Rainfall-Runoff Modeling: A Fuzzy Logic Approach

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Abstract—Rainfall-Runoff is very complex phenomena and its often required attention for modeling to estimate the runoff. Several methods are available for the rainfall-runoff modeling. The present study undertakes the rainfall-runoff modeling for Hadad rain gauge station of Dharoi sub-basin, Gujarat, India. In this study, the rainfall-runoff modeling has done using Fuzzy logic (FL) technique for the selected station. The dataset collected for the rain gauge stations was divided into different combination of training and testing ratio and the models were developed for Hadad rain gauge station with the selected combinations. Also, in Fuzzy logic, different combinations of rainfall were considered as the inputs to the model, and runoff was considered as the output. Input space partitioning for model structure identification was done by grid partitioning. A hybrid learning algorithm consisting of back-propagation and least-squares estimation was used to train the model for runoff estimation with the triangular membership function. The outputs generated were than compared to the observed outputs with different combinations of training and testing dataset by means of the model evaluation parameters coefficient of correlation (r), coefficient of determination (r^2) and discrepancy ratio (D.R) values..

I. INTRODUCTION

The hydrologic behavior of rainfall-runoff process is very complicated phenomenon which is controlled by large number of climatic and physiographic factors that vary with both the time and space. The relationship between rainfall and resulting runoff is quite complex and is influenced by factors relating the topography and climate.

In recent years, artificial neural network (ANN), fuzzy logic, genetic algorithm and chaos theory have been widely applied in the sphere of hydrology and water resource. ANN have been recently accepted as an efficient alternative tool for modeling of complex hydrologic systems and widely used for prediction. Some specific applications of ANN to hydrology include modeling rainfall-runoff process [1]. Fuzzy logic method was first developed to explain the human thinking and decision system by [2]. Several studies have been carried out using fuzzy logic in hydrology and water resources planning [3].

Adaptive neuro-fuzzy inference system (ANFIS) which is integration of neural networks and fuzzy logic has the potential to capture the benefits of both these fields in a single framework. ANFIS utilizes linguistic information from the fuzzy logic as well learning capability of an ANN. Adaptive neuro fuzzy inference system (ANFIS) is a fuzzy mapping algorithm that is based on Tagaki Sugeno-Kang (TSK) fuzzy inference system [4]. ANFIS used for many application such as, database management, system design and planning/forecasting of the water resources [5].

II. MATERIALS AND METHODS

A. Fuzzy Logic (Fl):

Fuzzy logic modelling is based on the theory of fuzzy sets. Unlike in an ordinary binary set, in a fuzzy set the boundary is not clearly defined and partial membership of elements is possible. Each element of the set is assigned a membership value which can be between 0 and 1 inclusively. The function that assigns this value is referred to as the membership function associated with the fuzzy set. Fuzzy numbers are special types of fuzzy sets defined on the set of real numbers. Fuzzy numbers are usually defined by using membership functions that have triangular shapes and are expressed as *(a.\, 02, a3)T* such that *a* < *a2* < 03. This triangular fuzzy numbers are shown in Figs 1. Other functions, such as the Gaussian function, can also be used as membership functions, but these increase the computational effort and provide no noticeable performance improvement [6].

To model a certain process using a fuzzy logic-based approach, the model variables are partitioned into different fuzzy classes and an IF...THEN type of rule is utilized to establish the resulting response of any combination of the fuzzy classes of the variables. The fuzzy arguments may be connected by logical connectors AND, OR, or XOR (either...or). The responses, referred to as the rule consequences, are also usually in the form of a fuzzy number. Unlike the usual type of rules on binary sets in which the conditions of the rule are either completely fulfilled or not, partial fulfilment of the conditions is possible in the case of rules on fuzzy sets. The consequence of the actual rule for a given set of model variable value depends on the degree to which they fulfil the condition of the rule. The truth value corresponding to the fulfilment of the conditions of a rule for a given set of values of the arguments is referred to as the degree of fulfillment (DOF) of the rule and has values in the interval [0,1]. This value is determined based on the membership value of each of the arguments and the logical connectors used

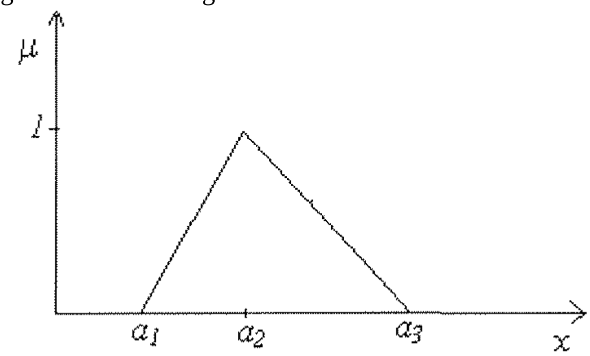

Fig. 2: Membership function of a triangular fuzzy number

Normally, several rules are partially satisfied for a given set of model variables and hence there are several associated fuzzy consequences, which are then combined into an overall fuzzy consequence using different techniques of rule combination. In this study, the 7 numbers of triangular membership functions are used to crisp the output.

III. STUDY AREA AND DATA

Area selected for the present study is the Dharoi sub basin which is the part of Sabarmati river basin. Study area is the Dharoi sub basin which is designated by line in Sabarmati river basin map. The area covering upper sub-basin and the catchment of the main river up to Dharoi dam is designated as Dharoi sub-basin. Constructed in 1978, the Dharoi dam is located about 165 km upstream Ahmadabad in village Dharoi of Mehsana district. This covers drainage area of the main river up to Dharoi dam.

Fig. 3: Dharoi sub-basin in Sabarmati Basin

In this study, long term monthly Rainfall and Runoff data are derived for Dharoi sub basin which is the part of Sabarmati river basin. Catchment area of the sub basin is 5,540 sq.km, out of which about 2,640 sq.km lies in Gujarat state.

