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Topic – Application of Fuzzy Logic and Artificial Neural Network for Flood Forecasting of River Barak

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Abstract
Fuzzy logic is used to simulate the ambiguity and uncertainty in decision making. Artificial Neural Network is a computational network similar to the neural network of human brain. Like human brain computational elements called neurons are arranged in different layers of the network. Adaptive Neuro Fuzzy Inference System (ANFIS) model combines the advantage of Fuzzy logic and Neural networks to capture the complex non-linear relationship between differentdatas. A case study is conducted to evaluate the effectiveness of the ANFIS model in forecasting flood of River Barak. The result obtained show that ANFIS model can predict flood accurately and timely.

Keywords: Fuzzy, ANN, ANFIS, Neuron, Flood, RMSE.

1.Introduction–Forecasting of flood is essential to save life and properties of inhabitants by issuing prior warning. Structural measure for flood control is expensive and cause environmental degradation. Flood forecasting method is relatively inexpensive.

Fuzzy logic is widely used to simulate the ambiguity and uncertainty in decision making. It is an aid which provides informationin a more comprehensible or natural form and can handle uncertainties at various levels. The knowledge contained in fuzzy system is transparent to the users. Fuzzy inference system (FIS) is a neural network learning algorithm for constructing a set of fuzzy if –then rules with appropriate membership functions from the specified input-output pairs.

Artificial neural network (ANN) is simplified imitation of computing by neurons of a human brain. Wide range of ANN structures are in use, among which the three layers feed forward structure is widely used. This network consists of training, cross-validation and testing.

Adaptive neuro-fuzzy inference system (ANFIS) is the procedure of developing Fuzzy Inference System using Artificial Neural Network. Suitability of ANFIS was studied by Ichiro Kita Moses Macalinao and Muhammad Aqil (2002) and was found that this model can be used successfully and provide high accuracy and reliability for river water level estimation.

2.Objective –

Objective of the present study is to verify the hybrid model of Fuzzy inference system and Artificial neural network (ANFIS) for flood forecasting of river Barak.

3.Methodology –

Fuzzy logic concept was introduced by Zedah in 1965. It has been widely used to simulate the ambiguity and uncertainty in decision making. It can handle imprecise data and concept of partial truth.

In fuzzy logic, variables are "fuzzified" through the use of membership function that defines the membership degree to fuzzy sets. High, Medium, Low etc. are used to indicate fuzzy set. The degree of membership varies from 0 to 1. The conversion of a real valued item into a degree of membership is called fuzzification. Membership function may be Triangular, Trapezoidal, and Gaussian etc.

Fuzzy algorithms are formed by the union (or operation) of individual fuzzy rules. The way in which the fuzzy operators (If, then, and, or) are implemented can have a significant impact on model performance.

There are numerous successful applications of fuzzy systems in control and modeling .They are suitable for situation where an exact model of a process is either impractical or very costly to built, but an imprecise model based on existing human expertise can do the job. In this situation fuzzy systems are considered the best alternative, though they do not perform optimally.

Fuzzy sets are an aid in providing information in a more comprehensible or natural form and can handle uncertainties at various levels. The knowledge contained in fuzzy systems is transparent to the user.

Fuzzy "if-then" rule - Fuzzy set and fuzzy operators are the subject and verbs of fuzzy logic. "If-then" rule statements are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy if-then rule assumes the form, if x is A then y is B, where, A and B are the linguistic values defined by fuzzy sets on the ranges x and y respectively. Then if part of the rule "x is A ‘’ is called the antecedent or premise, while the then part of the rule "y is B ’’ is called the consequent or conclusion.

Fuzzy rules - 1. Conjunctive system of rules:- In case of a system of rules that must be jointly satisfied, the rules are connected by "and" connectives. In this case the aggregated output (consequent), y, is found by the fuzzy intersection of all individual rule consequents y_i, where i=1,2,3,4------r as,

$Y = y_1$ and y_2 and ----------y_r.

This is defined by the membership function as,

$\mu_y(y) = \min.(\mu_{y1}(y), \mu_{y2}(y), \mu_{y3}(y)$----------).

2. Disjunctive system of rules:- The rules are connected by the "or" connectives. In this case the aggregated output is found by the fuzzy union of all individual rule contributions as,

$Y = y_1$ or y_2---------- y_r.

