Rainfall - Runoff Modeling Using Artificial Neural Network of Perumal Tank, Cuddalore District, Tamil Nadu, India

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Abstract -- Rainfall-runoff models are highly useful for water resources planning, development and flood mitigation. Rainfall-runoff analysis is quite difficult due to presence of complex nonlinear relationship in the transformation of rainfall to run-off however runoff analysis is very important for the predication of natural calamities like floods and drought. A rainfall-runoff model is a mathematical model describing the rainfall-runoff relations of a catchment area, drainage basin or washed. In the model calculates the rainfall into runoff. In rainfall-runoff modeling SCS-CN (Soil Conservation Service – Curve Number) method uses the soil information, rainfall, storm duration, soil texture, type & extent of vegetative cover and conservation practices are considered. A new dimension has been added to the modeling approach through the adoption of the ANN (Artificial Neural Network) technique as these models possess desirable attributes of universal approximation, and the ability to learn from examples. The ANN is well known as a flexible mathematical tool and has the ability to generalize patterns in precise and ambiguous input and output data sets without attempting to reach understanding as to the nature of the phenomena. In the present study a feed forward back propagation algorithm of ANN model is used for Perumal tank, Uppanar sub basin in Kurinjipadi Taluk of Cuddalore District.

Indexed Terms: Rainfall, Runoff, Soil Conservation Service, Curve Number, Artificial Neural Network

I. INTRODUCTION

A rainfall-runoff model is a mathematical model describing the rainfall - runoff relations of a catchment area, drainage basin or watershed. More precisely, it produces the surface runoff hydrograph as a response to a rainfall hydrograph as input. In other words, the model calculates the conversion of rainfall into runoff. A rainfall runoff model can be really helpful in the case of calculating discharge from a basin. Runoff analysis is very important for the prediction of natural calamities like floods and droughts and plays a vital role in the design and operation of various components of water resources projects like barrages, dams, and water supply schemes. Runoff analysis is also needed in water resources planning, development and flood mitigation.

The Hydrological models can be classified based on the phenomenon of importance, classified as event based models that stimulate a flood peak resulting due to single or multiple storm events or continuous models that stimulate the flow processes over a season or over a number of years preferably to develop rainfall runoff relationship on daily basis. The other classification is based on the mathematical theory being applied and are classified as deterministic models which seek to stimulate the physical processes in the catchment wherein rainfall gets transformed into runoff. In stochastic models the hydrological time series of a single or several variables such as rainfall, evaporation, stream flow etc, involving distribution in probability is applied.

In the present study the Perumal Tank under Paravanar sub basin of lower Vellar basin, lies in Cuddalore district has been selected as the area of study. The modeling has been simulated by two methods SCS-CN method and Artificial Neural Network (ANN) separately and results have been compared. In the SCS-CN method data defining the basin properties, like rainfall data, soil conditions, topographical condition (i.e. the vegetation available above the earth surface, building and roads etc), population density and rainfall data collected from the rain-gauge stations are required.

The ANN method basically creates a non-linear function by the rainfall and discharge of the historical data and forecasts future discharge using an optimum network suited for the given problem statement. The

SCS-CN and ANN have been compared. SCS-CN method has been in use for a long time (Since 1969) and gives satisfactory result and ANN is relatively new but it gives a wide range of future development aspects and come to an optimum conclusion which one of the method is best suited in context of future development. The rainfall runoff model used to predict the loss of human life and property etc., due to flood.

1. Objective of Study:

In 2015 year flood resulted in a loss of several lives and damage of property and crops in Cuddalore District. The study area mainly affected by inundation due to heavy rainfall and maximum discharge from Neyveli lignite mine water to Paravanar River through Sengal Odai. Sengal Odai drains into middle Paravanar and the middle Paravanar terminates at Perumal Tank.

- Rainfall runoff models based on SCS–CN method and Artificial Neural Network (ANN) have to be developed for Perumal Tank catchment area.
- Comparison of Mathematical conceptual model and ANN model with actual runoff.

2. Scope of study:

The Rainfall Runoff model provides for an integrated approach that enables interactions and feedbacks between all domains relevant to water resources management. Model plays a vital role in the design and operations of various components of water resources projects like barrages, dams, water supply schemes. Understanding the catchment yield and how this varies in time and space, particularly in response to climate variability.

Estimating the relative contributions of individual catchments to water availability over a much larger region and to identify how the changes in land-use and land management and for the estimation of flow for an un-gauged catchment. Modeling gives prior information about the flood and hence early flood warnings and safeguarding the properties, cattle, human, and prevention of economic losses and reducing the risk for people can be achieved.

