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An Use of Fuzzy Logic for Development and Analysis of Rainfall – Runoff Model

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ABSTRACT: *A rainfall – runoff model describes the relation between the rainfall and runoff for a particular catchment area. Rainfall–runoff modelling can be carried out within a purely analytical framework based on observations of the inputs to and outputs from a catchment area. The relationship between rainfall in a period and the corresponding runoff is quite complex. The aim of this paper is to develop Fuzzy Logic Model to estimate runoff for any amount of rainfall given for the area considered. The area considered for the study is Devgadhbaria of Panam catchment area, Gujarat, India. The data considered are for the months of June, July, August, September and October for 10 years, i.e. 1996 to 2005. The whole length of data is divided into two parts for training of model and for validation of the model. In 70%-30%, data set where 70% data are used for training of the model and 30% data are used for validation process and similarly for 60%-40% and 80%-20% data sets. The model operates on an 'if-then' principle, where the 'if' is a vector of fuzzy premises and the 'then' is a vector of fuzzy consequences. Three Fuzzy Logic Models i.e., FL Model 1, FL Model 2 and FL Model 3 have been developed considering data set of 70%-30%, data set of 60%-40% and data set of 80%-20% respectively. All Fuzzy Logic Model developed with nine numbers of linguistic variables for each input and output. The best Fuzzy Logic Model has been analysed on basis of various performance indices, i.e., the Root Mean Square Error and Co-efficient of determination. Among all three models, the best Fuzzy Logic model is Fuzzy Logic (FL) Model 2 with the RMSE of 3.42 mm by training and 4.55 mm by validation of the model, and co-efficient of determination by training of the model is 0.9954 and by validation of the model is 0.9921 which are nearer to 1, which may be used for prediction of future runoff for the area considered under study for any amount of rainfall given. The threshold rainfall has been determined for the area considered under study, which is 27 mm. So it gives a fair idea of the minimum amount of rainfall required for runoff generation in Devgadhbaria of Panam catchment area.*

Keywords*: Rainfall, Runoff, Modelling, Fuzzy Logic, Linguistic variable*

I. INTRODUCTION

A rainfall runoff model is a mathematical model describing the rainfall–runoff relations of a rainfall 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. Rainfall–runoff modelling can be carried out within a purely analytical framework based on observations of the inputs and outputs. Some models developed in this way are described where it is shown that it may also be possible to make some physical interpretation of the resulting models based on an understanding of the nature of catchment response. This understanding should be the starting point for any rainfall–runoff modelling study. The relationship between rainfall in a period and the corresponding runoff is quite complex and is influenced by the most of factors relating to the catchment and climate.

Džubáková [3] said that rainfall-runoff models have a wide application. Some of the models are used for hydrological simulations, some for runoff estimation of ungauged basins, for prediction of catchment response to changed conditions as well as for water quality investigations and measurements of meteorological impacts. At present, the watershed management gains the attention as well. Rainfall-Runoff modelling has already achieved important advancement in the past hundred years; there is still wide room for its further development. Mainly, the introduction of computing technologies offered, and is still offering, a lot of new possibilities.

Zadeh [4] applied the fuzzy theory to mathematically deal with the imprecision and uncertainty. Fuzzy logic extends upon traditional Boolean logic and deals with the imprecision in human experience. In attempt to obtain more flexibility and more effective capability of handling and processing uncertainties of complicated and ill-defined systems, Zadeh [4] proposed a linguistic approach as the model of human thinking which introduced "fuzziness" into systems theory. The goal of developing simple and efficient control strategies for complex systems has provided significant challenges to traditional control methodologies. It has also triggered a new field of research known as Fuzzy Logic Control (FLC). The new area originated from the seminal work of Zadeh on fuzzy algorithms [4] which introduced the idea of formulating the control algorithm by logical IF-THEN rules. Zadeh [5] said that from precision in the face of overpowering complexity, it is natural to explore the use of what might be called linguistic variables, that is, variables whose values are not numbers but words or sentences in a natural or artificial language. The motivation for the use of words or sentences rather than numbers is that linguistic characterizations are, in general, less specific than numerical ones. Several studies have been carried out using fuzzy logic in hydrology and water resources planning.