This is defined by the membership function as,

$\mu_y(y) = \max.(\mu_{y1}(y), \mu_{y2}(y), \mu_{y3}(y)$----------).

Defuzzification-It is the conversion of fuzzy quantity into crisp output. Various methods used are Height method, Centroid method, weighted average method, Mean-max method, Centre of target area method etc.

Artificial Neural Network (ANN) - The structural constituents of a human brain termed neurons are the entities, which perform computations such as cognition, logical influence, pattern recognition and so on. Hence, the technology, which has been built on a simplified imitation of computing by neurons of a brain, has been termed Artificial Neural Network (ANN).

ANN consists of a no. of interconnected computational elements called neurons that are arranged in a no. of layers. The connection between each pair of neuron is called a link and is associated with a weight that is a neumerical estimate of the connection strength. Every neuron in a layer receives and processes weighted inputs from neurons in the previous layer and transmits its output to neurons in the next layer. The weighted summation of the inputs to a neuron is converted to an output according to a transfer function (Typically a sigmoidal function).

There are a wide range of ANN structure, among which the three layer feed forward architecture is widely used. This network consists of three distinctive mode, Training, Cross-validation and Testing. In the training mode, the training data sets (consisting of input-output patterns) are presented to the network. The weights are found through an iterative process in which the back propagation learning algorithm is used to find the weights such that the difference between the given outputs and the predicted output is small.

Adaptive Neuro Fuzzy Inference System (ANFIS) - Jang (1993) introduced architecture and learning procedure for the FIS that uses a neural network learning algorithm for constructing a set of fuzzy if-then rules with appropriate MFs from the specified input–output pairs. This procedure of developing a FIS using the framework of adaptive neural network is called adaptive neuro-fuzzy inference system.

The basic structure of ANFIS is a model that maps input characteristics to input membership functions, input membership functions to rules, rules to a set of output characteristics, output characteristics to output membership functions and output membership function to a single valued output or a decision associated with the output.

There are two methods that ANFIS learning employs for updating MF parameters (1) Back propagation for all parameters (a steepest descent method) and (2) Hybrid method consisting of back propagation for the parameters associated with the input MF and least square estimation for the parameter associated with the output MF. As a result training error decreases, at least locally throughout the learning process. Therefore, the more the initial MF resembling the optimal ones, the easier it will be for the model parameter training to converge. Human expertise about the target system to be modeled may aid in setting up these initial MF parameters in FIS structure.

Fuzzy rule base models are of two types (1) Additive rule model and (2) Non- additive rule model. Additive rule model is of two types (a) Sugeno model and (b) Kosoko's model. Non-additive rule model is Mamdani model.

Sugeno or Takagi-sugeno-Kang model is simple and the no. of rule is less. The main feature of this model is that the output MF is either linear or constant. ANFIS is a graphical network representation of Sugeno type fuzzy model.

A typical Sugeno model has the form,

Output=**Z=ax+by+c**, where, Input 1=x and Input 2=y.

For a zero order Sugeno model, the output level Z is a constant (a=b=0)

For the first order Sugeno fuzzy model a typical rule set with two fuzzy If-then rule can be expressed as,

Rule 1. If x is A_1 and y is B_1, then, f1= $p_1x+ q_1y+r_1$.

Rule 2. If x is A_2 and y is B_2, then, $f_2= p_2x+q_2y+r_2$.

Where, A_1, A_2 and B_1, B_2 are Input parameters for input x and y respectively. p_1, q_1, r_1 and p_2, q_2, r_2 are the parameters of the output function. The functioning of the ANFIS is described as,

Layer 1. Every node in this layer produces MF grades of an input parameter. The node O_1 is explained by,

$O_{1,i}= \mu_{Ai}(x)$ for, i= 1, 2

$O_{1,i}=\mu_{Bi}(y)$ for, i= 1,2.

Where x (or y) is the input to the node I, A_i (or , B_i) is a linguistic fuzzy set associated with the node O_{1i}, is the membership function grade of a fuzzy set and it specifies the degree to which the given input x (or y) satisfies the quantities.

MFs can be any functions that are Gaussian, Generalized bell shaped, Triangular, Trapezoidal shaped function.

A generalized bell shaped function can be selected within this membership function and described as,

$$\mu_{Ai}(x) = \frac{1}{1+\left|\frac{x-c_i}{a_i}\right|^{2b_i}}$$

Where (a_i, b_i, c_i) are the parameter set which changes the shape of membership degree with maximum value equal to 1 and minimum 0.

