

# Rainfall Prediction Techniques using Artificial Neural Networks –A Brief Review

Himanshu Pant<sup>1</sup> Yadvendra Singh<sup>2</sup> Amrindra Pal<sup>3</sup>

<sup>1</sup>M. Tech Student <sup>2,3</sup>Assistant Professor

<sup>1,2</sup>B.T.K.I.T Dwarahat Almora, Uttarakhand, India <sup>3</sup>DIT University Dehradun, Uttarakhand, India

*Abstract*— Rainfall prediction due to its highly nonlinear and complicated process is very challenging and difficult Task for meteorologists in the current scenario. Prediction of this type of non-linearity present in rainfall Events can be modeled by advanced computer modeling and simulations. The Artificial Neural Network (ANN) is a new technique with a computational mathematical structure which is having capability to identify complex non-linear relationships between input and output data .This paper presents a review of available techniques based on Artificial Neural Networks which are used by various researchers for Prediction of rainfall.

**Keywords:** Rainfall, Non Linearity, Artificial Neural Network, Modeling, BPN, RBFN, SVM

**General Terms:** Rainfall Prediction, Artificial Neural Networks

## I. INTRODUCTION

Prediction of rainfall accurately is very crucial task for water resource management and flood control.

Broadly speaking the physical events that trigger rainfall are highly complex and nonlinear and uncertainty is always present in rainfall events.

For a developing country like India rainfall plays an important role as Indian economy is entirely dependent on agriculture and agriculture is dependent on rainfall. There are several rainfall prediction methods like statistical methods and numerical weather prediction but due to non-linearity of rainfall statistical methods are not able to provide satisfactory results. In Numerical weather prediction; predictions are generated by physical models based on system of equations that predict the future rainfall that is why it is also called dynamical methods of prediction.

Artificial Neural Networks are finding applications in various fields of science and engineering because they have capability to model linear as well as nonlinear systems without making assumptions which are prevalent in most of the traditional approaches.

This paper presents a brief literature review of rainfall prediction techniques employed by various researchers around the globe. This paper also emphasizes on various neural network architectures which can be of great help for new researchers working in this field. This paper is divided into sections. Section 1 provides an Introduction, Section 2 discusses about Artificial Neural networks, techniques used by different researchers are discussed in Section 3 .Section 4 discusses a brief literature review of rainfall prediction using Artificial Neural Networks and finally conclusion is presented in Section 5.

## II. ARTIFICIAL NEURAL NETWORKS

Artificial Neural Network is a kind of soft computing technique other than fuzzy logic and genetic algorithm which has been utilized by various researchers for rainfall prediction. Artificial Neural Networks are inspired by human brain which processes information in entirely different fashion as compared to conventional digital computer. It has capability to organize its structural constituents, known as neurons, so as to perform certain computations many times faster than the fastest digital computer in existence today<sup>[1]</sup>

Artificial Neural network resembles brain in two respects:<sup>[1]</sup>

- 1) Knowledge is acquired by the network from its environment through a learning process.
- 2) Interneuron connection strengths, which are also known as synaptic weights, are used to store the acquired knowledge.

### A. Mathematical Model of Neuron

Artificial Neural Network has three basic elements:

- 1) A set of synapses which are also called connecting links which has weight or strength of its own.
- 2) An adder for summing the input signals weighted by the respective synaptic strengths of the neuron.
- 3) An activation function which is also called as squashing function for limiting the amplitude range of the output signal to some finite value.

A mathematical model of neuron is depicted in Fig 1.This model also uses an externally applied bias which is denoted by  $b$ . The bias is used for increasing or decreasing the net input of the activation function depending on whether its value is positive or negative.

