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Various Artificial Neural Network Techniques for Predicting Rainfall: A Review

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Abstract

The Artificial Neural Networks are suitable for pattern recognition and pattern classification tasks due to their nonlinear nonparametric adaptive-learning properties. The Artificial Neural Network model is capable of making better predictions then Multiple Linear Regression models. The Artificial Neural Networks prove to be better predictors. Neural network simulations appear to be a recent development. Artificial Neural Network (ANN) is an information-processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. The prediction of Indian summer monsoon rainfall (ISMR) on a seasonal time scale has been attempted by various research groups using different techniques including artificial neural networks.

An accurate rainfall forecasting is very important for agriculture dependent countries like India. For analyzing the crop productivity, use of water resources and preplanning of water resources, rainfall prediction is important. Statistical techniques for rainfall forecasting cannot perform well for longterm rainfall forecasting due to the dynamic nature of climate phenomena. Artificial Neural Networks (ANNs) have become very popular, and prediction using ANN is one of the most widely used techniques for rainfall forecasting. This paper provides a detailed survey and comparison of different neural network architectures used by researchers for rainfall forecasting.

Key Words: ANN, Multiple Linear Regression models, Statistical techniques, biological nervous systems

Introduction

Rainfall prediction is an important meteorological problem that can greatly affect humanity in areas such as agriculture production, flooding, drought, and sustainable management of water resources. The dynamic and nonlinear nature of the climatic conditions have made it impossible for traditional techniques to yield satisfactory accuracy for rainfall prediction. As a result of the sophistication of climatic processes that produced rainfall, using quantitative techniques to predict rainfall is a very cumbersome task. The paper proposed four non-linear techniques such as Artificial Neural Networks (ANN) for rainfall prediction. ANN has the capacity to map different input and output patterns.

Accurate, timely, area specific forecasts of precipitation are very important in countries thriving on agro based economy. In this aspect, one of the major issue is sudden changes in weather, Weather forecasting is an application of science and technology to predict the atmosphere for a given location.Already so many tools and techniques were introduced, but always there is a need to predict accurate weather information to avoid loss of lives and assets.Due to ease in training, the multilayered Artificial Neural Network learning algorithm is the most common. In this work we have used both Artificial feed forward and feedback(Recurrent) Neural networks forboth parameterized and time series prediction model to predict next month rainfall in mille meter.The feed forward neural network is trained with back propagation algorithm, and feedback neural network is trained with gradient descent strategy.

Rainfall is a natural climatic phenomenon whose prediction is challenging and demanding as the world continues to witness an ever changing climate conditions. Its forecast plays an important role in water resource management and therefore, it is of particular relevance to agricultural sector, which contributes significantly to the economy of any nation. Rainfall is one of the most complex and difficult elements of the hydrological cycle to understand and model due to the tremendous range of variation over a wide range of scales both in space and time (French et al., 1992). The complexity of the atmospheric processes that generate rainfall makes quantitative forecasting of rainfall an extremely difficult task (Hung et al, 2008).

Generally, rainfall has strong influence on the operation of dams and reservoirs, sewer systems, traffic and other human activities. As a result, accurate rainfall forecasting is one of the greatest challenges in operational hydrology, despite many advances in weather forecasting in recent decades (Gwangseob and Ana, 2001). Many computational methods of modeling have been proposed in an attempt to predict rainfall accurately (Khaing and Thinn, 2008). According to Karim (2009), these models, regardless of their structural diversity generally fall into three broad categories: black box or system theoretical models, conceptual models and physically-based models. Black box models normally contain no physically-based input and output transfer functions. It is therefore considered to be purely empirical models.

The implementation of Artificial Neural Network is initiated in 1964[3], an importance is given to Soft Computing methodology in weather forecasting. In the actual complex system, there are multiple variables evolving together and influencing each other, therefore multivariate prediction is much important[3]. A Time Series model can be actually an integration of random and deterministic components [10]. If random components are eliminated then the deterministic components can then be easily modeled. Rainfall is an end product of number of complex atmospheric process which varies both in space and time. Hence time series Prediction is also important.