Layer 2. Every node in this layer is a fixed node labeled π, whose output is the product of all incoming signals.

$O_{2i} = w_i = \mu_{Ai}(x).\ \mu_{Bi}(y)$, for,i=1,2 -------------

Layer 3. The ith node of this layer labeled N, calculates the normalized firing strength as,

$O_{3i} = \overline{w_i} = \frac{W_i}{W_1+W_2}$ Where, i=1, 2, 3 ----------

Layer 4. Every node in this layer is an adaptive node with a node function,

$$O_{4i} = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i)$$

Where, $\overline{w_i}$ *is the output of layer* 3 *and* $\{p_{i,} q_{i,} r_i\}$ *is theparameter set of this node.*

Layer 5. The single node in this layer is a fixed node labeled ∑ which computes the overall output as the summation of all incoming signals.

$$Overall\ output = O_{5i} = \sum \overline{w_i}\, f_i = \frac{\sum w_i f_i}{\sum w_i}$$

4. Evaluation criteria for model performance:-

The performance of the model resulting from training, testing and validation is evaluated by RMSE (Root mean square error) using the following formulas,

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}[Q_i^o - Q_i^p]^2}{n}}$$

Where, Q_i^o =Measured discharge or, Discharge obtained from data.

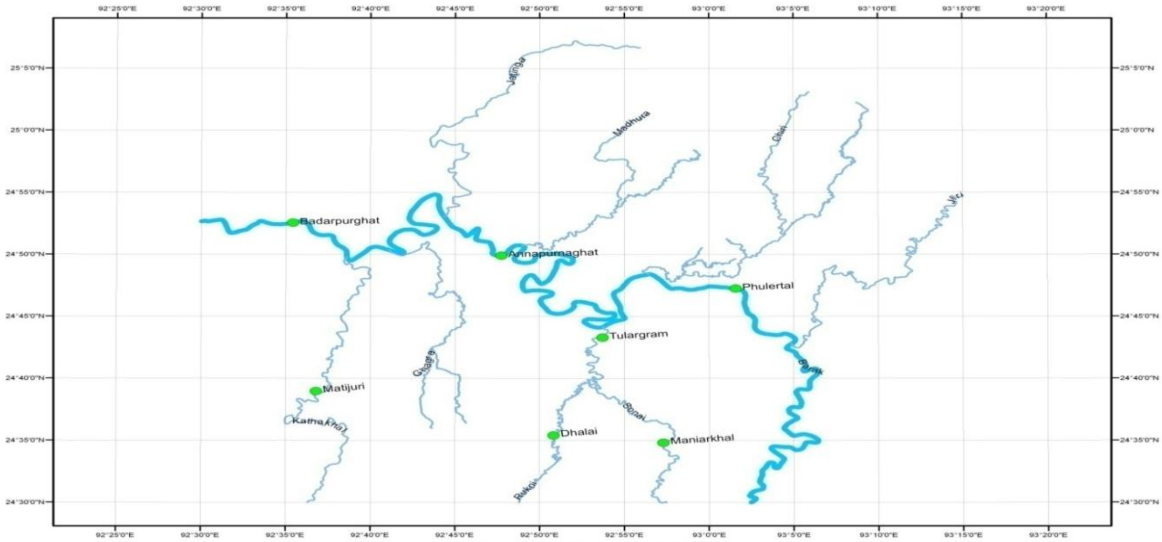
Q_i^p = Predicted discharge.

n= Total no. of data pairs considered.

RMSE furnishes a quantitative indication of the model error in units of the variable with the characteristics that larger error receives greater attention than smaller ones. The quantitative evaluation of model performance is made in terms of co-efficient of efficiency between the measured and simulated data.

5. Studyarea:-

Barak river basin of Southern Assam is the present study area. Catchment area of the river upto the points where the river crosses Indo-Bangladesh border comprises areas in Burma and different Indian states as Assam, Manipur, Mizoram and Nagaland.



BARAK RIVER NETWORK

Water level of Fulertol, Tulargram and Matijuri stations are taken as input and Badarpurghat station is considered as output.

Water level data from Central Water Commission has been collected and converted to stage data by regression analysis. Out of the data set, 4000 datas have been used for training, testing and validation. As per standard procedure, out of these 4000 data sets, 2000 data sets are used for training, 1000 for testing and 1000 for validation.