Aytek et al. [1] said that the relationship between rainfall and runoff is an important issue in surface hydrology. The accurate amount of stream flow from rainfall occupies an important place in the hydrological cycle. The need to predict the quantitative amount of rainfall and runoff is necessary to avoid risks of rain on the catchments and to warn the floods. Nawaz [7] presented results of further evaluation tests of a monthly rainfall-runoff model used for extending streamflow data records in England and Wales. Many different models exist to simulate the physical processes of the relationship between precipitation and runoff. Some of them are based on simple and easy-to-handle concepts, others on highly sophisticated physical and mathematical approaches that require extreme effort in data input and handling. Recently, mathematical methods using linguistic variables, rather than conventional numerical variables applied extensively in other disciplines, are encroaching in hydrological studies. Among these is the application of a fuzzy rule-based modelling. Hundecha et al. [8] developed fuzzy rule-based routines to simulate the different processes involved in the generation of runoff from precipitation. Hasan [6] presented the improvement of the fuzzy inference model primarily developed for predicting rainfall with data from United States Department of Agriculture (USDA) Soil Climate Analysis Network (SCAN) Station at the Alabama Agricultural and Mechanical University (AAMU) Campus for the year 2004. Pawar et al. [2] developed fuzzy logic based runoff prediction model using current day's rainfall as input and daily runoff as output for a Harsul watershed of Godavari basin in the Nashik district of Maharashtra, India. Patel and Suryanarayana [10] developed best linear and non linear regression model for the Devgadhbaria raingauge station of Panam Catchment area and also determined the threshold rainfall, which is 12 mm.

II. MODEL FORMULATION

Panam River is the major tributary of Mahi River. There are 14 raingauge stations in the whole catchment area. Among that 14 raingauge stations, Devgadhbaria raingauge station is selected for the study, as it has largest catchment area among all rainguage stations of Panam catchment area.

The daily data of rainfall and discharge of Devgadhbaria raingauge station of Panam catchment area have been collected from the State Water Data Center, Gandhinagar from the year 1996 to 2005 of the months June, July, August, September and October. The runoff were determined by Andhariya and Suryanarayana [9]. That rainfall and runoff is taken for the present study of Rainfall – Runoff Modelling using Fuzzy Logic.

In systems modeling and control, there are many difficulties which are commonly experienced by practicing engineers. For instance, it is generally difficult to accurately model a complex process by a mathematical model. The methodology of the fuzzy-logic modeling and control, based on fuzzy set theory and fuzzy logic, appears promising when the phenomena are too complex for analysis by conventional quantitative techniques, when the available sources of information are interpreted qualitatively, inexactly or uncertainly, and/or when qualitative and often conflicting performance objectives are considered. Thus, fuzzy-logic modeling and control may be viewed as a step towards a rapprochement between conventional and precise analytical approach and human-like decision making. The decision-making ability of the fuzzy model depends on the existence of a set of rules and a fuzzy reasoning mechanism.

The Fuzzy Logic (FL) model operates on an 'if-then' principle, where the 'if' is a vector of fuzzy premises and the 'then' is a vector of fuzzy consequences, to apply this principles efficiently, a Fuzzy Inference System (FIS) is a control system built using fuzzy set theory based on combining the fuzzy sets from each rule through aggregation operator to get a fuzzy set result, then defuzzify the fuzzy set for each output variable. A fuzzy set is totally characterized by a membership function (MF). The output membership functions in this study (namely runoff) is not necessarily linear, the FIS Mamdani has been adopted as it represents the output (runoff) more realistically.