An accurate prediction of rainfall is crucial for agriculture dependent countries like India, China, Australia, Pakistan, and Iran. Moreover, the prediction of rainfall also helps in prevention of flood and the management of water resources. The variations in timing and quantity of rainfall have the potential impact on the agriculture yield. Prior knowledge of rainfall behavior can help Indian farmers and policy makers to minimize crop damage. Following two models [1] are used for rainfall forecasting: Statistical methods and Numerical Weather Prediction (NWP) model. However, Statistical methods (such as ARIMA model) may not generate good results for non-linear process because statistical methods are developed based on the assumption of linear time series. Therefore, the statistical methods cannot clearly identify nonlinear pattern and irregularities in the time series. Local weather situations such as cloud, fog, and peak of strong rush of wind can affect the rainfall generation process. NWP models cannot solve the local weather situations because the local weather situations are unstable. This is the general problem with weather prediction models [1, 2].

Researchers have used different soft computing techniques like Genetic Algorithm (GA), ANN, and Fuzzy logic for rainfall forecasting. However, many researchers preferred to use of ANN for rainfall forecasting because :- 1) ANNs are data driven model and do not require restrictive assumptions about the form of the basic model. 2) ANN can also predict the pattern which is not provided during training (generalization). 3) ANN is efficient at training large-size of samples due to its parallel processing capability. 4) ANN has ability to implicitly detect complex nonlinear relationships between dependent and independent variables.
Rainfall forecasting can be done using statistical models namely AR (Auto Regressive), MA (Moving Average), ARMA (Auto Regressive Moving Average) [2], ARIMA (Auto Regressive Integrated Moving Average) [3], and Multiple Regression. Rainfall data is non-linear in nature. Amount, frequency, and intensity are three main characteristic of rainfall time series. These values vary from place to place, day to day, month to month and also year to year. Each statistical model has some limitations. AR model regresses against past values of the series. MA model uses past error as an explanatory variable. AR and MA both are suitable for developing models for univariate time series. The AR term only tells the number of linearly correlated lagged observations and is not appropriate for the data having nonlinear relationships. AR and MA can be combined together to form a general and useful class of the time series model known as the ARMA model. ARMA model can only be used for stationary time-series data and forecasting of short term rainfall. ARIMA model considers p, d, and q three variables where terms d means difference, p represents degree of auto-regressive, and q represent degree of moving average. Two parameters p and q are chosen by observing the autocorrelation function and partial autocorrelation function of the time series. The statistical approaches lack an ability to identify nonlinear patterns and irregularity in the time series.

Non linear and linear multiple regression models are also used by practitioners for rainfall prediction. One of the limitations of multiple regression models is multicollinearity, which may produce trivial solutions [18]. Traditional methods works on linear data but ANN works on linear as well as non linear data. Traditional methods make assumption based on time series data but ANN does not require restrictive assumption based on time series data. Therefore, for stationary (linear) time series, ANNs have the best performance than traditional methods [3, 4].

Heavy rainfall prediction is a major challenge for meteorological department as it is closely associated with the economy and life of human. It is a cause for natural disasters like flood and drought which are encountered by people across the globe every year. Accuracy of rainfall forecasting has great importance for countries like Nigeria whose economy is largely dependent on agriculture. Due to dynamic nature of the atmospheric conditions, statistical methods have failed to provide good accuracy for rainfall forecasting. Nonlinearity of rainfall data makes

Artificial Neural Network a better technique [6]. The accuracy of rainfall prediction is very important because of the current extreme change in climatic conditions all over the world [4]. Deterministic weather forecasting models have proved to be grossly inadequate and ineffective. They are mostly time consuming. Moreover, they lack the capacity to effectively handle large volume of data [5].