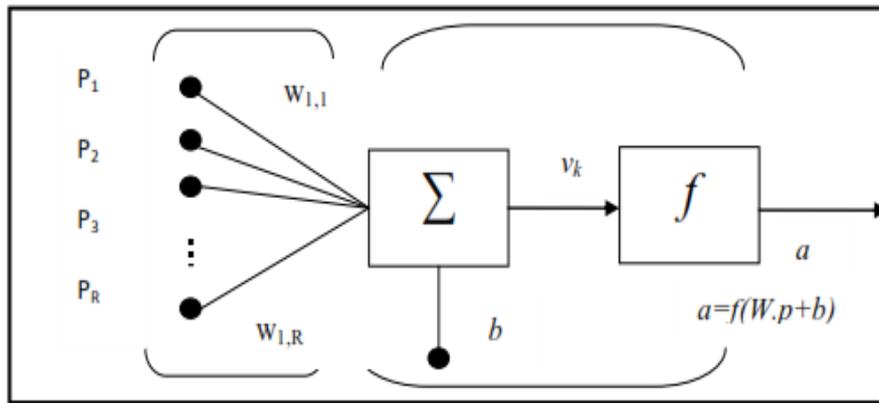


Fig. 1: Mathematical Model of Neuron

The net input at the summing junction is written as:

$$u_k = \sum W_{1i} P_{R} \dots \dots \dots (1)$$

Here summation is taken over entire inputs

And

$$v_k = u_k + b_k \dots \dots \dots (2)$$

This net input is then applied to an activation function, whose purpose is to limit the amplitude of the neuron to some finite value and helps in obtaining desired outputs. The output of \$k\_{th}\$ neuron is:

$$y_k = f(u_k + b_k) \dots \dots \dots (3)$$

A network can be single layered or multilayered depending on number of layers in the network. Typically a neural network has an input layer, hidden layer and a output layer. The function of hidden layer is to perform intermediary operations before directing inputs from input layer to output layer.

Whenever a network is constructed for a particular application, inputs and their respective targets are utilized to train the network. Training is provided to the network until it learns to map particular inputs to reasonable outputs. After the training phase is over the network is tested for its effectiveness to produce accurate outputs.

### III. TECHNIQUES

The following are the common types of neural network architectures which are used by various researchers in the field of rainfall prediction.

#### A. Back Propagation Neural Networks

Back propagation is a common method of teaching artificial neural network how to perform a given task. It is a specific technique for implementing gradient descent in weight space for multilayered neural network. Supervised learning method is employed and it is an implementation of Delta rule which requires a teacher that either knows or can calculate the desired outputs for a given set of inputs.<sup>[2]</sup> In these networks the errors are propagated in backward direction. The activation function which is used by artificial neurons is differentiable. There are two passes through the different layers of the network: forward pass and backward pass. In forward pass input is applied to the input nodes and its effect propagates layer by layer. In response to these inputs a set of outputs is produced as response of the network. During the forward pass the synaptic weights are fixed. Error signal which is generated by subtracting actual response from desired response. This error signal is propagated backwards and the synaptic weights are adjusted in order to make actual response to move closer to the desired response.

Back propagation network consists of input layer, output layer and at least one hidden layer. More number of hidden layers may be incorporated for producing more accurate outputs. Many researchers have used this network for rainfall prediction.

#### B. Radial Basis Function Networks (RBFN)

Radial basis function network consists of three layers Fig 2. The input layer has neurons with a linear function that simply feed the input signals to the hidden layer. Moreover, the connections between the input and hidden layer are not weighted. Input layer consists of \$m\_0\$ source nodes where \$m\$ represents the dimensionality of the input vector. Hidden layer has same number of computational units or processing units as the size of the training samples. Output layer consists of a single computational unit; size of the output layer is usually smaller than the that of the hidden layer.