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In Dharoi sub basin there are six Rain gauge stations existed but among them Hadad Rain gauge station's data is selected for the year 1968 to 2010 (42 years). Rainfall data are considered from June to October for each year so total 217 monthly data sets are used.

IV. METHODOLOGY

The selection of proper input and output data posses the prime importance and needs to be selected carefully. Here the Rainfall-Runoff model was developed using the Rainfall data as input and Runoff data as output.

Here, in the current study, Rainfall-Runoff datasets were firstly divided in the different combinations of training and testing data i.e. 80-20%, 70-30% and 60-40% that means the 80% datasets were used for training the model and remaining 20% dataset were taken for its testing purpose. The runoff model is developed with selected combinations of dataset for the Hadad rain gauge station.

The results obtained were evaluated by means of the model evaluation parameters and the best rainfall-runoff model from above three techniques for suitable combination of dataset was concluded. The model evaluation parameters used in this study are as follows:

Correlation coefficient (r):

$$r = \frac{\sum_{i=1}^{n}(Q\,(i) - \bar{Q})(\hat{Q}(i) - \tilde{Q})}{\sqrt{\sum_{i=1}^{n}(Q\,(i) - \bar{Q})^2 \sum_{i=1}^{n}(\hat{Q}(i) - \tilde{Q})^2}}$$

Coefficient of determination (r^2):

$$r^2 = \left(\frac{\sum_{i=1}^{n}(Q\,(i) - \bar{Q})(\hat{Q}(i) - \tilde{Q})}{\sqrt{\sum_{i=1}^{n}(Q\,(i) - \bar{Q})^2 \sum_{i=1}^{n}(\hat{Q}(i) - \tilde{Q})^2}}\right)^2$$

Discrepancy Ratio (D.R):

$$D.R = \frac{\sum_{i=1}^{n} Q(i)}{\sum_{i=1}^{n} \hat{Q}\,(i)}$$

Where $\hat{Q}$ (i) is the n estimated runoff value, Q(i) is the n observes runoff value, $\bar{Q}$ is the mean of the observed runoff values, and $\tilde{Q}$ is the mean of the estimated runoff values.

V. RESULTS AND DISCUSSION

A. *Fuzzy Logic Results*

Table. 1: Fuzzy logic results for Hadad rain gauge station

Ratio %	Training			Testing		
	r	r^2	D.R	r	r^2	D.R
80-20	0.99	0.98	0.99	1	0.99	1
70-30	0.99	0.99	1.02	0.99	0.98	1.04
60-40	0.99	0.99	1.02	1	0.99	1

Here, the table 1 shows that while using the Fuzzy logic technique, the best rainfall-runoff model comes out is 60-40% model with r value of 0.994 and r^2 value of 0.988 and discrepancy ratio value of 1.015 during training and r value of 0.995 and r^2 value of 0.991 and discrepancy ratio value of 0.998 during testing.

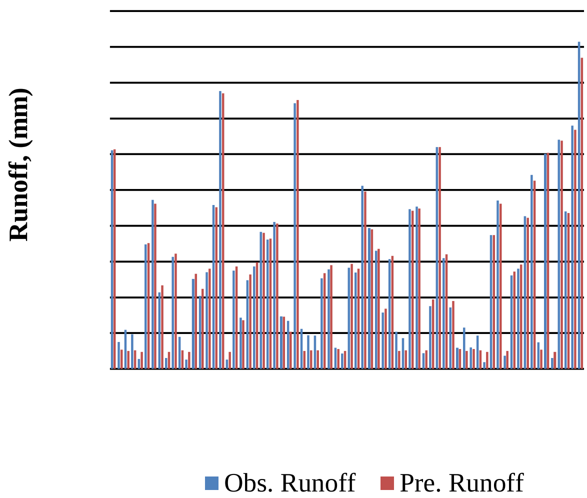

Fig. 4: comparison of observed runoff and predicted runoff of model 60-40% during training

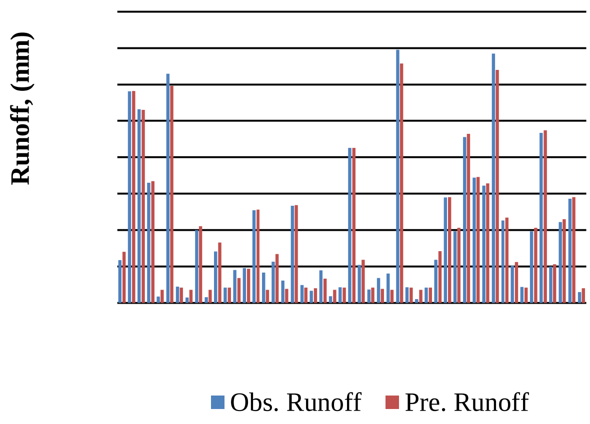

Fig. 5: comparison of observed runoff and predicted runoff of model 60-40% during testing

VI. CONCLUSIONS AND RECOMMENDATIONS

As seen from the results of the different combinations of training and testing data, the results of the fuzzy logic 60-40% model is the best among all. Hence, in this study, the best rainfall-runoff model for the Hadad rain gauge station is fuzzy logic 60-40% model with r value of 0.994 and r^2 value of 0.988 and discrepancy ratio value of 1.015 during training and r value of 0.995 and r^2 value of 0.991 and discrepancy ratio value of 0.998 during testing.

Hence, one can conclude that fuzzy logic provides efficient way to develop rainfall-runoff models. Also, one can use fuzzy logic technique for other hydrological modeling such as rainfall forecasting, evapotranspiration prediction, etc. for future.

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