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1. Introduction

Solar energy is being widely considered as important energy source for the future due to the environmental issues associated with the use of fossil fuels as well as their limited reserves. For the prediction, study, and design of solar energy systems, availability of a complete and accurate data on solar radiation and its components at a given location is essential [1]. Ideally, such information should be obtained from a dense network of stations where global, direct and diffuse radiations are routinely measured [2]. However, for many countries, particularly for developing ones, solar radiation measurements are not easily available [3]. On the other hand, while information exists on global solar radiation, the

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Nomenclature

Acronyms

erMAX	Maximum absolute relative error
MAE	Mean absolute error (kWh/m^2)
MARE	Mean absolute relative error
MBE	Mean bias error (kWh/m^2)
RMSE	Root mean squared error (kWh/m^2)
RMSRE	Root mean squared relative error
RRMSE	Relative root mean square error (%)

Greek Symbols

δ	Solar declination (°)
ω_{ss}	Sunset hour angle (°)
ϕ	Latitude (°)

Roman Symbols

n	Total number of observations
$\overline{H}_d^{i,c}$	*i*th calculated value (kWh/m^2)
$\overline{H}_d^{i,m}$	*i*th measured value (kWh/m^2)
$\overline{H}_d^{m,avg}$	Average of the measured value (kWh/m^2)
H	Monthly average daily global solar radiation (Wh/m^2)
H_0	Monthly average daily extraterrestrial radiation (Wh/m^2)
H_d	Monthly average daily diffuse solar radiation (Wh/m^2)
I_c	Solar constant ($=1367\ W/m^2$)
$K_T(=H/H_0)$	Monthly average daily clearness index
N_d	The number of the day corresponding to a given date
R^2	*R* squared
S	Monthly average daily sunshine duration (h)
S_0	Monthly average maximum possible daily sunshine duration (h)
t-stat	*t*-Statistic
U_{95}	Uncertainty at 95% (kWh/m^2)

measurement of diffuse data is relatively more tedious and more expensive, and it is carried out at relatively few stations [4,5]. Thus, many empirical correlations have been developed by various researchers to predict diffuse radiation for locations where no measured data are available. There are two categories of solar radiation models, available in the literature, based on other more readily measured quantities: parametric models in which detailed information of atmospheric conditions is required and decomposition models which usually use information only on global radiation for the estimation of direct and diffuse component [6].

From pioneer work of Liu and Jordan [7] who presented empirical relationships between daily diffuse to daily total radiation and monthly average daily diffuse to monthly average daily total solar radiation, a lot of papers have been published in which authors presented further decomposition models that are obtained by fitting datasets from different locations and time periods. Tapakis et al. [8] recently reviewed this topic. Most decomposition models relate the diffuse fraction (ratio of diffuse solar radiation to global solar radiation) as a function of the clearness index (ratio of global solar radiation to extraterrestrial radiation), relative sunshine duration or a combination of them with varying degree order polynomials [9]. However, as cited in [10] “although these models are typically derived following sound approaches, their performance appears to lessen once they are applied to regions other than those, which provided the initial data for model development”.

There are several studies in which authors compare different diffuse models for specific location, for example: Amritsar, India [11], Azores region (Graciosa Island) [12], Tabass, Iran [13], Pamplona, Spain [14], 22 locations in South Korea [15]. However, there is no comprehensive study in which these models are compared on a global scale, which could assist in the selection of most appropriate and accurate model based on the available measured meteorological data. In this study we used statistical analysis to evaluate performance of analyzed models using long term measurements at 267 different sites around the world. These sites are classified in five groups according to similar climatic conditions. Ten statistical quantitative indicators are used to evaluate different diffuse solar radiation models. These indicators are: mean absolute error (MAE), root mean squared error (RMSE), mean absolute relative error (MARE), uncertainty at 95% (U_{95}), root mean squared relative error (RMSRE), relative root mean square error (RRMSE), mean bias error (MBE), coefficient of determination (R^2), maximum absolute relative error (erMAX) and *t*-Statistic (*t*-stat). The results are also visually presented by means of Taylor diagrams, which give a clear picture of how close a particular model is to measured data and how it is relatively compared to other models.

2. Theoretical background

The monthly average daily extraterrestrial solar radiation on a horizontal surface is calculated from the following equation [16]:

$$H_0 = \frac{24 I_c}{\pi}[1+0.034\ \cos\ (360 N_d/365)] \times \left(\cos\ \phi\ \cos\ \delta\ \sin\ \omega_{ss} + \frac{2\pi\omega_{ss}}{360} \sin\ \phi\ \sin\ \delta \right) \quad (1)$$

where I_c is the solar constant ($=1367\ W/m^2$), ϕ is the latitude of the site, N_d is day of the year starting from January 1st (Table 1), and δ and ω_{ss} are the monthly mean daily solar declination and sunrise hour angle given, respectively, as [17]:

$$\delta = 23.45\ \sin \left(360 \frac{284+N_d}{365} \right) \quad (2)$$

$$\omega_{ss} = \cos^{-1}(-\tan\ \delta\ \tan \phi) \quad (3)$$

Table 1
Recommended average day for each month according to Klein [18].

Month	Date	N_d	Month	Date	N_d
January	17	17	July	17	198
February	16	47	August	16	228
March	16	75	September	15	258
April	15	105	October	15	288
May	15	135	November	14	318
June	11	162	December	10	344