Each unit is mathematically defined as

$$\phi_j(x) = \phi(\|x - x_j\|), j = 1, 2, \dots, n \dots \dots \dots (4)$$

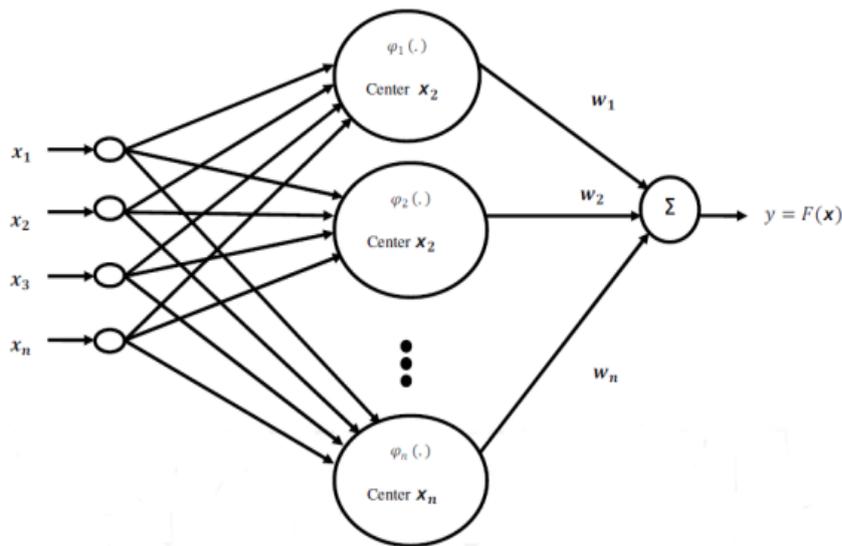


Fig. 2: Radial Basis Function Neural Network

The  $j$ th input data point  $x_j$  denotes the center of the radial basis function, and the vector  $x$  is the pattern applied to input layer. The output neuron is a summing unit to produce the output as a weighted sum of the hidden layer outputs as shown by:

$$F(x) = \sum w_j \phi_j(x) \dots \dots \dots (5)$$

Several researchers have used this network for accurate rainfall prediction and got good results.

### C. Support Vector Machines (SVM)

Support Vector Machines are another category of feed forward networks. It can be viewed as a binary learning machine with elegant properties. The main working principle of the machine can be summed up as for a given training sample the SVM constructs a hyper plane as decision surface in such a way that the margin of separation between the positive and negative examples is maximized.

SVM, a novel neural network algorithm, was developed by Vapnik and his colleagues<sup>[3]</sup>, which is a learning machine based on statistical learning theory, and which adheres to the principle of structural risk minimization seeking to minimize an upper bound of the generalization error, rather than minimize the training error which is utilized in ANN.<sup>[4,5]</sup>

Choosing kernel function and optimal kernel parameters are of core concern while working with SVM. The proper parameters setting can improve the SVM regression accuracy. Different kernel function and different parameter settings can cause significant differences in performance.

In recent years SVM have been utilized for prediction and they have proven to be effective for these applications.

## IV. LITERATURE REVIEW

Alex .J Cannon and Ian G. Mckendry<sup>[6]</sup> evaluated the prediction capabilities of two statistical models by taking data pertaining to the years 1958-1993. The authors used bootstrap based resampling procedure for making comparison between the predictions made by ASIMR employing neural networks with multiple linear regression and climatological models using pre-monsoon circulation PCs as predictors. The authors found that for May predictors there were small differences between predictions made by neural network and multiple regression models. Jiansheng Wu<sup>[7]</sup> presented a nonlinear ensemble rainfall forecasting model by integrating generalized linear regression with artificial neural networks. The author used different linear regression extract linear characteristics of rainfall. The nonlinear characteristics were extracted using different artificial neural networks algorithms and further ensemble members were extracted using principal component analysis (PCA) support vector machine regression is used for nonlinear ensemble model. The author finally concluded that novel nonlinear ensemble which includes linear regression, ANN and support vector machine regression outperforms all linear ensemble methods.

Harshani R.K. Nagahamulla et. al<sup>[8]</sup>, predicted rainfall of Sri Lanka using certain climatic indices like El-Nino Southern Oscillation (ENSO), Equatorial Indian Ocean Oscillation (EQUINDO), Ocean –Land Temperature Contrast (OLTC). The authors used these indices as predictor variables. The authors commented that Sri Lankan monsoon rainfall can be predicted with fairly decent accuracy although the authors also found that there were some differences in actual monthly rainfall and rainfall predicted by ANN models. A very basic architecture and network weight pruning is done which ceases architectural

