Approximation of Empirical and ANN Based Solar Radiation Models for Four Smart Cities in Tamil Nadu with Most Prompting Input Parameters

V.Annapoorna, G.S.Gayathri, P.S.Manoharan

Abstract: The abundant source of Solar Radiation is possible in different latitude of Tamil Nadu. The several Empirical models have developed and accuracy of the model is further validated with Artificial Neural Network models. The ANN and Empirical model is developed with different combination of input attributes. The Approximate Sunshine Solar Radiation, Temperature and Relative Humidity are the input attributes. In this paper, it has been evaluated that combination of Approximate Sunshine Solar radiation and temperature ANN based model is best for prediction of Daily Global Solar Radiation when compared to ST based Empirical model. The Correlation analysis is performed for selection of most relevant input attributes. And hence the estimation of daily global solar radiation is performed with minimum number of input attributes. The training and testing of each model is performed by ANN Simulink model. And from this training input variables, the overfitting of the model is reduced. The estimated GSR is validated with experimental data which is collected from Tamil Nadu Agriculture University.

Keywords — Approximate Sunshine Solar radiation, Artificial Neural Network, Empirical Models, Meteorological Parameters, Classification, South India.

I INTRODUCTION

Solar energy is the most reliable source of energy that has the capability to endue and convert into electricity and living organisms on earth. It is the renewable energy sources that has high potential to meet the challenge around the world with respect to the environment issues associated with other non-renewable energy resources. The availability of solar radiation data is important for solar energy application especially in the developing countries. Since the cost of radiation measuring instrument is high. And it is not practically possible to implement the pyranometer at all the location. Therefore it is essential to assessment solar radiation models based on commonly available meteorological data such as temperature, sunshine duration, and relative humidity and so on. Selection of input parameter is the first step to develop models for estimation of daily global solar radiation. The prediction model has developed based on sunshine duration and clearness index [1]. Predicting the daily global solar radiation by day of the year using sigmoid curve fitting analysis and regression coefficient has been evaluated for different models [2]. Prediction of direct normal radiation and global solar radiation using neural network is proposed in [3]. The network configuration to select the number of hidden neuron and transfer function of different models has been evaluated. And similarly the estimation model is developed based on temperature, sunshine duration, clearness index and relative humidity. Int his the author extended an idea for selecting the most relevant input parameter for estimating the monthly averaged daily global solar radiation for different latitude [4]. The empirical model such as angstrom linear and nonlinear models has developed for horizontal surface. And accuracy model is assessed for central region of India at Bhopal [5]. Regression analysis is performed for thirteen locations in Turkey using linear, quadratic and third order polynomial equation [6]. The author recommended the idea to select the geostatistical interpolation and stochastic interpolation simulation approach based on distance between the target area and nearest neighbour station [7]. The estimation of future solar irradiance using timeseries analysis is discussed. In this work the short term, medium and long term solar radiation forecasting has been carried out using an algorithm such as EWMA and WCMA. And then suggested that for short term forecasting WCMA algorithm is suitable for long term forecasting pro energy algorithm is most suitable [8]. The number of input variables is reduced by selecting the most relevant variables using support vector machine algorithm. And exploratory variables such as sunshine duration, temperature, relative humidity, longitude, latitude and altitude are identified as most relevant input variable [9, 10, 11]. Artificial neural network modeling based Estimation of daily global solar radiation using on meteorological data has developed. The accuracy of the model is evaluated with and without considering particulate matter as an input variable [12]. The input predictor clearness index and sunshine duration is most important input variable is estimated and is assumed as solar radiation for humid — sub tropical climatic region [13, 14, 15]. Estimation of monthly global solar radiation by temperature and sunshine duration as an input parameter based model has analyzed for southern region of India [16, 17, 18]. The model has developed for prediction of global solar radiation based on selecting relevant input parameters using WEKA for Artificial Neural Network [19]. The accuracy and model has developed with ANN is detailed studied in following literatures [20–24]. The unique

Revised Manuscript Received on November 15, 2019
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empirical model cannot be selected for southern region of Tamil Nadu, since as the latitude and longitude varies the prediction accuracy of the model is varied. Therefore, the correlation between different input parameters and output parameter has to be studied to evaluate the prediction accuracy. The computation time for empirical model is huge. Hence, in this work it has concentrated to develop the more accurate and unique model with suitable input attributes to estimate daily global solar radiation is a significant research gap.

This work is focused on the identification of most relevant input attributes and to reduce complexity of the data using Artificial Neural Network. It also concentrated to improve the correlation coefficient and to reduce the error of selected solar radiation models. In this a comparison studies has been performed to select best model among ANN and Empirical Model. Six ANN models are observed. Sunshine data is not available for all position. Therefore, the temperature based ANN models developed instead of sunshine data. ANN Hybrid model is developed with more than one attribute combination. Based on the statistical errors such as Mean Absolute Percentage Error, Root Mean Square Error, Mean Square Error, Mean Absolute Error and Correlation Coefficient, the accurate and unique model is selected for southern region. The developed ANN and Empirical models are evaluated for prediction of daily global solar radiation for four cities in Tamil Nadu namely Chennai, Coimbatore, Trichy and Madurai. The estimated daily global solar radiation standards of all models are compared with experimental data of Tamil Nadu Agriculture University (TNAU), Madurai.

