



Neural Network Models for Prediction of Evaporation Based on Weather Variables

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Abstract. Artificial Neural networks (ANNs) is a computation method that can be utilized for predictions. In this study prediction of evaporation using ANN's multilayer perceptron (MLP) is attempted considering different weather variables *viz.* Relative Humidity Morning & Evening, Bright Sunshine Hours, Rainfall, Maximum & Minimum temperature, Mean Temperature and Mean Relative Humidity. The analysis is done over different parts of India *viz.* Raipur, Pantnagar, Karnal, Hyderabad and Samastipur. Weather of four lag weeks from week of forecast is considered for the model development. The lag periods were also utilized to develop weather indices. Subsequent two years were not included while developing the model for predicting evaporation for different locations. The performance of the developed models was evaluated based on Root Mean Square Error (RMSE).

Keywords: Artificial Neural Networks · Prediction models · Weather indices
Backpropagation algorithm · Mean absolute percentage error

1 Introduction

In agricultural field, a weather based model can be an effective tool to predict the future scenario for the crops. Weather is an important factor that influence the crop yield and pest infestation in the field, thus prediction of evaporation is important to monitor the crop water requirement and management of available resources. Most of the researchers have established linear relationship between the input variables and the output variable, but due to high complex data in agriculture and non-linear nature of weather data, the research focus has shifted toward development of non-linear model for prediction. For the development of non-linear model Artificial Neural Network (ANN) has evolved out in better way than any other technique. Its application become largely focus on solving complex problems with great ease. Different problem domains *viz.* medical, stocks, finance, engineering, security, character recognition, agriculture etc. have utilized ANN technique to solve their problem domains. The advance characteristic features of ANN includes mapping capabilities that is they can easily map input patterns to their associated outputs. They can predict new outcomes from the past data. The artificial neural network can also form full patterns from the noisy or incomplete data.

Time-series analysis was used for predicting relative humidity and forecasting of temperature [1]. MLP network is formed using three layers with 6 neurons in hidden

layer and sigmoid activation function to forecast temperature [2], another researcher [3] have predicted temperature forming ANN using three layer MLP network, in this training is done through back propagation and relative humidity, atmospheric temperature, atmospheric pressure, wind velocity and wind direction are considered as independent variable. Researchers [4, 5] have also applied neural network technique for plant disease forecasting. Most of them have worked on the comparison of ANN and traditional statistical methods and found that ANN work better than these traditional methods. Some researchers have forecasted [6] wheat productivity of Junagadh (Gujarat) using data on weather conditions to develop ANN model and found that the results based on ANN are better than those from multiple linear regression model (MLR). [7] Developed neural network model for forecasting crop yield (rice, wheat, sugarcane for central plain zone, eastern plain zone,) and important diseases of mustard crop in different locations using weather variables. Multilayer perceptron (MLP), a neural network architecture was found to be better than weather indices model on basis of MAPE.

It is recommended from the study that one hidden layer is first choice for any feed forward network formation but if one hidden layer with large number of neurons could not perform well then second layer with few processing neurons could be attempted. In this study, prediction of evaporation is done using ANN technique. MLP algorithms namely backpropagation and conjugate gradient descent is applied using one hidden layer consisting of seven neurons. In the network formation, hyperbolic activation function is used. The input layer consist of independent variables (various combination of weather variables) and output layer consist of evaporation as output variable.

2 Data

Different locations of India were considered for the model development. In this study, weekly meteorological data for different locations *viz.* Raipur (21.25° N, 81.62° E): 1985–2012; Karnal (29.68° N, 76.99° E): 1973–2005; Pantnagar (29.02° N, 79.49° E): 1970–2008; Hyderabad (17.38° N, 78.48° E): 2006–2012; Samastipur (25.86° N, 85.78° E): 1984–2010. Weather variables *viz.* maximum & minimum temperature (maxt & mint), relative humidity in the morning & in the evening (rhi & rhii), rainfall (rf), bright sunshine hours (bsh), evaporation (evap), mean temperature (meant), mean relative humidity (meanrh) were used. Various combinations of independent variables were considered i.e. (i) maxt (ii) meanrh (iii) meant and meanrh (iv) meant, meanrh and bsh (v) meant, meanrh, bsh and rf (vi) meant, meanrh, bsh and rf.

