International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

An Analysis of Global Solar Radiation Estimation Techniques

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ABSTRACT

Solar radiation reaching on earth is the most fundamental renewable energy source in nature. Solar energy is the engine that powers the bio system, the ocean and atmospheric current system and affects the global climate. The data availability on solar radiation is a crucial problem. There are very few meteorological stations that measure the global solar radiation. In many developing countries like India, solar radiation measurements are not easily available due to the cost, maintenance and calibration requirements of the measuring equipment. In this respect, it is important to estimate the solar radiation based on readily available meteorological data for design and efficient operation of solar energy system. Recently several empirical formulas using various parameters are considered to estimate the solar radiation around the world. Several statistical models and computational algorithms are used for estimating the solar radiation. In this paper, investigations on prediction of global solar radiation are carried out and various computational algorithms used are discussed.

KEYWORDS

Solar energy, Solar radiation, Solar constant, Statistical Methods, Modern Optimization Techniques

1 INTRODUCTION

Solar radiation is the radiant energy that comes from the sun. This radiant energy is the primary source of energy that provides light and heat for the earth and energy for photosynthesis. Solar energy is the most adequate renewable energy that occupies one of the most important places among the various possible energy sources. It is free and completely non-polluting in nature. It is the most essential energy source for physical, chemical and biological processes on the earth's surface that drives processes as diverse as snow melting, evapotranspiration and crop growth. It also acts as energy provider for soil temperature, soil heat flux, surface and air temperature, water loss through evaporation and transpiration, plant and animal activity [6].

The knowledge of global solar radiation is vital in the prediction, study and design of the economic feasibility of systems that use solar energy. It is essential for the metabolism of the environment and its inhabitants. Solar radiation data provide information on how much of the sun's energy strike the surface at a place on earth during a specific period. These data are the major source for designing and sizing solar energy systems, architectural designs, crop growth models, hydrological models, and design of irrigation systems. The solar energy data are not always available due to the high cost and installation difficulties in solar measurement. As a result, there is a high demand to develop alternative ways of predicting the solar energy data. There are many regions in India that do not have measured solar energy data and to solve this problem various prediction models were developed to estimate the potential of solar energy based on location coordinates and meteorological parameters [49].

The factors that took the world to a very acute energy crisis especially in the developing countries like India are the rapid increase in population, high standard of living, urbanization, transportation, industrialization, and fast depleting fossil fuels. The major objective of this work is to examine the various solar radiation predicting models such as linear, non-linear models including fuzzy logic models and ANN models and their techniques used are presented in this paper.

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2 THE SOLAR RADIATION

Sun is the prominent feature in the solar system which emits radiant energy in the form of electromagnetic waves. Earth is the only planet in the solar system which receives an optimum amount of solar radiation that makes life sustainable on it [58]. Solar radiation is the earth's primary natural source of energy. The radiation is the transfer of energy by electromagnetic waves that reaches the earth from the sun. It is produced directly from the source outward in all directions at an average distance of 150 million kilometers from the sun. It covers a wide range of wavelengths extending from microwaves and radiowaves, through infrared, visible, ultraviolet and x-rays to gamma rays [59].

2.1 SOLAR CONSTANT

Solar irradiance is the radiant energy from the sun represented in watts per square meter (W/m^2). The solar constant is the amount of solar radiation received outside the Earth's atmosphere on a surface normal to the incident radiation per unit time and per unit area at the earth's mean distance from the Sun. The world meteorological organization has fixed the value of solar constant at 1367 W/m2. The orbit of the earth is elliptical and the distance from the sun varies over the course of the year. Due to changes in sun's luminosity, a small variation of the solar constant is also possible [23]. It is the primary value for the studies of global energy balance and climate. The measurement of solar constant is reliable only when they are obtained from space satellite observations.

2.2 FACTORS INFLUENCING SOLAR RADIATION

Solar radiation entering the earth's atmosphere is absorbed, scattered, reflected or transmitted. All these processes result in reduction of the energy flux density. The atmospheric absorption occurs due to the presence of ozone, water vapor and other gases such as CO, O_2, CO_2, NO_2, CH_4 and particulate matter.