II. STUDY AREA

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Paravanar River is one of the major drains in Cuddalore District. It originates from Semakkottai forest area at Virdhachalam Taluk and confluence in Bay of Bengal at Cuddalore. The upper part of river called Upper Paravanar, middle part of river called as Middle Paravanar and the lower part of river called as Lower Paravanar.

Perumal tank is one of the biggest tanks in Tamilnadu State located in kundiyamallur to Agaram village in kurinjipadi and Cuddalore Taluk of Cuddalore District. The location of this tank lies between Latitude of 11˚35' N and Longitude of 79˚ 40' E at an altitude of 5.50 m above MSL. It falls in the survey of India topo sheet 58 M/10.

III. METHODOLOGY

The SCS approach involves the use of simple empirical formulas and readily available tables and curves, developed by the Soil Conservation Services (SCS, 1985). The Curve numbers are varied for different soil, land use/ land cover and hydrologic conditions. The Curve Number (CN) is a function of land use and HSG. CN values range between 0 and 100, with the higher CN values associated with higher runoff potential. Traditionally, an area weighted average curve number is used for the entire watershed to study the runoff of a watershed.

Neural network methodology, extracts information from the input data, is a crucial step that is badly affected through the selection of initial weights and the stopping criteria of learning. If a well designed neural network is poorly trained, the weight values will not be close to their optimum and the performance of the neural network will suffer. The training and validation procedures for specific network architectures were repeated in order to handle uncertainties of the initial weights and stopping criteria. In the preliminary investigation it is found that 10 trails were enough to find the best result. The performance efficiencies of each trail were recorded and compared. The result with the highest R-value of the training data set is considered the optimal ANN prediction for the network.

The SCS curve number method is a simple method used on large scale for determination of the approximate runoff value corresponding to a certain rainfall quantity in a certain area. Although the method is designed for a single storm, it can be scaled to calculate the annual values for runoff in an area. The SCS Curve number method only forecasts the quantity of runoff formed in any point of the catchment but does not model the flow routing or the distribution of runoff through time. The rainfall depth and an empirical parameter named the Curve Number are mandatory.

The Curve Number (CN) value can be obtained from the hydrologic soil group, land use and moisture conditions of the soil, the last two values being more important. The SCS-CN method is based on the water balance equation and two fundamental hypotheses.

The soil moisture condition before rainfall will significantly affects surface runoff capacity and CN values because it can check and balance the infiltration rate and quantity. Considering the effects, the SCS divided the Antecedent soil Moisture Content (AMC) represented by Antecedent Precipitation Index the 5-day antecedent rainfall amount into three levels of AMC are recognized by SCS as follows:

AMC-I: Soils are dry but not to wilting point.

AMCII: Average conditions.

AMCIII: Wet conditions.

IV. RESULTS AND DISCUSSION

The Curve Number (CN) is a function of land use and HSG. CN values range between 0 to 100, with higher CN values associated with higher runoff potential. Traditionally, an area weighted average curve number is used to study the runoff of a watershed. Appropriate curve number values for catchment area were assigned based on the USDA – SCS curve number tables (SCS, 1975) considering Antecedent Moisture Conditions (AMC).

The CN values arrived at based on the combination of land use, and Hydrologic soil group were meant for AMC-II condition. CN values for AMC for various Curve Number the runoff is estimated for different AMC-I (dry condition) and AMC-III (wet condition) conditions were calculated using interpolation equations.

