HBRP PUBLICATION

Journal of Water Resource Research and Development
Volume 5 Issue 1

# Comparison of ANN, Fuzzy Logic and Regression Tree Models for Reservoir Inflow Forecasting

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***ABSTRACT***

*In* water resources planning and management the forecasting of reservoir inflow for various time steps is one of the important components which can help in decision making regarding allocation of water for various sectorial demands and the quantity of water to be reserved for catering to the future demand. *The present study demonstrates the capability of three forecasting techniques namely Artificial Neural Network consisting of two layer feed forward neural network with back propagation algorithm, Mamdani type Fuzzy Model and Regression Tree Method consisting of coarse, medium and fine tree models applied in the prediction of weekly inflow values of the Deer Creek Reservoir in Utah, United States. The data used for forecasting is daily data for a span of 60 years comprising of a total of nine parameters. ANN model has been created using 45 year data for training and the remaining 15 year data is used for testing and validation. Optimum architectures have been chosen based on the performance criteria of Root Mean Square Error, Coefficient of Correlation and the Coefficient of Determination. The result of this study has also been compared by evaluating the performance criteria of models created from the three methods of forecasting to choose the best one. The final results concluded that ANN to be an effective tool when compared to the other two methods when forecasting inflow in Deer Creek Reservoir using atmospheric data.*

***Keywords:****-Reservoir inflow; artificial neural networks; fuzzy logic; regression trees, decision making, performance measure*

## INTRODUCTION

One of the most important things in the world which is required by plants and animals to support life is water. Without water life wouldn't be possible. But today the term water scarcity and water wastage are more commonly used.

One may wonder how both these extremes are prevalent. Location and geography make water resources management complex and diverse. Water resources planners of the country deal with many diverse, dynamic and contradictory problems, demands and issues related to water and land use. Managing the available water resources has become a tough and challenging task because of the complexities occurring due to both natural and man-made causes. The natural causes are mainly due to two extreme hydrological events viz., flood and drought, ever increasing demand for water due to growing population, industrial development, irrigation, hydropower generation, silting up of water bodies, etc.

Man-made causes are altering flood plain and water courses, change of land use, global warming, deforestation leading to soil erosion, river / channel encroachment, upstream diversion etc. The inflow prediction is required to know the quantity of water available in advance for decision making in the case of multipurpose reservoirs. It is very helpful for planners in macro scale. Data-based forecasting methods for inflow forecasting applications are becoming increasingly popular due to their fast development times, minimal information requirements, and ease of real-time implementation[9]. Statistical models, such as multiple linear regression, autoregressive moving average, and artificial neural network models, have historically been used in data flood forecasting.

Hydrological literature comprises many applications of artificial neural networks[8,9,12,13,15,17](Mohamaddi et al. 2005; El Shafie et al 2011. Fuzzy and neuro-fuzzy modelling are other approaches that apply to the application of different learning algorithms built in neural network literature to Fuzzy Modeling or Fuzzy Inference Framework (FIS) [4].

Fuzzy and neuro-fuzzy (NF) models have been used to solve a variety of water resources engineering problems, including flood forecasting[5] vulnerability of reservoir operating policies (Singh and Mujumdar 2002), knowledge-based systems[5], river flow modeling [19], hydrological time series modeling [6]. Decision trees, first published in the 1960's, are one of the most powerful methods for data mining; they have been widely used in many disciplines [7].

Usage of regression trees in water resources engineering is still at the early stage. They have been used for Groundwater Productivity-Potential Mapping [10], modelling water demand in Sevilla city [14]. Random Forests (RF) is a supervised machine learning algorithm, which has recently begun to gain popularity in applications for water management. Random Forests use regression trees as base learner.