Configuration from optimality and further only linear dependencies between the predictor variables and predict ant variables are considered which limitation of this research work is. The authors concluded that for more accurate prediction sophisticated training method and optimal weight adjustment could be done. L. Al-Matarneh et.al<sup>[9]</sup>, proposed models for weather forecasting by utilizing two soft computing techniques viz. Artificial Neural networks and fuzzy logic for two different regions that are Amman airport and Taipei\China. There are four phases in this research, first phase is problem awareness phase second phase is suggestion phase third phase is development phase and finally fourth phase is evaluation and conclusion phase. Every phase has its respective features. Scaling of data was done in the range of 0.1-0.9. Feed forward

neural network using Levenberg Marquardt algorithm back propagation was used for the neural network model. For the neural network model three neurons were used in the input layer twenty neurons were used in the hidden layer and single neuron in the output layer. Efficiency of the weather forecasting models were evaluated using two statistical measures which are Variance Accounted For (VAF) and Mean Absolute Error (MAE). The results reveal that for Amman Airport neural network model the best variance accounted for during training is 93.128 and the best variance accounted for during testing is 92.305. The number of neurons in the hidden layer for the best case was found out to be 20. The fuzzy logic model was modeled using FMID toolbox of MATLAB. 4 number of clusters with fuzziness parameter of 2, Type of antecedent and consequent were taken as 2 and 1 respectively. Taipei\ China NN model was developed using one of the most familiar of neural network architectures which is feed forward type with back-propagation training. The network consists of one input layer, one hidden layer, and one output layer, respectively in the arrangement. For this model the arrangement of neurons was 4 neurons in input layer, 10 neurons in the hidden layer and one neuron in the output layer. The best variance accounted for this model was found out to be 99.9859 during training and 98.2926 during testing for 10 number of neurons in the hidden layer. Saeed R. Khodashenas et. al <sup>[10]</sup>, developed several artificial neural network models for prediction of monthly precipitation data in Mashhad synoptic station. The data for this research work is taken from years 1958-2008. From the total 636 monthly precipitation data 580 data was taken for training the networks and the remaining of data selected randomly was used to validate the models. A three layered feed forward perceptron model using back propagation algorithm was designed. Statistical properties were calculated to examine the performance of the models and it was found that in the best model of monthly prediction, the correlation coefficient (R), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), 0.93, 0.99 mm, 6.02 mm, respectively. Two neural architectures M531 and M741 have been designed where the numerals indicate the neurons in the input layer, hidden layer and output layer respectively. The authors found M741 model best amongst the two. the prediction performance was assessed in terms of several statistical measures like R, RMSE, MAE, VAF and NDVI. For this case (M741) these parameters obtained as 0.93, 0.99 mm, 6.02 mm, 85.27 and 0.048, respectively. Dr. Shaymaa Abdul Muttaleb Alhashimi <sup>[11]</sup>, developed and implemented three rainfall prediction models which were based on autoregressive integrated moving average (ARIMA), Artificial Neural Network model and multi linear regression model (MLR) model. A feed forward network was utilized for monthly based predictions. Also these models were compared in terms of several statistical indices including the correlation coefficient (R) and Root Mean Square Errors (RMSE). The data set used in this research work includes monthly measurements for the rainfall, mean temperature, wind speed and relative humidity from year 1970 to 2008 for Kirkuk station. The models were trained with (25 years) of monthly rainfall data. The ANN, ARIMA and MLR approaches are applied to the data to extract the weights and