1. Fuzzification of Input and output variables using convenient linguistics subsets such as low, medium, high, etc.
2. IF-Then rules constructed based on expert knowledge and available information to combine the linguistic inputs subsets to the output fuzzy sets using the logical operator such as "and".
3. The implication part of fuzzy system is defined as the shape of the consequent based on the premise (antecedent) part.
4. Finally, having a crisp value, the resulted fuzzy set is defuzzified using the appropriate defuzzification method such as centroid.

The data used for applying Fuzzy Rule to the developed model is Rainfall (mm) as input and Runoff (mm) as output.

Here, the whole length of data is divided into two parts for training and for validation of the model. The three data sets have been made i.e., 70%-30%, 60%-40% and 80%-20%. In 70%-30% data set where 70% data are used for development of the model and 30% data are used for validation process and similarly for 60%-40% and 80%-20% data sets.

By observing the range of data i.e. rainfall and runoff, the range is divided into subsets for each linguistic variable. Here, same numbers of linguistic variables are taken for rainfall and runoff, because rainfall is directly proportional to runoff. This type of fuzzy logic model may be developed with three, five, seven and more numbers of linguistic variables. Here, Models have been developed considering nine linguistic variables i.e., very very vey low, very very low, very low, low, medium, high, very high, very very high and very very very high for both input and output.

Three Fuzzy Logic Models i.e., Model 1, Model 2 and Model 3 have been developed considering data set of 70:30%, data set of 60:40% and data set of 80:20% respectively. Based on the RMSE and co-efficient of determination (r^2), the best model has been analysed.

It should be noted that a certain amount of rainfall is always required before any runoff occurs. This amount, usually referred to as threshold rainfall, represents the initial losses due to interception and depression storage as well as to meet the initially high infiltration losses. The threshold rainfall depends on the physical characteristics of the area and varies from catchment to catchment. By putting different values of rainfall in the best model developed, the threshold rainfall has been obtained where the value of runoff exceeds zero.

III. RESULTS AND DISCUSSION

The three Fuzzy Logic (FL) Models have been developed for prediction of runoff value for the area considered under study.

FL Model 1 for 70%-30% dataset, in which 70% data is used for training of the model and 30% data is used for validation of the model. Similarly, FL Model 2 for 60%-40% dataset and FL Model 3 for 80%-20% dataset.