II DATABASE

The majority of literature not focused on Estimation of daily global solar radiation in southern region of Tamil Nadu, were great potential exit. And most of literature models are developed with sunshine data which data is not possible for all location and accuracy of the model varies with different latitude. Fig. 1 shows the selected geographical study region in different latitude of Tamil Nadu in India. The meteorological data is collected from Tamil Nadu Agriculture University.

The Approximate Sunshine Radiation, maximum temperature, minimum temperature and relative humidity are the input attribute selected for four different locations in Tamil Nadu were collected from TNAU. Latitude, longitude and climatic classification are the geographical parameters shown in Table I. And collected data is separated as a $2/3^{rd}$ training dataset and $1/3^{rd}$ testing dataset. These data is further processed with six ANN and thirteen Empirical models. MATLAB 2017a computing software is used for developing ANN models and Curve Fitting tools in MATLAB is used for developing Empirical models.

Table- I: Geographical parameters for particular location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Climatic Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madurai</td>
<td>9.92</td>
<td>78.12</td>
<td>Southern</td>
</tr>
<tr>
<td>Trichy</td>
<td>10.79</td>
<td>78.70</td>
<td>Cauvery delta</td>
</tr>
<tr>
<td>Coimbatore</td>
<td>11.01</td>
<td>76.95</td>
<td>Western</td>
</tr>
<tr>
<td>Chennai</td>
<td>13.08</td>
<td>80.27</td>
<td>North eastern</td>
</tr>
</tbody>
</table>

Here the four different zone performances are analyzed through training set of data and testing remaining set of data. And comparative studies have made between the ANN and Empirical models.

III EMPIRICAL MODEL DEVELOPMENT

The five years solar radiation data is taken as input variable. In the present study, the models were developed by correlating the data of $(\frac{E}{F_0})$ The approximate sunshine duration on the horizontal surface is considered about 120 MJ/(m²/day) of measured solar radiation and the maximum possible radiation $(\bar{S}_0)$ based on measured data from the considered location

$$ F_0 \approx \frac{H_e x (1 + 0.033 \cos \left( \frac{225 - n}{365} \right) ) x \left( \cos \delta \cos \phi \cos \omega s + \frac{1}{\sin \omega s} \sin \delta \right)}{\sin \omega s} \ldots (1) $$

Where, $H_e$, is the solar constant with the value of 1367 $(\frac{W}{m^2}), \bar{S}_0$ is the terrestrial global solar radiation on the earth surface $(\bar{H}),$ and the extraterrestrial radiation $(H_0)$ $n$ is the Julian day of the year, $\phi$ is the location latitude, and $\delta$ and $\omega s$ is mathematically defined as:

$$ \delta = 23.45 \sin \left( \frac{360 (126 + 5 \phi)}{365} \right) \ldots (2) $$

$$ \omega s = \frac{z}{15} \ldots (3) $$

$$ \cos \omega s = - \tan \phi \tan \delta \ldots (4) $$

The estimation of global solar radiation is depends on the meteorological data and geometrical data. Therefore, models can be classified in to three following:

1. Approximate Solar Radiation
2. Temperature
3. Hybrid parameters
Approximation of Empirical and ANN Based Solar Radiation Models for Four Smart Cities in Tamil Nadu with Most Prompting Input Parameters.

A. SUNSHINE – BASED MODELS STUDY SELECTED

Thirteen numbers of models are employed for estimation of daily global solar radiation from commonly available meteorological parameters available in the literature. Five models are developed with sunshine duration as input parameters. These models are developed and statistical index are analyzed by Curve fitting tool in MATLAB as referred in literature [15]. Most of the literature has shown the highest accuracy result on sunshine based model. Hence, the clearness index is related with sunshineduration.

