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

V.Annapeachi, 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 performedfor 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 trainingofinputvariables,theoverfittingofthemodelisreduced. The estimated GSR is validated with experimental data which is collected from Tamil Nadu AgricultureUniversity.

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

I INTRODUCTION

Solarenergyisthemostreliablesourceofenergythathas capacitytoendureandconversethelifeofalllivingorganism on earth. It is the renewable energy sources that has high potentialtomeetachallengearoundtheworldwithrespectto the environment issues associated with other non-renewable energy resources. The availability of solar radiation data is important 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 itis essential to assessment solar radiation models based on commonlyavailablemeteorologicaldatasuchastemperature, sunshine radiation 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 clearnessindex[1].Predictingthedailyglobalsolarradiation bydayoftheyearinsixcitiesusingcurvefittinganalysisand regressioncoefficienthasbeenevaluatedfordifferentmodels [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 andtransferfunctionofdifferentmodelshasbseenevaluated. And similarly the estimation model is developed based on temperature, sunshine duration, clearness index and relative humidity.Inthis,theauthorextendedanideaforselectingthe most relevant input parameter for estimating the monthly averageddailyglobalsolarradiationfordifferentlatitude[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 futuresolarirradianceusingtimeseriesanalysisisdiscussed. In this work the short term, medium and long term solar radiation forecasting has been carried out using an algorithm such that EWMA and WCMA. And then suggested that for short term forecasting WCMA algorithm is suitable and for long term forecasting pro energy algorithm is most suitable [8].Thenumberofinputvariableisreducedbyselectingmost 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 durationismostimportantinputvariabletoestimatediffused 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]. Theunique

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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 ishuge. 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 hasbeenperformedtoselectbestmodelamongtheANNand 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 are developed with more thanoneattributecombination.Basedonthestatisticalerrors 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 dailyglobal solarradiationforfourcitiesinTamilNadunamelyChennai, 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 dailyglobalsolarradiationinsouthernregionofTamilNadu, were great potential exit. And most of literature models are developedwithsunshinedatawhichdataisnotpossibleforall 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 meteorologicaldataiscollectedfromTamilNaduAgriculture University.

Fig. 1. Location of study region

The Approximate Sunshine Radiation, maximum temperature, minimum temperature and relative humidityare 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 2/3rd trainingdatasetand1/3rdtestingdataset.Thesedataisfurther processed with six ANN and thirteen Empirical models. MATLAB 2017a computing software is used for developing ANNmodelsandCurveFittingtoolsinMATLABisusedfor developing Empiricalmodels.

Table- I: Geographical parameters for particular location.

Location	**Latitude**	**Longitude**	**Climatic Zone**
Madurai	9.92	78.12	Southern
Trichy	10.79	78.70	Cauvery delta
Coimbatore	11.01	76.95	Western
Chennai	13.08	80.27	North eastern

Here the four different zone performances are analyzed throughtrainingasetofdataandtestingremainingsetofdata. And comparative studies have made between the ANN and Empiricalmodels.

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 $\left(\frac{\bar{s}}{\bar{s}_0}\right)$. The approximate sunshine duration on the horizontal surface is considered about *120 MJ/(m^{2}day)*ofmeasuredsolarradiationandthemaximum possible radiation $(\bar{s}_0)$based on measured data from the considered location

$$H_0 = \frac{24}{\pi} Hsc\left(1 + 0.033\cos\left(\frac{360}{365} \times n\right)\right) X \left(\cos\emptyset\cos\delta\ \sin\omega s + \frac{\pi}{180}\omega s \sin\emptyset\sin\delta\right) \quad (1)$$

Where, $H_{sc}$is the solar constant with the value of1367 $\left(\frac{\bar{H}}{H_0}\right)$ W/m^2, istheratioofglobalsolarradiationattheearth surface $(\bar{H})$ and the extraterrestrial radiation (H_0), n is the Julian day of the year, $\emptyset$ is the location latitude, and$\delta$and ωs is mathematically defined as:

$$\delta = 23.45^{\circ} \sin\left[\frac{360(284+n)}{365}\right] \quad (2)$$

$$s_0 = \frac{2}{15}\ \omega s \quad (3)$$

$$\cos\omega s = -\tan\emptyset\tan\delta \quad (4)$$

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

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A.SUNSHINE – BASED MODELS STUDY SELECTED

Thirteennumbersofmodelsareemployedforestimation of daily global solar radiation from commonly available meteorological parameters is available in the literature. Five models are developed with sunshine duration as input parameters. These models are developed and statistical index areanalyzedbyCurvefittingtoolinMATLABasreferredin 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

$$\frac{\bar{H}}{H_0} = a + b\left(\frac{\bar{s}}{so}\right) \quad (5)$$

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

$$\frac{\bar{H}}{H_0} = 0.891 + 0.090\left(\frac{\bar{s}}{so}\right) \quad (6)$$

$$\frac{\bar{H}}{H_0} = -0.532 + 0.173\left(\frac{\bar{s}}{so}\right) \quad (7)$$

$$\frac{\bar{H}}{H_0} = -0.533 + 0.168\left(\frac{\bar{s}}{so}\right) \quad (8)$$

$$\frac{\bar{H}}{H_0} = -0.536 + 0.177\left(\frac{\bar{s}}{so}\right) \quad (9)$$