The major purpose of this study is to evaluate the capability of three forecasting techniques namely Artificial Neural Network consisting of two layer feed forward neural network, Mamdani type Fuzzy Model and Regression Tree Method consisting of coarse, medium and fine tree models – in the prediction of weekly inflow values of the Deer Creek Reservoir in Utah, United States. The objective being to determine the best method among the three for the study area. A commonly used performance evaluation criterion has been used to assess the performance of the developed models.

## STUDY AREA AND DATA AVAILABILITY

The area chosen for the study is Deer Creek Reservoir on the Provo River in western Wasatch County, Utah, USA, about 26 km north - east of Provo. It is a 72 m earth fill dam with a 397 m long crest. The dam contains 2,150,000 m3 of water, and creates an 188,190,000 $m^3$ capacity reservoir.

Construction was carried out from 1938 to 1941. The reservoir provides agricultural, recreation, domestic, and industrial water. The Deer Creek Dam is an significant component of the United States-managed *Provo River Project*. The Pennsylvanian Oquirrh Formation dam and outlet works tunnel was built in the Pennsylvanian Oquirrh Formation's limestone, shale, and quartz sandstone.

At 30 degrees, rock units dip in upstream. Alluvial deposits up to 86 ft. thick underlie dam and spillway shells. By excavating a cut-off trench through the river alluvium, grouting the foundation rock, and constructing a concrete cut-off wall, a successful cut-off was attained. The rock was cracked but the base found no faults.

An additional shallow cut-off trench was excavated below zone 2 downstream of the centre to extract a sequence of clay and organic material from 4 to 15 ft. deep. The Deer Creek Power Plant was built on the substructure provided during the Deer Creek Dam construction process. Though it is a multipurpose project, the primary objective is to provide water for irrigation.

Nevertheless, it embodies a hydropower plant, the capacity of which was fixed based on the quantity of water released for irrigation. The Water Users association of Provo river owned this plant in 1958 on a lease basis and since then it was operated and maintained by them. The maintenance was scheduled usually during winter season due to low water flow.

John C. Fremont made the first published record concerning this area in the account of his 1843 expedition. In the spring of 1822, General William H. Ashley led a party of fur traders westward from St. Louis and established a trading post at Utah Lake, known as Fort Ashley, in 1825. It is said that the Provo River and the city of Provo were named after a trapper called Provost, who had been in the vicinity of Utah Lake in 1820.

A party moved south from Salt Lake in March 1849 with the aim of creating a colony on the Provo River. At present, the settlement in Old Fort Field comes under Provo's town limits.

The fort was established to cultivate various types of crops. In the first year, commercial crops like wheat, rye, and corn were planted over an area of 200 acres. Subsequently in 1850, settlements at American Fork, Lehi, and Pleasant Grove were founded. Brigham Young submitted a proposal in 1856 with a purpose of utilizing water available in the Provo River, Which seem to be more or less similar to the proposal used by the Bureau 80 years later.


***Fig.1:***-*Location of study area (Courtesy: Google Maps)*

The data required for the study is available from 1960. All the data are obtained from the following open source databases, namely, National Weather Service Forecast Office – Salt Lake City, Utah database, Frontier Weather by DTN database and United States Bureau of Reclamation database. Zeroes present in the data tend to reduce the learning capability. Hence, zeroes were replaced by very small values which in practical cases would have no significance.

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***Table 1:**-Content of Input Data Used*

| S.No | Data Considered | Nature of Data | Unit |
|---|---|---|---|
| 1) | Temperature | a) Daily average<br>b) Daily Maximum<br>c) Daily Minimum | Fahrenheit |
| 2) | Cold Day Demand (CDD) | Daily total | Fahrenheit |
| 3) | Hot Day Demand (HDD) | Daily total | Fahrenheit |
| 4) | Precipitation | Daily total | Centimeter |
| 5) | Snow Depth | Daily total | Centimeter |
| 6) | Water Level | Daily maximum | Meter |
| 7) | Storage | Daily maximum | Cubic Meter |
| 8) | Evaporation | Daily total | Cubic Meter |
| 9) | Inflow | Daily total | Cubic Meter per second |