Group 1

The Angstrom and Prescott first order polynomial model is given by

\[
\frac{\overline{H}}{H_0} = a + b \left( \frac{\overline{D}}{D_0} \right)
\]  
(5)

The following Eq. (6-9) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai.

\[
\frac{\overline{H}}{H_0} = 0.891 + 0.090 \left( \frac{\overline{D}}{D_0} \right)
\]  
(6)

\[
\frac{\overline{H}}{H_0} = -0.532 + 0.173 \left( \frac{\overline{D}}{D_0} \right)^2
\]  
(7)

\[
\frac{\overline{H}}{H_0} = -0.533 + 0.168 \left( \frac{\overline{D}}{D_0} \right)
\]  
(8)

\[
\frac{\overline{H}}{H_0} = -0.536 + 0.177 \left( \frac{\overline{D}}{D_0} \right)
\]  
(9)

Group 2

Kadir Bakirci [2017] developed the nonlinear Model such as the quadratic (second order polynomial) form.

\[
\frac{\overline{H}}{H_0} = a + b \left( \frac{\overline{D}}{D_0} \right) + c \left( \frac{\overline{D}}{D_0} \right)^2
\]  
(10)

Where \(a\), \(b\) and \(c\) are quadratic model regression coefficient. Eq. (11-14) as follow below the models developed for four cities Vishnu and Annam [2018] proposed model for Madurai

\[
\frac{\overline{H}}{H_0} = 0.310 - 0.542 \left( \frac{\overline{D}}{D_0} \right) + 0.149 \left( \frac{\overline{D}}{D_0} \right)^2
\]  
(11)

Obtained model for Trichy location

\[
\frac{\overline{H}}{H_0} = -0.381 + 0.118 \left( \frac{\overline{D}}{D_0} \right) + 0.495 \left( \frac{\overline{D}}{D_0} \right)^2
\]  
(12)

Derived model for Western Zone (Coimbatore)

\[
\frac{\overline{H}}{H_0} = 0.250 - 0.883 \left( \frac{\overline{D}}{D_0} \right) + 0.902 \left( \frac{\overline{D}}{D_0} \right)^2
\]  
(13)

Estimated second order polynomial model for Chennai

\[
\frac{\overline{H}}{H_0} = -0.918 + 0.313 \left( \frac{\overline{D}}{D_0} \right) - 1.182 \left( \frac{\overline{D}}{D_0} \right)^2
\]  
(14)

Group 3

The third-order polynomial Liu and Jordan based Model are as follows;

\[
\frac{\overline{H}}{H_0} = a + b \left( \frac{\overline{D}}{D_0} \right) + c \left( \frac{\overline{D}}{D_0} \right)^2 + d \left( \frac{\overline{D}}{D_0} \right)^3
\]  
(15)

\[
\frac{\overline{H}}{H_0} = -0.817 + 0.473 \left( \frac{\overline{D}}{D_0} \right) - 0.872 \left( \frac{\overline{D}}{D_0} \right)^2 + 0.543 \left( \frac{\overline{D}}{D_0} \right)^3
\]  
(16)

\[
\frac{\overline{H}}{H_0} = 0.710 - 0.352 \left( \frac{\overline{D}}{D_0} \right) + 0.743 \left( \frac{\overline{D}}{D_0} \right)^2 - 0.441 \left( \frac{\overline{D}}{D_0} \right)^3
\]  
(17)

\[
\frac{\overline{H}}{H_0} = 0.524 - 0.272 \left( \frac{\overline{D}}{D_0} \right) + 0.469 \left( \frac{\overline{D}}{D_0} \right)^2 - 0.253 \left( \frac{\overline{D}}{D_0} \right)^3
\]  
(18)

\[
\frac{\overline{H}}{H_0} = 0.682 - 0.381 \left( \frac{\overline{D}}{D_0} \right) + 0.712 \left( \frac{\overline{D}}{D_0} \right)^2 - 0.252 \left( \frac{\overline{D}}{D_0} \right)^3
\]  
(19)

Group 4

If the coefficient associated with exponential is negative then, its result in decreased value. If the coefficient associated with exponential is positive then, its result in increased value.

\[
\frac{\overline{H}}{H_0} = a \left( \frac{\overline{D}}{D_0} \right)^b
\]  
(20)

The following Eq. (21-24) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai. It is the exponential model derived for four cities by considering sunshine duration as the input parameters.

\[
\frac{\overline{H}}{H_0} = 0.233 \left( \frac{\overline{D}}{D_0} \right)^{1.47}
\]  
(21)

\[
\frac{\overline{H}}{H_0} = 0.435 \left( \frac{\overline{D}}{D_0} \right)^{0.403}
\]  
(22)

\[
\frac{\overline{H}}{H_0} = 0.446 \left( \frac{\overline{D}}{D_0} \right)^{0.397}
\]  
(23)

\[
\frac{\overline{H}}{H_0} = 0.594 \left( \frac{\overline{D}}{D_0} \right)^{0.358}
\]  
(24)

Group 5

The following Eq. (25-29) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai. It is the natural logarithmic model derived for four cities by considering sunshine duration as the input parameters.

\[
\frac{\overline{H}}{H_0} = a + b \log \left( \frac{\overline{D}}{D_0} \right)
\]  
(25)

\[
\frac{\overline{H}}{H_0} = -0.361 + 0.486 \log \left( \frac{\overline{D}}{D_0} \right)
\]  
(26)

\[
\frac{\overline{H}}{H_0} = -0.121 + 0.964 \log \left( \frac{\overline{D}}{D_0} \right)
\]  
(27)

\[
\frac{\overline{H}}{H_0} = -0.125 + 0.954 \log \left( \frac{\overline{D}}{D_0} \right)
\]  
(28)

\[
\frac{\overline{H}}{H_0} = 0.126 + 0.100 \log \left( \frac{\overline{D}}{D_0} \right)
\]  
(29)
B. TEMPERATURE BASED MODELS

The four temperature based empirical models are developed. Instead of Sunshine data, the temperature data are used. Since Sunshine data is not readily available in every location, these following models are referred in literature [11].

