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Determining the Sensitivity of Rainfall- Runoff Model using Artificial Neural Network Approach

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Abstract: Rainfall runoff modeling using neural network technique has been attempted. Neural network gives good non linear relationship and mimics the physical behavior of the real case example: Neural network architecture with input layer, single hidden layer and an output layer was selected. Daily lag time precipitations and daily stream flow are considered as inputs. Different scenario of input combinations for runoff as output was tried. The response of output for input variation was analyzed. It was observed that mean square error show minimum value for a combination of three day lag precipitation and two day lag runoff, further variation increases the mean square error. Nethravathi basin originating from Western Ghats and flowing towards the west reaching the Arabian Sea was selected as study area.

Keywords: *Neural Network, Sensitivity, Rainfall-Runoff.*

Introduction:

Rainfall runoff models are useful in planning and management of stream flow. Different models have been adopted for rain fall runoff modeling. Mathematical models and empirical models are majorly adopted. Artificial neuron network is one of the recognized and well established models used in hydrological applications. Good prediction provides good planning for available and the predicted stream flows. Many input parameters have been adopted for rainfall runoff modeling, some of them are geographical characteristics, climatic factors and others. Different parameters are selected for rainfall runoff modelling, among them antecedent precipitation and runoff are majorly adopted. Drawbacks in physical models to get the required data have made it difficult to use in modelling, so as an alternative neural network and other empirical models are practiced. In the present study artificial neural network (NN) was adopted for modelling rainfall runoff. A parametric study has been carried out and sensitivity of the parameters selected was observed. NN modelling has been carried in many research works in past [1], [2], [4], [6]. In recent years they have been adopted for prediction and forecasting [3], [9], [10].

NN was trained using gradient descent method and the weights connected were optimized. NN architecture consists of many factors number of neurons in hidden layer, bias-value, momentum and learning rate were the factors selected. The neural network architecture was obtained by trial and error method. The aim of the study is to examine neural network technique to find the sensitivity of the inputs for rainfall runoff model

Neural Networks

Neural network (NN) models are inspired by nervous system and are adopted more commonly for rainfall runoff modeling due to its ability to capture non linearity. Neural network consists of input layer, one or more hidden layers and an output layer. All the layers consist of neurons, which are connected using weights between each other neuron. Typical neural network architecture has been shown below.

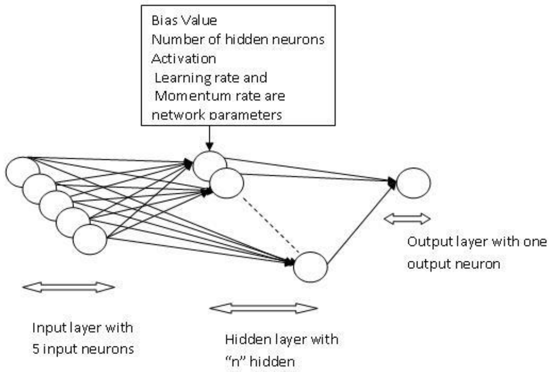

Figure 2: *Neural network architecture*

Information will be passed from each input neuron to all hidden neurons through these weights. Then information will be transferred from transfer function to the hidden neuron in hidden layer. Then all the values will be summed up at hidden neurons in hidden layer and then the information will be passed to the output neuron through connecting weights at output layer. Bias value was used to eliminate the dominant solutions. The whole process of feed forward from input layer to output layer has been termed as feed forward process.

The value at output layer was compared with the expected value, in supervised learning (adopted in present study). The error difference of observed value and predicted value are noted. Then errors are back propagated to obtain optimized weights. Chain rule was adopted to get the updated weights. The process of weights updating from feed forward back propagation is known as back propagation process. This updating continues until the desired solutions are obtained. Gradient descent method was used as learning technique in the current study. Learning rate helps to faster the learning process and momentum pushes the solution towards convergence. Minimization of mean square error was considered as objective of the neural network [8].

In the current study neural network with an input layer having, different combination of inputs were selected and tried to check the sensitivity of the model. In the present study the input layer consisting of antecedent precipitation and runoff as inputs neurons (3 days precipitation lag and 2 day runoff lag) was selected. Single hidden layer (the hidden neurons were selected by varying from 2 to 25 and which number gives minimum error was selected). Output layer consists of only 1 hidden neuron. Hidden layer and output layer consists of tangent sigmoid transfer function. Other network parameters selected were Bias value, Leaning rate, momentum and activation constant at hidden layer and output layer (Figure 2). The best combinations of network parameter were selected by varying one parameter value and keeping the other entire values constant [7]. Finally an optimized network weights were obtained. The error difference was computed by equation shown below.

$$E = \frac{1}{2}\left(T_o - O_o\right)^2 \qquad (1)$$

Study Area:
Nethravathi River basin located is in Karnataka, India along $74^{o}\ 45^{l}$ E to $75^{o}45^{l}$ E longitude and $12^{o}\ 30^{l}$ N to $13^{o}\ 10^{l}$ N latitude on Western Ghats (Figure 1) was selected as study area. The catchment stretches around 3184 km^2. The basin receives rainfall mainly during monsoon months (June to September) and it also continues till November. The daily rainfall data and stream flow data was obtained from Indian Meteorological Department (IMD) and Central Water Commission (CWC) were used in the study.