3 Methodology

3.1 Generation of Weather Indices

In this methodology two indices were developed for each weather variables *viz.* (i) The first indices consist of total accumulation of weather variable, this represents the total accumulation of weather (ii) second indices consist of weighted value of weather

variables, weight being as correlation coefficients between variable to forecast and weather variables in respective weeks, this indicates the distribution of weather with special reference to its importance in different week in respect to week of forecast. On the same pattern the combined effect of weather variable (taken two weather variable at a time) were also attempted. The form of the model was [8–11].

$$Y = a_0 + \sum_{i=1}^p \sum_{j=0}^1 a_{ij} Z_{ij} + \sum_{i \neq i'}^p \sum_{j=0}^1 b_{ii'j} Z_{ii'j} + \varepsilon \quad (1)$$

$$Z_{ij} = \sum_{w=n_1}^{n_2} r_{iw}^j X_{iw} \quad (2)$$

$$Z_{ii'j} = \sum_{w=n_1}^{n_2} r_{ii'w}^j X_{iw} X_{i'w} \quad (3)$$

where

Y Forecast variable

X_{iw} i^{th} weather variable in w^{th} week

r_{iw} correlation coefficient between Y and i^{th} weather variable in w^{th} week

$r_{ii'w}$ correlation coefficient between Y and product of X_i and $X_{i'}$ in w^{th} week

p number of weather variables

n_1 initial week for which weather data was included in the model

n_2 final week for which weather data was included in the model

E error term

In this study results based on the interaction of weather variables were not found to be satisfactory thus have considered only single weather variables as independent variable.

3.2 Model Based on Artificial Neural Networks

Artificial Neural Network consists of processing units which communicate to one another by sending signals over a large weighted connection. The network is adapted based on the architecture of human brains which consists of neurons to receive and transmit the signals to another neuron and thus eventually forming a network. Similarly, ANN consist of processing units and connections i.e. artificial neurons and weights between them respectively. The artificial neuron transports the signals to another neurons and so on to form the network. The values stored in the weights simulate the information so that network learn, memorize and then form relationships to form a stronger network. ANNs can learn and generalize from experience. Neural network consists of neurons, connections between them i.e. weights and three layers namely input layer, hidden layer(s) and output layer. The network is trained using the data with known output, the procedure is termed as supervised learning. After training, the network model formed is used to predict the output of new input data. In the present

study, two algorithms is used to train the neural network namely back propagation and conjugate gradient descent respectively. Evaporation considered to be output unit and weather variables were the input units. One hidden layers having seven neurons were used in the network. Activation function is needed in hidden units to introduce non-linearity into the model. Choice of activation function depends on heuristic rules for example if learning involves deviation from average, use hyperbolic tangent and logistics activation function is used for classification problems [12]. The hyperbolic tangent function is presented mathematically as

$$f(x) = [e^x - e^{-x}]/[e^x + e^{-x}] \quad (4)$$

In this study hyperbolic function (tanh) is used as activation function with one hidden layer having seven neurons for training neural network to predict evaporation for different places in India.

4 Learning Algorithm Used

4.1 Backpropagation

Backpropagation is a common method to train a neural network. The algorithm calculates the weights which is used in the network formation. It calculates the gradient to adjust the weights of the neuron which is a fundamental unit of the ANN. Here in this algorithm, error function is to be minimized with respect to weights and the bias. If the study consider linear activation function then the activation of the output unit is calculated as linear function of input units, weights and the bias respectively. Multilayer perceptron (MLP) is learned by back propagation method, it is a supervised procedure in which neural network is created based on data having known outputs. Figure 1 represents the flow chart of Backpropagation algorithm working method to minimize the errors. The model for the neural network first calculate the error and if its minimized then this model is ready for prediction, otherwise the model will first update the parameters (weights) and train the network again with the updated weights and then calculate the error to see whether it is minimized or not. Once the model with minimized error is ready, the prediction can be performed. The training to model is given by some learning algorithms, These algorithms were mainly classified into three broad categories namely Supervised learning, Unsupervised learning and reinforced learning. In Multilayer Perceptron supervised learning algorithm is used to train the network. The neural network is created arranging the neurons in successive layers. The information flows form input neurons to output neurons via hidden layers. In this study one hidden layer having seven neurons were considered to develop the model.