Group 1

The following Eq. (30-49) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai. These are the model derived for four cities by considering Temperature as the input parameters.

\[
\frac{\bar{H}}{H_a} = (1 - \exp(-0.511\Delta T^{0.905}))^{31}
\]  
\[
\frac{\bar{H}}{H_a} = (1 - \exp(-0.751\Delta T^{0.769}))^{32}
\]  
\[
\frac{\bar{H}}{H_a} = (1 - \exp(-0.179\Delta T^{0.201}))
\]  
\[
\frac{\bar{H}}{H_a} = (1 - \exp(-0.751\Delta T^{0.719}))
\]

Group 2

\[
\frac{\bar{H}}{H_a} = a(T_{max} - T_{min})^{0.5} + b
\]
\[
\frac{\bar{H}}{H_a} = 0.246(T_{max} - T_{min})^{0.5} + 0.420
\]
\[
\frac{\bar{H}}{H_a} = 0.131(T_{max} - T_{min})^{0.5} + 0.327
\]
\[
\frac{\bar{H}}{H_a} = 0.272(T_{max} - T_{min})^{0.5} - 0.516
\]
\[
\frac{\bar{H}}{H_a} = 0.131(T_{max} - T_{min})^{0.5} + 0.327
\]

Group 3

\[
\frac{\bar{H}}{H_a} = a + b\left(\frac{T_{min}}{T_{max}}\right)
\]
\[
\frac{\bar{H}}{H_a} = 0.294 + 0.434\left(\frac{T_{min}}{T_{max}}\right)
\]
\[
\frac{\bar{H}}{H_a} = 0.251 + 0.117\left(\frac{T_{min}}{T_{max}}\right)
\]
\[
\frac{\bar{H}}{H_a} = 0.501 - 0.817\left(\frac{T_{min}}{T_{max}}\right)
\]

C. HYBRID BASED MODELS

Here, four groups of models are developed with more than one attributes as input parameters. Relative Humidity and Approximate Solar Radiation combination are developed in first group. And the combination of Relative humidity and Temperature based models are performed in second group. Similarly three attribute combination has developed in third group. It involves attribute as Approximate Solar Radiation, Relative humidity and Temperature. And finally the fourth group has developed by the combination of Approximate Solar Radiation and Temperature.

Group 1

\[
\frac{\bar{H}}{H_a} = 0.253 - 0.172\left(\frac{T_{min}}{T_{max}}\right)
\]

Group 4

\[
\frac{\bar{H}}{H_a} = a + b\left(\frac{T_{min}}{T_{max}}\right)\left(\frac{T_{min}}{T_{max}}\right)^c
\]
\[
\frac{\bar{H}}{H_a} = 0.586 + 0.593\left(\frac{T_{min}}{T_{max}}\right)\left(\frac{T_{min}}{T_{max}}\right)^{0.389}
\]
\[
\frac{\bar{H}}{H_a} = 0.257 + 0.161\left(\frac{T_{min}}{T_{max}}\right)\left(\frac{T_{min}}{T_{max}}\right)^{0.688}
\]
\[
\frac{\bar{H}}{H_a} = 0.623 + 0.591\left(\frac{T_{min}}{T_{max}}\right)\left(\frac{T_{min}}{T_{max}}\right)^{0.688}
\]
Approximation of Empirical and ANN Based Solar Radiation Models for Four Smart Cities in Tamil Nadu with Most Prompting Input Parameters.

Group 2
The following Eq. (55-59) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai. These are the model derived for four cities by considering Temperature and Relative humidity as the input parameters.

\[ \frac{H}{H_0} = a + b \left( \frac{T_{\min}}{T_{\max}} \right) + c(RH) \] (55)

\[ \frac{H}{H_0} = 0.128 + 0.301 \left( \frac{T_{\min}}{T_{\max}} \right) + 0.951(RH) \] (56)

\[ \frac{H}{H_0} = 1.712 - 0.785 \left( \frac{T_{\min}}{T_{\max}} \right) - 0.116(RH) \] (57)

\[ \frac{H}{H_0} = 0.123 + 0.406 \left( \frac{T_{\min}}{T_{\max}} \right) - 0.754(RH) \] (58)

\[ \frac{H}{H_0} = 1.082 - 0.274 \left( \frac{T_{\min}}{T_{\max}} \right) - 0.567(RH) \] (59)

