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General models for estimation of the monthly mean daily diffuse solar radiation (Case study: Algeria)

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ABSTRACT

In this study, 10 empirical models are developed correlating monthly mean daily diffuse solar radiation with monthly mean sunshine records and global solar radiation data. The aims of this study are: (i) analyzing the correlation between the diffuse fraction and the sunshine fraction/clearness index measured data using these 10 empirical equations at six Algerian stations: Algiers, Constantine, Ghardaia, Bechar, Adrar, and Tamanrasset, and to present new constants for each selected location. (ii) The performance of the proposed models with the new correlation constants are validated and checked their accuracy by comparing it with measured values at the six stations using seven statistical error tests, in order to choose the best models for estimating the monthly mean daily diffuse solar radiation, and (iii) develop generalized models for estimating the diffuse solar radiation data in other Algerian locations in the absence of the measured diffuse radiation data.

This study finds that the quadratic and cubic equation which based on global solar radiation data performed the best accuracy. Moreover, these two regression models can be used for the proposed generalized models for predicting the monthly mean diffuse solar radiation over Algeria.

1. Introduction

The amount of solar energy (or solar radiation) available on the earth's surface depends on astronomical, physical, geographical and meteorological factors such as atmospheric transmittance, extraterrestrial radiation, latitude, inverse relative distance between the earth and the sun, the actual duration of sunshine, sunset hour angle, relative humidity, ambient temperature and cloudiness at relevant locations [1,2]. The information concerning available solar radiation data is essential for meteorological and agricultural experts, architects, designers and engineers in the design and selection of solar energy conversion systems, architectural design, greenhouse structures, heating and cooling systems; the knowledge of accurate solar radiation data is extremely important for the selection, optimal design and evaluation of the system performance [2,3].

Solar radiation consists of two parts; extraterrestrial solar energy above the atmosphere and terrestrial global solar energy under the atmosphere [4]. The extraterrestrial solar radiation is attenuated when passing through the earth's atmosphere, the radiation extinction is mainly due to either absorption by different atmospheric components, such as ozone, water vapor, oxygen and carbon dioxide; or scattering by air molecules and aerosol particles (that is liquid or solid particles suspended in the atmosphere and follow the motion of the air within certain broad limits). Some atmospheric components are permanent and almost constant but others, especially aerosols, change from place to place and vary with time, these atmospheric processes can further attenuate the global solar energy and change the diffuse and direct radiation ratio. The best solar radiation at any place on the earth would be that measured at this specific location continuously and accurately over long term, the most of these solar radiation data registered by meteorological stations are global irradiance data measured on a horizontal surface [5]. Nevertheless, it is of great interest to know the diffuse part of global solar radiation data at this specific location for several purposes, especially for designing and sizing photovoltaic systems [6]. Thus, it is so important to elaborate diffuse solar radiation data based on high performance models, by establishing mathematical relations between the diffuse solar radiation on a horizontal surface and the most readable available meteorological observed data such as: global solar radiation, sunshine duration, air temperature, humidity and precipitation.

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Nomenclature

K_t	clearness index (H_g/H_0)	S	monthly mean daily sunshine duration (h)
K_d	diffuse fraction (H_d/H_g)	S_0	monthly mean daily daylight hours (h)
H_0	monthly mean daily extraterrestrial solar irradiance on a horizontal surface (MJ/m^2)	I_{sc}	solar constant (W/m^2)
H_g	monthly mean daily global solar irradiance on a horizontal surface (MJ/m^2)	d_r	relative earth-sun distance
H_d	monthly mean daily diffuse solar irradiance on a horizontal surface (MJ/m^2)	δ	solar declination (rad)
a, b, c, and d	regression constants.	ω_s	sunset hour angle (rad)
		φ	latitude (rad).
		J	number of day in the year

In order to achieve this, several empirical models have been developed and used to predict the diffuse solar radiation all over the world using various meteorological parameters. Liu and Jordan [7] developed the first correlation between the diffuse fraction K_d and clearness index K_t, and following the work, many researchers have studied and modified this model with different data, regions and time scales.