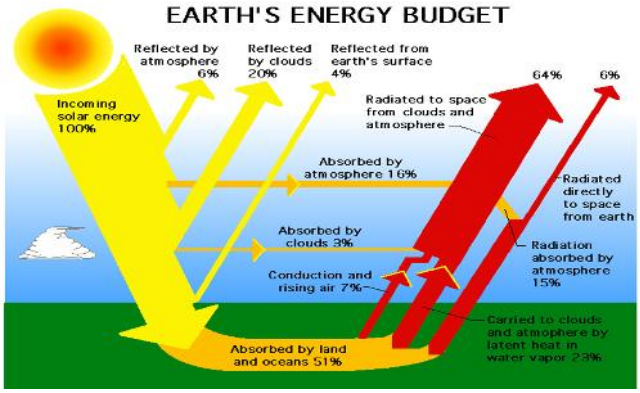

Fig.1. Incoming radiant energy reaching the earth [5]

Fig.1. shows the factors that cause reduction of the solar energy while reaching the surface of the earth. As the solar radiation passes through the atmosphere a part of the radiation is reflected into space by clouds, also the air molecules absorb a part of incoming radiation. Oxygen and ozone absorb the ultraviolet radiation; water vapor and carbon dioxide absorb some energy in the infrared range. In addition, the solar radiation is scattered by droplets in clouds, by atmospheric molecules and by dust particles resulting in the attenuation of radiation [23].

2.3 SOLAR RADIATION CLASSIFICATION

The solar radiation is classified into different types, Direct, Diffuse, Reflected, Global Solar Radiation, Terrestrial and Extraterrestrial Solar Radiation.

2.3.1 DIRECT OR BEAM RADIATION

The solar radiation which comes directly from the sun and reaches the surface of the earth travelling on a straight line without change of direction is called as beam or direct radiation. Shadows of the objects are formed while the sun rays travel in a straight line. The shadows indicate the presence of direct radiation [19] [54].

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2.3.2 DIFFUSE RADIATION

Solar radiation that gets scattered by molecules and particles while passing through the earth's atmosphere and reaches the surface of the earth is called as diffuse radiation [19]. It is also termed as skylight, diffuse skylight, or sky radiation due to the changes in the color of the sky.

2.3.3 REFLECTED RADIATION

Reflected solar radiation is part of global solar radiation that is reflected from the receiving surface such as ground, hills and water bodies [19]. It is measured in percentage of the total energy in the incident electromagnetic waves.

2.3.4 GLOBAL/TOTAL SOLAR RADIATION

Global solar radiation (GSR) is the rate of measuring the total incoming solar energy including direct, diffuse and reflected components on a horizontal plane at the Earth's surface. The sum of the direct and diffuse component gives the most accurate measurements.

2.3.5 TERRESTRIAL RADIATION

Terrestrial radiation is the total infrared radiation emitted by the Earth and its atmosphere in the temperature range of approximately 200-300K. It is also termed as outgoing longwave radiation or thermal infrared radiation [53].

2.3.6 EXTRATERRESTRIAL RADIATION

Extraterrestrial radiation is the intensity of solar radiation outside the earth's atmosphere on a horizontal surface which is almost constant at around 1367 Watts/meter2 (W/m2). The earth's orbit is elliptical so the value varies throughout the year as the distance between the earth and sun varies during the year in a predictable way [60].

2.4 SOLAR RADIATION MEASURING INSTRUMENTS

Different radiation measuring instruments are required for different purposes.

Table 1 shows the most commonly used instruments for measuring the incoming solar energy.

Table 1: Instruments used for solar radiation measurements [10][57]

Solar Radiation Component	Instruments Used
Sunshine Duration	Campbell-Stokes sunshine recorders
Direct Radiation	Angstrom and Thermoelectric Pyrheliometers
Diffuse Radiation	Thermoelectric Pyranometer with shading ring
Reflected Radiation	Inverted Pyranometer
Global Solar Radiation	Thermoelectric Pyranometer
Terrestrial Radiation	Angstrom Pyrgeometer
Extraterrestrial Radiation	Satellites and high altitude balloons & aircrafts

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3 IMPORTANCE OF FORECASTING SOLAR ENERGY

Solar energy is clean renewable free source of energy that has a less environmental impact than conventional energy. It is abundant and non-polluting energy source that does not produce any greenhouse gas such as carbon dioxide during electricity production [31]. Measuring solar radiation has a wide range of applications in agriculture and engineering. It is mainly used in monitoring the effect on plant growth, generating electricity for lighting, heating and cooling, analysis of evaporation and irrigation, transportation, environmental cleanup, design electricity generation for architecture and buildings, health impacts, weather and climate predictive models [55]. Fig.2. shows the applications of solar energy in various sectors.