Group 3
The following Eq. (60-64) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai. These are the model derived for four cities by considering Approximate Solar Radiation, Temperature and Relative humidity as input parameters.

\[ \frac{H}{H_0} = a + b \left( \frac{S}{30} \right) + c \left( \frac{T_{\min}}{T_{\max}} \right) + d(RH) \] (60)

\[ \frac{H}{H_0} = 0.762 + 0.964 \left( \frac{S}{30} \right) + 1.149 \left( \frac{T_{\min}}{T_{\max}} \right) + 0.267(RH) \] (61)

\[ \frac{H}{H_0} = -0.175 + 0.108 \left( \frac{S}{30} \right) - 0.190 \left( \frac{T_{\min}}{T_{\max}} \right) + 0.264(RH) \] (62)

\[ \frac{H}{H_0} = 0.880 + 0.578 \left( \frac{S}{30} \right) - 0.689 \left( \frac{T_{\min}}{T_{\max}} \right) - 4.63(RH) \] (63)

\[ \frac{H}{H_0} = 1.022 + 0.122 \left( \frac{S}{30} \right) - 0.741 \left( \frac{T_{\min}}{T_{\max}} \right) + 0.234(RH) \] (64)

Group 4
The following Eq. (65-69) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai. These are the model derived for four cities by considering Approximate Solar Radiation and Temperature as the input parameters.

\[ \frac{H}{H_0} = a + b \left( \frac{S}{30} \right) + c \left( \frac{T_{\min}}{T_{\max}} \right) \] (65)

\[ \frac{H}{H_0} = 0.209 + 0.104 \left( \frac{S}{30} \right) + 1.611 \left( \frac{T_{\min}}{T_{\max}} \right) \] (66)

\[ \frac{H}{H_0} = -0.409 + 0.113 \left( \frac{S}{30} \right) + 0.411 \left( \frac{T_{\min}}{T_{\max}} \right) \] (67)

\[ \frac{H}{H_0} = 0.760 + 0.435 \left( \frac{S}{30} \right) - 0.783 \left( \frac{T_{\min}}{T_{\max}} \right) \] (68)

\[ \frac{H}{H_0} = -0.487 + 0.119 \left( \frac{S}{30} \right) + 0.477 \left( \frac{T_{\min}}{T_{\max}} \right) \] (69)

IV ANN BASED MODEL DEVELOPMENT
ANN is simple to predict to predict the behavior of complex systems with multiple input domains. The ANN Gradient descent approach is used to functioned ANN output and the target. The ANN target can be attained by adjusting weights and bias es of ANN output. AN N can perform tasks that which cannot be performed by linear method. ANN learns and does not need to be reprogrammed. Simultaneously, the performance of multiple inputs can be analyzed. The four ANN models to assess the daily global solar radiation are given in Table II. The model has developed by using single input parameter such as Approximate Solar Radiation, Relative Humidity and Temperature.

Table -II: Models developed by using ANN

<table>
<thead>
<tr>
<th>Models</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANN-S</td>
<td>S, SO</td>
</tr>
<tr>
<td>ANN-T</td>
<td>T_{max}, T_{min}</td>
</tr>
<tr>
<td>ANN-ST, TH, SH, STH</td>
<td>S, S, T_{max}, T_{min}, RH</td>
</tr>
</tbody>
</table>

Andalso models havedevelopedby usingthecom binationof Approximate Solar Radiation, temperature and relative humidity as combination of input variables. The correlation result for different attribute is presented in a Table III. Maximum temperature is the first input parameter gives the best correlation of 0.780 to assess the solar radiation. Approximate Solar Radiation is the second input parameter gives the correlation of 0.666. Relative humidity gives the least correlation 0.336. Prediction result is better, when the R value is higher.

Table -III: Correlation developed by ANN for different attributes with measured GSR

<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Correlation R</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright sunshine</td>
<td>0.666</td>
<td>2</td>
</tr>
<tr>
<td>T_{max}</td>
<td>0.780</td>
<td>1</td>
</tr>
<tr>
<td>T_{min}</td>
<td>0.531</td>
<td>3</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>0.3361</td>
<td>4</td>
</tr>
</tbody>
</table>

The correlation Coefficient R values ranges between 0.336 and 0.666. The necessity of the Correlation analysis is to reduce the number of input attributes. And also it is used to obtainare素养thathowtheoutputputdataisrelevanttotheinput attributes. Regression plots developed between input attributes and output data using neural network is shown in Fig.
2. Maximum temperature is the first input parameter gives the best correlation of 0.780 to enhance the prediction of global solar radiation.

