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Modeling daily runoff for watershed using multilayer perceptron technique

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Abstract
To predict daily runoff for watershed, using ANN based Multi Layer Perceptron technique, a study was conducted on Nekpur watershed. Four parameters i.e; daily rainfall, previous day rainfall, next previous day rainfall, and previous day runoff were used in Neuro Solution Version 5.0 software for prediction of daily runoff. The ten years data of rainfall and runoff (1994-2003) were collected from DVC Hazaribagh, Jharkhand. Out of 10 years data, 8 years data (1994-2001) were used for training period. Fifteen ANN models for 5 neuron combination were run during the training period to predict daily runoff. The Statistical parameter i.e; Root Mean Square Error (RMSE), Correlation Coefficient(r), and Coefficient of Efficiency (CE), were used to compare observed and predicted runoff for selection of best fitted model-neuron combination for each model. Selected models were again used to generate predicted daily runoff and compared for different error and correlation coefficient. The result of the study indicates that minimum root mean square error (RMSE=0.00104) and maximum correlation coefficient (R^2=0.888) was observed for Model 2-Neuron 4 combination. It was concluded that ANN model can be used effectively for prediction of daily runoff for Nekpur watershed.

Keywords: Rainfall, runoff, development of Model, ANN, multi layer perceptron

1. Introduction
Water resources are essential renewable resources that are the basis for existence and development of a society. Proper utilization of these resources requires assessment and management of the quantity and quality of the water resources both spatially and temporally. The surface water, in the form of lakes and river discharge (runoff) is predominately obtained from rainfall after being generated by the rainfall-runoff process. In order to make decision for planning, design and control of water resource systems, long runoff series are required. The latter are not often available with reasonable length. On the other hand, for flood control and reservoir regulation future, flows shall be forecasted with rainfall-runoff models. A number of rainfall-runoff models exist for generation of flow, forecasting and other purposes. The rainfall-runoff models are useful in planning and management of stream flow. The different models have been adopted for rainfall-runoff modeling. Mathematical models and empirical models are majorly adopted. Artificial Neural Network is an information processing paradigm that is inspired by the processing elements or neurons working in parallel to solve specific problems. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. In the present study, an attempt has been made to develop an ANN runoff prediction model using rainfall as well as past runoff values for a specified lag tie as inputs of Nekpur watershed situated at Girdih district in Jharkhand state.

2. Objectives
i). Formulation of the ANN model based on multi layer Perceptron technique for prediction of the daily runoff for Nekpur watershed.
ii). Performance evaluation and validation of formulated model for study area.

3. Materials and Methods
i). Study Area
The study area is situated in district Girdih of Jharkhand state in India at latitude of 24°16’ N and longitude of 86°32’ E having an elevation of 298 m above from mean sea level (MSL). The climate of watershed is sub-tropical with three distinct seasons viz. winter (October to February), summer (March to May) and monsoon (June to September). The daily mean temperature of the watershed ranges from 10 °C to 40 °C.

ii). Data Collection

The daily rainfall and runoff data of monsoon season (1st June to 30th September) during the years 1994-2003 at Nekpur watershed were obtained from Soil and Water Conservation Division of Damodar Valley Corporation, Hazaribagh. The rainfall and runoff data during years 1994-2001 were used for development and calibration of the model whereas the data during years 2002-2003 were used for verification and performance evaluation of the developed model.

iii). ANN Base MLP Model

The original concept of an ANN was developed in 1943 by Warren McCulloch and Walter Pitts, who proposed conceptualization of human brain function based on a network of interconnected cells. The human brain is a natural neural network which has billions of neurons. A neuron may have many dendrites, which branch out in a tree like structure, and receive signals from other neurons. The axon conducts electric signals generated at the axon hillock along its length. The brain analyzes the patterns of signals being sent to it and interprets the type of information being received. Based on this concept, the ANN model was proposed in which artificial neurons imitate biological neurons also known as perceptrons. Typically, the MLP is organized as a set of interconnected layers of artificial neurons, input, hidden and output layers (Fig. 1). When a neural group is provided with data through the input layer, the neurons in the first layer propagate the weighted data and randomly selected bias through the hidden layers. Once the net sum at a hidden node is determined, an output response is provided at the node using a transfer function. The MLP can be trained by a back-propagation algorithm, which works by iteratively changing a network's interconnecting weights such that the overall error is reduced. Mathematically it has been proved that an MLP can approximate any function from a one finite dimensional space to another up to any desired degree of accuracy. This means that MLP should theoretically be applicable to any hydrological modeling problem. The output of each node is obtained by computing the value of the activation function with respect to the product of the input vector and the weight vector plus the value of the bias associated with that node. Mathematically this can be represented as:

