ARTICLE IN PRESS

Urban Climate xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

Models for forecasting monthly mean daily global solar radiation from in-situ measurements: Application in Tropical Climate, India

D.V. Siva Krishna Rao K, M. Premalatha*, C. Naveen

Solar Energy Laboratory, Department of Energy and Environment, National Institute of Technology (NIT), Tiruchirappalli 620 015, Tamil Nadu, India

ARTICLE INFO

Keywords:
Global solar radiation
Utilization
Energy
Temperature
Statistical tools

ABSTRACT

Radiation availability varies with reference to the geometrical location. It is necessary to develop the models to predict the daily global solar radiation (GSR) for the locations where there is a huge potential of radiation exists and to improve the utilization of energy. This study aimed to develop the solar radiation models with readily available input parameters for Tiruchirappalli, which covers an annual mean daily global solar radiation of 4.50 kWh/m^2-day.

Exponential model (EM), modified exponential model (MEM), power series model (PSM), Hargreaves and Samani model (HSM), Hargreaves-model (HGM) and Hunt models (HUM) which uses air temperature and extra-terrestrial radiation on a horizontal surface as input parameters were developed and validated. Dumas model which uses air temperature and maximum possible sunshine duration (S_o) as input parameters was also verified. Dumas model was modified as hybrid models to check for their applicability. The performance of the models was analyzed by using the statistical tools. Out of all the models, HSM and PSM had shown an accurate estimation of daily GSR (errors: 6.62% & 7.95% respectively) for the selected location. Dumas model's performance was also found satisfactory (error: 11.02%).

1. Introduction

Global solar radiation (GSR) data is a fundamental input for solar energy applications such as photovoltaic power generation and solar-thermal systems. The GSR data should be reliable and available for design, and evaluation of solar technologies for any location (Bulut and Büyükalaca, 2007). However, measuring instruments of meteorological parameters are not readily available at most of the Indian locations due to cost of the instruments and lack of meteorological stations (Katiyar and Pandey, 2010). India is a tropical country with latitude lying between 7° and 37°, longitudinal axis along with equator which makes it to receive enormous amount of solar energy. There are about 300 clear sunny days in most parts of the country per year with a mean GSR value of 4–7 kWh/m^2/day [source: Government of India. New and renewable energy policy statement 2005. Ministry of non-conventional energy sources, Government of India; 2005]. This available solar energy could be captured and utilized efficiently only with the availability of accurate values of daily GSR data. So, it is necessary to develop the models to estimate the GSR for Indian locations (Rao et al., 2012) where there are no observatory stations. The model development should be on the basis of the more readily available data (Wu et al., 2007) as input parameter. Besharat et al. (2013) classified the solar radiation models available in the literature into four categories, i.e., sunshine based models-used sunshine duration as input parameter (Katiyar and Pandey, 2010; Chelbi et al., 2015; Almorox and Hontoria, 2004; Bakirci, 2009a; Bakirci, 2009b; Yorukoglu and Celik, 2006), cloud-based models-used cloud index as input parameter (Thornton and Running, 1999; Black, 1956), temperature-based models used temperature as input parameter (Liu et al., 2009; Dumas

* Corresponding author at: Solar Energy Laboratory, Department of Energy and Environment, National Institute of Technology (NIT), Tiruchirappalli 620 015, India.
E-mail address: latha@nitt.edu (M. Premalatha).

https://doi.org/10.1016/j.uclim.2017.11.004
Received 20 June 2017; Received in revised form 8 November 2017; Accepted 21 November 2017

et al., 2015; Yacef et al., 2014; Almorox et al., 2013; Shamshirband et al., 2015; Abraha and Savage, 2008; Li et al., 2013a) and other meteorological parameter based models (Besharat et al., 2013; Glover and McCulloch, 1958; Raja and Twidell, 1990; Annandale et al., 2002)-used latitude, longitude and altitude etc., as input parameters. Almorox et al. (2013) classified input parameters used in the solar radiation models, based on the astronomical factors, geographical factors, geometrical factors, physical factors and meteorological factors. Majority of the empirical models had been developed to estimate the solar radiation by using air temperature, relative humidity, sunshine duration, cloud cover, and precipitation as input variables. Air temperature-based models had been widely used since air temperature data was readily available. Hargreaves and Samani (1982) were the first to suggest that incident radiation could be evaluated from the difference between daily maximum and daily minimum temperatures. Hargreaves et al. (1985) presented an equation expressing solar energy as a function of air temperature. They established a nonlinear relationship between the temperature difference of maximum, minimum on a daily basis and daily GSR. Droogers and Allen (2002) extended the Hargreaves model and include the ratio of atmospheric pressure at the site and at sea level into the model.