Fig. 2. Regression plots developed between input attributes and output data using neural network

**A. TESTING PERFORMANCE**

The selected best ANN-ST model is tested for four sites in Tamil Nadu. The best model is selected based on the training error. The model has a less error and high correlation is selected as the best model. Fig. 3 gives the Simulink model for testing analysis. Initially the network has the threelayers. Input as a first layer, hidden is the middle layer and target as an output layer. In input layer, two parameters are taken as input such as Sunshine radiation and temperature - minimum and maximum. The log sigmoidal and purlin are the function of the network. Since, the solar irradiance data varied for every month. It is also a seasonal data which is lead to non-linear data.

Fig. 3. Simulink of selected best ST-ANN model

In hidden layer five neurons are used and weights are obtained. Hidden to output layer is the second layer where a single output is obtained. The solar irradiance data is obtained in the output layer. The Simulink model is tested for foursites and daily solar irradiance is predicted. The weights adjustment in the network is shown in Fig. 4. The five neurons carries the weights in the hidden layer is product with the input parameters. The single output solar irradiance is predicted very accurately based on the collected data.

![Weights adjustment of the model network](image)

And regression curves drawn between the measured and the observed data. The converged weights are given in equations 70 to 73. The weights and biases between the input and the hidden neurons are given in 72 and 73. The weights in the hidden neurons are dot product with the input parameters.

\[
\begin{bmatrix}
W_{11} & W_{12} & W_{13} \\
W_{21} & W_{22} & W_{23} \\
W_{31} & W_{32} & W_{33} \\
W_{41} & W_{42} & W_{43} \\
W_{51} & W_{52} & W_{53}
\end{bmatrix} =
\begin{bmatrix}
0.058 \\
-1.672 \\
-1.005 \\
-1.516 \\
0.103
\end{bmatrix}
\] (70)

\[
\begin{bmatrix}
b_1 \\
b_2 \\
b_3 \\
b_4 \\
b_5
\end{bmatrix} =
\begin{bmatrix}
2.532 \\
0.876 \\
-0.418 \\
-1.961 \\
-2.689
\end{bmatrix}
\] (71)

Where, \(W_{11}\) - Weight between first input parameter and first hidden neuron.

\(W_{12}\) - Weight between first input parameter and second hidden neuron.

\(W_{22}\) - Weight between second input parameter and second hidden neuron.

\(W_{33}\) - weight between third input parameter and third hidden neuron.

\(b_1\) is the bias of the first neuron.

\(b_2\) is the bias of the second neuron.

The weight and bias between the hidden neuron and output layer is given in the equations 72 to 73. It is second layer of the network.
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\[
\begin{bmatrix}
W_{31} \\
W_{32} \\
W_{33} \\
W_{34} \\
W_{35}
\end{bmatrix} = \begin{bmatrix}
-0.755 \\
-0.399 \\
1.296 \\
0.384 \\
0.518
\end{bmatrix}
\]

(72)

\[
[b] = [0.408]
\]

(73)

Where, \( W_{ij} \) is the weight between second hidden layer output and the output layer.

\( b \) is the bias of the hidden neuron.

The correlation between measured and observed GSR is shown in Fig. 5. From this figure it is analysed that agreement between the estimated and measured daily global solar radiation is very high.

The regression coefficient \( R^2 \) value for Madurai is 0.9908 and 0.9828 for Trichy, which shows the higher accuracy for selected smart cities. Similarly the regression coefficient for Coimbatore and Chennai is 0.93813 and 0.99614. The ANN model performance gives the higher accuracy than empirical model. By the comparative studies it is analysed that for south India the ST model is best for assessment of daily global solar radiation.

\[
\begin{bmatrix}
W_{31} \\
W_{32} \\
W_{33} \\
W_{34} \\
W_{35}
\end{bmatrix} = \begin{bmatrix}
-0.755 \\
-0.399 \\
1.296 \\
0.384 \\
0.518
\end{bmatrix}
\]

(72)

\[
[b] = [0.408]
\]

(73)

\[
\text{MAPE}=3.6\%, \text{RMSE}=0.580 \text{ (MJ m}^{-2}\text{ day}^{-1}) \text{, MAE}=0.153 \text{ (MJ m}^{-2}\text{ day}^{-1}) \text{ and this model can be used for the location where the sunshine radiation is only available.}
\]

Table - IV: Error statistics and Empirical coefficient of estimation of daily GSR in Madurai and Trichy

\[
\begin{align*}
\text{MAPE} &= 3.6\%, \text{RMSE} = 0.580 \text{ (MJ m}^{-2}\text{ day}^{-1}), \text{MAE} = 0.153 \text{ (MJ m}^{-2}\text{ day}^{-1}) \text{ and this model can be used for the location where the sunshine radiation is only available.}
\end{align*}
\]