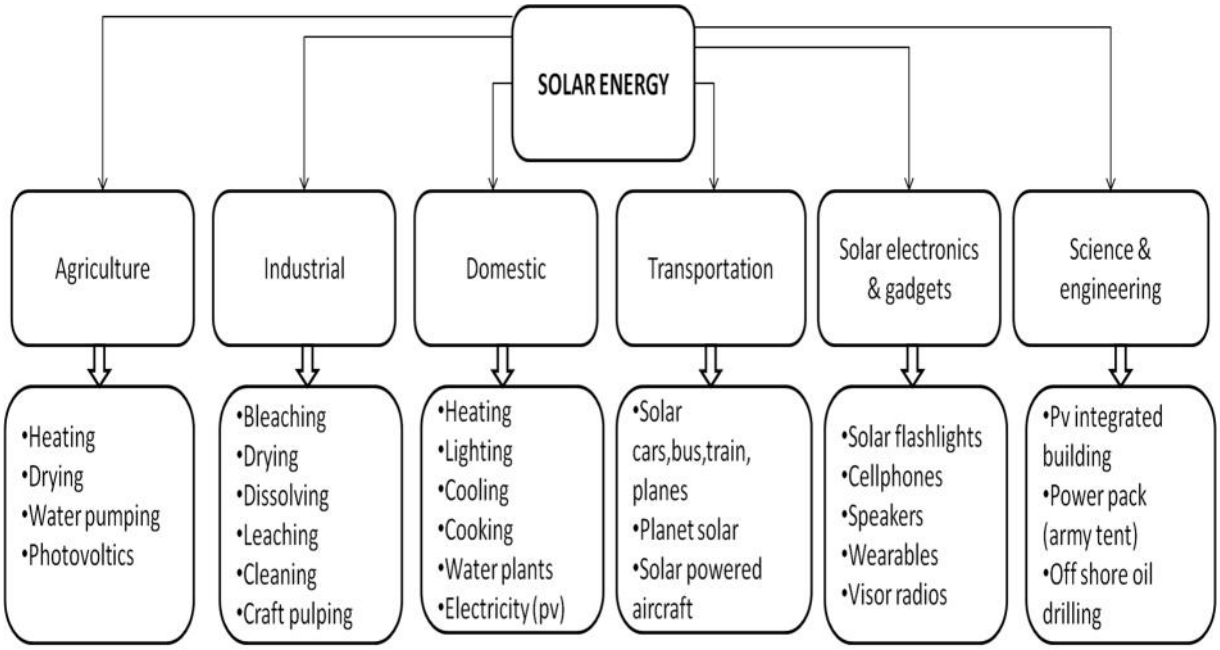

Fig.2. Applications of solar energy

4 FORECASTING TECHNIQUES USED TO ESTIMATE GSR

Solar radiation plays a vital role in many areas including climatology, atmospheric sciences, hydrology and energy applications. Many researchers have modelled weather data using various statistical and optimization techniques for forecasting global solar radiation. The meteorological parameters are the most important factors for developing a proper solar radiation model at any location. The most commonly used meteorological parameters include maximum and minimum, mean atmospheric temperature, latitude, longitude, altitude, soil temperature, atmospheric pressure, vapor pressure, relative humidity, wind speed, rainfall, cloud cover and sunshine duration [37].

There are several techniques for forecasting solar radiation based on historical data; they are categorized as statistical models and computational models such as Artificial Neural Networks, Fuzzy Logic, Wavelet Neural System, Genetic Algorithm and Adaptive Neuro-Fuzzy Inference System (ANFIS).