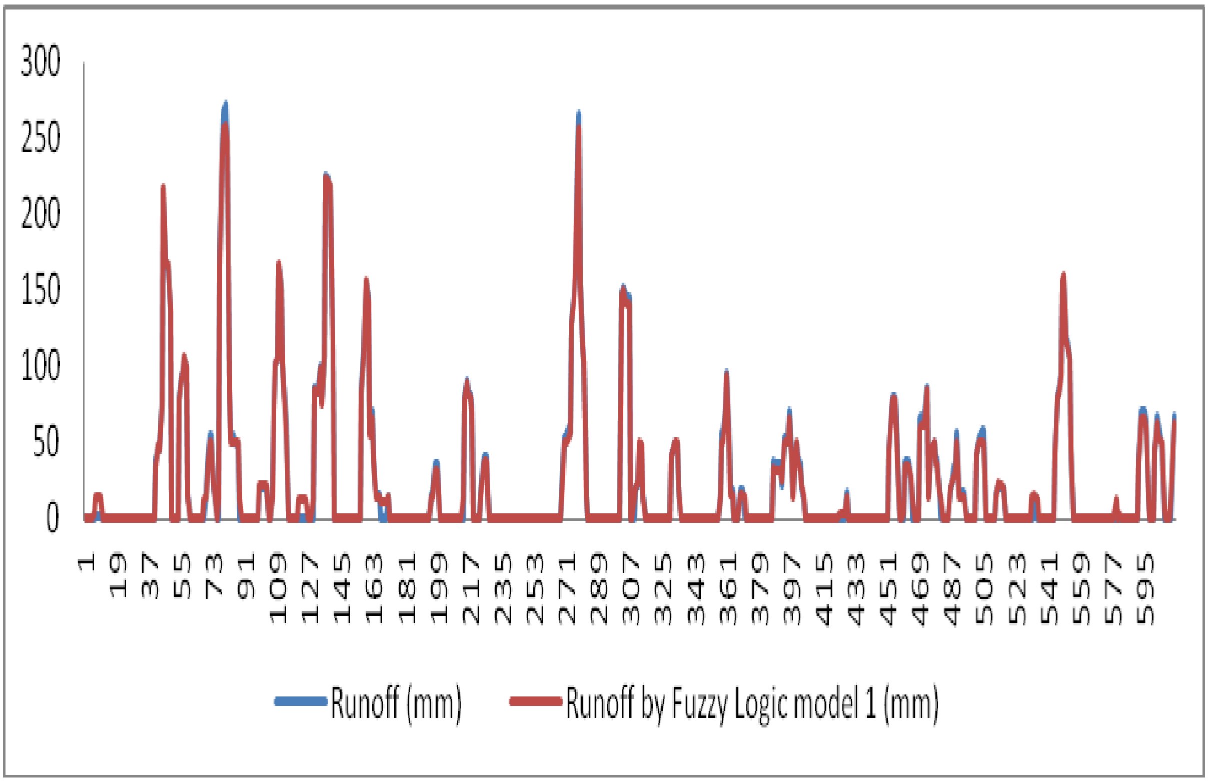

Fig. 1: Actual Runoff vs. Predicted Runoff by Fuzzy Logic Model 1 during training for 70%-30% dataset

Fig. 1 shows, the comparison of actual Runoff (mm) and predicted runoff (mm) by FL Model 1 during training for 70%-30% dataset.