Group 2

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

$$\frac{\bar{H}}{H_0} = a + b\left(\frac{\bar{s}}{so}\right) + c\left(\frac{\bar{s}}{so}\right)^2 \quad (10)$$

Where *a*, *b* and *c* are quadratic model regression coefficient. Eq.(11-14)asfollowbelowisthemodelsdevelopedforfour cities Vishnu and Annam [2018] proposed model for Madurai

$$\frac{\bar{H}}{H_0} = 0.310 - 0.542\left(\frac{\bar{s}}{so}\right) + 0.149\left(\frac{\bar{s}}{so}\right)^2 \quad (11)$$

Obtained model for Trichy location

$$\frac{\bar{H}}{H_0} = -0.381 + 0.118\left(\frac{\bar{s}}{so}\right) + 0.495\left(\frac{\bar{s}}{so}\right)^2 \quad (12)$$

Derived model for Western Zone (Coimbatore)

$$\frac{\bar{H}}{H_0} = 0.250 - 0.883\left(\frac{\bar{s}}{so}\right) + 0.902\left(\frac{\bar{s}}{so}\right)^2 \quad (13)$$

Estimated second order polynomial model forChennai

$$\frac{\bar{H}}{H_0} = -0.918 + 0.313\left(\frac{\bar{s}}{so}\right) - 1.182\left(\frac{\bar{s}}{so}\right)^2 \quad (14)$$

Group 3

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

$$\frac{\bar{H}}{H_0} = a + b\left(\frac{\bar{s}}{so}\right) + c\left(\frac{\bar{s}}{so}\right)^2 + d\left(\frac{\bar{s}}{so}\right)^3 \quad (15)$$

$$\frac{\bar{H}}{H_0} = -0.817 + 0.473\left(\frac{\bar{s}}{so}\right) - 0.872\left(\frac{\bar{s}}{so}\right)^2 + 0.542\left(\frac{\bar{s}}{so}\right)^3 \quad (16)$$

$$\frac{\bar{H}}{H_0} = 0.710 - 0.392\left(\frac{\bar{s}}{so}\right) + 0.743\left(\frac{\bar{s}}{so}\right)^2 - 0.441\left(\frac{\bar{s}}{so}\right)^3 \quad (17)$$

$$\frac{\bar{H}}{H_0} = 0.524 - 0.272\left(\frac{\bar{s}}{so}\right) + 0.469\left(\frac{\bar{s}}{so}\right)^2 - 0.253\left(\frac{\bar{s}}{so}\right)^3 \quad (18)$$

$$\frac{\bar{H}}{H_0} = 0.682 - 0.381\left(\frac{\bar{s}}{so}\right) + 0.712\left(\frac{\bar{s}}{so}\right)^2 - 0.252\left(\frac{\bar{s}}{so}\right)^3 \quad (19)$$

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.

$$\frac{\bar{H}}{H_0} = a\left(\frac{\bar{s}}{so}\right)^b \quad (20)$$

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 modelderived for four cities by considering sunshine duration as the input parameters.

$$\frac{\bar{H}}{H_0} = 0.233\left(\frac{\bar{s}}{so}\right)^{1.47} \quad (21)$$

$$\frac{\bar{H}}{H_0} = 0.435\left(\frac{\bar{s}}{so}\right)^{0.403} \quad (22)$$

$$\frac{\bar{H}}{H_0} = 0.446\left(\frac{\bar{s}}{so}\right)^{0.397} \quad (23)$$

$$\frac{\bar{H}}{H_0} = 0.594\left(\frac{\bar{s}}{so}\right)^{0.358} \quad (24)$$

Group 5

The following Eq. (26-29) are obtained daily global solar radiation model based on DB for Madurai, Trichy, Coimbatore and Chennai. It is the natural logarithmic model derivedforfourcitiesbyconsideringsunshinedurationasthe inputparameters.

$$\frac{\bar{H}}{H_0} = a + b\ log\left(\frac{\bar{s}}{so}\right) \quad (25)$$

$$\frac{\bar{H}}{H_0} = -0.361 + 0.486\ log\left(\frac{\bar{s}}{so}\right) \quad (26)$$

$$\frac{\bar{H}}{H_0} = -0.121 + 0.964\ log\left(\frac{\bar{s}}{so}\right) \quad (27)$$

$$\frac{\bar{H}}{H_0} = -0.125 + 0.954\ log\left(\frac{\bar{s}}{so}\right) \quad (28)$$

$$\frac{\bar{H}}{H_0} = 0.126 + 0.100\ log\left(\frac{\bar{s}}{so}\right) \quad (29)$$