4.2 Conjugate Gradient Descent

Conjugate gradient descent (CGD) is the most popular iterative method for solving linear equations. The basic back propagation algorithm adjust the weights in negative

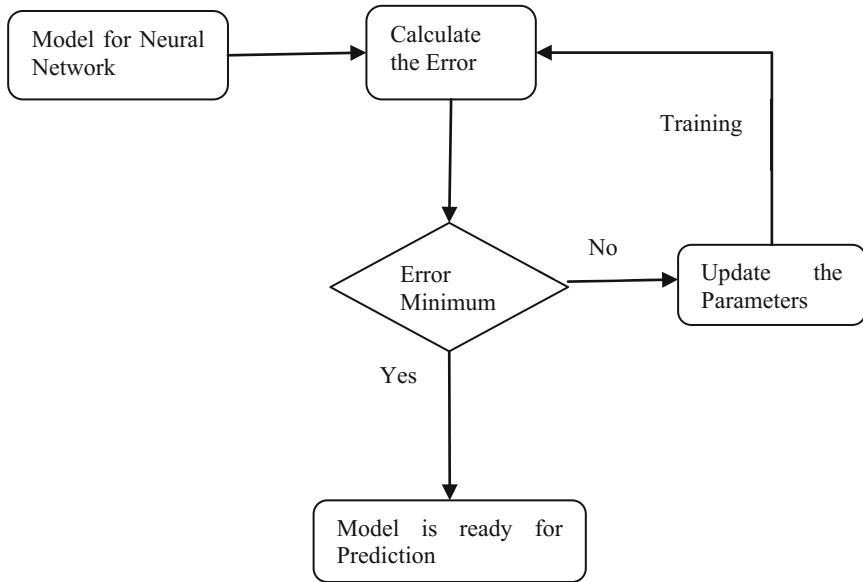


Fig. 1. Flow chart followed by backpropagation algorithm to minimize the error while training the model

direction of the gradient, in this direction performance function is decreasing. If performance function is decreasing more rapidly in negative gradient direction it doesn't mean convergence attains at faster rate. In CGD, the search is performed along conjugate directions, it attains faster convergence. In CGD algorithm firstly, vector sequence of iterates were generated, the residuals corresponding to these iterates were also generated along with the directions used to update these residuals and iterates. The algorithm now selects the direction vectors as a conjugate of its successive gradients obtained as the process progresses. These directions are determined sequentially at each step of iterations.

5 Evaluation Criteria Used

Root Mean Square Error (RMSE) is used to evaluate the performance of the prediction models. Mathematically represented as follows

$$RMSE = \sqrt{\frac{1}{m} \sum_{i=1}^m (o - p)^2} \quad (5)$$

6 Results and Discussion

Different locations of India *viz.* Raipur, Karnal, Pantnagar, Hyderabad and Samastipur were considered for prediction model development. In this study evaporation was considered as dependent variable and all other weather variables *viz.* maximum temperature (maxt), minimum temperature (mint), rainfall (rf), relative humidity morning (rhi), relative humidity evening (rhii), bright sunshine hours (bsh), mean temperature (meant) and mean relative humidity (meanrh) were taken as independent variables. The data for all the locations is divided into two sets; one forms the training set and other the testing test. Two subsequent year were out of sample data on which prediction model is run. Multilayer perceptron (MLP) is utilized to develop the model consisting of two phases algorithm of Backpropagation and Conjugate Gradient Descent (CGD). The neural network is formed considering one hidden layers having 7 neurons having hyperbolic activation function. The neural network formed with the training data is run for two subsequent years which were not included while development of model. The model performance is monitored with the help of Root Mean Square Error (RMSE), various combinations of independent variables like (i) meant (ii) meant and meanrh (iii) maxt and maxrh (iv) meant, meanrh and bsh (v) meant, meanrh, bsh and rf; were tried and tested considering RMSE for each case. The model having lowest RMSE is the best to predict the evaporation. Table 1 represents the RMSE for different locations considering various combinations of independent variables.

Table 1. RMSE for different location with various combinations of weather variables

S. No.	Locations	MeanTemp	MeanTemp and MeanRh	MaxTemp and MaxRh	MeanTemp, MeanRh and Bsh	MeanTemp, MeanRh, Bsh and Rf
1.	Raipur	1.55	0.98	1.04	1.10	1.14
2.	Karnal	1.88	1.04	1.15	1.20	1.10
3.	Pantnagar	1.49	1.47	1.71	2.01	3.12
4.	Hyderabad	2.21	0.95	2.73	2.46	2.54
5.	Samastipur	1.32	1.01	1.33	2.35	1.05

Table 1 shows that the combination of mean temperature (average value of maxt and mint) and mean relative humidity (average value of rhi and rhii) have least RMSE for all the considered locations. The model developed using mean temperature and mean relative humidity as independent variables provides close approximation of predicted values with the observed one for all the locations. Figure 2 Shows the graphs of observed and predicted values for these locations. The graphs were shown only for the combination of MeanTemp and MeanRh to predict the evaporation as it has least value of Root Mean Square Error and thus provides better accuracy with the developed model.