The first empirical relation between global solar radiation under clear sky conditions and bright sunshine duration was proposed by Angstrom (1924) for predicting global solar radiation. Later the Angstrom correlation modified by Prescott (1940) and Page (1964) were used all over the world to estimate the global solar radiation. Many researchers have developed specific models for individual countries based on the availability of meteorological data [44]. In this paper the forecasting techniques are broadly classified into two categories: (i) Statistical Methods (ii) Modern Optimization Techniques are reviewed in the literature.

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ISSN 2394 – 3386
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4.1 STATISTICAL METHODS

Statistical time series models are based on the correlation between past observations and future values to estimate solar irradiance. Table 2 illustrates various statistical techniques used for predicting solar radiation.

Table 2: Statistical techniques used to predict solar radiation

Technique	Analysis Period	Location	Year & Reference
Atmospheric Deterministic Model & Data-Driven Intelligent Methods	1984-1995	Athens, Greece	1994, [46]
Parametric Models & Decomposition Models	1961-1990	Hong Kong, China	2001, [52]
Generalized Additive Models	1981-2001	Pampas, Argentina	2004, [17]
Non-Linear Method	1980-1999	Egypt	2005, [36]
Regression Method	1983-1987	Amman, Jordan	2006, [6]
Multiple Linear Regression	2003-2005	Bishkek, Kyrgyzstan	2009, [51]
Empirical models and the geostatistical interpolation methods	1975-2006	Ankara, Turkey	2010, [34]
Comparison of Regression and Neural Networks Models	1996-2002	Salta, Argentina	2010, [35]
Classical Empirical Regression Models & Time-Series ARIMA Models	1995-2007	Al-Ain, UAE	2011, [20]
Empirical models based on Angstrom-Prescott model	2004-2007	Terengganu, Malaysia	2011, [38]
Regression Model	1991-2007	Uyo, Nigeria	2012, [22]
Linear, Non-linear and ANN models	1975-2004	Malaysia	2012, [49]
Linear Regression Technique	2007-2012	Nepal, India	2013, [27]
Linear Regression Methods	2009-2011	Troyes-Barberey City, France	2013, [3]
Site-dependent & Multiple Linear Regression models	1971–2000	China	2013, [33]
Empirical models	1960-2010	India	2013, [25]
Regression models	2008	Jharkhand, India	2013, [29]
Empirical models	1961-2009	Pakistan	2013, [16]
Empirical models	2004-2008	Yazd, Iran	2013, [12]
Multiple Linear Regression	2010-2013	Bejaia, Algeria	2014, [39]
Gaussian Process Regression Methods	2002-2003	Turkey	2016, [26]

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4.2 MODERN OPTIMIZATION TECHNIQUES

The modern optimization technique surveys some of the most recent advances for estimating solar radiation. The most popular techniques such as Artificial Intelligence (AI) and Satellite based models Geographic Information System (GIS) and Remote Sensing Information (RSI) are widely used to predict solar radiation. Artificial Intelligence (AI) technique has a wide range of applications including engineering, medicine, modelling, optimization, prediction, forecasting and solve complex problems due to its self adaptive natural intelligence. AI paradigms including artificial neural network (ANN), fuzzy inference systems, genetic algorithm, machine learning, Adaptive neuro-fuzzy inference system (ANFIS), Gene expression programming (GEP), Support Vector Regression (SVR), Multi-Layer Perceptron (MLP) and Optimal Brain Surgeon (OBS) are reviewed in the literature. These techniques give better results than traditional methods. Table 4 represents the recent advanced techniques used for predicting solar radiation.

Table 3: Modern optimization techniques used to predict solar radiation

Technique	Analysis Period	Location	Year & Reference
Artificial Neural Network (ANN)	1989-1993	India	2007, [28]
Feed Forward ANN	1998-2002	Abha City In Saudi Arabia	2008, [48]
Multi-Layer Perceptron (MLP) Neural Network	1971-1989	Ajaccio, France	2010, [9]
Artificial Neural Network (ANN)	1994-2003	Gusau, Nigeria.	2011, [2]
Artificial Neural Network (ANN)	2005-2008	Anatolia, Turkey	2011, [4]
Artificial Neural Network (ANN)	February-June 2011	Algeria	2012, [1]
Feed Forward ANN	March-December 2010	Madurai, India	2012, [41]
ANN Model Based On Multi-Nonlinear Regression (MNLR) Method	2000-2006	Turkey	2012, [37]
Artificial Neural Network (ANN)	2007	Qena, Egypt	2013, [11]
ANN Post-Processing Technique	2011	La Reunion Island, France	2014, [40]
Artificial Neural Network (ANN)	2001-2010	Bangkok, Thailand	2014, [24]
ANN Back Propagation Algorithm	2000-2009	India	2016, [42]
GISTEL (Solar Radiation By Teledetection)	February 2011	Algeria	2013, [13]
Imperialist Competitive and Genetic Algorithms	1984-2005	Iran	2013, [18]
Genetic Algorithm (GA)	1974-2005	Iran	2013, [14]
Remote Sensing Information System: MODIS (Moderate Resolution Imaging Spectroradiometer)	2005	Spain	2014, [15]
AI Techniques (ANN,ANFIS,MLR) & Empirical Equations	1974-2010	Turkey	2015, [21]
Remote Sensing And Weather Forecast Models	July-December 2013	Lamezia Terme, Italy	2015, [50]
Spectral Analytical Model Using HRV Images	February-May 2012	Algeria	2015, [8]
Gene Expression Programming (GEP)	1995-2014	Mashhad, Iran	2015, [47]
Hybrid Model (Clustering & Multilayer Perceptron Neural Network (MLPNN)	2006-2009	Washington, USA	2016, [32]
AI Methods (GEP, ANN, ANFIS) & Empirical Equations	1992-2009	Kerman, Iran	2016, [43]
ANN Model Based on Spatial Interpolation	1961-2010	China	2016, [30]
Neural Network Model (Multi-Layer Perceptron (MLP) & Optimal Brain Surgeon (OBS)	2004-2013	Abu Dhabi, UAE	2017, [45]

5 SOLAR ENERGY: INDIAN SCENARIO

India has higher potential of solar power. Most parts of India get 250-300 days of clear sunny weather in a year. The energy potential over India is about 5,000 million GWh per year. The annual solar radiation incidence over India is equal to 4-7 kWh per square meter per day with an annual radiation ranging from 1200-2300 kWh per square meter [7].

A recently released document by the Ministry of New & Renewable energy (MNRE) shows that Indian solar potential has been estimated to be 748 GW. 5,525 MW of solar power generation capacity added by India for the fiscal year 2016, that takes the total from this clean source to 12,288 MW. The cumulative solar power generation capacity of 6,763 MW was achieved in 2015-16. The capacity was 1,686 MW in 2012-13 which increased to 2,632 MW in 2013-14 and to 3,744 MW in 2014-15. Fiscal year 2017 has a large scale solar power projects, India has plans to add 5,000 MW of rooftop and 10,000 MW. Andhra Pradesh has the largest cumulative solar production capacity of 1,867 MW as on March 31, 2017 and 1,812 MW by Rajasthan and 1,691 MW by Tamil Nadu [56].

The government of India has targeted large scale solar energy power projects. India's biggest solar power plant was inaugurated at Diken in Neemuch district of Madhya Pradesh on March 1, 2014, by the then Chief Minister of Gujarat Narendra Modi. Jawaharlal Nehru National Solar Mission (JNNSM) launched by the Centre is targeting 20,000 MW of solar energy power by 2022 [7]. The Minister for Power, Coal and Renewable energy Piyush Goyal has said that India will achieve 40 per cent cumulative Electric power capacity from non-fossil fuel based energy resources by 2030. This will be achieved with the help of transfer of technology and low cost International Finance which includes Green Climate Fund [56].

CONCLUSION

The energy demand has become a serious problem all over the world. The coal and oil fired conventional electricity generation is the major cause for climate change, global warming and greenhouse gas emissions. In this respect an alternative renewable energy plays an important role. Renewable energy is clean, natural and non-polluting source of energy including wind, solar, hydro, wave, biomass, geothermal. Solar energy is an important source of renewable energy for generating electricity with less environmental impact. Solar power has a wide range of applications in designing power plants, agriculture, meteorology, science and engineering. This paper presents the various forecasting models reviewed in the literature. Artificial Intelligence (AI) computational techniques give more accurate results than other models. Hence it is suggested that AI computational technique can be used for predicting solar radiation with the available meteorological parameters.

REFERENCES

[1] Abdelhafid Hasni, Abdelkrim Sehli, Belkacem Draoui, Abdesselam Bassou & Belkacem Amieur, "Estimating global solar radiation using artificial neural network and climate data in the south-western region of Algeria", Energy Procedia 18: 531 – 537, 2012.

[2] AbdulAzeez M. A, "Artificial Neural Network Estimation of Global Solar Radiation Using Meteorological Parameters in Gusau, Nigeria", Archives of Applied Science Research, 3 (2):586-595, 2011.

[3] Abedelhak Ben Jemaa, Souad Rafa, Najib Essounbouli, Abdelaziz Hamzaoui, Faicel Hnaien, Farouk Yalaoui, "Estimation of Global Solar Radiation Using Three Simple Methods", Energy Procedia 42: 406 – 415, 2013.

[4] Ahmet Koca, Hakan F. Oztop, Yasin Varol, Gonca Ozmen Koca, "Estimation of solar radiation using artificial neural networks with different input parameters for Mediterranean region of Anatolia in Turkey", Expert Systems with Applications 38: 8756–8762, 2011.

[5] Ajit P. Tyagi, "Solar radiant energy over India", India meteorological department ministry of earth sciences, New Delhi, 2009.

[6] Al-Salaymeh A, "Modelling of global daily solar radiation on horizontal surfaces for Amman city", Emirates Journal for Engineering Research, 11 (1), 49-56, 2006.
[7] Aniket Dwivedi, Ajay Bari and Gaurav Dwivedi, "Scope and Application of Solar Thermal Energy in India-A Review", International Journal of Engineering Research and Technology, Volume 6, Number 3, pp. 315-322, 2013.
[8] Boulifa M, Adane A, Rezagui A, et Ameur Z, "Estimate of the global solar radiation by cloudy sky using HRV images", Energy Procedia 74: 1079 – 1089, 2015.
[9] Christophe Paoli, Cyril Voyant, Marc Muselli, Marie Laure Nivet, "Forecasting of preprocessed daily solar radiation time series using neural networks", Solar Energy, Elsevier, 84 (12), pp.2146-2160, 2010.
[10] Daryl R. Myers, "Solar radiation modelling and measurements for renewable energy applications: data and model quality", Energy 30:1517–1531, 2005.
[11] Emad A. Ahmed and El-Nouby Adam M, "Estimate of Global Solar Radiation by Using Artificial Neural Network in Qena, Upper Egypt", Journal of Clean Energy Technologies, Vol. 1, No. 2, April 2013.
[12] Fariba Besharat, Ali A. Dehghan, Ahmad R. Faghih, "Empirical models for estimating global solar radiation: A review and case study", Renewable and Sustainable Energy Reviews 21: 798–821, 2013.
[13] Fariza Meziani, Mina Boulifa, Zohra Ameur, "Determination of the global solar irradiation by MSG-SEVIRI images processing in Algeria", Energy Procedia 36: 525–534, 2013.
[14] Farzad Fathian, "Predicting Global Solar Radiation using Genetic Algorithm (GA)", Bulletin of Environment, Pharmacology and Life Sciences, Vol 2 (6): 54- 63, 2013.
[15] Gabriel Lopez and Francisco Javier Batlles, "Estimating solar radiation from MODIS data", Energy Procedia 49: 2362-2369, 2014.
[16] Gadiwala, M. S, Usman A, Akhtar M, Jamil K, "Empirical Models for the Estimation of Global Solar Radiation with Sunshine Hours on Horizontal Surface in Various Cities of Pakistan", Pakistan Journal of Meteorology Vol. 9, Issue 18, 2013.
[17] Guillermo P. Podesta, Liliana Nunez, Carlos A. Villanueva, Maria A. Skansi, "Estimating daily solar radiation in the Argentine Pampas", Agricultural and Forest Meteorology 123: 41–53, 2004.
[18] Hajar Bagheri Tolabi and Moradi M. H, "New technique for global solar radiation estimation by Imperialist competitive and Genetic Algorithms", Technical Journal of Engineering and Applied Sciences 3 (8): 703-708, 2013.
[19] Hajar Bagheri Tolabi, Moradi M H and Shahrin Bin Md Ayob, "A review on classification and comparison of different models in solar radiation estimation", International Journal of Energy Research, 38:689 –701, 2014.
[20] Hassan A. N. Hejase and Ali H. Assi, "MATLAB-Assisted Regression Modeling of Mean Daily Global Solar Radiation in Al-Ain, UAE", Engineering Education and Research Using MATLAB, Dr. Ali Assi (Ed.), 2011.
[21] Hatice Citakoglu, "Comparison of artificial intelligence techniques via empirical equations for prediction of solar radiation", Computers and Electronics in Agriculture 118: 28-37, 2015.
[22] Ituen, Eno. E., Esen, Nsikan. U., Nwokolo, Samuel. C. and Udo, Ema. G. "Prediction of global solar radiation using relative humidity, maximum temperature and sunshine hours in Uyo, in the Niger Delta Region, Nigeria", Advances in Applied Science Research, 3 (4):1923-1937, 2012.
[23] Jamil Ahmad M and Tiwari G. N., "Solar radiation models - A review", International Journal of Energy Research 35:271–290, 2011.
[24] Jompob Waewsak, Chana Chancham, Marina Mani and Yves Gagnon, "Estimation of Monthly Mean Daily Global Solar Radiation over Bangkok, Thailand using Artificial Neural Networks", "Energy Procedia 57: 1160 – 1168, 2014.
[25] Katiyar A. K and Pandey C. K, "A Review of Solar Radiation Models-Part I", Journal of Renewable Energy, Volume 2013, Article ID 168048, 11 pages, 2013.
[26] Kızıltan O and M Sahin, "Calculation of Solar Radiation by Using Regression Methods", Journal of Physics: Conference Series **707** : 012049, 2016.

[27] Krishna R. Adhikari, Binod K. Bhattarai, Shekhar Gurung, "Estimation of Global Solar Radiation for Four Selected Sites in Nepal Using Sunshine Hours, Temperature and Relative Humidity", Journal of Power and Energy Engineering, 1, 1-9, 2013.
[28] Krishnaiah T, Srinivasa Rao S, Madhumurthy K, Reddy K S, "Neural Network Approach for Modelling Global Solar Radiation", Journal of Applied Sciences Research, 3(10): 1105-1111, 2007.
[29] Kumari Namrata, Sharma S P, Saksena S B L, "Comparison of Different Models for Estimation of Global Solar Radiation in Jharkhand (India) Region", Smart Grid and Renewable Energy, 4, 348-352, 2013.
[30] Ling Zou, Lunche Wang, Aiwen Lin, Hongji Zhu, Yuling Peng, Zhenzhen Zhao, "Estimation of global solar radiation using an artificial neural network based on an interpolation technique in southeast China", Journal of Atmospheric and Solar Terrestrial Physics146:110–122, 2016.
[31] Madhu Kumari and Dr. Prasoon Kumar Singh "Impacts of Solar Power in India: A Review", International Journal of Research & Review, Vol.4; Issue: 5; 2017.
[32] Mahmoud Ghofrani, Mohadeseh Ghayekhloo, Rasool Azimi, "A novel soft computing framework for solar radiation forecasting", Applied Soft Computing 48: 207–216, 2016.
[33] Mao-Fen Li, Li Fan, Hong-Bin Liu, Peng-Tao Guo, Wei Wu, "A general model for estimation of daily global solar radiation using air temperatures and site geographic parameters in Southwest China", Journal of Atmospheric and Solar-Terrestrial Physics 92: 145–150, 2013.
[34] Mehmet H. Sonmete, Can Ertekin, Hakan O. Menges, Haydar Hacıseferogullari, Fatih Evrendilek, "Assessing monthly average solar radiation models: a comparative case study in Turkey", Environ Monit Assess, 2010.
[35] Monica Bocco1, Enrique Willington, and Monica Arias, "Comparison of Regression and Neural Networks models to estimate Solar Radiation", Chilean Journal of Agricultural Research 70(3):428-435, 2010.
[36] Mossad El-Metwally, "Sunshine and global solar radiation estimation at different sites in Egypt", Journal of Atmospheric and Solar-Terrestrial Physics 67: 1331–1342, 2005.
[37] Muammer Ozgoren, Mehmet Bilgili, Besir Sahin, "Estimation of global solar radiation using ANN over Turkey", Expert Systems with Applications 39: 5043–5051, 2012.
[38] Muzathik A M , Nik W B W, Ibrahim M Z , Samo K B, Sopian K and Alghoul M A, "Daily Global Solar Radiation estimate based on sunshine hours", International Journal of Mechanical and Materials Engineering (IJMME), Vol.6, No.1, 75-80, 2011.
[39] Ouali K, Alkama R, "A new Model of global solar radiation based on meteorological data in Bejaia City (Algeria)", Energy Procedia 50: 670 – 676, 2014.
[40] Philippe Lauret, Maimouna Diagne, Mathieu David, "A Neural Network Post-processing Approach To Improving NWP Solar Radiation Forecasts", Energy Procedia 57: 1044 – 1052, 2014.
[41] Premalatha N and Dr. ValanArasu A, "Estimation of global solar radiation in India using artificial neural network", International Journal of Engineering Science & Advanced Technology, Volume-2, Issue-6, 1715 – 1721, 2012.
[42] Premalatha Neelamegama and Valan Arasu Amirtham, "Prediction of solar radiation for solar systems by using ANN models with different back propagation algorithms", Journal of Applied Research and Technology 14: 206–214, 2016.
[43] Saeid Mehdizadeh, Javad Behmanesh, Keivan Khalili, "Comparison of artificial intelligence methods and empirical equations to estimate daily solar radiation", Journal of Atmospheric and Solar-Terrestrial Physics 146:215–227, 2016.
[44] Saffaripour M H, Mehrabian M A, Bazargan H "Predicting solar radiation fluxes for solar energy system applications", International Journal of Environmental Science and Technology 10: 761-768, 2013.
[45] Sajid Hussain and Ali Al Alili, "A pruning approach to optimize synaptic connections and select relevant input parameters for neural network modelling of solar radiation", Applied Soft Computing 52: 898–908, 2017.