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B.TEMPERATURE BASED MODELS

The four temperature based empirical models are developed.InsteadofSunshinedata,thetemperaturedataare used. Since Sunshine data is not readily available in every location.Thesefollowingmodelsaredevelopedasreferredin 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.

$$\frac{\overline{H}}{H_0} = (1 - exp(-a\Delta T)^b) \quad (30)$$

$$\frac{\overline{H}}{H_0} = (1 - exp(-0.511\Delta T)^{0.905}) \quad (31)$$

$$\frac{\overline{H}}{H_0} = (1 - exp(-0.751\Delta T)^{0.769}) \quad (32)$$

$$\frac{\overline{H}}{H_0} = (1 - exp(-0.179\Delta T)^{0.201}) \quad (33)$$

$$\frac{\overline{H}}{H_0} = (1 - exp(-0.751\Delta T)^{0.719}) \quad (34)$$

Group 2

$$\frac{\overline{H}}{H_0} = a(T_{max-}T_{min})^{0.5} + b \quad (35)$$

$$\frac{\overline{H}}{H_0} = 0.246(T_{max-}T_{min})^{0.5} + 0.420 \quad (36)$$

$$\frac{\overline{H}}{H_0} = 0.131(T_{max-}T_{min})^{0.5} + 0.327 \quad (37)$$

$$\frac{\overline{H}}{H_0} = 0.272(T_{max-}T_{min})^{0.5} - 0.516 \quad (38)$$

$$\frac{\overline{H}}{H_0} = 0.131(T_{max-}T_{min})^{0.5} + 0.327 \quad (39)$$

Group 3

$$\frac{\overline{H}}{H_0} = a + b\left(\frac{T_{min}}{T_{max}}\right) \quad (40)$$

$$\frac{\overline{H}}{H_0} = 0.294 + 0.434\left(\frac{T_{min}}{T_{max}}\right) \quad (41)$$

$$\frac{\overline{H}}{H_0} = 0.251 + 0.117\left(\frac{T_{min}}{T_{max}}\right) \quad (42)$$

$$\frac{\overline{H}}{H_0} = 0.501 - 0.817\left(\frac{T_{min}}{T_{max}}\right) \quad (43)$$

$$\frac{\overline{H}}{H_0} = 0.253 + -0.172\left(\frac{T_{min}}{T_{max}}\right) \quad (44)$$

Group 4

$$\frac{\overline{H}}{H_0} = \left(a + b\left(\frac{T_{min}}{T_{max}}\right)\right)\left(\frac{T_{min}}{T_{max}}\right)^c \quad (45)$$

$$\frac{\overline{H}}{H_0} = \left(0.588 + 0.593\left(\frac{T_{min}}{T_{max}}\right)\right)\left(\frac{T_{min}}{T_{max}}\right)^{0.389} \quad (46)$$

$$\frac{\overline{H}}{H_0} = \left(0.257 + 0.161\left(\frac{T_{min}}{T_{max}}\right)\right)\left(\frac{T_{min}}{T_{max}}\right)^{0.688} \quad (47)$$

$$\frac{\overline{H}}{H_0} = \left(0.623 + 0.591\left(\frac{T_{min}}{T_{max}}\right)\right)\left(\frac{T_{min}}{T_{max}}\right)^{0.468} \quad (48)$$

$$\frac{\overline{H}}{H_0} = \left(0.254 + 0.116\left(\frac{T_{min}}{T_{max}}\right)\right)\left(\frac{T_{min}}{T_{max}}\right)^{0.688} \quad (49)$$

C. HYBRID BASED MODELS

Here, four groups of models are developed with morethanoneattributesinputparameters.RelativeHumidity andApproximateSolarRadiationcombinationaredeveloped 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

The following Eq. (50-54) 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 Relative humidity as the input parameters.

$$\frac{\overline{H}}{H_0} = a + b\left(\frac{\overline{s}}{so}\right) + c(RH) \quad (50)$$

$$\frac{\overline{H}}{H_0} = 0.107 + 0.961\left(\frac{\overline{s}}{so}\right) + 0.114(RH) \quad (51)$$

$$\frac{\overline{H}}{H_0} = 0.153 + 0.968\left(\frac{\overline{s}}{so}\right) + 0.343(RH) \quad (52)$$

$$\frac{\overline{H}}{H_0} = 0.741 + 0.789\left(\frac{\overline{s}}{so}\right) - 0.118(RH) \quad (53)$$

$$\frac{\overline{H}}{H_0} = 0.357 + 0.119\left(\frac{\overline{s}}{so}\right) - 0.866(RH) \quad (54)$$

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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 fourcitiesbyconsideringTemperatureandRelativehumidity as the inputparameters.