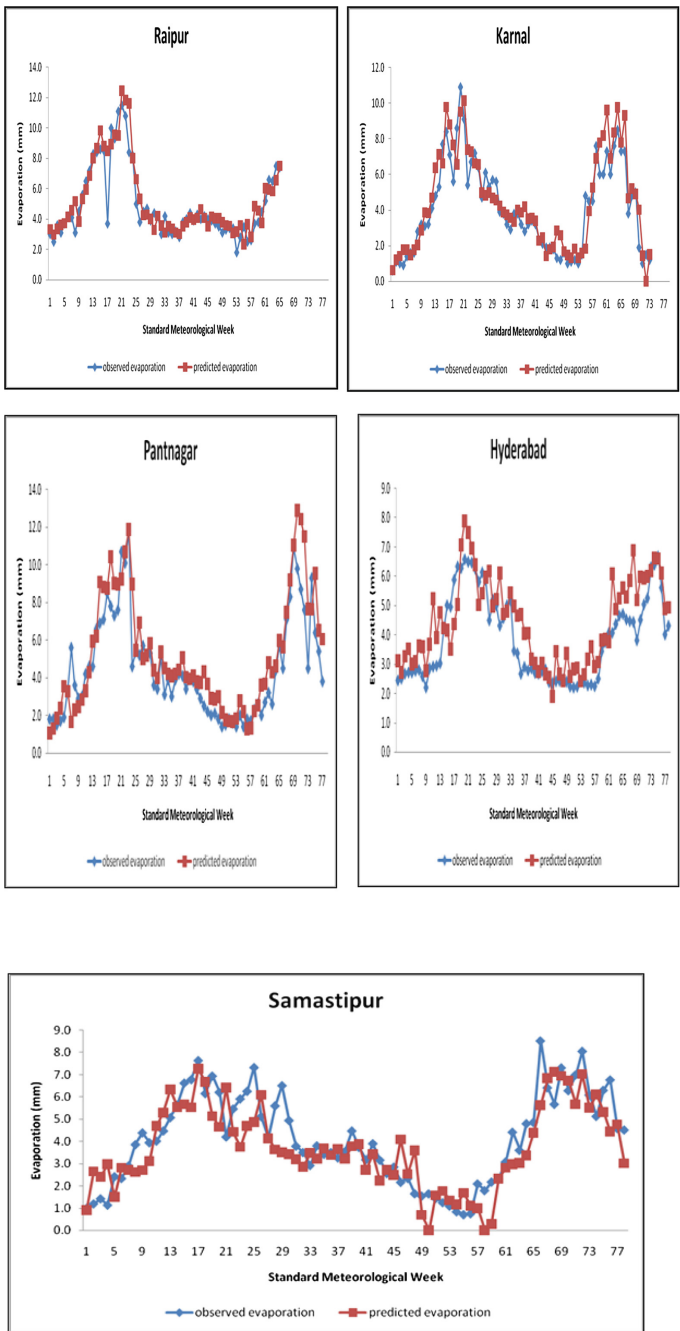


Fig. 2. Graphs representing observed and predicted values of evaporation for various locations using mean temperature and mean relative humidity as independent variables

7 Conclusion

In this study prediction of evaporation for different locations (Raipur, Karnal, Pantnagar, Hyderabad and Samastipur) using various combinations of weather variables viz. (i) meant (ii) meant and meanrh (iii) maxt and maxrh (iv) meant, meanrh and bsh (v) meant, meanrh, bsh and rf, was done using ANN. Weather of four weeks lag from week of forecast is considered for the model development. Weather based indices were also developed and considered as independent variables but the results of prediction in such case is not in close approximation with observed ones hence the error rate is very high, thus, four-week lag data of all-weather variables were considered as independent variables against evaporation as dependent variable. Predictive model was run on two subsequent years which were not considered in model development. Artificial neural network was formed using multilayer perceptron having two algorithms namely back propagation and conjugate gradient descent. Various combinations of independent variables were tried, and their evaluation were tested using RMSE. Lowest RMSE for all the locations were found with meant and meanrh. This indicates that model developed with meant and meanrh as independent variable gives better prediction of evaporation for the considered locations.

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