## METHODS OF FORECASTING

### i) Artificial Neural Network

Artificial Neural Networks (ANN) are black box models that are used to approximation and forecasting needs in several different fields of science and engineering throughout the world. In recent years, AI techniques like Artificial Neural Networks (ANN) has become prominent as a result of the limitations of Guide curve methods. An Artificial Neural Network (ANN) is a massively parallel-distributed-information-processing system that has certain performance characteristics resembling human brain's biological neural network. The structural architecture of an ANN model is constructed defining 1) the number of layers, 2) the number of hidden neurons in each layer, 3) selection of transformation function's type. Performance of the network is usually evaluated by parameters such as 1) RMSE (root mean square error); 2) CC- (correlation coefficient); 3) e- (relative error). All these parameters are to be evaluated for both training and testing sets. Based on the performance criteria the network is improved by adjusting the architectural parameters by trial and error method.

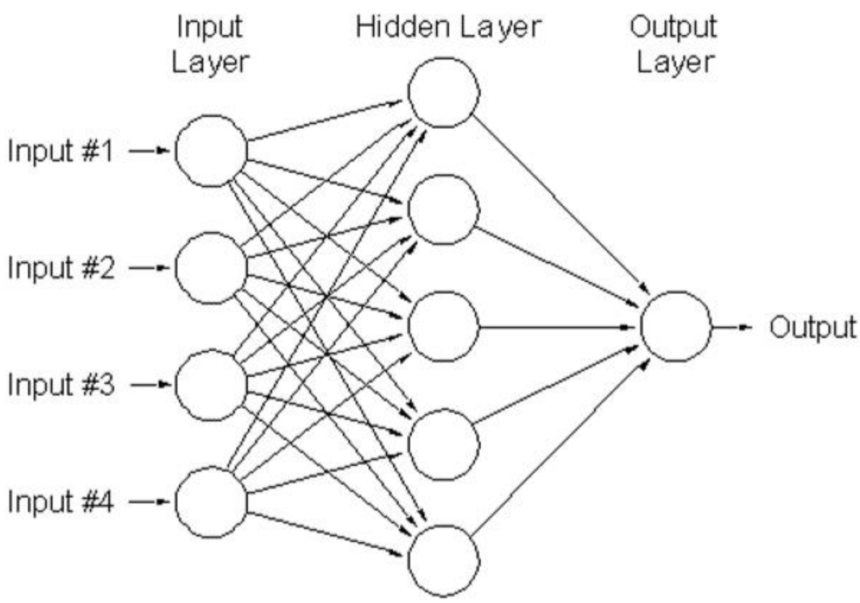


***Fig.2:**-Typical Artificial Neural Network*

 

(The inputs should be of parameters affecting the output. For example, for inflow forecasting precipitation is taken as input.)

ANN is a computing system roughly designed after the neural synapses present in human brain. Though not so efficient, they work in roughly similar ways. The brain learns from experiences, and so do these systems. They learn tasks by comparing samples, generally without any particularly assigned goals. One notable advantage of Neural Networks is their ability to learn in nonlinear ways. An Artificial Neural Network uses a collection of connected joints or nodes called artificial neurons – resembling biological neurons. The connections between the neurons are called as synapses. It is through these synapses that signals are transmitted. The artificial neuron which receives the signal can process it and then signal artificial neurons connected with it. By changing the signal path the input-output relationship is analysed and the model is created.

Neural networks operate on the principle of learning from training data. When applying neural networks for forecasting, elaborate knowledge is required regarding choosing of an appropriate network type, network architecture characteristics, appropriate training algorithm, selection of parameters and nature of parameters. An important point is that no proper method is available for choosing these properties. The properties which make an efficient forecast in a model may not guarantee an efficient forecast in another model. Hence all the properties are to chosen by trial and error method.