Almorox et al. (2013) considered five models published in the literature based on the temperature and compared with the linear regression temperature model. Meteorological data were acquired from an automatic weather station and reported − 11.27% of MPE in the estimation of daily GSR at Cordoba, Argentina. Almorox et al. (2011) derived coefficients of seven existing models and developed one new model for estimating daily GSR data using temperature measured data for seven stations located in Madrid, Spain. A maximum MAPE of 29.17% and minimum MAPE of 15.56% were reported in their study. MPE reported lies in between − 3.56% and − 20.38%.

Rahimikhoob (2010) developed a model to estimate the daily GSR using artificial neural network and air temperature data in a semi-arid environment. The data was collected from 1994 to 2003 from weather station of Ahwaz located in Khuzestan plain in the southwest of Iran. RMSE and relative error (RE) were used as statistical tools and reported RE as 14%. Veeraboina and Yesuratnam Guduri (2014) compared the potential of monthly solar radiation using air temperatures at three cities (Hyderabad, Vishakhapatnam, and Anantapur) of Andhra Pradesh, India. In that study, the coefficients of two existing models were derived and used for estimating the monthly mean daily GSR for the above-mentioned locations. Daut et al. (2011) developed a method to estimate the solar radiation in Perlis, Northern Malaysia by combining Hargreaves method and linear regression. The data used for model development was taken from meteorological station in Chuping, state of Perlis. Maximum and minimum measured temperatures were used in the model development.

Li et al. (2013a) developed a model to estimate the daily GSR using measured temperature data and site geographical parameters (latitude, longitude and altitude) for Guizhou and Sichuan basin of southwest China. The long-term data of daily solar radiation and air temperature at five sites in southwest China were obtained from the China Meteorological Administration and used for solar radiation model. Yacef et al. (2014) developed combined empirical models and a Bayesian neural network (BNN) model to estimate the daily GSR on a horizontal surface in Ghardaia, Algeria. A database of daily GSR, maximum and minimum air temperatures of the year 2006 was used to estimate the coefficients of the empirical models. An MPE of 10.77% was reported in their work and concluded that BNN model produced less error than empirical models.

Dumas et al. (2015) evaluated the energy balance for an atmospheric layer near the soil. A linear relationship between the daily GSR on a horizontal surface and maximum possible sunshine hours (S_o) with the daily temperatures was established and named as Dumas Equation. Monthly mean daily GSR values were estimated with good accuracy by using Dumas Equation.

From the above literature, it could be concluded that temperature-based models were used for predicting the daily GSR with good accuracy and these models utilized readily available temperature data (Rahimikhoob, 2010) as an input parameter. All the models were site-specific and new models need to be developed for each location separately. In the above said literature, the coefficients of existing GSR models were derived for a location of interest. The coefficients of a few existing models were derived for Indian conditions to predict the GSR. Importantly, as India is not being a member of the International energy agency (Padmavathi and Daniel, 2013), it is essential to develop a precise solar radiation model which utilizes commonly available parameters, such as maximum and minimum temperature as input parameters and the coefficients of existing models need to be derived for Indian conditions. Further, recently derived Dumas Equation (Dumas et al., 2015) reported as an accurate model and the accuracy of the model need to be validated for Indian climatic conditions.

Hence, the objectives of the present work are

a) To select a location in the Southern region of India, especially Tamil Nadu, where a great amount of solar potential exists, to fulfill the above mentioned research gaps.
b) To develop the new models for predicting the radiation as a function of temperature for the selected location.
c) To check the applicability of the temperature based existing models for the present location.
d) To verify the applicability and accuracy of the Dumas Equation for the selected Indian location.
e) To use the statistical tools for validation of the results.

2. Methodology

A location in India was considered and site specifications are given in Table 1. Tiruchirappalli is situated in central south-eastern India, almost at the geographic center of the state of Tamil Nadu. It experiences tropical savanna climate under the Koppen classification. It receives the enormous amount of solar energy throughout the year (source: National Renewable Energy Laboratory, NREL, Anthony Lopez, Billy Roberts; April 25, 2013).

Global solar irradiance on a horizontal surface and ambient temperature were continuously measured using pyranometer (make: