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Overview of Solar Radiation Estimation Techniques with Development of Solar Radiation Model Using Artificial Neural Network

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ABSTRACT

Estimation Solar radiation is the most significant part of the optimization of solar power. This may be achieved if the solar radiation is predicted well in advance. Meteorological stations have radiation measuring devices like pyranometer, pyrheliometer, radiometer, solarimeter, etc. however, it may not be available at the location of interest for researchers. Due to this limitation solar radiation estimation models are devised based on location details like Altitude, Latitude, Longitude, and metrological details like Wind Speed, Ambient Temperature, Relative Humidity, Day Temperature, etc. These radiation models provide Global Solar Radiation (GSR) as output. These models are statistically tested based on error calculation like Mean Bias Error, Mean Absolute Error, Root Mean Square Error, etc. This paper is framed to briefly provide the idea behind different solar radiation estimation models with the methodology used. Soft computing-based models are mainly analyzed here. ANN-based Global Solar Irradiance Estimation Model has been developed using geographical parameters like Elevation, Latitude, Longitude, Longitude, and meteorological parameters like Months of a year, Days of a month, Temperature, Atmospheric Pressure, Relative Humidity, and Wind Speed. The data are downloaded from the National Solar Radiation Database (NSRDB) for 2014 (latest available). From this paper, the reader will come to know about various techniques used in solar radiation estimation. The developed ANN-based model has better results for training, testing, validation, and all with Regression value of 0.94304, 0.9488, 0.94766, 0.94556 respectively. The MSE is found to be 0.0089147 at epoch 0. The obtained values of R and MSE indicates the suitability of the developed model.

1. Introduction

Optimization of renewable sources of energy is one of the thrust areas for the researchers, now a days. There are many advantages of renewable sources over non-renewable sources like abundancy, non-pollutant, etc. in comparison to other sources of renewable energy like biomass, wind, hydropower, geothermal, solar energy is most preferable due to its profound abundancy over the earth. The sun radiates about 1,20,000 TW of radiation per hour which is more than sufficient to fulfill the energy need of the world for a year [1-2]. Solar energy with huge potential can meet the need of earth's energy requirements [3]. Solar energy has a great lead as per the application point of view over other renewable sources of energy [4]. The solar radiation is available as extraterrestrial and global solar radiation. The first one is found above the atmosphere while the second one is under the atmosphere. Global solar radiation is measured by the measuring instruments like Pyrheliometer in case of direct beam solar radiation and by Solarimeter, Pyranometer, Radiometer in case of diffused solar radiation [5]. These measuring devices are of very high cost and they are installed at a few meteorological stations. This means, measuring devices may not be available at the locations of interest for the researchers [6]. Due to this limitation, solar radiation is estimated based on the location and meteorological parameters

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such as latitude, longitude, altitude, sunshine hour, air temperature, wind speed, cloud cover, humidity, days of a month, etc.

As per the nature of the forecasting models, it may be categorized as Mathematical/Classical/Statistical Models, Machine Learning Models, Cloud Motion Models, Numerical Weather Prediction Models, and Hybrid Models. Persistence Models provide a standard forecast in comparison to the realization of other models.

Empirical models mostly depend on the following factors [7]:

- Astronomical elements such as hour angle, solar declination, earth-sun distance, etc.
- Meteorological elements like humidity, air temperature, sunshine duration, precipitation, evaporation, etc.
- Geographical elements like altitude, longitude, latitude, etc.
- Physical elements like water vapor content scattering of dust, scattering of air molecules, etc.
- Geometrical elements such as tilt angle, sun elevation, sun azimuth, etc.

Further, based on types of input meteorological parameters, empirical models may be categorized as Sunshine, Cloud, Temperature, and other meteorological parameter-based models.

This paper is oriented as follows. Section 2 and section 3, provide a brief survey of the classical solar radiation estimation model and development of a new global solar irradiation model. Results have been quoted in section 4 and conclusion of the work has drawn section 5.

2. Summary of Empirical/ Classical/ Statistical Model of Solar Radiation Estimation

In earlier days Solar Radiation estimation was carried out using various mathematical relations [8-9], which were widely tested and evaluated across the globe. Later on, its revised versions like quadratic, cubic, exponential, and logarithmic, were also advised by various researchers [10-13]. A comparative study reveals that some revised models have better results than that of the A-P Model [14-17]. Another author found similar results while evaluating linear, quadratic, cubic, and exponential models in Iran [15]. Insignificant difference between these models were reported after testing and evaluating [17]. After this, several researchers modified A-P Model by incorporating other parameters like atmospheric pressure, precipitation, air temperature, relative humidity, etc. [18-24].

As sunshine models are subjected to availability of sunshine hour [25-26], so to overcome with this, a model was devised based on maximum and minimum temperatures [27]. Later on, this model was also improved by several researchers [28]. By using precipitation, atmospheric pressure, and relative humidity data, model developed by [27] and was modified by [29]. Many researchers found that the accuracies of the model of [27] and other models [30] highly varies for various geographical locations and local climate of the location of interest [31].

In addition to the above two categorizations, some authors have used other parameters like precipitation, atmospheric pressure, and relative humidity to estimate solar radiation. However, due to the complex radiation process, it is a challenging task nowadays also to develop the perfect empirical model [32]. Several empirical models were developed, evaluated, and reviewed by researchers [33-37].

3. Development of Global Horizontal Solar Radiation Estimation Model based on ANN

In Section 2, maximum types of classical as well as machine learning models are briefed and found that Artificial Neural Network-based estimation models have better performance in comparison to others [38-39]. The development of the ANN-based model is detailed below.

3.1. Geographical and Meteorological data Collection and Processing

The present analysis is carried out for New-Delhi (National Capital of India). The measured geographical parameters such as Latitude, Longitude, Elevation and meteorological parameters such as Months of a year, Days of a month, Temperature, Atmospheric Pressure, Humidity, and Wind Speed are downloaded from National Solar Radiation Database (NSRDB) for 2014 (latest available). As, data of different downloaded parameters were having different ranges and units, so max-min normalization of data was performed ranging between 0-1 by equation (1);

$$v_i' = \left[\left(\frac{v_i - B}{A - B}\right).(M - N)\right] + N \qquad (1)$$

where v_i' is the Normalized value of the variable, v_i is downloaded value of the variable, A is Maximum value, B is the minimum value, M is the new maximum value, and N is the new minimum value.

3.2. Methodology

A computer program has been performed under MATLAB R2016a using Neural Network/Data Manager Tool: nntool. Its configuration details are listed in Table 1 below.

Table 1: NN Tool Customization

Sl. No.	Particulars	Configuration Details
1	Network Type	Feed Forward Back Propagation
2	Training Function	TRAINLM
3	Adaptation Learning Function	LEANGDM
4	Error Function	MSE
5	Number of Hidden Layers	02
6	Properties for Layer-1	Transfer Function: TANSIG, No. of Neurons: 10
7	Properties of Layer-2	Transfer Function: TANSIG
8	Training Info	Input and Output
9	Training Parameters	Epochs: 1000, max_fail: 1000
10	Data Division	Random (dividerand)
11	Training	Levenberg-Marquardt (trainlm)
12	Performance	Mean Squared Error (MSE)
13	Calculation	MEX
14	Plot Interval	1 Epochs

The Mean Square Error (Equation-2) is used for error calculation and evaluation of the developed model.

$$MSE = \left(\frac{1}{n}\right)\sum_{j=1}^{n}\left(SR_{i(ANN)} - SR_{i(actual)}\right)^2 \quad (2)$$

where n is the number of inputs, $SR_{i(ANN)}$ is estimated Global Solar Irradiance, $SR_{i(actual)}$ estimated Global Solar Irradiance.

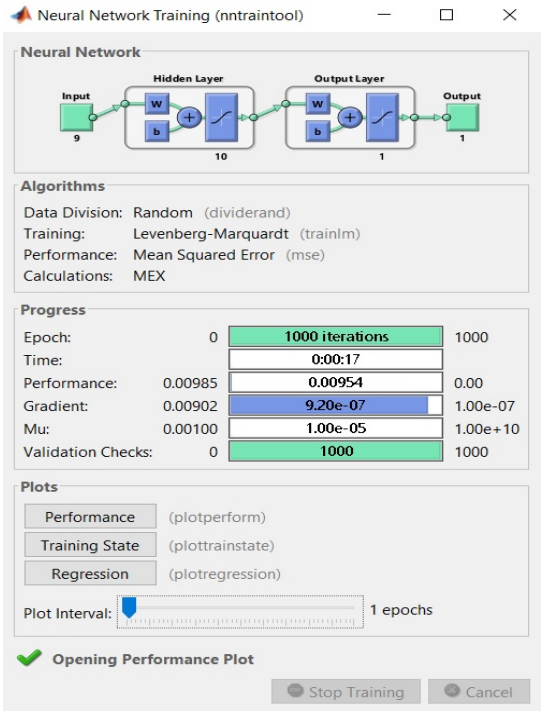

Figure 1. Neural Network Training Environment

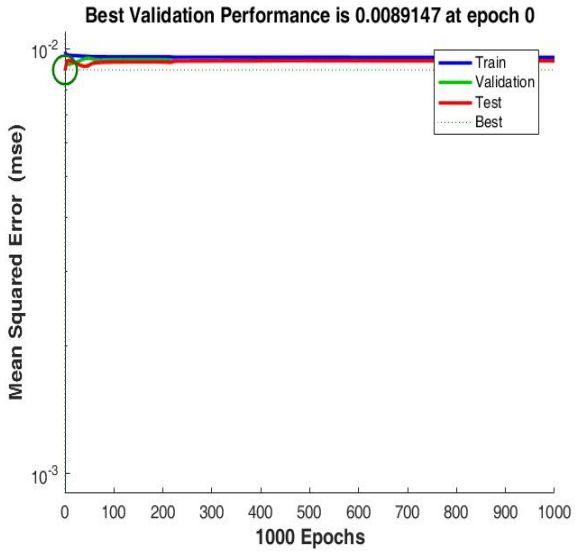

Figure 2. Performance Plot

4. Results

The training environment of the Neural Network Train tool is in Figure 1. Where architecture of the applied neural network is represented along with detail of algorithms, plot interval, and progress of training.

Figure 2 is the performance plot after the training, testing, and validation. It is a plot between epochs and Mean Squared Error. The best validation performance is 0.0089147 at epoch 0. Also, training, validation, testing, and best performance curve is shown by blue, green, red, and dotted lines respectively.

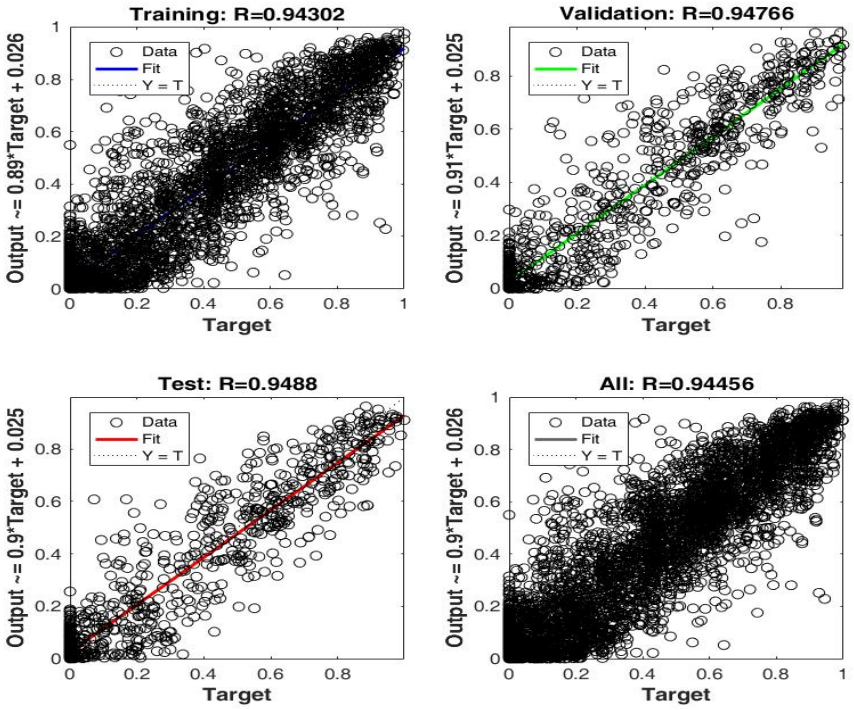

Figure 3 is the plot between Target and Output. This graph is plotted for training, testing, validation, and all. The R-value of Training is 0.94304, for Testing is 0.9488, for validation is 0.94766 and for all it is 0.94556. These values are listed in Table 2. R-value closer to 1 and MSE value closer to 0 are assumed to be a better one.

Table 2: R Value Analysis

Sl. No.	Particulars	R
1	Training	0.94302
2	Validation	0.94766
3	Testing	0.9488
4	All	0.94456

5. Conclusion

The implantation of Artificial Neural Network in the modeling of Global Solar Radiation is reported. The developed model shows that selection of ANN model has lesser MSE and considerably good values of R. The model is developed by using meteorological parameters like Months of a year, Days of a month, Temperature, Pressure, Humidity, Wind Speed and Latitude, Longitude, Elevation of New Delhi, India for 2014. This model may be used for the estimation of Global Solar Irradiance for other stations also.

Conflict of Interest

We declare that there is no conflict of interest of this article.

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References

[1] K. Kapoor, K. K. Pandey, A. K. Jain, & A. Nandan, "Evolution of solar energy in India: A review", Renewable and Sustainable Energy Reviews, **40**, 475–487, 2014. https://doi.org/10.1016/j.rser.2014.07.118

[2] A. B. Jemaa, S. Rafa, N. Essounbouli, A. Hamzaoui, F. Hnaien, & F. Yalaoui, "Estimation of Global Solar Radiation Using Three Simple Methods", Energy Procedia, **42**, 406–415, 2013. https://doi.org/10.1016/j.egypro.2013.11.041

[3] S. A. Kalogirou, "Artificial Neural Networks and Genetic Algorithms for the Modeling, Simulation, and Performance Prediction of Solar Energy Systems", Green Energy and Technology, 225–245, 2013. https://doi.org/10.1007/978-1-4471-5143-2_11

[4] D. Pandey, A. Choudhary, "A Review of Semiconductor Solar PV Cell and Development of Solar Radiation Estimation Models", Journal of Semiconductor Devices and Circuits, **5**(1):20-6, 2018.

[5] T. Khatib, A. Mohamed, & K. Sopian, "A review of solar energy modeling techniques", Renewable and Sustainable Energy Reviews, **16**(5), 2864–2869, 2012. https://doi.org/10.1016/j.rser.2012.01.064

[6] J. Zhang, L. Zhao, S. Deng, W. Xu, & Y. Zhang, "A critical review of the models used to estimate solar radiation", Renewable and Sustainable Energy Reviews, **70**, 314–329, 2017. https://doi.org/10.1016/j.rser.2016.11.124

[7] F. Besharat, A. A. Dehghan, & A. R. Faghih, "Empirical models for estimating global solar radiation: A review and case study", Renewable and Sustainable Energy Reviews, **21**, 798–821, 2013. https://doi.org/10.1016/j.rser.2012.12.043

[8] A. Angstrom, "Solar and terrestrial radiation. Report to the international commission for solar research on actinometric investigations of solar and atmospheric radiation", Quarterly Journal of the Royal Meteorological Society, **50**(210), 121–126, 2007. https://doi.org/10.1002/qj.49705021008

[9] J. A. Prescott, "Evaporation from a water surface in relation to solar radiation", Trans. Roy. Soc. S. Aust., **46**:114-8, 1940.

[10] H. Ögelman, A. Ecevit, & E. Tasdemiroğlu, "A new method for estimating solar radiation from bright sunshine data", Solar Energy, **33**(6), 619–625, 1984. https://doi.org/10.1016/0038-092x(84)90018-5

[11] V. Bahel, H. Bakhsh, & R. Srinivasan, "A correlation for estimation of global solar radiation", Energy, **12**(2), 131–135, 1987. https://doi.org/10.1016/0360-5442(87)90117-4

[12] J. Almorox, & C. Hontoria, "Global solar radiation estimation using sunshine duration in Spain", Energy Conversion and Management, **45**(9-10), 1529–1535, 2004. https://doi.org/10.1016/j.enconman.2003.08.022

[13] D. B. Ampratwum, & A. S. S. Dorvlo, "Estimation of solar radiation from the number of sunshine hours", Applied Energy, **63**(3), 161–167, 1999. https://doi.org/10.1016/s0306-2619(99)00025-2

[14] A. Manzano, M. L. Martín, F. Valero, C. Armenta, "A single method to estimate the daily global solar radiation from monthly data", Atmospheric Research, **166**, 70–82, 2015. https://doi.org/10.1016/j.atmosres.2015.06.017

[15] K. Mohammadi, S. Shamshirband, M. H. Anisi, K. A. Alam, & D. Petković, "Support vector regression based prediction of global solar radiation on a horizontal surface", Energy Conversion and Management, **91**, 433–441, 2015. https://doi.org/10.1016/j.enconman.2014.12.015

[16] A. Teke, & H. B. Yildirim, "Estimating the monthly global solar radiation for Eastern Mediterranean Region", Energy Conversion and Management, **87**, 628–635, 2014. https://doi.org/10.1016/j.enconman.2014.07.052

[17] M. Chelbi, Y. Gagnon, & J. Waewsak, J. "Solar radiation mapping using sunshine duration-based models and interpolation techniques: Application to Tunisia", Energy Conversion and Management, **101**, 203–215, 2015. https://doi.org/10.1016/j.enconman.2015.04.052

[18] K. H. Lee, "Improving the correlation between incoming solar radiation and sunshine hour using DTR", International Journal of Climatology, **35**(3), 361–374, 2014. https://doi.org/10.1002/joc.3983

[19] M. H. Saffaripour, M. A. Mehrabian, & H. Bazargan, "Predicting solar radiation fluxes for solar energy system applications", International Journal of Environmental Science and Technology, **10**(4), 761–768, 2013. https://doi.org/10.1007/s13762-013-0179-2

[20] K. Bakirci, "Prediction of global solar radiation and comparison with satellite data", Journal of Atmospheric and Solar-Terrestrial Physics, 152-153, 41–49, 2017. https://doi.org/10.1016/j.jastp.2016.12.002

[21] J. Liu, J. Liu, H. W. Linderholm, D. Chen, Q. Yu, D. Wu, & S. Haginoya, "Observation and calculation of the solar radiation on the Tibetan Plateau" Energy Conversion and Management, **57**, 23–32, 2012. https://doi.org/10.1016/j.enconman.2011.12.007

[22] J. L. Chen, & G. S. Li, "Estimation of monthly average daily solar radiation from measured meteorological data in Yangtze River Basin in China", International Journal of Climatology, **33**(2), 487–498, 2012. https://doi.org/10.1002/joc.3442

[23] J. Fan, X. Wang, L. Wu, F. Zhang, H. Bai, X. Lu, & Y. Xiang, Y., "New combined models for estimating daily global solar radiation based on sunshine duration in humid regions: A case study in South China", Energy Conversion and Management, **156**, 618–625, 2018. https://doi.org/10.1016/j.enconman.2017.11.085

[24] G. N. Okonkwo, A. O. Nwokoye, "Estimating global solar radiation from temperature data in Minna location", European Scientific Journal,**10**(15), 2014.