The selection of network architecture affects the efficiency of outputs directly. As discussed by Ahmed Gad (2019) for simple problems an optimal network architecture exists, but for systems with large number of parameters it may not be the case.

When training ANN there are numerous hyperparameters to select such as no. of hidden layers, no. of hidden neurons, learning rate etc,. Creating the optimal mix results in optimal network architecture. Creating such an optimal mix of hyperparameters is a very challenging task.

**Multi-layer Perceptron**

Multi-Layer Perceptron (MLP) is one of the most commonly used types of ANN architecture for practical applications used in reservoir applications. It has already been reported in literature that other types of ANN architectures like Radial Basis Function and Recurrent Neural Networks do not have any significant advantage over MLP architecture. The selection of architecture affects both the accuracy of prediction and a network's learning ability.

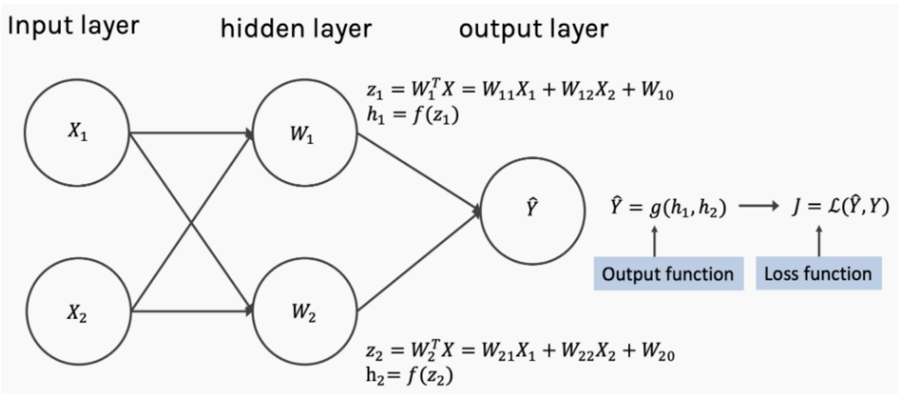


***Fig.3:****-Multi-Layer Perceptron*

(A neural network with one hidden layer and two features - the simplest possible multi-layer multi-feature network)

**Back Propagation Neural Network**

The most popular ANN architecture in hydrological modeling is the Multi-Layer perceptron (MLP) trained using a back-propagation (BP) algorithm [ASCE Task Committee on Application of Artificial Neural Networks in Hydrology (2000)]. The main advantage of back-propagation neural networks (BPNN) is that they are easy to handle and can approximate any input/output map. The disadvantage is that they train slowly, require lots of training data, and the algorithm may converge to a local minimum [16].

The development of a successful ANN project consists of a cycle of six phases, as illustrated in Figure 4 [3]. The problem definition and formulation (phase 1) relies heavily on an adequate understanding of the problem, especially of the relationships between cause and effect.

Before the final selection of the modeling technique, the advantages of ANNs over other techniques should be assessed. System design (phase 2) is the first step in the actual ANN design in which the model determines the form of ANN and the rule of learning which suits the problem. This step also involves data collection, pre-processing of data to match the form of ANN used, statistical data analysis and partitioning of the data into three different subsets (training, testing and validation). System design (phase 3) involves network training using the testing and training subsets and evaluating network output simultaneously by examining the prediction error.

Ptimum selection of the different parameters (e.g., network size, learning rate, number of training cycles, appropriate error, etc.) will affect final network design and performance. This brings the model to Phase 2 again. In the system verification (phase 4), while network construction requires ANN testing against the test data while training is underway, it is good practice for the 'best' network to be tested using the validation subset for its generalization capabilities.

Verification is intended to confirm the ANN-based model's ability to react precisely to examples never used in network creation. This process also includes comparing the performance of the ANN-based model with that of other (if available) methods, such as statistical regression and expert systems.