Some techniques have been proposed in the past to overcome the difficulties associated with rainfall prediction. The concept of modular modelling and combining different models has attracted more attention recently in rainfall forecasting. In modular models, several sub-processes are first identified, and then separate models (also called local or expert models) are established for each of them [5]. So far, various modular models have been proposed, depending on soft or hard splitting of training data. Soft splitting means that the dataset can be overlapped, and the overall forecasting output is the weighted average of each local model [7]. Machine learning methods have already proven to be good replacement for traditional deterministic approaches in weather prediction [8].

Artificial Neural Networks (ANN) is one of the most recent advances in machine learning. It has the capability to learn to correctly denote primary data, detect the important features, increase effectiveness of prediction compared to traditional models. ANN also improve the understanding of the significance of data and offers further understanding on the composition of rainfall data [9]. Stimulated by the characteristics of ANN. This paper proposed different Neural Network based approach for prediction of rainfall. Our main contributions in this paper are as stated below:
Four Neural Network learning models that have the capacity to predict rainfall with minimal Root Mean Square Error (RMSE) was proposed.

- Better classification accuracy was achieved through the application of Feed Forward Neural Network (FFNN), Cascade Forward Neural Network
- (CFNN), Recurrent Neural Network (RNN), and Elman Neural Network (ENN) on rainfall data.
- An average RMSE value of 6.601 for ELMAN was achieved. The proposed model was evaluated using different performance metrics.
- A recent review of state-of-the-art techniques for rainfall prediction is presented.

ARIMA is usually superior in statistical techniques, when the data is reasonably long and the correlation between past observations is stable. Therefore, for long memory series, ANNs and ARIMA models are generating the same results. However, for short memory series, ANNs are generating better results. However, neural networks can have different architecture which depends on the number of layers, activation function, training algorithm, and control feedback. A few surveys exist on rainfall forecasting. D.Nayak et al.. [5] Surveyed different techniques like MultiLayer Perceptron Neural Network (MLPNN), Back Propagation Algorithm (BPA), Radial Basis Function Network (RBFN), SOM (Self Organization Map) and SVM (Support Vector Machine).

From the survey, they concluded that most of the researchers used back propagation algorithm for rainfall prediction. B.Rani and A.Govardhan [6] used Multi Layer Perceptron Neural Network (MLPNN) for rainfall forecasting and compared obtained results with the results obtained using ARIMA technique. They concluded that, back propagation algorithm was giving better accuracy. Shoba G. and Shobha G. [7] analyzed the various algorithms like Adaptive Neuro Fuzzy Inference System (ANFIS), ARIMA and SLIQ Decision tree for prediction of rainfall. R.Sangari and M.Balamurugan [8] compared data mining techniques such as K-Nearest Neighbour (KNN), Naïve Byes, Decision Tree, Neural Networks, and Fuzzy Logic for rainfall forecasting. They also compared the performance of these techniques and concluded that neural networks were giving highest accuracy of 85.77 %.

Concepts of Neural Network Architecture

Researchers have used different soft computing techniques such as GA, ANN, and Fuzzy logic for rainfall forecasting. However, many researchers preferred to use ANN for rainfall forecasting. A neural network is a massively parallel distributed processor made up of simple processing units, which has a natural tendency for storing experiential knowledge and making it available for use [5]. Neuron works like human brain; it can receive inputs, process them and produce the relevant outputs. Main advantages of neural network are ability to represent non-linearity exists between input and output variables.

A single layered or multi layered network of neurons is formed when a neuron links with the other neurons via connection link. A multilayer ANN contains 3 layer: an input layer, an output layer, and one or more hidden layer. The hidden layer is useful for performing intermediary computations before mapping the input to the output layer. When a model is constructed for specific application, training of model is done by using inputs and the corresponding targets until it learns to relate a particular input with an output. A network is trained until the change in weights in a training cycle reaches a minimum value. After training, a model is validated by checking whether it produces accurate output or not. Multilayered networks are capable of memorizing data due to large number of synaptic weights available in network.

