Journal of Atmospheric and Solar–Terrestrial Physics 157–158 (2017) 16–34

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar–Terrestrial Physics

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

Generalized models for estimation of diffuse solar radiation based on clearness index and sunshine duration in India: Applicability under different climatic zones

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A R T I C L E I N F O

Keywords:
Diffuse solar radiation
Clearness index
Relative sunshine period
Climatic zones

A B S T R A C T

Generalized models for assessment of monthly average diffuse solar radiation over India were established using long-term solar radiation data available for 15 years (1986–2000) obtained from Indian Meteorological Department (IMD), Pune. Regression analysis was employed to correlate the diffuse fraction ($\overline{K}_d$)with clearness index ($\overline{K}_t$)and relative sunshine period v$\left(\frac{\overline{S}}{\overline{S}_o}\right)$ together. Seven new models (with two input variables i.e. global solar radiation and relative sunshine period) were developed using data of the measurement sites. Well-established models from literature were also compared with the proposed models. Statistical tests used to evaluate the accuracy of models were mean bias error, root mean square error, mean percentage error, coefficient of determination, t-statistics and normalized median absolute deviation. Global performance indicator (GPI) was used to rank the models. Further, the empirical models were applied on the five representative locations under diverse climatic zones (i.e. Hot & Dry, Warm & Humid, Temperate, Cold and Composite climates) prescribed by the Energy Conservation Building Code (ECBC) for India. Proposed models were also compared within each climatic zone and best model was recommended. Developed models were found to have good performance on collective data as well as under each climatic zone individually.

1. Introduction

Solar energy is a form of renewable energy resource which is available abundantly and freely on the surface of the earth. These advantages make it a perfect solution to the energy crisis the world is experiencing today. Further, exploitation of solar energy reduces the dependence on conventional energy resources, consequently improving the environmental condition and reducing ozone depletion. Therefore, solar energy potential of location of interest is assessed prior to installation and commissioning of solar energy projects (Jamil et al., 2016). Feasibility of solar energy schemes largely depends on the correct information on solar radiation and its components (Li et al., 2015). The important component that defines the quality of solar radiation is the diffuse radiation. The data on diffuse solar radiation is seldom available due to high cost incurred in setting up the meteorological and data-logging facility for long-term measurements. Also, there is always an uncertainty in the measurement of diffuse solar radiation due to their inherent anisotropic nature. Unlike many developed nations, the developing and underdeveloped countries therefore, doesnot have such meteorological stations to measure all weather conditions, although solar radiation potential of many locations may be high. Thus, diffuse solar radiation is mostly calculated from the empirical models. Such models find application in estimation of diffuse solar radiation used to analyze the performance of solar based devices such as solar collector, solar concentrators, solar PV-panels, solar-wind energy grids, decentralized solar energy systems, solar desalination plants etc. Other than that, researchers require this information for long-term weather forecast and environmental data analysis. Therefore, models for assessment of monthly-average diffuse solar radiation are required to evaluate the performance for projects extending over a period of years.

Primitive approach developed by Liu and Jordan (1960) for the assessment of diffuse component was developed on global solar radiation and similar methodology have been followed by many researchers over the years (like Al-Mohamad, 2004), Diez-Mediavilla et al. (2005), Tarhan and Sari (2005a), Aras et al. (2006) and Noorian et al. (2008) to name a few).

Abbreviations: ECBC, Energy Conservation Building Code; *GPI*, Global Performance Indicator; *IMD*, Indian Meteorological Department; *MBE*, Mean Bias Error (MJ/m2-day); *MPE*, Mean Percentage Error (%); *NMAD*, Normalized Median Absolute Deviation; *RMSE*, Root Mean Square Error (MJ/m2-day); t-stats, t-statistics

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http://dx.doi.org/10.1016/j.jastp.2017.03.013
Received 20 September 2016; Received in revised form 1 March 2017; Accepted 24 March 2017
1364-6826/

Nomenclature

$\overline{H}_d$	diffuse solar radiation on a horizontal surface (MJ/m^2-day)
$\overline{H}$	global solar radiation on a horizontal surface (MJ/m^2-day)
$\overline{H}_o$	extraterrestrial radiation (MJ/m^2-day)
H_{SC}	solar constant (W/m^2)
$\overline{K}_d$	cloudiness index
$\overline{K}_t$	clearness index
n	day of the year
R^2	coefficient of determination
$\overline{S}_o$	maximum possible sunshine duration (hours)
$\overline{S}$	actual sunshine duration (hours)

Greek letters

δ	angle of declination (degrees)
ϕ	latitude (degrees)
ω_s	sunset hour angle (degrees)

Factors such as extremes and average of ambient temperature, cloudiness, humidity etc. have also been deployed to evaluate diffuse solar radiation models (El-Sebaii et al., 2010). Other practices have been developed by Haydar et al. (2006), Boland et al. (2001), Boland et al. (2008), Iqbal (1979) where diffuse fraction was correlated with sunshine duration, while the classical form of Liu and Jordan (1960) have again been followed by some others (correlating diffuse fraction with the clearness index) like Oliveira et al. (2002), Tarhan and Sari, (2005b) and Jacovides et al. (2006) etc.