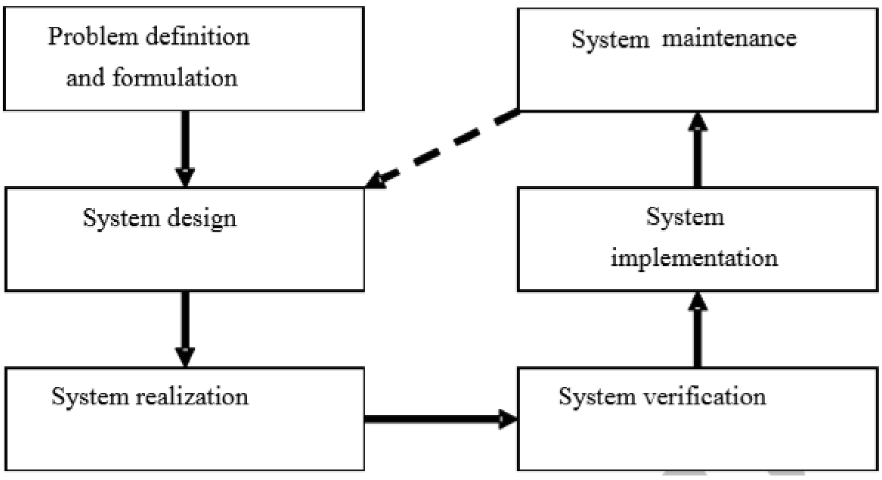


***Fig.4:****-The phases in developing an ANN system*

System Implementation (phase 5) involves embedding the network obtained in an acceptable operating framework such as a hardware controller or computer program. There should also be final testing of the integrated framework before its release to the end user. System maintenance (phase 6) includes upgrading the framework built when changes arise in the environment or framework variables (e.g., new data) requiring a new development cycle.

**ii) Fuzzy Logic**

Fuzzy logic is a mathematical concept, the use of which is found during various periods of time by many researchers in different fields. The use of fuzzy logic has brought about a great improvement. Many things have become simpler due to the use of fuzzy logic and that has helped save time, money and energy. In 1965 Lotti Zadeh suggested Fuzzy logic for the first time. Before Zadeh, many researchers such as Plato, Hegel, Marx, Lukasiewicz etc. had made many efforts in this area.

Some gave three valued logic and some gave four valued or five valued logic, which is the extension of Boolean logic, which only accepts two true or false values (0 or 1). Lotti Zadeh described mathematics as fuzzy sets and fuzzy logic in his work "Fuzzy sets". Before the advent of fuzzy logic, mathematics is limited only to two true or false premises (0 or 1). But this spectrum has been expanded by fuzzy logic to real numbers (0,1).