6.Results and analysis :-The following table of results are obtained by using Fuzzy logic toolbox of MATLAB. Low, medium and high are the categories selected considering computation time and Root mean square error.

Grid partitioning method is used for FIS generation , method of optimisation used is hybrid, error tolerance is considered as zero. Number,type of input and output functions are selected using the table below,

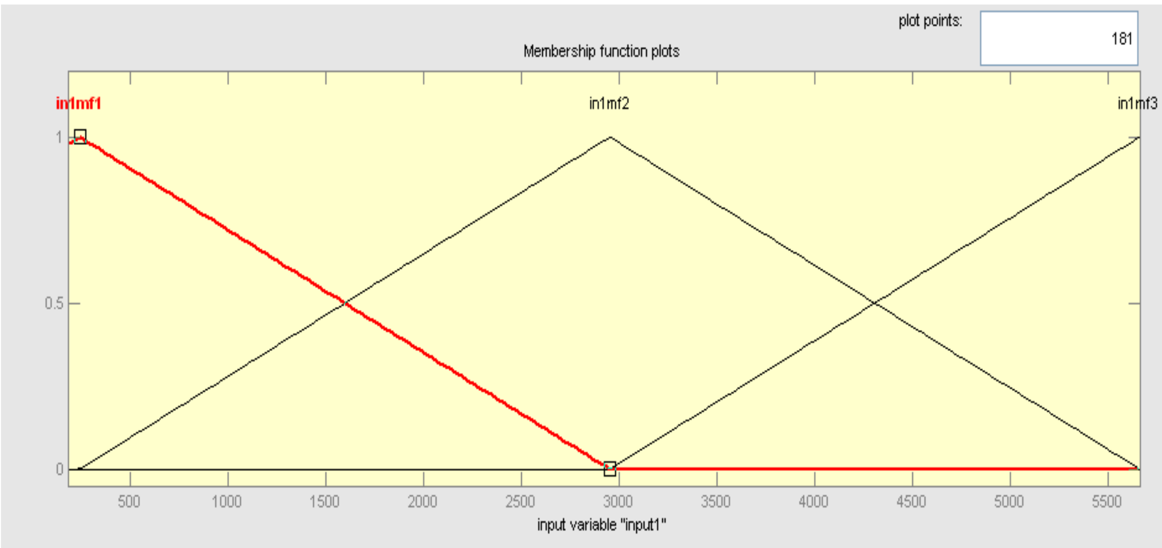
No. of input MF	Type of input MF	Type of output MF	Epochs	RMSE			Difference of RMSE between	
				Training	Checking	Testing	Training & Checking	Training & Testing
3 3 3	Triangular	Constant	3	205.82	229.45	232.05	**23.63**	**26.23**
4 4 4	Triangular	Constant	3	166.9	396.95	477.29	203.05	310.39
5 5 5	Triangular	Constant	3	153.56	698.47	324.17	544.91	170.61
6 6 6	Triangular	Constant	3	139.2	787.25	398.5	648.05	259.3
No. of Input MF selected is 3 3 3,for input MF type, consider the following,								

3 3 3	Trapezoidal	Constant	3	335.17	410.49	497.19	75.32	162.02
3 3 3	Gbell	Constant	3	191.98	182.97	370.64	9.01	178.66
3 3 3	Gauss	Constant	3	185.41	222.27	382.31	36.86	196.9
3 3 3	Gauss2	Constant	3	311.4	354.0	414.42	42.6	103.02
3 3 3	Pi	Constant	3	409.53	464.89	492.78	55.36	83.25
3 3 3	Dsig	Constant	3	222.16	203.36	279.68	18.8	57.52
3 3 3	Psig	Constant	3	222.08	210.2	281.86	11.88	59.78
Triangular MF selected, corresponding to minimum error. For Output MF,consider the following,								
3 3 3	Triangular	Linear	3	165.76	27595.2	361.95	27233.2	196.19
Constant type Output MF selected. For no. of epochs, the following parameters has been selected for trial,								
3 3 3	Triangular	Constant	4	205.82	229.45	232.05	23.63	26.23
3 3 3	Triangular	Constant	6	205.82	229.45	232.06	23.63	26.24
3 3 3	Triangular	Constant	20	205.82	229.47	232.09	23.65	26.27

From the table, for minimum difference, between the errors , input MF is 1 and is triangular, output MF is constant and epoch is 3.