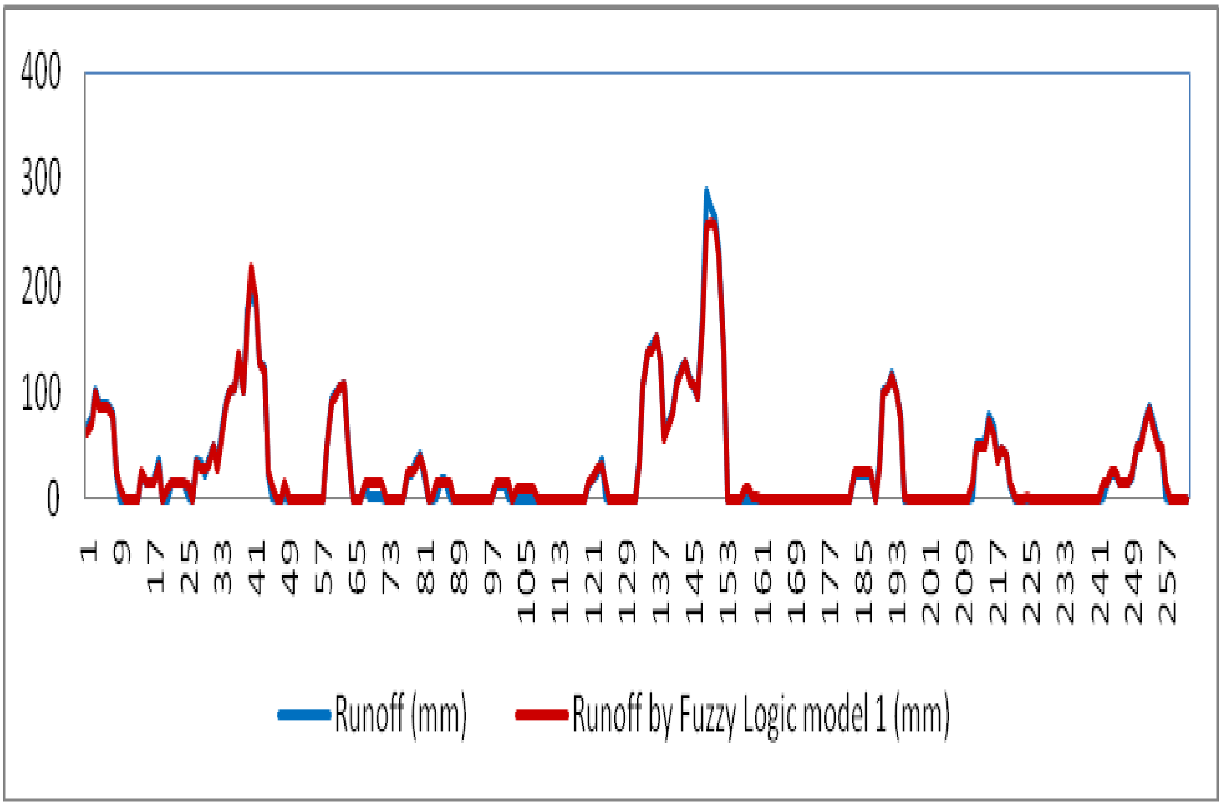

Fig. 2: Actual Runoff vs. Predicted Runoff by Fuzzy Logic Model 1 during Validation for 70%-30% dataset

Fig. 2 shows, the comparison of actual Runoff (mm) and predicted runoff (mm) by FL Model 1 during training for 70%-30% dataset.

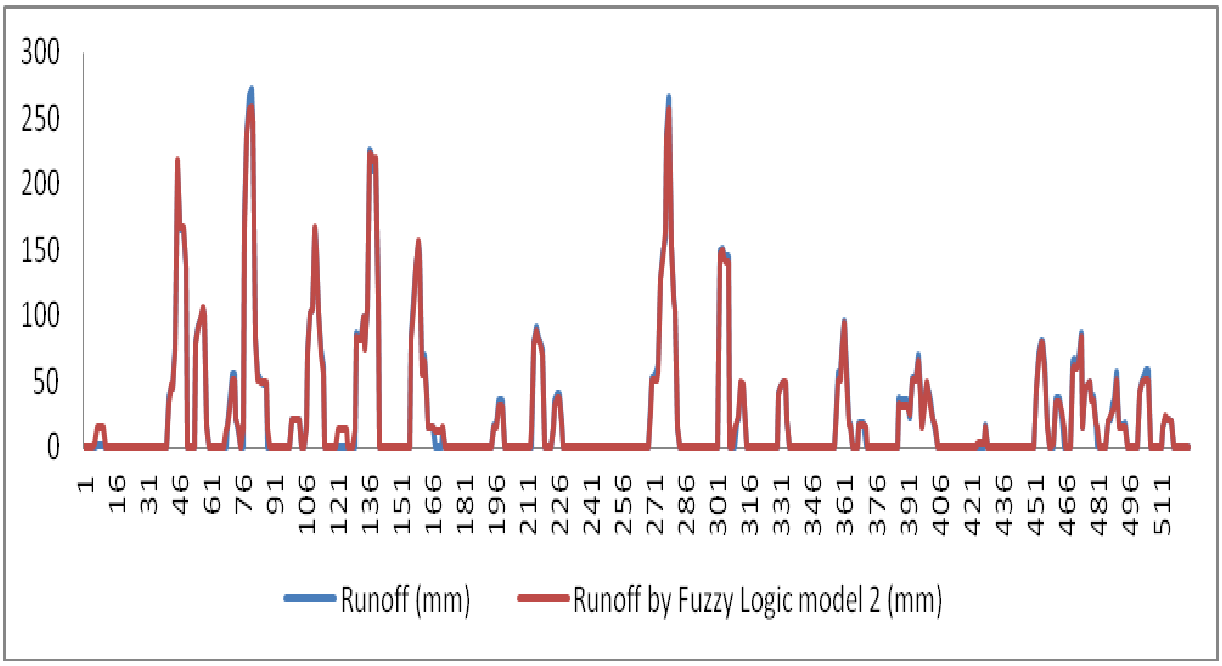

Fig. 3: Actual Runoff vs. Predicted Runoff by Fuzzy Logic Model 2 during training for 60%-40% dataset

Fig. 3 shows, the comparison of actual Runoff (mm) and predicted runoff (mm) by FL Model 2 during training for 60%-40% dataset.