$$y = f\left(\sum_{i=1}^{n} x_i w_i + b\right)$$

where, x_i (i = 1,2,... n) are inputs and w_i (i = 1,2, … n) are respective weights, b is the bias, y is the output and f(.) is the activation function. The net input to the node can be expressed as:

$$\text{net} = \sum_{i=1}^{n} x_i w_i$$

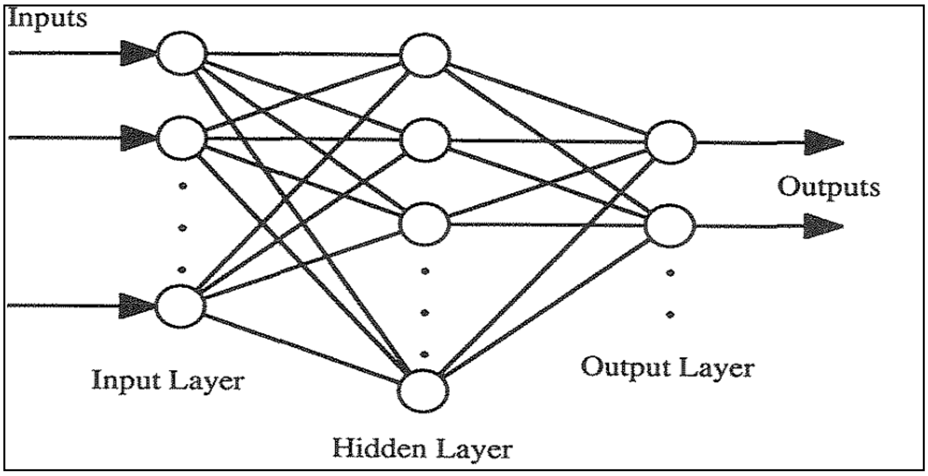

Fig 1: A Basic View of MLP

iv). Development of ANN Models

In this study the neural networks was applied to predict the runoff on daily basis for Nekpur watershed, Jharkhand, India. The daily data of rainfall and runoff time series of a period (June to September) was used for training and testing of the models. The data was divided in two sets, a training data sets considering of the data for the first 8 years (1994-2001) and a testing data set of remaining two years (2002 – 2003). The input pairs in the training data set were applied to the network of a selected architecture and training is performed using back propagation algorithm for Artificial Neural Networks (ANN).

v). Performance Evaluation of models

The developed model was evaluated by comparing observed and predicted values. In this study, the different performance evaluation indices were applied to test the performance of the developed ANN models. The visual observation based on the graphical comparison between observed and predicted values is one of the best methods for the performance evaluations of the models. Since, the visual observations comparison may have personal bias; it is not much accurate method for performance evaluation. Therefore, following statistical and hydrological indices was used for testing the goodness of fit for comparison between observed and predicted values of runoff data.

vi). Statistical Indices

a) Correlation coefficient (r)

The correlation coefficient (r) is an indicator of degree of closeness between observed and predicted values. If observed and predicted values are completely independent, the CC will be zero. The correlation coefficient is estimated by the following equation:

$$r = \frac{\sum_{j=1}^{n}\left\{\left(Y_j - \bar{Y}\right)\left(Y_{ej} - \bar{Y}_{ej}\right)\right\}}{\sqrt{\sum_{j=1}^{n}\left(Y_j - \bar{Y}\right)^2 \sum_{j=1}^{n}\left(Y_{ej} - \bar{Y}_{ej}\right)^2}}$$

$\bar{Y}$ = mean of observed values,

$\bar{Y}_{ej}$ **= mean of predicted values,**

Y_j = observed values,

Y_{ej} = predicted values and

n = number of observation

b) Coefficient of efficiency (CE)

Coefficient of efficiency (CE) has been recommended by many researchers in the field of hydrology for evaluating the model performance. A negative efficiency represents that the predicted values are less than the observed mean. The value of CE is determined by the following equation:

$$CE = \left[1 - \frac{\sum_{j=1}^{n}\left(Y_j - Y_{ej}\right)^2}{\sum_{j=1}^{n}\left(Y_j - \bar{Y}\right)^2}\right] \times 100\%$$

c) Root mean square error (RMSE)