the regression coefficients respectively. The performances of the models were evaluated by using remaining (13 years) of data. The authors compared R2 values (0.91, 0.85, and 0.823) of the models and found that ANN model can be used as an appropriate forecasting technique to predict the monthly rainfall, which is preferable over the ARIMA model and MLR model. Autocorrelation and partial autocorrelation is calculated at different lags of monthly rainfall data with 95% confidence level were used for estimating the parameters of ARIMA model. According to the authors ANN model with four inputs have higher R2 (0.91) and lower RMSE values (27.278) for testing dataset. Kyaw Htike and Othman O. Khalifa <sup>[12]</sup>, this research work focused on design ,implementation and comparison of rainfall forecasting models using focused time delay neural network (FTDNN). To find the optimal parameters of the network the authors experimented with several architectural configurations. The networks were trained to provide predictions in the form of one step ahead predictions .The authors used 80% of the for training and validation, and the remaining 20% was used for testing. Each of the datasets contains the rainfall level (measured in mm) during the period of January 1980 to May 2009 for a total of 29 years. The authors acquired the required dataset from Malaysia Meteorological Department and this data was converted into biannually, quarterly and monthly sampled values. Mean Absolute Percent Error was chosen as statistical measure for performance evaluation of the model. The authors found sharp degradation in accuracy while moving from yearly to biannually to quarterly to monthly sampled values. For the yearly dataset the accuracy of training and testing phase is 99.99 and 94.25 respectively. The testing accuracy for these four cases are 94.25, 81.11, 76.03, and 56.02. Clearly it is evident that monthly sampled value has least testing accuracy of 56.02 and yearly sampled value has highest testing accuracy of 94.25. A. J. Litta et. al <sup>[13]</sup>, investigated the capabilities of six learning algorithms namely, Step, Momentum, Conjugate Gradient, Quick Propagation, Levenberg-Marquardt, and Delta-Bar-Delta, in predicting thunderstorms events that occurred in Kolkata during the calendar dates of May 3, 11, 15, 2009 and the usefulness for the advanced prediction were studied and their performances were evaluated by a number of statistical measures. The authors found that Levenberg Marquardt algorithm was able to accurately and precisely predict the thunderstorm affected surface parameters. The predictions were made for the interval duration of 1hr, 3 hrs. 24hrs in advance. This study evaluates the utility of ANN for estimating hourly surface temperature and relative humidity using meteorological parameters. The authors did sensitivity experiments to test the impact of learning algorithms on severe thunderstorm prediction that occurred over Kolkata on the above stated dates. The authors also stressed that ANN could yield more accurate results, if good data selection strategies, training paradigms, and network input and output representations are determined properly. Nizar Ali Charnia and Dr. Sanjay .V. Dudul <sup>[14]</sup>, presented a committee of artificial neural network based model using wavelet decomposition method for prediction of monthly rainfall from the preceding events of rainfall for different geographical locations of India .The data for this study is taken from Indian Institute of Tropical Meteorology which constitutes rainfall data for 50 years (1955-2005). Rainfall prediction is done for North Central India, Nagpur Station and entire country. The data for Nagpur station is obtained from IMD Pune. Wavelet transformation is done to extract two coefficients approximate coefficients and detailed coefficients of the rainfall data series. After obtaining these coefficients artificial neural network is used for extracting the useful information. Two artificial neural network were developed one was fed with approximate coefficients of the rainfall data series and other was fed with the detail coefficients of the rainfall data series. After the inverse wavelet transform of the combination of these two model outputs which is the recombination step