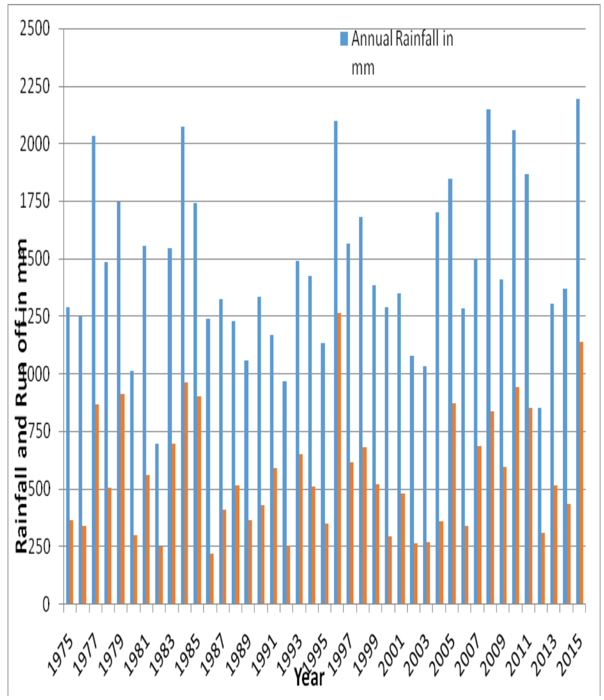

Fig. 1: Analysis of annual rainfall and runoff

- Analysis of annual rainfall Vs runoff

The graph plotted for Rainfall Vs Runoff for 40 years by rainfall in 'x' axis and runoff in 'y' axis. From the graph the regression equation and coefficient determination (R^2) is arrived.

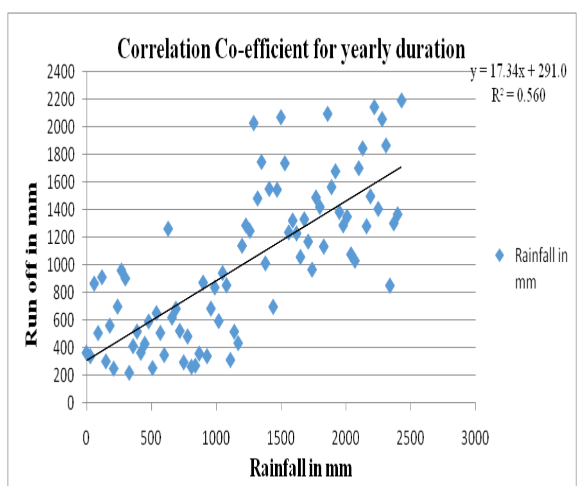

Fig. 2: Correlation co-efficient for annual rainfall - runoff

- Runoff analysis by ANN method:

Neural networks are composed of simple elements operating i n parallel. These elements are inspired by biological nervous systems. As in nature, the connections between elements largely determine the network function. You can train a neural network to perform a particular function by adjusting the values of the connections (weights) between elements.

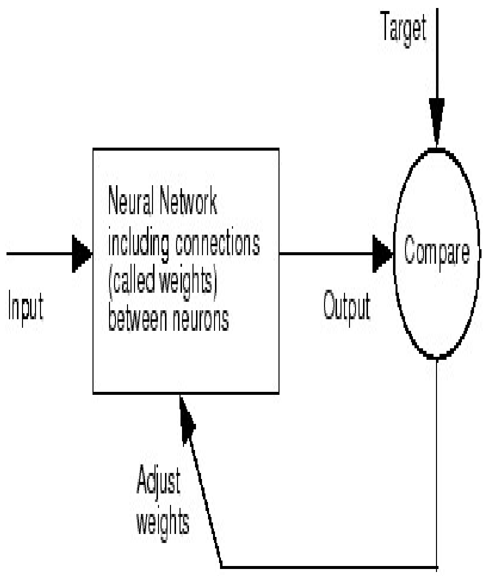

Fig. 3: ANN model line diagram

- ANN performance:

ANN performance consist of average squared of error (ASE), coefficient of determination, (R^2) and mean absolute error for input and target data.

$$\mathrm{ASE} = \frac{\sum_{i=1}^{N}\left(Qt_i - \hat{Q}t_i\right)^2}{N},$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(Qt_i - \hat{Q}t_i\right)^2}{\sum_{i=1}^{N}\left(Qt_i - \bar{Q}t_i\right)^2},$$

$$\mathrm{MARE} = \frac{\sum_{i=1}^{N}\left|\left(\hat{Q}t_i - Qt_i/Qt_i\right)\right|}{N} \times 100,$$

Where Q_{ti} and-Q_{ti} is an predicted and actual flow, N is an number of data,

The R^2 statistic measures the linear correlation between the actual and predicted flows values. The optimal value of R^2 is equal to 1.0. The graphical performance indicator gives better results when the data pairs are closing to 45° line and the good superposition between the desired and calculated flow values in the training and testing phase.

The data base for the rain fall runoff model predicted over the year (1986-2015) for the testing phase and training data as (1960-1988). In the training phase 30 years data was used and remaining using the validation phase of ANN. The accuracy of the model based on the 1000 iterations by the 10 hidden layers by the neurons.

A two layer feed forward network with sigmoid hidden neurons ans linear neurons ca fit multi dimensional mapping problems arbitrarily well, given consistent data and enough neurons in its hidden layer. The network will be trained with Levenberg-Marquardt backpropgation algorithm. unless there is not enough memory in which case scaled conjugate fradient (trainscg) will be used.