Jiang [8] employed several empirical equations to estimate monthly mean daily diffuse solar radiation for eight typical meteorological stations in China, either from monthly mean daily sunshine duration and/or monthly mean daily global solar radiation. Karakoti et al. [9] used seven generalized empirical models based on sunshine duration, temperature and relative humidity to predict monthly mean daily diffuse solar radiation for 23 stations in India. While Pandey and Katiyar [10] employed the correlation between the diffuse fraction and the sunshine fraction to estimate the daily diffuse solar radiation over four prominent Indian locations. On the other side, Li et al. [11] proposed two models in addition to eight existing models based on multiple predictors including the clearness index, relative sunshine duration, ambient temperature and relative humidity for estimating the diffuse solar radiation at Guangzhou station in China. Despite the enormous amount of studies on the estimation of diffuse solar radiation using empirical correlations in locations across the world, not much work has been done on modeling diffuse solar radiation over Algeria. Koussa et al. [12] carried out a statistical comparison of 10 existing models for estimating monthly mean daily global and diffuse solar radiation in three main Algerian sites (Bouzareah, Ghardaia, and Adrar).

The main objective of this study is establishing and testing 10 empirical models with new correlation coefficients, based on sunshine fraction/clearness index measured data at six Algerian stations: Algiers, Constantine, Ghardaia, Bechar, Adrar, and Tamanrasset, in order to choose the best model for each station, and to develop generalized models for estimating the diffuse solar radiation data in other Algerian locations in the absence of the measured diffuse radiation data.

2. Data and methodology

2.1. Data

2.1.1. Study area

Algeria is located in the center of North Africa along the Mediterranean coastline, between latitudes 19° and 38° north and longitudes 8° west and 12° east. Its southern part includes a significant portion of the Sahara (almost 86% of the total surface of the country, which represents 2,048,297 km^2 [13]). The climate of Algeria is transitional and divided into three types, (1) A Mediterranean in the north. (2) A continental semi-arid in the high plateau regions. (3) A true desert arid climate in the Sahara. As shown in Table 1, solar radiation falling between 4.66 kW h/m^2 and 7.26 kW h/m^2, this corresponds to 1700 kW h/m^2/year in the north and 2650 kW h/m^2/year in the south. The insulation time over the quasi-totality of the national territory exceeds 3000 h annually and may reach 3500 h in the Sahara.

This geographic location, in the Sun Belt region, and climatic conditions such as the abundant sunshine duration trough the year, signifies that Algeria in a position to play an important strategic role in the implementation of solar technology in the north of Africa, and one of the countries with the highest solar radiation levels in the world, this solar potential exceeds 6 billion GW h/year [13].

2.1.2. Observed climate data

The measurement of solar radiation is achieved by the National Office of Meteorology (NOM) through its network of 81 long-term meteorological stations, while only 7 stations record solar radiation on a horizontal surface. On the other hand, The Renewable Energy Development Center of Bouzareah (Algiers) and its annexes of Ghardaia and Adrar can record the solar radiation data in these three sites.

In this work, the measured monthly mean daily data of global and diffuse solar radiation on horizontal surface (MJ/m^2), as well as the monthly mean daily sunshine duration (h) for the selected sites, were obtained from Algerian National Office of Meteorology (NOM) and the Renewable Energy Development Center of Bouzareah and its annexes.

The retained models were evaluated for six Algerian sites with the three different climates; Algiers with the Mediterranean climate in the northern part of the country; Constantine for the continental semi-arid climate in the High Plateaus; Ghardaia, Bechar, Adrar and Tamanrasset in the center and southern part of the country for the desert arid climate (Fig. 1). Detailed geographic, climatic characteristics, and the time period from which data were used for establishing the models as well as evaluating them of these sites are given in Table 2.

2.2. Methodology

2.2.1. Model introduction

Many empirical models and correlations to estimate the monthly mean daily diffuse solar radiation have been reported in the literature. In this study, the monthly mean data of daily global, diffuse radiation and bright sunshine hours for the 6 locations of Algeria are exploited, the other required parameters such as extraterrestrial radiation and maximum possible sunshine hours are worked out using the standard following relations [14]:

$$H_0 = \left(\frac{24 \times 60}{\pi}\right) I_{sc} d_r [\cos(\varphi)\cos(\delta)\sin(\omega_s) + \omega_s \sin(\varphi)\sin(\delta)] \quad (1)$$

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \quad (2)$$

$$\delta = 0.4093\sin\left[\frac{2\pi}{365}(248 + J)\right] \quad (3)$$