predictions are made. The authors found multilayer perceptron containing two hidden layers optimal for approximate Coefficient prediction. For the detailed coefficients focused time lag recurrent network with Gamma memory is found out to be best. Wavelet decomposition was done to truncate the frequency components so that it becomes easier for the neural network to achieve higher accuracy. Kesheng Lu and Lingzhi Wang<sup>[3]</sup>, proposed a novel modular type support vector machine to simulate rainfall prediction. The authors utilized a bagging sampling technique for generating different training sets. By taking different kernel functions of support vector machine utilizing different parameters training is done to generate different regression based on different training sets. Partial least square technology is also employed for selection of appropriate number of SVR combination members. A  $\nu$ -SVM is produced by learning from all the base models. The developed forecasting model can be described in stages: In the first stage division of data is done using bagging and boosting techniques. In the second phase these training sets are given input to various SVM regression models and after that different single SVM regression predictors are generated which are based on diversity principle. In the third stage to select the ensemble members PLS models are used and finally in the fourth stage  $\nu$ -SVM regression is used to create the combination members which produces the forecasting outputs. The models were evaluated in terms of certain performance evaluation criteria like Normalized Mean Square Error, mean absolute percent error and Pearson relative coefficient. The authors claimed that the proposed new model performs satisfactorily well for complex forecasting problems. Sunyoung Lee et.al<sup>[15]</sup>, proposed divide and conquer approach for prediction of rainfall where the whole geographical region is subdivided into four sub divisions and each region is modeled using different technique. Larger regions were modeled using RBF technique using only the location information. Smaller regions were modeled using Orographic effect where precipitation is proportional to elevation. The prediction model in these two areas was generated using simple regression based models. The authors found that comparison between the data observed with the results obtained from RBF networks indicate that good predictions are achieved while linear models revealed poor predictions. The authors indicate that large prediction errors are due to the fact that Orographic effect does not exist. For the RBF models Gaussian functions are used as activation function for the hidden layer. Seema Mahajan and Himanshu Mazumdar<sup>[16]</sup>, in this study the authors proposed a new method of rainfall prediction for 30 Indian sub divisions. The authors obtained rainfall data of these subdivisions from Indian Institute of Tropical Meteorology Pune. For prediction of next one year rainfall the authors generated a combination of Fast Fourier Transform and Feed Forward Neural Network and filtering is performed on the raw interpolated rainfall data to separate the periodic components. During training these periodic components and delayed periodic components are given input to the network. During the testing inverse FFT provides the predicted rainfall value by amount of training input-output delay. The designed model is tested with 140 year's Indian subdivisions rainfall data. The experimental results of 30 subdivisions show that next one year rainfall prediction accuracy is above 92%. An interactive user friendly application is developed using C # .Net tool to implement the proposed model. The model was initially trained using 50 neurons. The authors found that lower number of neurons produces faster learning but error was more. 100-500 neurons produced accurate results. For 30 sub divisions the prediction error was below 8%. The authors suggested that this study would be useful in crop planning for agricultural country like India. Lalit Mohan Pant and Ashwagosh Ganju<sup>[17]</sup> investigated the application of neural networks for prediction of Avalanche on Chowkibal Tangdhar road axis in Jammu and Kashmir. Multilayered Feed forward Artificial Neural Network was developed. The networks were developed and trained using month wise past snow and weather parameters which was recorded at Stage II observatory for assessing the avalanche and non-avalanche activities. The authors considered two approaches for training the network. In the first approach the authors only utilized avalanche activities that occurred in the axis for training the network while in the second approach opinion of experienced forecasters was also included for the prediction purpose. The designed network performance varies from 67-82%. For validation of designed models winter data of 2001-2002 is used. The network architecture was in the form of 7, 3, 1 and four layered network with 7, 4, 2 and 1 give optimal solutions. The authors found that with inclusion of opinion of experienced forecasters prediction accuracy increased significantly. Kumar Abhishek et.al<sup>[18]</sup>, designed ANN model to predict average monthly rainfall for Udupi district of Karnataka, India models for developed for monsoon seasons. Three algorithms were tested which were Back propagation algorithm, layered recurrent network and cascade back propagation. The authors found back propagation algorithm best among the three tested.