El Mghouchi et al. (2015) evaluated four empirical models available in literature to predict the global, direct and diffuse solar radiation for Tetuan City, Morocco and describe the suitability of model based on the

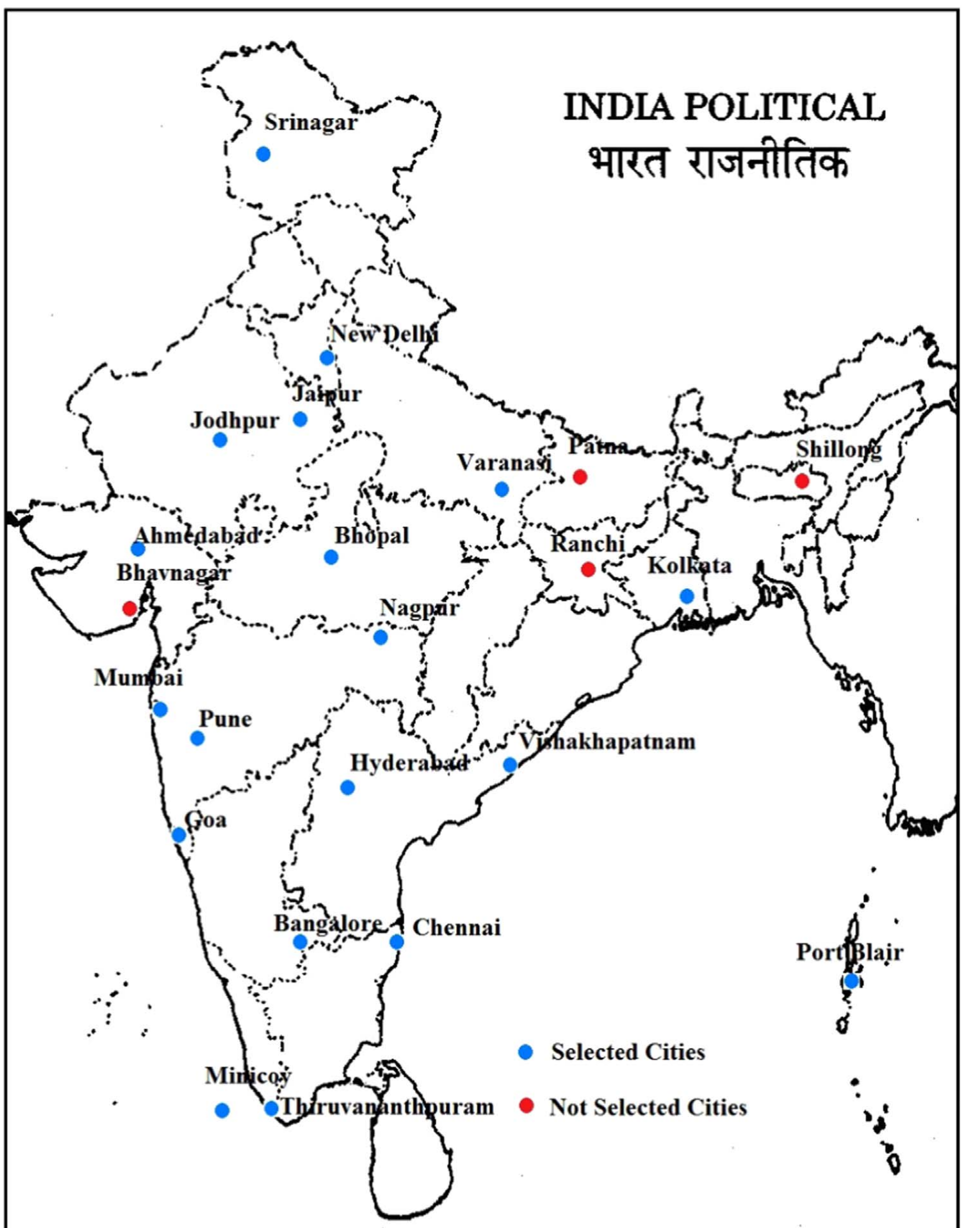

Fig. 1. 23 meteorological locations of India.