Issues Involved in Rainfall Forecasting

Challenges in yearly, monthly, and weekly data are as follows. In yearly rainfall data, there is no simple method for determination of the rainfall parameters such as wind speed, humidity, and soil temperature etc. Too few or too many input parameters can affect either the learning or prediction capability of the network. User cannot use same model over long period of time because parameters are varying from day to day, month to month, or year to year. Therefore, new parameters cannot be fitted in the developed model. Forecasting of yearly data is dependent on a sampling interval of input data. In yearly data, if the training set is large then it provides good accuracy. Noises and distortion associated with the random fluctuations are possible in daily or weekly rainfall data. Therefore, daily or weekly rainfall data may not be accurately predicted. Monthly predictions are better than weekly predictions when compared with actual rainfall data, and show a high correlation. Yearly rainfall data give more useful information than monthly or daily data.

Challenges while applying different types of NN modeling for yearly, monthly, and weekly rainfall data are described as follows. In yearly rainfall prediction, average rainfall data is used as input to ANN. Therefore, ANN can easily predict approximate peak value of yearly rainfall data. However, an issue of minor peak detection occurs in the yearly rainfall prediction due to averaging of monthly rainfall data. These minor peak values can be predicted accurately using additional meteorological parameters. In monthly rainfall prediction, actual rainfall data almost meets with the predicted data except for the sharp peak values. Peak detection is major issue in weekly rainfall prediction. Weekly rainfall data contains approximately same range of rainfall (e.g., 6-15 mm) but also contains some peak values (e.g., 25 mm). Due to that average weekly rainfall can be predicted exactly, but peak values can be predicted approximately.

Number of hidden layer and nodes

Main issue in design of NN is the selection of number of hidden layers [12, 13]. The hidden nodes of hidden layer allow neural network to capture the pattern in the data, and perform non linear mapping between input and output variables. Researchers have used one hidden layer for rainfall forecasting. But usage of one hidden layer may require large number of hidden nodes and due to that training ability of neural network gets minimized [12]. Many practitioners [4, 14, 18, 25] have used two hidden layers for rainfall forecasting. NN architecture with two hidden layers provides better accuracy on training and test data compared to one hidden layer architecture. More than two hidden layers give same result as achieved with two hidden layers [12].

Artificial Neural Network (ANN) which is one of the artificial intelligent techniques is a typical black box model. The development of this model has recently become an important alternative tool to conventional methods such as regression methods in modeling of non linear functions. ANN was first developed in the 1940s and the development as experienced a renaissance in iterative auto-associable neural networks (Hung et al, 2008). In recent decades, various commercially available algorithms such as MATLAB, NuExpert, NeuNet, Easy NN, ALYUDA-Forecaster, etc have been developed to overcome a number of limitations in the early networks. This makes the practical applications of ANN more appreciable in the field of hydrology. The operation is based upon the neural structure of the human brain.

An ANN provides the user a model free tool, which can generate input-output mapping for any set of data as complex pattern recognition can be attempted without making any initial assumptions. In addition, ANN could learn and generalize from examples to produce meaningful solution even when the input data contain errors or is incomplete (Luk et al, 2000). Haykin (1994) identified the following areas of application of ANN model: pattern matching, adaptive learning, prediction, data compression, self-organization and function optimization. Training of the network with the relevant data enable the network with the ability of making predictions based on any input it encounters (Kumarasiri and Sonnadara, 2006). Based on the structure of the learning algorithm of neural networks, various neural network models have been studied to solve different modeling problems. Karim (2009) demonstrated ANN's ability as a universal approximator when applied to complex systems that may be poorly described or understood using mathematical equations.