The R^2 Value statistic measures the linear correlation between actual and predicted flow .The ASE and MARE statistic measures are used to quantify the error between observed and predicted values. The optimum values for R^2 is equal to 1 and ASE and MARE is equal to 0.

The following regression plots display the network outputs with respect to targets for training, validation, and test sets. For a perfect fit, the data should fall along a 45 degree line, where the network outputs are equal to the targets. For this problem, the fit is reasonably good for all data sets, with R values in each case of 0.89 or above.

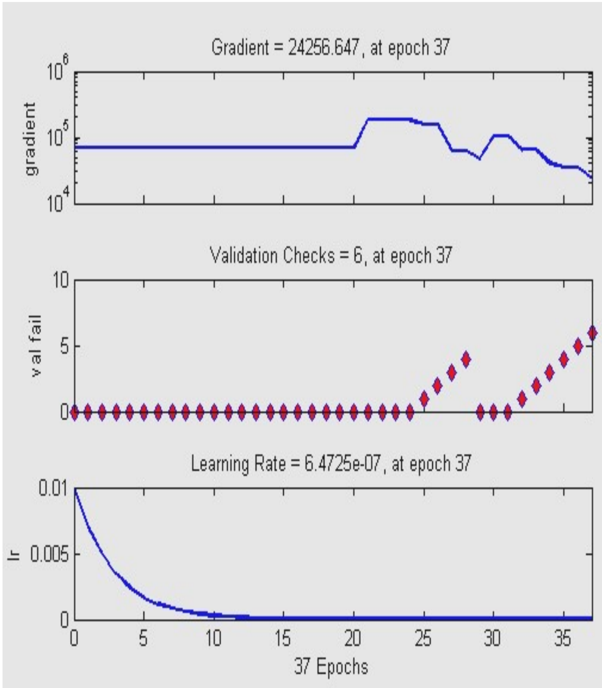

Fig. 4: Numbers of Iterations

The graphical performance indicate the better results when the pairs are closing to 45^0 line and the good superposition between the desired and calculated flow values in the training phase and testing phase.

From the above figure 45^0 line shows the excellent regression fit with the predicted flow of rainfall model respectively The statistical model of predicted discharge as shown in the below. The network model good agreed with the training and testing phases.

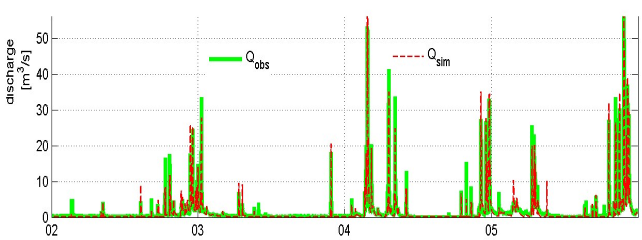

Fig. 5: Thirty years of discharge for the rainfall-runoff model

V. SUMMARY AND CONCLUSION

Based on the analysis performed in Artificial Neural Network and SCS-CN method following conclusions are drawn

- SCS-CN method considers the infiltration losses and soil properties, so conceptually it is very sound. The modified discharge value coming out to be much higher than the observed value, so for designing purpose it is not economical rather safer.
- SCS-CN method requires too many field data e.g. topography, soil type, Moisture condition etc, which are sometimes not available so a lot of assumptions are to be made.
- The daily runoff values are estimated using SCS-CN method and it is used to calculate monthly and annual runoff values. The regression equation Y= 17.34x + 291.0 is derived from the annual rainfall Vs runoff graph and the value of Coefficient determination "R^2" is 0.560 given below.
- The derived regression equation can be effectively used to predict the runoff.
- The testing phase value 0.53088 is less than the training phase value 0.99248 which shows the error is minimum.
- 45^0 line shows the excellent regression fit with the predicted flow of rainfall model and the predicted correlation R^2 value 0.89122 which is closely related to 1 shows the model is good with negligible error.
- The good performance and convergence of the model and the predicted and actual values of discharge for the entire database are identical. The network model agreed with the training and testing phases.
- The excellent regression fit with the predicted flow of rainfall model and the predicted correlation R^2 value 0.89122 which is closely related to 1 show the model is good with negligible error.
- The predicted and actual values of discharge for the entire database are identical. The network model good agreed with the training and testing phases.
- The performances of ANN model and conceptual models were quite similar. Hence, the ANN model is an important alternative to the SCS-CN model for the rainfall runoff analysis.

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