## V. CONCLUSION

This paper presents a brief review of rainfall prediction techniques. The paper focuses on available techniques for rainfall prediction. From the review it was found that most of the researchers employed back propagation neural networks and achieved significantly good results. Other models based on RBF and SVM are also discussed. Extensive and appropriate references are also provided in support of various developments of Artificial Neural Network research provided with the paper would be of great help for any future researchers who are working in this field for precise and more accurate prediction of rainfall in coming future years.

## REFERENCES

- [1] Simon Haykin, Neural Networks and Learning Machines Third Edition Prentice Hall International Pvt. Ltd.
- [2] Enireddy Vmsidhar , K.V.S.R.P. Varma, P.Sankara Rao and Ravikanth Satapati, "Prediction of Rainfall using Backpropagation Neural Network Model", International Journal of Computer Science and Engineering, Vol 02, No. 04, 2010, pp 1119-1121.
- [3] Kesheng Lu and Lingzhi Wang, "A Novel Nonlinear Model Based on Support Vector Machine for Rainfall Prediction", Fourth International Joint Conference on Computational Sciences and Optimization, 2011, doi 10.1109/CSO.2011.50.

- [4] F.E.H, Tay and L. Cao, “Modified support vector machines in financial time series forecasting”, *Neurocomputing*, Vol. 48(1-4), 2002, pp 841-861.
- [5] V. Vapnik , S Golowich and A Smola, “ Support Vector method for function approximation , regression estimation and signal processing”. In Edited by M. Mozer , M. Jordan and T. Petsche, *Advance in neural information processing system*, Vol. 9 Cambridge ,MA: MIT Press,1997 pp 847-861.
- [6] Alex J. Cannon and Ian G. Mckendry, “Forecasting All - India Summer Monsoon Rainfall using Regional Circulation Principal Components: A comparison between Neural Network and multiple regression models”, *International Journal of Climatology*, 1999, pp 1561-1578.
- [7] Jiansheng Wu, “A novel Nonlinear Rainfall Forecasting model incorporating linear and nonlinear regression”, *IEEE Fourth International Conference on Natural Computation*, 2008, pp34-38
- [8] Harshani R.K. Nagahamulla, Uditha R. Ratnayake and Asanga Ratnaweera , “Monsoon Rainfall Forecasting in Sri Lanka using Artificial Neural Networks”, *Sixth International Conference on Industrial and Information Systems, ICIIS*, Aug 16-19,2011, Sri Lanka pp 305-309
- [9] L. Al-Matarneh, A. Sheta, S. Bani-Ahmad, J. Alshaer and L. Al-oqily, “Development of Temperature based Weather Forecasting Models using Neural Networks and Fuzzy Logic”, *International Journal of Multimedia and Ubiquitous Engineering*”, Vol 9 No.12, 2014, pp 343-366.
- [10] Saeed R. Khodashenas, N. Khalili, K. Davari, “Monthly Precipitation Prediction by Artificial Neural Networks” (Case study: Mashhad Synoptic station) , *NOVATECH 2010*.
- [11] Dr. Shaymaa Abdul Muttaleb Alhashimi, “Prediction of Monthly Rainfall In Kirkuk Using Artificial Neural Network And Time Series Models”, *Journal of Engineering and Development*, Vol. 18, No.1, January 2014 pp 129143.
- [12] Kyaw Htike and Othman O. Khalifa, “Rainfall Forecasting Models Using Focused Time-Delay Neural Networks”, *International Conference on Computer and Communication Engineering (ICCCE 2010)*, 11-13 May2010, Kuala Lumpur, Malaysia
- [13] A. J. Litta, SumamMary Idicula, and U. C. Mohanty , “Artificial Neural Network Model in Prediction of Meteorological Parameters during Premonsoon Thunderstorms”, *International Journal of Atmospheric Sciences*, Hindawi Publishing Corporation, Vol. 2013, Article ID 52583, <http://dx.doi.org/10.1155/2013/525383>.
- [14] Nizar Ali Charnia and Dr. Sanjay .V. Dudul, “Committee of Artificial Neural Networks for Monthly Rainfall prediction using wavelet transform”, *International Conference on Business Engineering and Industrial Applications IEEE*, 2011, 978-1-4577-1280-7/11.
- [15] Sunyoung Lee, Sungzoon Cho and Patrick M. Wong, “Rainfall Prediction Using Artificial Neural Networks” *Journal of Geographic Information and Decision Analysis*, vol. 2, no. 2, 1998, pp. 233 – 242.
- [16] Seema Mahajan and Himanshu Mazumdar, “Rainfall Prediction using Neural Net based Frequency Analysis Approach”, *International Journal of Computer Applications*, Volume 84 – No 9, December 2013, pp 7-11.
- [17] Lalit Mohan Pant and Ashwagosha Ganju , “Application of Neural Networks for Avalanche Forecasting” *Defence Science Journal* Vol 56 No 4 October 2006 pp 559-567.
- [18] Kumar Abhishek, Abhay Kumar, Rajeev Ranjan, Sarthak Kumar, “ A Rainfall Prediction Model using Artificial Neural Network”, 2012 *IEEE Control and System Graduate Research Colloquium*.