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

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

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

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

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

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 the input parameters.

$$\frac{\bar{H}}{H_0} = a + b\left(\frac{\bar{s}}{so}\right) + c\left(\frac{T_{min}}{T_{max}}\right) + d(RH) \quad (60)$$

$$\frac{\bar{H}}{H_0} = 0.762 + 0.964\left(\frac{\bar{s}}{so}\right) + 1.149\left(\frac{T_{min}}{T_{max}}\right) + 0.267(RH) \quad (61)$$

$$\frac{\bar{H}}{H_0} = -0.175 + 0.108\left(\frac{\bar{s}}{so}\right) - 0.190\left(\frac{T_{min}}{T_{max}}\right) + 0.264(RH) \quad (62)$$

$$\frac{\bar{H}}{H_0} = 0.880 + 0.578\left(\frac{\bar{s}}{so}\right) - 0.689\left(\frac{T_{min}}{T_{max}}\right) - 4.63(RH) \quad (63)$$

$$\frac{\bar{H}}{H_0} = 1.022 + 0.122\left(\frac{\bar{s}}{so}\right) - 0.741\left(\frac{T_{min}}{T_{max}}\right) + 0.234(RH) \quad (64)$$

Group 4

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 and Temperature as the input parameters.

$$\frac{\bar{H}}{H_0} = a + b\left(\frac{\bar{s}}{so}\right) + c\left(\frac{T_{min}}{T_{max}}\right) \quad (65)$$

$$\frac{\bar{H}}{H_0} = 0.209 + 0.104\left(\frac{\bar{s}}{so}\right) + 1.611\left(\frac{T_{min}}{T_{max}}\right) \quad (66)$$

$$\frac{\bar{H}}{H_0} = -0.409 + 0.113\left(\frac{\bar{s}}{so}\right) + 0.411\left(\frac{T_{min}}{T_{max}}\right) \quad (67)$$

$$\frac{\bar{H}}{H_0} = 0.760 + 0.435\left(\frac{\bar{s}}{so}\right) - 0.783\left(\frac{T_{min}}{T_{max}}\right) \quad (68)$$

$$\frac{\bar{H}}{H_0} = -0.487 + 0.119\left(\frac{\bar{s}}{so}\right) + 0.477\left(\frac{T_{min}}{T_{max}}\right) \quad (69)$$

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 ANNoutput and the target. The ANN target can be attained by adjusting weightsandbiasesofANNoutput.ANNcanperformatasks thatwhichcannotperformbylinearmethod.ANNlearnsand 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 andTemperature.

Table -II: Models developed by using ANN

Models	Variables
ANN-S	S, So
ANN-T	T_{max}, T_{min}
ANN-ST, TH, SH,STH	S,S ρ T_{max}, T_{min},RH

Andalsomodelshavedevelopedbyusingthecombinationof Approximate Solar Radiation, temperature and relative humidityascombinationofinputvariables.Thecorrelation 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 leastcorrelationof0.336.Predictionresultisbetter,whenthe R value ishigher.

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

Input Variable	Correlation R	Rank
Bright sunshine	0.666	2
T_{max}	0.780	1
T_{min}	0.531	3
Relative Humidity	0.3361	4

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 obtainaresultthathowtheoutputdataisrelevanttotheinput attributes.

Regressionplots developed between input attributes and output data using neural network is shown inFig.

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2. Maximumtemperatureisthefirstinputparametergivesthe best correlation of 0.780 to enhance the prediction of global solar radiation.

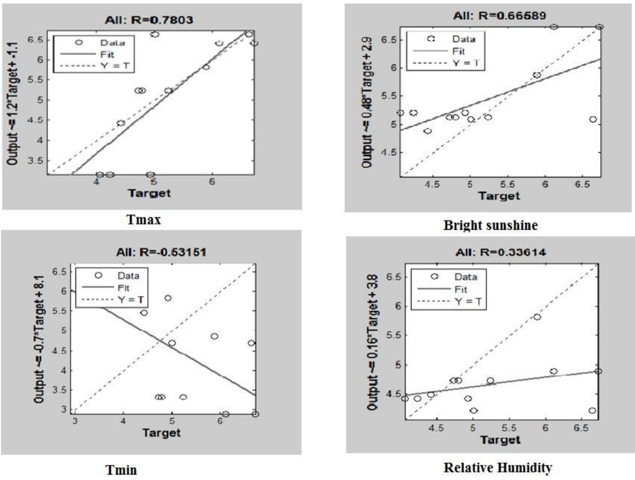

Fig .2. Regression plots developed between input attributes and output data using neural network

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 trainingerror.Themodelhasalesserrorandhighcorrelation isselectedasthebestmodel.Fig.3givestheSimulinkmodel 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 thefunction 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.