And further the temperature based model gives the worst performance for this location. Hybrid model H2, gives the worst performance compared to other hybrid models. Since the model is based on Temperature and Relative Humidity. It does not depend on Sunshine radiation. And it can analyze that combination of sunshine radiation and Temperature (H4 or ST) based model is the most relevant input parameter to predict the DSR. Trichy is very hottest city in the Tamil Nadu and is located on the central south-eastern of India. For Trichy, the best performance is presented by model H4 in hybrid category with R value of 0.95, MSE=0.29 (MJ m\(^{-4}\)day\(^{-1}\)), MAPE=3.2%, RMSE=0.538 (MJ m\(^{-2}\)day\(^{-1}\)), MAE=0.162 (MJ m\(^{-2}\)day\(^{-1}\)). In sunshine model S5 gives the best performances with R value of 0.756, MSE=1.13 (MJ m\(^{-4}\)day\(^{-1}\)), MAPE=1.1%, RMSE=1.06 (MJ m\(^{-2}\)day\(^{-1}\)), MAE=0.532 (MJ m\(^{-2}\)day\(^{-1}\)). Temperature based model gives the worst performance. Since according to the climatic condition, the minimum and maximum temperature of the southeastern region varies randomly every day. Hence the temperature based models is not suited for south eastern region of India. Similarly, thirteen models are performed for Chennai and Coimbatore. Table V gives a summary of error statistics and empirical coefficients of the thirteen empirical models for south western and south central are presented in India. Chennai is located on the north eastern of India and it has tropical wet and dry climate. For Chennai, the best performance is presented by model H4 in hybrid category with regression coefficient R=0.987, MSE=0.165 (MJ m\(^{-4}\)day\(^{-1}\)), MAPE=1.1%, RMSE=0.404 (MJ m\(^{-2}\)day\(^{-1}\)),

V OVERALL PERFORMANCE

The performances of sunshine, temperature and hybrid empirical model are analyzed through the Curve Expert Software. Each location was analyzed with thirteen models. An error statistics and empirical coefficients result of the thirteen empirical models for Madurai and Trichy are presented in Table IV. For Madurai Hybrid model H4 gives the best GSR estimation with least MSE=0.20 (MJ m\(^{-2}\)day\(^{-1}\)), MAPE=5.1%, RMSE=0.440 (MJ m\(^{-2}\)day\(^{-1}\)), MAE=0.224 (MJ m\(^{-2}\)day\(^{-1}\)) and regression coefficient value of 0.962. Sunshine based model S5 gives the best estimation with MSE=0.34 (MJ m\(^{-4}\)day\(^{-1}\)).
MAE = 0.08 (MJ m\(^{-2}\) day\(^{-1}\)). S4 is the second best model with R = 0.78, MSE = 1.17 (MJ m\(^{-2}\) day\(^{-1}\)), MAPE = 1.1%, RMSE = 1.08 (MJ m\(^{-2}\) day\(^{-1}\)). The third best model is T3 in temperature category with R = 0.659, MSE = 0.75 (MJ m\(^{-2}\) day\(^{-1}\)), MAPE = 1.8%, RMSE = 0.867 (MJ m\(^{-2}\) day\(^{-1}\)), MAE = 0.09 (MJ m\(^{-2}\) day\(^{-1}\)).

### Table V: Error statistics and Empirical coefficient of estimation of daily GSR in Chennai and Coimbatore

<table>
<thead>
<tr>
<th>City</th>
<th>Error Statistics</th>
<th>Empirical Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chennai</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coimbatore</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coimbatore is located on the southwestern India and thus has a pleasant climate. For Coimbatore, the best performance is presented by model H4 in hybrid category with regression coefficient R = 0.918, MSE = 0.40 (MJ m\(^{-2}\) day\(^{-1}\)), MAPE = 2.1%, RMSE = 0.632 (MJ m\(^{-2}\) day\(^{-1}\)), MAE = 0.04 (MJ m\(^{-2}\) day\(^{-1}\)). T4 is the second best model with R = 0.865, MSE = 0.476 (MJ m\(^{-2}\) day\(^{-1}\)), MAPE = 1.1%, RMSE = 0.68 (MJ m\(^{-2}\) day\(^{-1}\)), MAE = 0.06 (MJ m\(^{-2}\) day\(^{-1}\)).

S3 is the third best model with R = 0.681, MSE = 1.423 (MJ m\(^{-2}\) day\(^{-1}\)), MAPE = 3.4%, RMSE = 1.19 (MJ m\(^{-2}\) day\(^{-1}\)), MAE = 1.89 (MJ m\(^{-2}\) day\(^{-1}\)). Overall, the model H4 performed best for all four studies with R value between 0.918 and 0.987, RMSE value between 0.404 to 0.632, MSE values between 0.163 and 0.404 and MAPE value between 1.1 and 5.1. The higher accuracy is obtained by using most relevant input attributes. The H2 has least performance, since model has developed with least attributes. H4 has highest accuracy, since it depends on most relevant attribute as Approximate Solar Radiation and Temperature. Therefore, the approximate solar radiation and temperature data plays an important role for estimation of global solar radiation. Temperature input parameters gives best estimation for only pleasant climate such as Coimbatore, since the maximum temperature 35.9°C and minimum temperature is 19.8°C.