[46] Santamouris M and Mihalakakou G, " Modeling the Global Solar Radiation on the Earth's Surface Using Atmospheric Deterministic and Intelligent Data-Driven Techniques", Journal of climate volume 12, American Meteorological Society, 1999.
[47] Seyyed Mohammad Mousavi, Elham S. Mostafavi, Alireza Jaafari, Arefeh Jaafari, Fariba Hosseinpour "Using measured daily meteorological parameters to predict daily solar radiation", Measurement 76: 148–155, 2015.
[48] Shafiqur Rehman and Mohamed Mohandes, "Artificial neural network estimation of global solar radiation using air temperature and relative humidity", Energy Policy 36: 571–576, 2008.
[49] Tamer Khatib, Azah Mohamed, Marwan Mahmoud and Sopian K "An Assessment of Diffuse Solar Energy Models in Terms of Estimation Accuracy", Energy Procedia 14, 2066 – 2074, 2012.
[50] Teresa Lo Feudo, Elenio Avolio, Daniel Gulli, Stefano Federico, Claudia Roberta, Calidonna, Annamaria Sempreviva, "Comparison of hourly solar radiation from a ground–based station, remote sensing and weather forecast models at a coastal site of South Italy (Lamezia Terme)", Energy Procedia 76: 148 – 155, 2015.
[51] Turk Togrul, "Estimation of solar radiation from angstroms coefficients by using geographical and meteorological data in Bishkek, Kyrgyzstan", J. of Thermal Science and Technology, 2009.
[52] Wong L. T and Chow W. K, "Solar radiation model", Applied Energy 69: 191–224, 2001.
[53] https://www.accessscience.com/content/terrestrial-radiation/685700
[54] http://www.aeronsystems.com/types-of-solar-radiation/
[55] http://www.akimoo.com/importance-of-solar-radiation-measurement
[56] http://economictimes.indiatimes.com/articleshow/58113364.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst
[57] http://www.eppleylab.com/
[58] http://www.indiaenvironmentportal.org.in/files/srd-sec.pdf
[59] http://naturalfrequency.com/wiki/solar-radiation
[60] https://pvpmc.sandia.gov/modeling-steps/1-weather-design-inputs/irradiance-and-insolation-2/extraterrestrial-radiation/