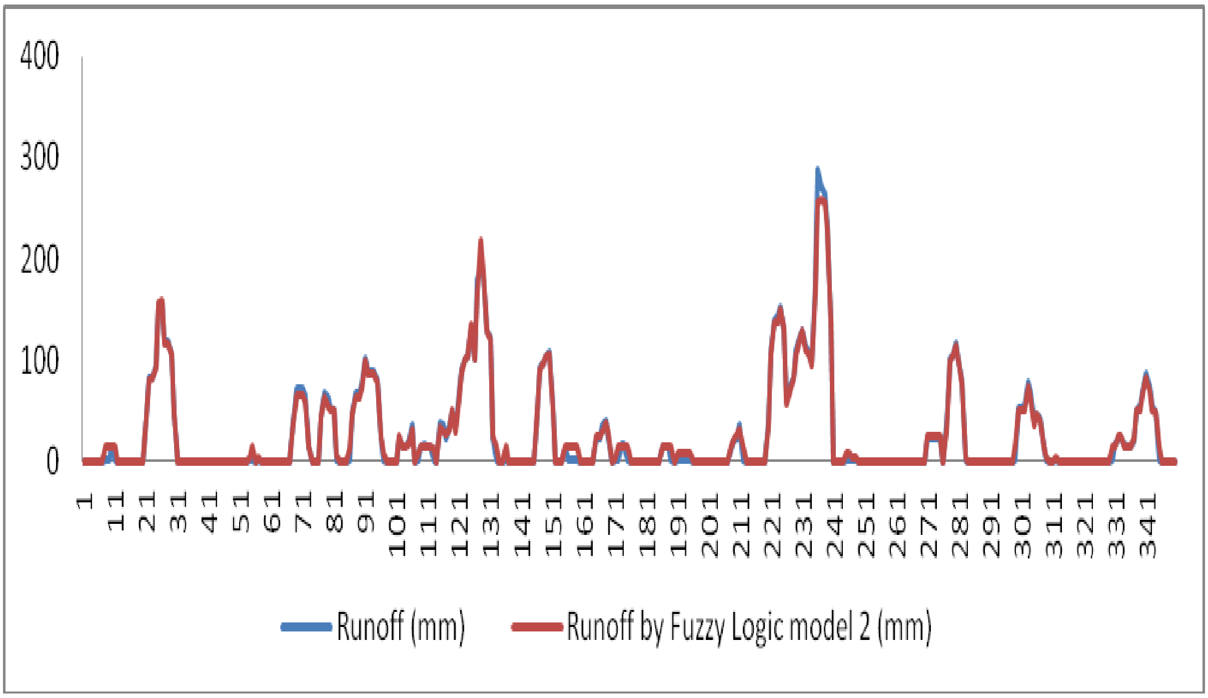

Fig. 4: Actual Runoff vs. Predicted Runoff by Fuzzy Logic Model 2 during Validation for 60%-40% dataset

Fig. 4 shows, the comparison of actual Runoff (mm) and predicted runoff (mm) by FL Model 2 during validation for 60%-40% dataset.