In this section the performance of best evaluated parametric model is compared with ANN-ST and Empirical model. Some of days predicted data is far different from measured data. And for predicted data of ANN is closer to the measured data. It is achieved by training a large number of data and data has learned by the network. The mean square error of ANN and empirical model is shown in Fig. 6. It is evaluated that error between the measured data and predicted data is minimized in ANN. So the prediction accuracy can be improved by ANN.

![Fig. 6. Evaluation of measured and predicted data of ANN and Empirical model](image)

When compared to ANN, the error calculated from the empirical is higher and the accuracy is minimized. Hence the ANN – ST model can be used for predictive based problems. The performance indicator for both selected ANN-ST and Empirical-ST model is given in Table VI. The mean square error, mean absolute error, mean absolute percentage error, root mean square error and regression coefficient are the statistical indicator which has calculated for four cities. From the
Approximation of Empirical and ANN Based Solar Radiation Models for Four Smart Cities in Tamil Nadu with Most Prompting Input Parameters.

Table - VI: Performance indicators of the selected ANN- ST and Empirical- ST models for four sites.

<table>
<thead>
<tr>
<th>Model/ Location</th>
<th>MAE (MJ m⁻² day⁻¹)</th>
<th>MAPE (%)</th>
<th>MSE (MJ m⁻² day⁻¹)</th>
<th>RMSE (MJ m⁻² day⁻¹)</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Empirical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madurai</td>
<td>0.224</td>
<td>5.1</td>
<td>0.200</td>
<td>0.440</td>
<td>0.303</td>
</tr>
<tr>
<td>Trichy</td>
<td>0.16</td>
<td>3.2</td>
<td>0.29</td>
<td>0.538</td>
<td>0.388</td>
</tr>
<tr>
<td>Chennai</td>
<td>0.08</td>
<td>1.1</td>
<td>0.165</td>
<td>0.404</td>
<td>0.724</td>
</tr>
<tr>
<td>Coimbatore</td>
<td>-0.04</td>
<td>2.1</td>
<td>0.40</td>
<td>0.632</td>
<td>0.707</td>
</tr>
<tr>
<td><strong>ANN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madurai</td>
<td>0.128</td>
<td>4.3</td>
<td>0.016</td>
<td>0.2076</td>
<td>0.990</td>
</tr>
<tr>
<td>Trichy</td>
<td>0.149</td>
<td>3.0</td>
<td>0.022</td>
<td>0.173</td>
<td>0.982</td>
</tr>
<tr>
<td>Chennai</td>
<td>0.086</td>
<td>1.8</td>
<td>0.007</td>
<td>0.134</td>
<td>0.996</td>
</tr>
<tr>
<td>Coimbatore</td>
<td>0.055</td>
<td>1.0</td>
<td>0.003</td>
<td>0.110</td>
<td>0.938</td>
</tr>
</tbody>
</table>

Initially for Coimbatore has the highest accuracy of 0.999, since it has a mild climate and solar radiation is not varied rapidly. Next to it, Madurai is achieved the highest accuracy of 0.998. And similarly for Trichy, the regression coefficient is about 0.992. Compared thesefourcitiesChennaihaslowest accuracy of 0.988. Similarly the error statistics has calculated. The highest accuracy of ST based ANN model is 0.996 and ST based Empirical model is 0.707. The accuracy of ANN – ST model is high, since the large number of data is learned during training process. And with this selected best model is ST based ANN model for four sites. Thus the empirical model tested for four sites in Tamil Nadu with Most Prompting Input Parameters.

V. CONCLUSION

In this work, the comparative studies have made between Empirical and ANN models for the prediction of GSR. Three sub-classes of model have developed namely temperature, sunshine and hybrid model. It is foundsunshine and temperature is most influencing parameter for estimation of daily GSR. And relative humidity is minimum influencing parameter. In both empirical and ANN, the combination of sunshine and temperature model gives the best result. Further this selected best model is tested for four sites in Tamil Nadu, which denotes the highest accuracy. And compared to ANN - ST, the empirical- ST gives worst performance for four

cities. Hence the ANN - ST model can be used for prediction of daily global solar radiation. This combination of temperature and sunshine based ANN model is best for prediction of daily global solar radiation in southern states of India.

Predicted and estimated daily average GSR of best hybrid model H4 for four cities in Tamil Nadu is shown in Fig 8. The average daily GSR computed for four smart cities of Tamil Nadu using H4 model. The accuracy of ST based ANN model is 0.996 and ST based Empirical model is 0.707. The accuracy of ANN – ST model is high, since the large number of data is learned during training process. And with this selected best model is ST based ANN model for four sites. Thus the empirical model tested for four sites in Tamil Nadu, which denotes the highest accuracy. And compared to ANN - ST, the empirical- ST gives worst performance for four

REFERENCES


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