Artificial neural network has been widely applied in modeling of many nonlinear hydrologic processes such as numerical weather and global climate model (Kang and Ramirez, 2009); rainfall-runoff model (Hsu et al., 1995; Shamseldin, 1997); stream flow model (Zealand et al., 1999; Modarres, 2008; and Karim, 2009); precipitation prediction (Kevin, 2008; and Khaing and Thinn, 2008); rainfall modeling (Sunyoung et al, 1998; Hung et al, 2008; and Somvanshi et al, 2006); and simulation of daily temperature (Ricardo and Jean, 1999). According to Khaing and Thinn (2008), among the forty eight (48) studies conducted using ANN between 1988 and 1994, Adya and Collopy (1998) found that neural network models produced superior predictions. The results obtained showed that effectively implemented and validated neural network models out-performed all comparative methods such as linear regression, stepwise polynomial regression, multiple regression, discriminant analysis, logic models and rulebased system.

ANN model

An ANN is a highly interconnected network of many simple processing units called neurons, which are analogous to the biological neurons in the human brain (Andy et al, 2004; Hung et al, 2008; Kumarasiri and Sonnadara, 2006; and Luk et al, 2001). Neural networks essentially involve a nonlinear modeling approach that provides a fairly accurate universal approximation to any function. Its approximation power comes from the parallel processing of the information from the data. No prior assumption of the model form is required in the model building process. The model is characterized by a network of three layers of simple processing units, which are connected to one and other. The layers are input, hidden and output layer as shown in below Figure.

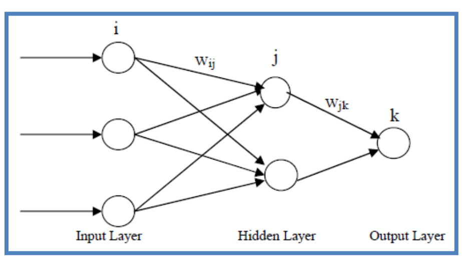

Fig : Typical ANN topology

The number of nodes in the input layer and the output layer are determined by the number of input and output parameters. The first layer i, (independent variables) that receive input information, is called an input layer. The last layer k, (dependent variables) which produces output information, is called an output layer. There exists between the output and input layers the hidden layers j. There can be one or more hidden layers with many nodes. Information is

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transmitted through the connections between nodes in different layers with the aid of connection weights wij and wjk. Somvanshi et al (2006) recommended the use of one hidden layer in preliminary studies. Having more than one hidden layer will definitely increase the number of parameters to be estimated. This may slow down the training process without reasonably improving the efficiency of the network.

Various ANN models have been proposed for the rainfall modeling since its inception. Multilayer perceptron (MLP) otherwise known as feed forward back propagation (FFBP) and the radial basis function (RBF) network are the most widely used model. MLP maintains high level of research interest due to its ability to map any function to arbitrary degree of accuracy (Modarres, 2008). It is composed of multiple simple processing nodes, or neurons, assembled in several different layers. Each node computes a linear combination of weighted inputs (including a bias terms) from the links feeding into it (Ricardo and Jean, 1999).

The idea of ANNs is based on the belief that working of human brain can be imitated by making the right connections using silicon and wires as living neurons and dendrites [6].The human brain is composed of 100 billion nerve cells called Neurons. They are connected to other thousand cells by Axons. Stimuli from external environment or inputs from sensory organs are accepted by Dendrites. These inputs create electric impulses, which quickly travel through the neural network. A neuron can either send the message to other neuron to handle the issue or block the message from processing forward.

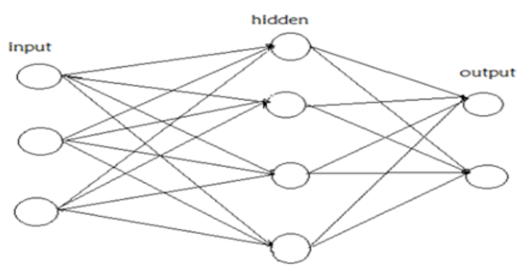

Fig.: Fully Connected Artificial Neural Network

ANNs are composed of multiple nodes, which imitate the biological neurons of human brain. The neurons are connected by links that interact with each other. These nodes can take input data and perform simple operations on the data. The result of these operations is passed to other neurons. The output at each node is called its activation or node value.Each link is associated with weight. ANNs are capable of learning, which takes place by altering weight values.