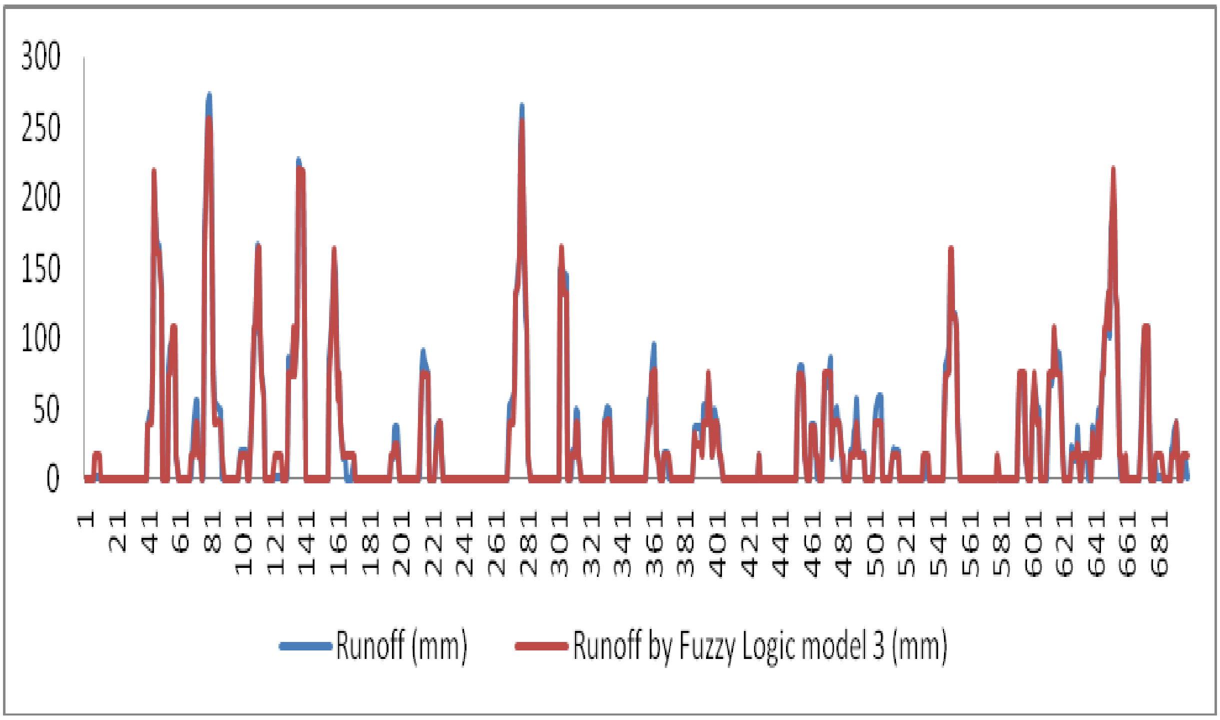

Fig. 5: Actual Runoff vs. Predicted Runoff by Fuzzy Logic Model 3 during training for 80%-20% dataset

Fig. 5 shows, the comparison of actual Runoff (mm) and predicted runoff (mm) by FL Model 3 during training for 80%-20% dataset.