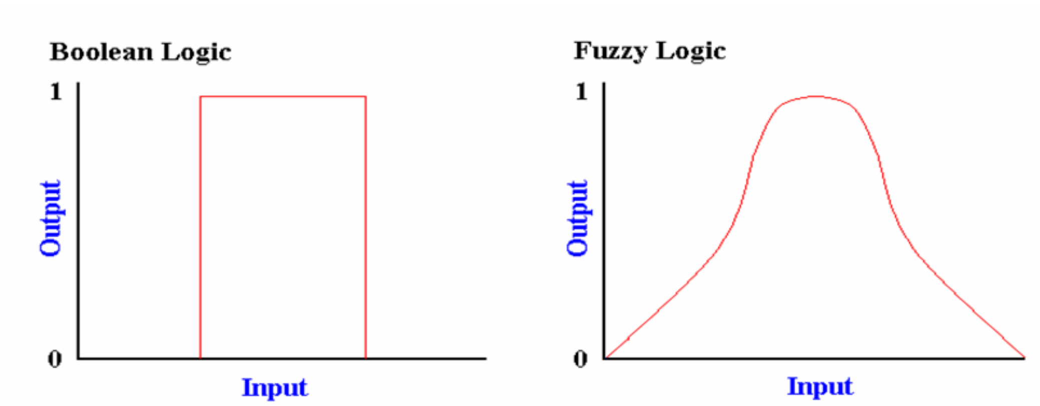


***Fig.5:-****Membership function of Boolean and Fuzzy logic Systems*

Boolean logic only accepts two values (i.e) true or false values (0 or1). We can consider the highs and lows in this. There is nothing between them that is it doesn't take the medium term. This can be achieved by the more detailed principle of fuzzy logic, since it takes values [O, l]. Regardless of this definition, it is possible to think about low, high and medium as well as very low, very high. So, Fuzzy Logic can be considered as an extended version of Boolean Logic. Fuzzy means not well known, or not very obvious. Fuzzy logic is an argument that can be true or false, or has a true intermediate value. It is developed for handling the partial truth principle. Degree of truth is defined by function of the membership. An affiliate function on a set X is any function from X to an actual unit interval [O, l].

**Fuzzy Logic Control**

Fuzzy logic controller goes forward in three stages. The first step is to fuzzify. In this step crisp variable is converted to fuzzy variable. In the second stage some rules are set up in the If- Then format. In the third stage called defuzzification, fuzzy output is converted back to crisp variable.

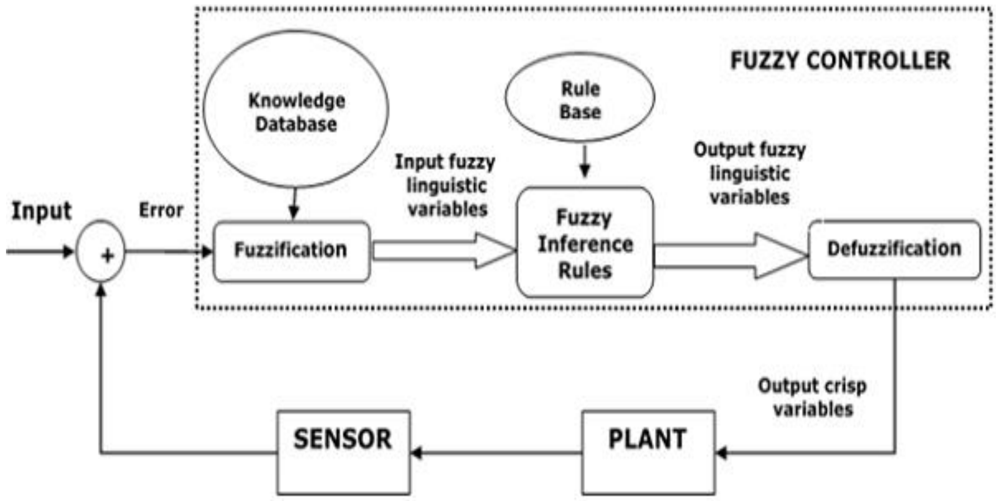


***Fig.6:-****Typical Fuzzy Controller*

A fuzzy rule system is defined as a set of rules that consists of sets of input variables or premises A, in the form of fuzzy sets with membership functions μ A, and a set of consequences B, also in the form of fuzzy sets. Typically, a fuzzy if-then rule takes the form:

if x is A then y is B

where A and B are linguistic values defined by fuzzy sets on variables X and Y, respectively. The "if" part of rule "x is A" is referred to as an antecedent or assumption, and the "then" part of rule "y is B" is called the consequence. In the case of binary or two-valued logic, if the assumption is valid then the result is valid as well. In a fuzzy law, if the assumption is valid to some degree of membership then the result is valid to the same degree as well.

**iii) Regression Tree**

Various types of date mining tools are available for defining multiple covariate-based classification systems or for developing a prediction algorithm for a target variable. Among which, the Regression tree method is widely used by various researchers in the world. This approach breakdowns a population into different segments that resembles an inverted tree which comprises of root node, interior nodes, and leaf nodes.