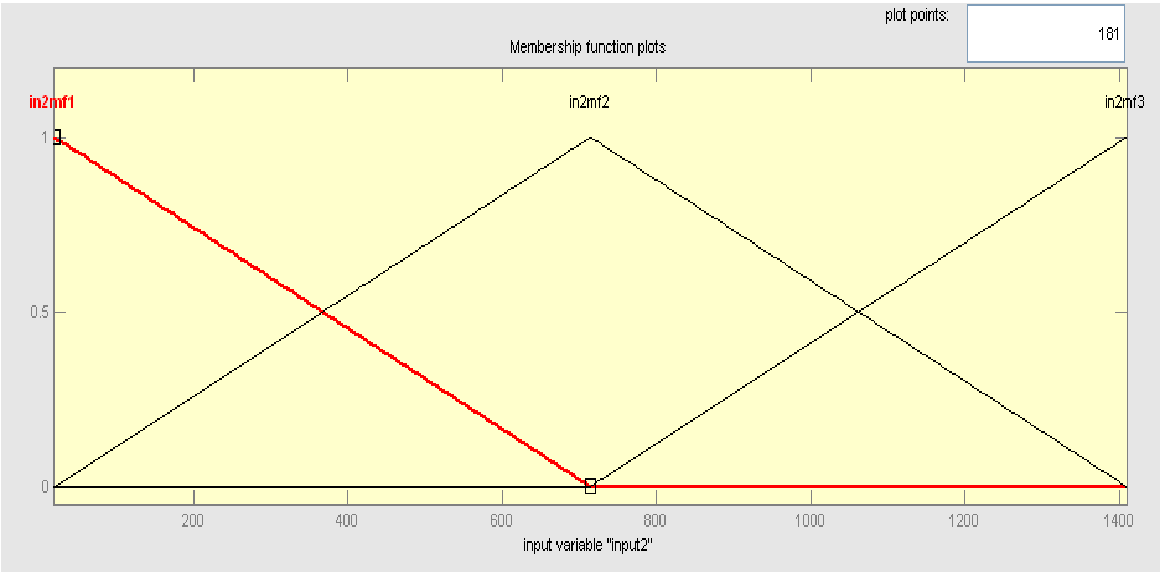
The root mean square error for training is 205.82, checking 229.45 and for validation 232.05.

Defuzzification is used to get the final output.



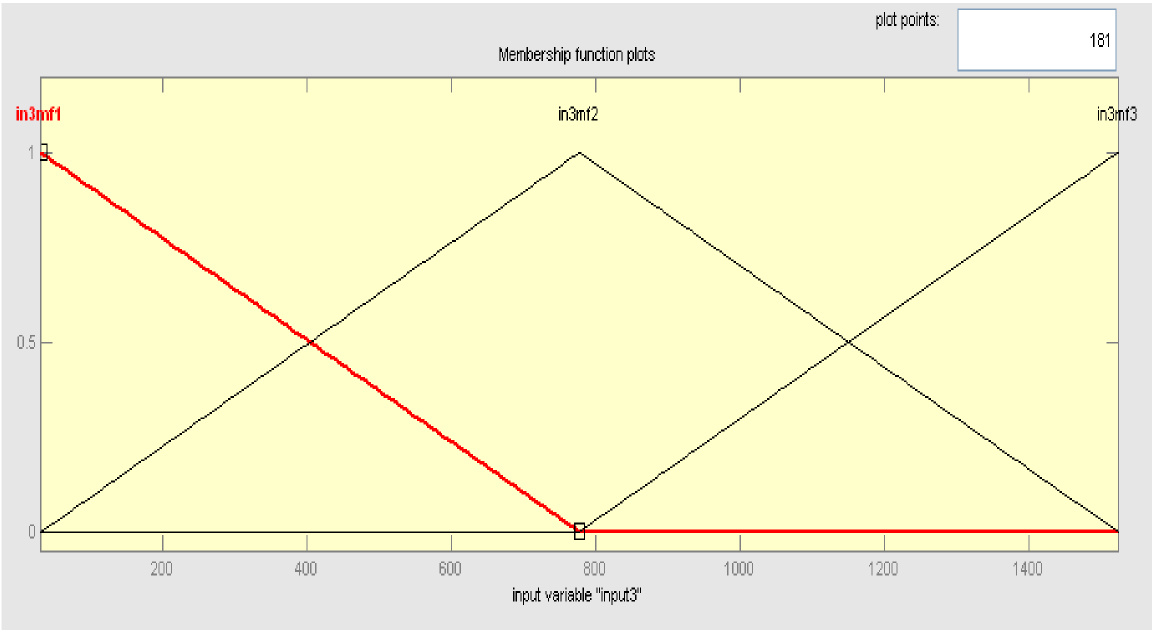
Membership function diagram for Input-1 (Discharge at Fulertol).