Types of Artificial Neural Networks

There are two Artificial Neural Network topologies – Feed Forward and Feedback.

Feed Forward ANN

In the Feed Forward ANN the flow of information is unidirectional. A unit sends information to other unit but the vice versa does not take place, that means there are no feedback loops. These types of Artificial Neural Networks are used in pattern generation, pattern recognition or pattern classification. They have fixed inputs and outputs.

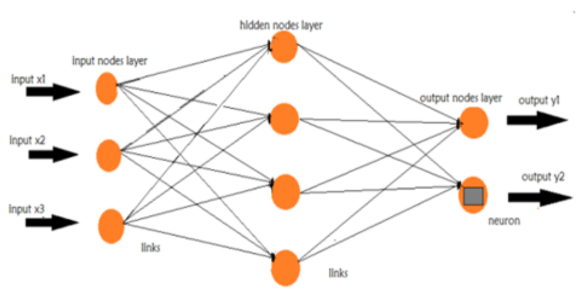

Fig: Fully Connected Feed Forward Artificial Neural Network.

Feedback ANN

Here, feedback loops are allowed. They are used in content addressable memories.

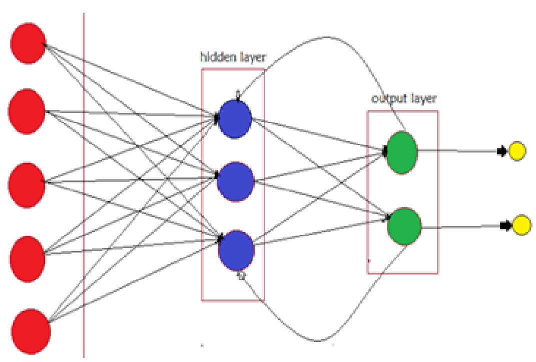

Fig.: Feedback Artificial Neural Network

ANN training algorithms

The training of the network is aimed at determining the main control parameters of ANN called weights. The processes of estimating these parameters are known as training where optimal connection weights are determined by minimizing an objective function (Somvanshi et al, 2006). There are basically two types of training mechanisms: supervised and unsupervised training. A supervised training algorithm also known as back propagation training algorithms requires an external teacher to guide the training process. The goal of supervised training is to minimize the error at the output layer by searching for a set of connection strengths that cause the ANN to produce outputs that are equal to or closer to the targets (Shiru and McCann, 2011 and Karim, 2009). A supervised training mechanism is normally adopted in most of the engineering applications. An unsupervised training algorithm called self-organizing neural network is used when the training set lacks target output values (Shiru and McCann, 2011).

The most famous self-organizing neural network is the Kohonen's Self Organizing Map (SOM) classifier, which divides the input-output space into a desired number of classes (Karim, 2009). In supervised training, the network compares the generated values with the target values. The error resulting from the comparison is propagated backward through the network, and the weights are adjusted to minimize this error. The procedure continues until network generates value of error closer to the validation value.

Conclusion

Rainfall is one of the key entities of hydrological cycle that strongly influence the operation of dams and reservoirs, flood control, drought mitigation, operation of sewer systems, agricultural practice, traffic conditions and other human activities. As a result, accurate modeling of rainfall plays an important role in the management of water resources. This paper presented survey of different NNs used by researchers for rainfall forecasting, and issues requiring attention while applying NNs for rainfall forecasting. The survey shows that FFNN, RNN, and TDNN are suitable to predict rainfall than other forecasting techniques such as statistical and numerical methods. The survey also shows that neural network performs well for yearly rainfall forecasting.

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