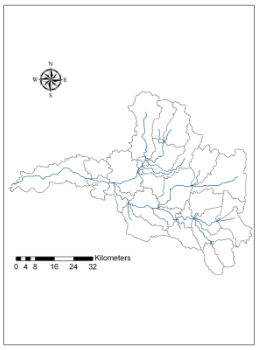

Figure 1 *– Study area, Nethravathi river basin*

Fourteen Rain gauge stations of Nethravathi basin were selected and their corresponding Thiessen weights were found. It was evident that only 12 stations contributed for their weight ratio to compute the average rainfall over the basin. In current research work, different combination of inputs for stream flow as output was carried out. Evaporation, base flow and other parameters were ignored in the study. The input variables were lag time of daily precipitation and runoff.

The daily rainfall and daily runoff data for years 1991 to 2001 were selected for modeling. The stream flow and rainfall data was normalized accordingly [5] for range between of 0.05 to 0.95 from the equation 2.

$$x_s = 0.05 + 0.90\left(\frac{x_i}{x_{\max}}\right) \qquad (2)$$

Where, x_s = normalized value of x_i ; x_i = the observed value; x_{max} = maximum value of the data set used.

Results:
The input data were normalized between 0.05 to 0.95 ranges. Daily rainfall and runoff data of Netravathi river basin were selected and they were used for the study. Neural network model was developed for rainfall runoff modeling. The parametric study of neural network architecture was carried. The network parameters associated in optimizing the architecture is shown in Table 2. The inputs for the network were rainfall and runoff. The different combination of inputs to check the sensitivity of the error response for varying inputs was done. The different input variation checked has been listed in Table 1. Initially by using only one lag time precipitation as input for stream flow as output corresponding mean square error observed was higher. By varying rainfall lag and stream flow lag as input, at a combination of three day lag precipitation and two day lag stream flow minimum mean square error was observed

Table 1: *Input combination and its mean square error (MSE).*

Trial. No.	Inputs	Output	Minimum MSE from NN (normalized)
1	P_t	Q_t	0.002553
2	P_t , P_{t-1}	Q_t	0.002014
3	P_t , P_{t-1} , Q_{t-1}	Q_t	0.000378
4	P_t , P_{t-1} , P_{t-2}	Q_t	0.001803
5	P_t , P_{t-1} , P_{t-2} , Q_{t-1}	Q_t	0.000401
6	P_t , P_{t-1} , P_{t-2} , Q_{t-1} , Q_{t-2}	Q_t	0.000348
7	P_t , P_{t-1} , P_{t-2} , P_{t-3} , Q_{t-1}	Q_t	0.000394
8	P_t , P_{t-1} , P_{t-2} , P_{t-3} , Q_{t-1} , Q_{t-2}	Q_t	0.000402

It was also observed that for one day ahead runoff of forecasting model, two day lag rainfall showed good minimum error value but it was not the optimum value. The input variables: P_t = is current day rainfall;

P_{t-1} = one day lag rainfall; P_{t-2} = two day lag rainfall; P_{t-3} = three day lag rainfall; Q_t = current day runoff; Q_{t-1} = one day lag runoff; Q_{t-2} = two day lag runoff;

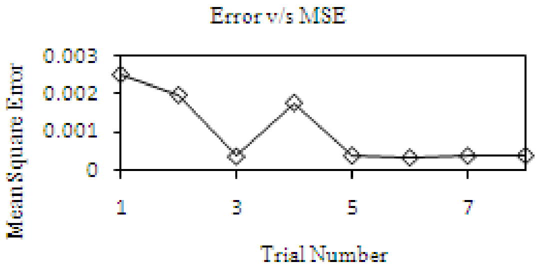

Figure 2: *Plot for input combination trial number (First column in Table 1) to mean square error*

In Table 1 at serial number 6 (i.e. P_t , P_{t-1} , P_{t-2} , Q_{t-1} , Q_{t-2} input variable) combinations shows the lowest value and indicates that runoff senses only up to theses input variables and beyond this it does not show a good prediction ability.

Table 2: *Parameters of Neural network architecture*

Sl. No	Network parameters	Range
1	Number of hidden neurons	2 – 25
2	Learning rate	0.1 – 0.99
3	Momentum rate	0.1 – 0.99
4	Bias value	0.000001-0.00001
5	Activation constant	1- 10

Conclusion:

It was observed that the runoff of the present day was sensitive only for rainfall lag up to three day and runoff lag up to days. Further increase in the lag did not showed any much improvement in the mean square error, so it can be stated that the runoff is sensitive for only up to certain lag of rainfall and runoff, due to good correlation.

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