The Root mean square error (RMSE) is determined to measure the prediction accuracy. It always produces positive values by squaring the errors. The RMSE is zero for perfect fit and increased values indicate higher discrepancies between predicted and observed values (Wilks, 1995). The Root Mean Square Error between observed and predicted values is determined by the following equation:

$$RMSE = \sqrt{\frac{\sum_{j=1}^{n}\left(Y_j - Y_{ej}\right)^2}{n}}$$

4). Result and Discussion

This chapter deals with the development and application of ANN model to predict daily runoff for Nekpur watershed in Girdih, India. The daily data of rainfall and runoff of Nekpur watershed of monsoon period (1^{st} June to30^{th} September) during years 1994-2001 were used for the training or calibration of the model, whereas the data of years 2002-2003 were used for verification (testing) of the developed model. Qualitative performance of the model has been checked by the visual observation, whereas, quantitative performance was verified by estimating the values of statistical and hydrological indices such as correlation coefficient (r), coefficient of efficiency (CE), root mean square error (RMSE). The fifteen models having high values of r, and 1CE and lower values of RMSE considered as the better fit model. The quantitative performance evaluations of best fifteen models are shown in Table. The Table also indicate the minimum MSE = 0.00104, maximum Correlation Coefficient = 0.888. Thus it is concluded that Model 2 Neuron 4 will be used for prediction of daily runoff.

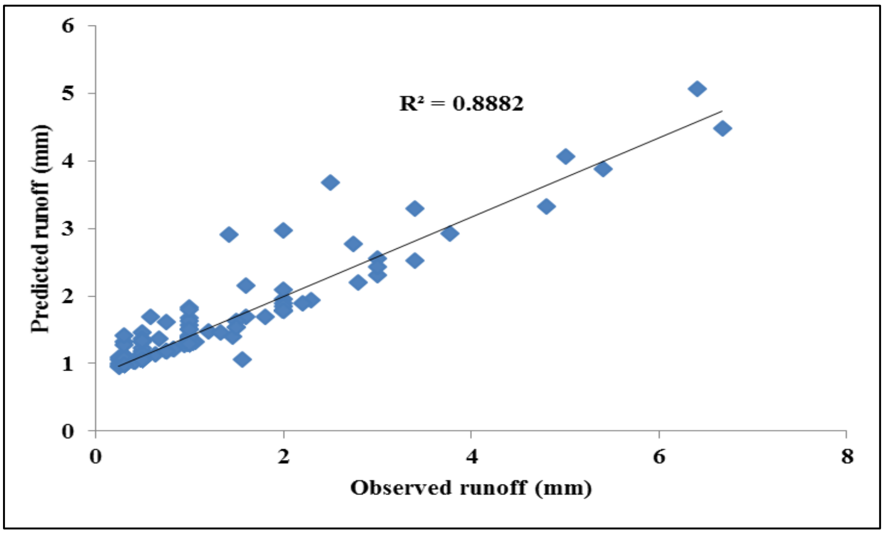

Fig 2: Correlation graph between observed and predicted runoff by model 2, neuron 4 during the validation period.

Table 1: Statistical parameters and characteristics of different selected models combination during testing and training period

S. No	Model	Structure	Training			Testing		
			RMSE	R	CE	RMSE	r	CE
1	M1	1-2-1	0.00574	0.4744	0.2244	0.00132	0.87293	0.6147
2	M2	1-4-1	0.00592	0.44998	0.2003	0.00104	0.94234	0.6118
3	M3	1-4-1	0.00586	0.45898	0.2090	0.00105	0.93274	0.6755
4	M4	2-4-1	0.00573	0.48119	0.2271	0.00166	0.84024	0.6289
5	M5	2-4-1	0.00572	0.47997	0.2287	0.00148	0.83307	0.4068
6	M6	2-6-1	0.00589	0.45594	0.2056	0.00128	0.78804	0.4845
7	M7	3-6-1	0.00582	0.46714	0.2157	0.00178	0.79373	0.3936

8	M8	1-4-1	0.00531	0.53709	0.2838	0.00215	0.86891	0.6715
9	M9	2-2-1	0.00563	0.49087	0.2409	0.00222	0.71903	0.2061
10	M10	2-2-1	0.00592	0.44916	0.2025	0.00177	0.80125	0.4232
11	M11	2-2-1	0.00583	0.46323	0.2140	0.00194	0.82704	0.466
12	M12	3-10-1	0.00572	0.48273	0.2301	0.0029	0.80870	0.555
13	M13	3-8-1	0.00361	0.71986	0.5148	0.00358	0.81609	0.602
14	M14	3-2-1	0.00586	0.45833	0.2115	0.00184	0.82158	0.4223
15	M15	4-2-1	0.00553	0.50491	0.2562	0.00289	0.76420	0.4143

5. Conclusion

The following conclusions are drawn on the study:

1. ANN models can be used to predict daily runoff for watershed. The Two input parameters i.e; Rainfall and Runoff are sufficient to predict daily runoff.
2. 15 ANN models for various Neuron combinations were used during testing period 2001-2003.
3. Out of 75 Model-Neuron combinations, 15 best fitted were selected based on comparison between observed and predicted values and statistical parameters.
4. After validating the 15 Model, it was concluded that Model 2 for Neuron 4 is the best suitable for prediction of runoff.

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