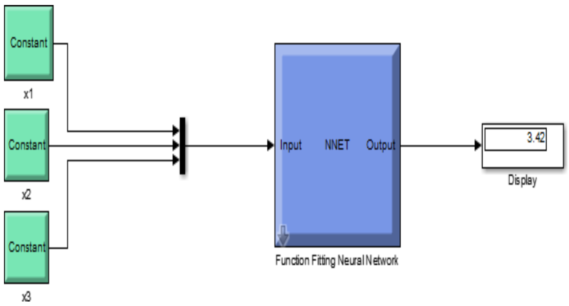

Fig. 3. Simulink of selected best ST-ANN model

In hidden layer five neurons are used and weights are obtained. Hidden to output layer is the second layer where a singleoutputisobtained.Thesolarirradiancedataisobtained intheoutputlayer.TheSimulinkmodelistestedforfoursites and daily solar irradiance is predicted. The weights adjustmentinthenetworkisshowninFig.4.Thefiveneurons 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 collecteddata.

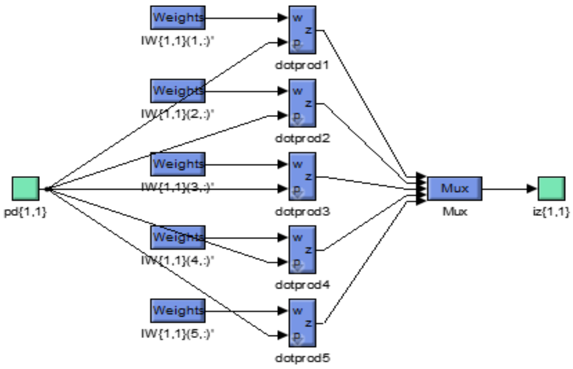

Fig. 4. Weights adjustment of the model network

Andregressioncurveisdrawnbetweenthemeasuredand the observed data. The converged weights are given in equations 70 to 73. The weights and biases between the inputandthehiddenneuronsaregivenin72and73.The weights in the hidden neurons are dot product with the inputparameters.

$$\begin{bmatrix} W11 & W12 & W13 \\ W21 & W22 & W23 \\ W31 & W32 & W33 \\ W41 & W42 & W43 \\ W51 & W52 & W53 \end{bmatrix} = \begin{bmatrix} -0.058 & 1.967 & 2.426 \\ -1.672 & -1.475 & 0.916 \\ -1.005 & -0.026 & 2.060 \\ -1.316 & 1.370 & 1.144 \\ 0.103 & -1.441 & 1.683 \end{bmatrix} \quad (70)$$

$$\begin{bmatrix} b1 \\ b2 \\ b3 \\ b4 \\ b5 \end{bmatrix} = \begin{bmatrix} 2.532 \\ 0.876 \\ -0.418 \\ -1.961 \\ -2.689 \end{bmatrix} \quad (71)$$

Where, *W11* - Weight between first input parameter and first hidden neuron.

W12 - Weight between first input parameter and second hiddenneuron.

W22 - Weight between second input parameter and second hiddenneuron.

W33 - weight between third input parameter and third hidden neuron.

b1 is the bias of the first neuron.

b2 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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$$\begin{bmatrix} W31 \\ W32 \\ W33 \\ W34 \\ W35 \end{bmatrix} = \begin{bmatrix} -0.755 \\ -0.309 \\ 1.296 \\ 0.384 \\ -0.518 \end{bmatrix} \quad (72)$$

$$[b]=[0.408] \quad (73)$$

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.

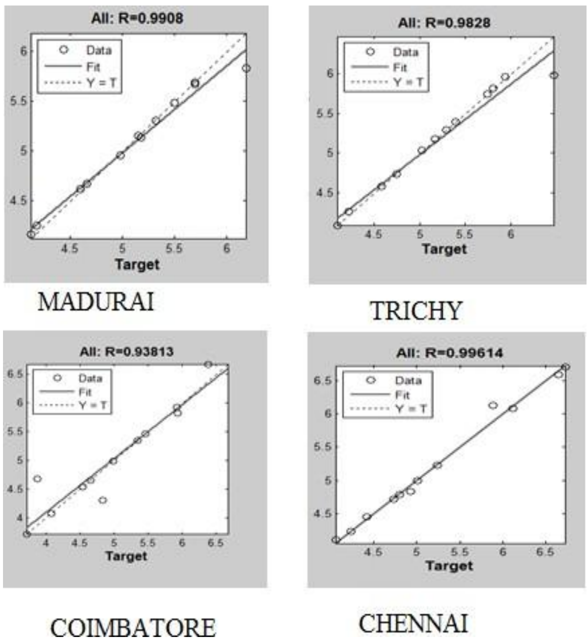

Fig. 5. Scatter plots showing the correlation between measured and observed GSR from selected model ANN (H4 or ST).

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 (MJm^{-4}day^{-1}), MAPE=5.1%, RMSE=0.440(MJm^{-2}day^{-1}), MAE=0.224(MJ m^{-2}day^{-1}) and regression coefficient value of 0.962. Sunshine based model S5 gives the better GSR estimation with MSE=0.34 (MJm^{-4}day^{-1}), MAPE=3.6%, RMSE=0.580 (MJ m^{-2}day^{-1}), MAE=0.153 (MJ m^{-2}day^{-1}) 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

Model/ Location	MAE	MAPE	MSE	RMSE	R	EMPIRICAL COEFFICIENTS			
MADURAI	(MJ m^{-2}day^{-1})	(%)	(MJ^2 m^{-4}day^{-1})	(MJ m^{-2}day^{-1})		a	b	c	d
S1	0.11	2.2	0.33	0.57	0.85	-0.024	0.882		
S2	-0.18	3.1	0.29	0.53	0.90	0.181	-0.570	0.581	
S3	-0.07	1.2	0.29	0.54	0.86	-0.817	0.473	-0.872	0.542
S4	0.16	4.0	0.32	0.56	**0.91**		0.908		
S5	0.15	3.6	0.34	0.58	0.86	-0.361	0.486		
T1	0.45	4.5	0.65	0.810	0.06	0.511	0.905		
T2	0.46	9.2	0.65	0.804	0.180	0.246	0.420		
T3	0.47	1.0	0.63	0.801	0.219	0.294	0.434		
T4	0.12	2.0	0.65	0.804	0.359	0.588	0.593	0.389	
H1	1.21	2.5	0.189	0.434	0.925	0.107	0.961	0.114	
H2	-1.13	2.4	0.462	0.679	**0.745**	0.128	0.301	0.951	
H3	-0.26	5.5	0.211	0.459	0.952	0.762	0.964	1.149	0.267
H4	**0.224**	**5.1**	**0.200**	**0.440**	**0.962**	0.209	0.104	1.611	
Model/ Location	**MAE**	**MAPE**	**MSE**	**RMSE**	**R**	**EMPIRICAL COEFFICIENTS**			
TRICHY	**(MJ m^{-2}day^{-1})**	**(%)**	**(MJ^2 m^{-4}day^{-1})**	**(MJ m^{-2}day^{-1})**		**a**	**b**	**c**	**d**
S1	0.63	1.3	1.13	1.06	0.752	-0.532	0.173		
S2	0.66	1.4	1.19	1.09	0.753	-0.381	0.118	0.495	
S3	0.7	1.5	1.26	1.12	0.751	0.710	-0.392	0.743	-0.441
S4	0.09	1.0	1.14	1.07	0.754	0.435	0.403		
S5	0.53	1.1	1.13	1.06	**0.756**	-0.121	0.964		
T1	0.21	4.4	0.702	0.837	0.364	0.751	0.769		
T2	0.22	4.6	0.698	0.835	0.37	0.131	0.327		
T3	0.23	4.8	0.701	0.837	0.368	ccc	0.117		
T4	0.06	1.2	0.734	0.856	0.38	0.257	0.161	0.688	
H1	0.12	3.0	0.28	0.529	0.932	0.153	0.968	0.343	
H2	-0.44	9.2	0.594	0.770	**0.66**	1.712	-0.785	-0.116	
H3	0.26	5.4	0.283	0.531	0.934	-0.175	0.108	-0.190	0.264
H4	**0.16**	**3.2**	**0.29**	**0.538**	**0.95**	-0.409	0.113	0.411	

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 DGSR. 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 for each 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}),

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MAE=0.08 (MJ m^{-2}day^{-1}). S4 is the second best model with R=0.78, MSE=1.17 (MJ m^{-4}day^{-1}), MAPE=1.1%, RMSE=1.08 (MJ m^{-2}day^{-1}), MAE=0.78 (MJ m^{-2}day^{-1}). The thirdbestmodelisT3intemperaturecategorywithR=0.659, MSE=0.75 (MJ m^{-4}day^{-1}), MAPE=1.8%, RMSE=0.867 (MJ m^{-2}day^{-1}), MAE=0.09 (MJm^{-2}day^{-1}).

Table-V:ErrorstatisticsandEmpiricalcoefficientof estimationofdailyGSRinChennaiandCoimbatore