[25] H. Khorasanizadeh, K. Mohammadi, & M. Jalilvand, "A statistical comparative study to demonstrate the merit of day of the year-based models for estimation of horizontal global solar radiation", Energy Conversion and Management, **87**, 37–47, 2014. https://doi.org/10.1016/j.enconman.2014.06.086

[26] S. S. Sharifi, V. Rezaverdinejad, & V. Nourani, "Estimation of daily global solar radiation using wavelet regression, ANN, GEP and empirical models: A comparative study of selected temperature-based approaches", Journal of Atmospheric and Solar-Terrestrial Physics, **149**, 131–145, 2016. https://doi.org/10.1016/j.jastp.2016.10.008

[27] H. Hargreaves George, & A. Samani Zohrab, "Reference Crop Evapotranspiration from Temperature", Applied Engineering in Agriculture, **1**(2), 96–99, 1985. https://doi.org/10.13031/2013.26773

[28] M. Benghanem, & A. Mellit, "A simplified calibrated model for estimating daily global solar radiation in Madinah, Saudi Arabia", Theoretical and Applied Climatology, **115**(1-2), 197–205, 2013. https://doi.org/10.1007/s00704-013-0884-2

[29] R. Chen, E. Kang, S. Lu, J. Ji. X. Yang, Z. Zhang, & J. Zhang, "New methods to estimate global radiation based on meteorological data in China", Energy Conversion and Management, **47**(18-19), 2991–2998, 2006. https://doi.org/10.1016/j.enconman.2006.03.025

[30] K. L. Bristow, & G. S. Campbell, "On the relationship between incoming solar radiation and daily maximum and minimum temperature", Agricultural and Forest Meteorology, **31**(2), 159–166, 1984. https://doi.org/10.1016/0168-1923(84)90017-0

[31] J. Fan, B. Chen, L. Wu, F. Zhang, X. Lu, & Y. Xiang, Y., "Evaluation and development of temperature-based empirical models for estimating daily global solar radiation in humid regions", Energy, **144**, 903–914, 2018. https://doi.org/10.1016/j.energy.2017.12.091

[32] J. L. Chen, L. He, Q. Chen, M. Q. Lv, H. L. Zhu, Z. F. Wen, & S. J. Wu, "Study of monthly mean daily diffuse and direct beam radiation estimation with MODIS atmospheric product", Renewable Energy, **132**, 221–232, 2019. https://doi.org/10.1016/j.renene.2018.07.151

[33] M. Despotovic, V. Nedic, D. Despotovic, & S. Cvetanovic, "Review and statistical analysis of different global solar radiation sunshine models", Renewable and Sustainable Energy Reviews, **52**, 1869–1880, 2015. https://doi.org/10.1016/j.rser.2015.08.035

[34] F. Besharat, A. A. Dehghan, & A. R. Faghih, "Empirical models for estimating global solar radiation: A review and case study", Renewable and Sustainable Energy Reviews, **21**, 798–821, 2013. https://doi.org/10.1016/j.rser.2012.12.043

[35] N. Chukwujindu Samuel, "A comprehensive review of empirical models for estimating global solar radiation in Africa", Renewable and Sustainable Energy Reviews, **78**, 955–995, 2017. https://doi.org/10.1016/j.rser.2017.04.101

[36] W. Yao, Z. Li, Y. Wang, F. Jiang, & L. Hu, "Evaluation of global solar radiation models for Shanghai, China", Energy Conversion and Management, **84**, 597–612, 2014. https://doi.org/10.1016/j.enconman.2014.04.017

[37] M. H. Sonmete, C. Ertekin, H. O. Menges, H. Hacıseferoğullari, & F. Evrendilek, "Assessing monthly average solar radiation models: a comparative case study in Turkey", Environmental Monitoring and Assessment, **175**(1-4), 251–277, 2010. https://doi.org/10.1007/s10661-010-1510-8

[38] A. Choudhary, D. Pandey, and A. Kumar, "A Review of Various Techniques for Solar Radiation Estimation," 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE), NOIDA, India, 169-174, 2019. https://doi.org/10.1109/RDCAPE47089.2019.8979001

[39] A. Choudhary, D. Pandey, and S. Bhardwaj, "Artificial Neural Network based Solar Radiation Estimation: A Case Study of Indian Cities", International Journal on Emerging Technologies, **11**(4): 257– 262, 2020.