Membership function -1(mf1) =Low, Membership function-2(mf2) =Medium
Membership function-3 (mf3) =High.

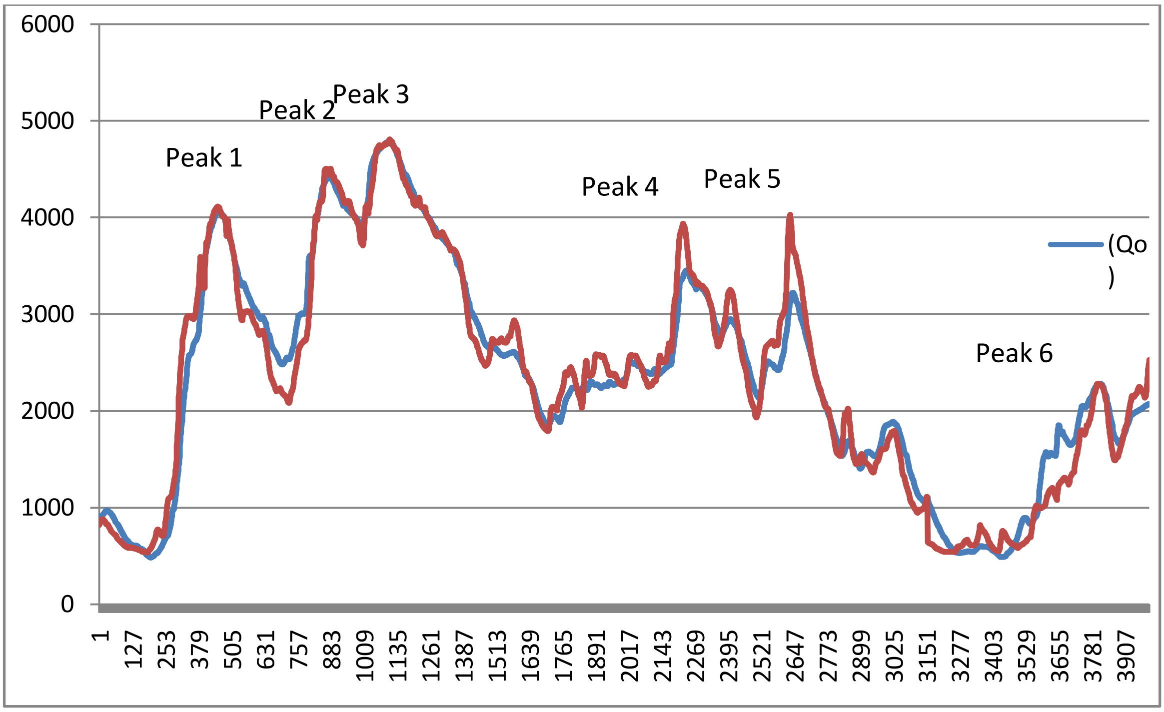


Membership function diagram for Input-2.(Discharge at Tulargram).

Membership function -1(mf1)=Low, Membership function-2(mf2)=Medium
Membership function-3 (mf3)=High.



Membership function diagram for Input-3 (Discharge at Matijuri)



Q_o = Observed output discharge. Q_{P} = Predicted output discharge.

Comparison of Observed and Predicted output discharge.

From the graph the Discharge difference and Time lag between the Observed and Predicted discharge is found out as shown in chart below,

No. of peak	1	2	3	4	5	6
Discharge difference (Q_0~Q_p)(m^3/sec.)	22	14	62	95	121	38
Difference of time (T_o~T_p) (Hours.).	1	3	2	6	5	2

The results show that output discharge obtained from calculation matches closely with observed discharge .Hence, the model perfom successfully with the datas obtained from Barak river.

7. Conclusion: - Fuzzy logic and artificial neural network as ANFIS can be used successfully for prediction of flood.

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