Model/ Location	MAE	MAPE	MSE	RMSE	R	EMPIRICAL COEFFICIENTS			
CHENNAI	**(MJ m^{-2}day^{-1})**	**(%)**	**(MJ^2 m^{-4}day^{-1})**	**(MJ m^{-2}day^{-1})**		a	b	c	d
S1	-0.75	1.5	1.15	1.07	0.77	-0.536	0.177		
S2	-0.67	1.3	1.21	1.10	0.76	-0.918	0.313	-1.182	
S3	-1.69	3.0	-4.21	2.05	0.75	0.682	-0.381	0.712	-0.252
S4	-0.59	1.1	1.17	1.08	**0.78**	0.594	0.358		
S5	-1.55	3.1	1.15	1.07	0.77	0.126	0.100		
T1	0.13	2.6	0.657	0.81	0.06	0.751	0.719		
T2	0.08	1.6	0.725	0.851	0.645	0.131	0.327		
T3	0.09	1.8	0.73	0.854	0.637	0.253	-0.172		
T4	0.04	8.2	0.75	0.867	0.659	0.254	0.116	0.688	
H1	0.11	2.1	0.174	0.417	0.984	0.357	0.119	-0.866	
H2	0.27	5.4	0.981	0.990	**0.19**	1.082	-0.274	-0.567	
H3	-0.19	3.8	0.23	0.479	0.971	1.022	0.122	-0.741	0.234
H4	**0.08**	**1.1**	**0.165**	**0.404**	**0.987**	-0.487	0.119	0.447	
Model/ Location	**MAE**	**MAPE**	**MSE**	**RMSE**	**R**	EMPIRICAL COEFFICIENTS			
Coimbatore	**(MJ m^{-2}day^{-1})**	**(%)**	**(MJ^2 m^{-4}day^{-1})**	**(MJ m^{-2}day^{-1})**		a	b	c	d
S1	-1.28	2.3	1.39	1.17	0.60	-0.533	0.168		
S2	-1.55	2.8	1.42	1.19	0.63	0.250	-0.883	0.902	
S3	-1.89	3.4	1.42	1.19	0.68	0.524	-0.272	0.469	-0.253
S4	-0.97	1.7	1.37	1.17	0.62	0.446	0.397		
S5	-1.23	2.2	1.41	1.18	0.59	-0.125	0.954		
T1	0.16	2.1	0.453	0.673	0.812	0.179	0.201		
T2	0.07	1.2	0.454	0.6737	0.864	0.272	-0.516		
T3	0.1	1.8	0.458	0.676	0.861	0.501	-0.817		
T4	0.06	1.1	0.476	0.68	**0.865**	0.623	0.591	0.468	
H1	0.03	5.2	0.459	0.677	0.875	0.741	0.789	-0.118	
H2	-0.16	2.3	0.505	0.710	0.84	0.123	0.406	-0.754	
H3	-0.27	4.9	0.457	0.676	0.87	0.880	0.578	-0.689	-4.63
H4	**-0.04**	2.1	**0.40**	**0.632**	**0.918**	0.760	0.435	-0.783	

CoimbatoreislocatedonthesouthwesterninIndiaandithas 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^{-4}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^{-4}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^{-4}day^{-1}), MAPE=3.4%, RMSE=1.19 (MJ m^{-2}day^{-1}), MAE=-1.89 (MJ m^{-2}day^{-1}). Overall, the model H4performed 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 SolarRadiationandTemperature.Therefore,theapproximate 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 is19.8°C.

In this section the performance of best evaluated parametricmodeliscomparedwithANN-STmodelbasedon their result. Thirteen models have developed using curve expert software for different location. And then it have analysed that ST based parametric model (H4) gives the best result during training the data. Similarly for ANN-ST model gives the best result with minimized error and improved performance. Comparison of measured and predicted data of ANNandEmpiricalmodelisshowninFig.6.InthisJan2018 data has predicted using both ST based model in ANN and Empirical. It shows that the ANN predicted data is high accuracy, while compared to the ST-empirical. Since the mathematical model derived is not well suited for the daily solar radiationprediction.

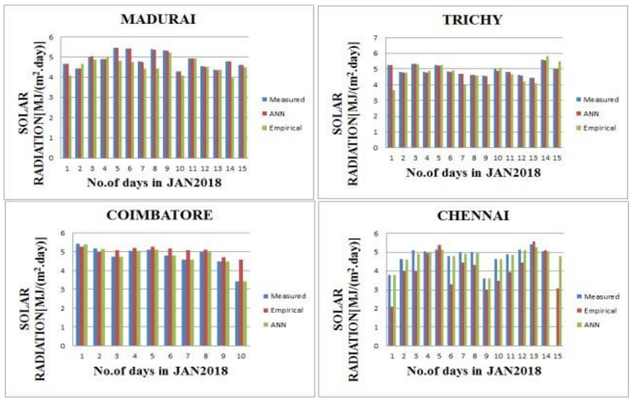

Fig .6. Evaluation of measured and predicted data of ANN and Empirical model

Some of days predicted data is far different from measured data.AndforpredicteddataofANNisclosertothemeasured data.Itisachievedbytrainingalargenumberofdataanddata has learned by the network. The mean square error of ANN and empirical model is shown in Fig. 7. It is evaluated that error between the measured data and predicted data is minimized in ANN. So the prediction accuracy can be improved byANN.