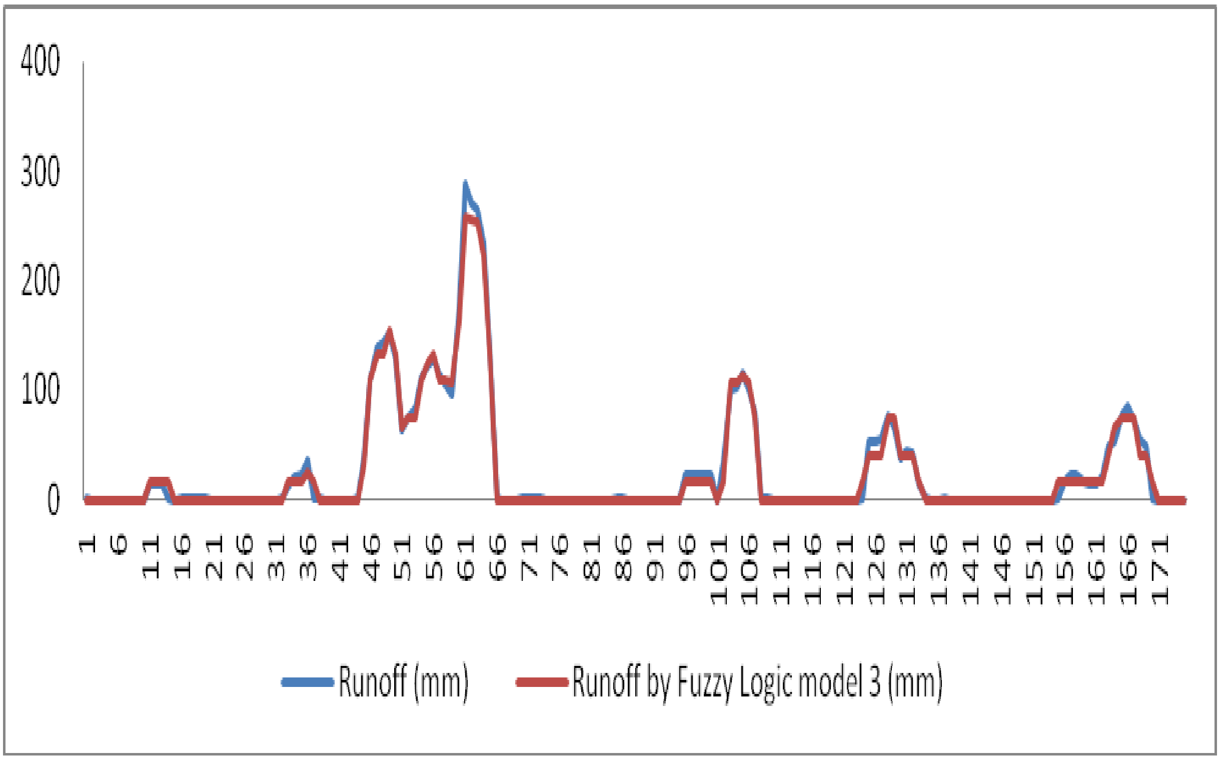

Fig. 6: Actual Runoff vs. Predicted Runoff by Fuzzy Logic Model 3 during validation for 80%-20% dataset

Fig. 6 shows, the comparison of actual Runoff (mm) and predicted runoff (mm) by FL Model 3 during validation for 80%-20% dataset.

The Root Mean Square Error (RMSE) by training of the Model & by validation of the model and also co-efficient of determination (r^2) by training & by validation of the Model are shown in Table 1 below:

Table 1: RMSE and r^2 of Developed Fuzzy Logic Models

Model		r^2	RMSE (mm)
Model 1	By training	0.9950	3.44
	By validation	0.9922	4.85
Model 2	By training	0.9954	3.42
	By validation	0.9921	4.55
Model 3	By training	0.9825	6.33
	By validation	0.9909	5.51

From Table 1, the obtained RMSE of the Model 2 is around 4% less than Model 1 and around 33% less than Model 3 and co-efficient of determination (r^2) of Model 2 is more nearer to 1. So, Model 2 is best Fuzzy Logic model for the area considered under study.

A certain amount of rainfall is always required before any runoff occurs. By putting different values of rainfall in the best model developed, the threshold rainfall has been obtained where the value of runoff exceeds zero. "The threshold value of rainfall, by the best model of the study, is 27 mm." Which shows, at 27 mm of the rainfall, the runoff occurs.

IV. CONCLUSION

It can be concluded that the all three Fuzzy Logic Rainfall – Runoff Models gives good output for the period considered for the study. Among all three Rainfall – Runoff Fuzzy Logic Models, which are developed with nine linguistic variables, the best model is selected on the basis of RMSE and co-efficient of determination (r^2).So, the best Fuzzy Logic model is Fuzzy Logic (FL) Model 2 as it has less RMSE i.e., 3.42 mm during training phase and 4.55 mm during validation phase, when compared to remaining models and co-efficient of determination (r^2) values are nearer to 1, i.e., 0.9954 by training and 0.9921 by validation. Therefore, the best Fuzzy Logic Model may be used for prediction of future runoff for any amount of rainfall given for Devgadhbaria of Panam Catchment area. Also, the threshold rainfall by the best Fuzzy Logic Rainfall – Runoff model is obtained to be 27 mm, which is applicable to the area considered under the study. So, it gives a fair idea of the minimum amount of rainfall required for runoff generation in Devgadhbaria of Panam catchment area.

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