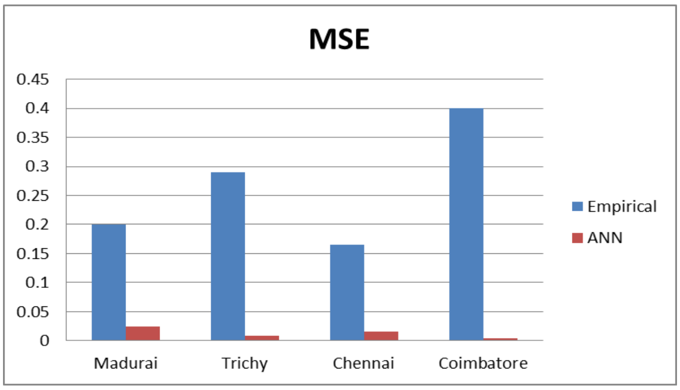

Fig .7. Mean square error comparison between ANN and Empirical

When compared to ANN, the error calculated from the empirical is higher and the accuracy is minimized. Hencethe ANN – ST model can be used for predictive basedproblems. 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 errorand regression coefficient are the statistical indicator which has calculated for four cities. Fromthe

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tableitisanalyzedthatthehighestaccuracyisachievedusing ANN-ST model for four sites.

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

Model/ Location	MAE	MA PE	MSE	RMSE	R
Empirical	**(MJ m^{-2}day^{-1})**	(%)	**(MJ^2 m^{-4}day^{-1})**	**(MJ m^{-2}day^{-1})**	
Madurai	0.224	5.1	0.200	0.440	0.303
Trichy	0.16	3.2	0.29	0.538	0.388
Chennai	0.08	1.1	0.165	0.404	0.724
Coimbatore	-0.04	2.1	0.40	0.632	0.707
ANN					
Madurai	0.128	4.3	0.016	0.2076	0.990
Trichy	0.149	3.0	0.022	0.173	0.982
Chennai	0.086	1.8	0.007	0.134	0.996
Coimbatore	0.055	1.0	0.003	0.110	0.938

reaches in the month of January and April. And the lowest GSR value reaches in the month of October and December. And then for Coimbatore the highest GSR values reaches betweenJanuarytoAugustmonthandlowestvaluereachesin the month of September to December. The correlation between measured and estimated GSR is given in the scatter plots shown in Fig. 8. The regression is analyzed from best hybrid model H4 (ST) for four selected cities. It is noted that the correlation coefficient ranges from 0.9381 to0.9961.

Hence H4 model with combination of Approximate SolarRadiationandTemperatureissuitableforfourdifferent zones in Tamil Nadu. And unique model has developed for southernregion.

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 isabout0.992.ComparedthesefourcitiesChennaihaslowest

VICONCLUSION

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 andtemperatureismostinfluencingparametersforestimation of daily GSR. And relative humidity is minimuminfluencing parameter. In both empirical and ANN, the combination of sunshineandtemperaturemodelgivesthebestresult.Further thisselectedbestmodelhastestedforfourcitiesin Tamil

accuracy of 0.9883. Similarly the error statistics has calculated between the measured data and predicted data of empirical. The lowest accuracy has obtained for all sites. Since the daily the solar radiation data and temperature is rapidly changes. Hence the Madurai and Trichy has a lowest accuracyof0.303and0.388.ChennaiandCoimbatorehasthe accuracy of 0.724 and 0.707. Since these both has located in centralandwesternofTamilNadu.Butitsresultisnotcloser to 1, which denotes the highest accuracy. And compared to ANN-ST, the empirical-ST gives worst performance forfour

cities.HencetheANN-STmodelcanbeusedforpredictionof daily global solar radiation. This combination oftemperature andsunshinebasedANNmodelisbestforpredictionofdaily global solar radiation in southern states ofIndia.

Predicted and estimated daily average GSR of best hybrid modelH4forfourcitiesinTamilNaduisshowninFig.8.The average daily GSR computed for four smart cities of Tamil Nadu using H4model.

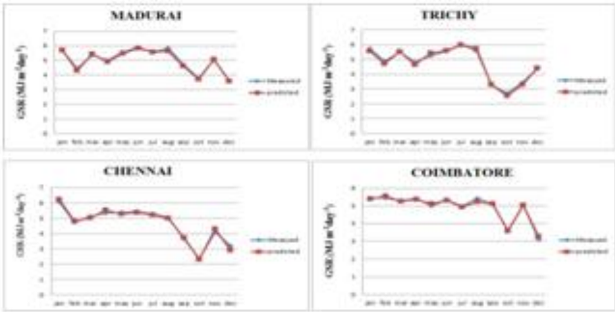

Fig .8. Comparison of Empirical (H4) with measured daily average GSR.

ForMaduraithemonthlymeandailyGSRreachesitshighest values between months of March to August. And GSR reaches its lowest value between months of September to February.AndthenforTrichyreachesitshighestvaluesinthe July month. And it reaches lowest value in the month of October.Similarly,fortheChennaithehighestGSRvalue

Nadu and 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.Duetodeeplearningofthedata,itcouldachievethe required ANN target and over fitting is alsoreduced.

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