Data mining is used to collect valuable information from vast databases and to view it in visualizations that are simple to understand. Decision trees are one of the most powerful methods employed in data mining which was first published in the 1960's. They have been widely used in many disciplines to provide solutions to various types of real world problems [7].

They are robust, avoid confusion and trustworthy even when the data sets have missing values. This method has the flexibility to use discrete as well as continuous variables as target variables or as independent variables.

Among its various applications, Prediction is one of most significant. If the historical data is available, this model can be comfortably applied to predict the result of future records for the required time step. The following figure displays a basic decision tree model with a single binary target variable Y (0 or 1) and two continuous variables, x1 and x2, varying from 0 to 1.

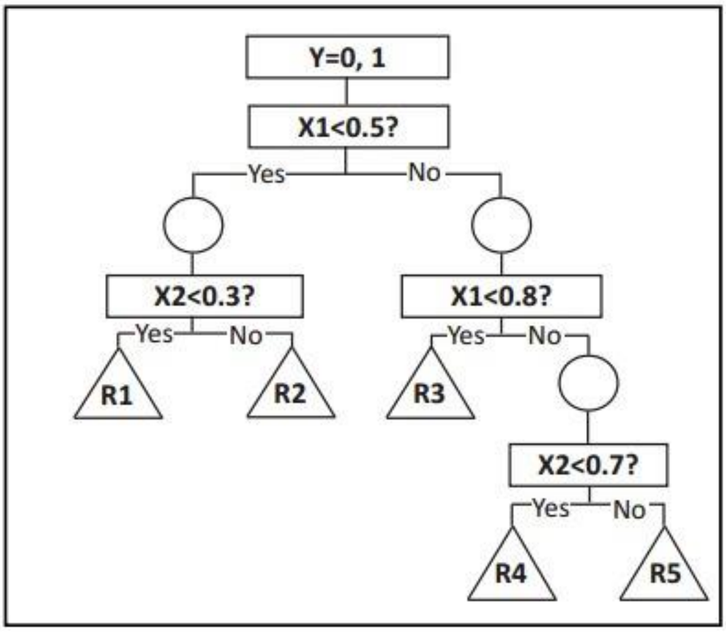


***Fig.7:**-Sample decision tree based on binary target variable Y*

**MODELS AND ARCHITECTURE**

All the methods produce best forecast only on certain architectural form. These forms are obtained using trial and error method and evaluated using the performance criteria. All the three models were created using Matlab, which provides very user friendly graphical user interface.

**i) Artificial Neural Network**

A two-layer feed-forward network with hidden neurons sigmoidal in nature and output neurons linear in nature is used. Arbitrarily it can fit multi-dimensional mapping problems well, given proper data and optimum neurons in its hidden layer. The training algorithm which has been used is Levenberg - Marquardt back propagation algorithm. Out of the total data seventy percentage was used for training the data, fifteen percent for validation and the remaining fifteen percent for testing.

To evaluate the effect of replacing zeroes by meagre values, forecasting was done using both the set of data. The results showed the processed data to yield better results. So that set of data was chosen for forecasting using the remaining two methods.

***Table 2:**-Selection of ANN architecture*

| Base Architectural Parameter | Chosen Property |
| --- | --- |
| Number of Neurons | 10 |
| Training Algorithm | Leveberg – Marquardt |
| Learning Rate | 0.1 |
| Momentum Rate | 0.85 |
| Initial Weight | 0.3 |
| Maximum Epochs | 60 |

**ii) Fuzzy Logic**

The fuzzy logic technique which has been adopted is Mamdani system. It is the most popular fuzzy logic technique. Mamdani systems can look particularly appealing because they are designed to incorporate expert knowledge in the form of naturally expressed IF-THEN rules. While this is an attractive feature for modeling and simulating complex systems, there are some important drawbacks in its actual application.

***Table 3:**-Selection of Fuzzy Logic architecture*

| **Base Architectural Parameter** | **Chosen Property** |
|---|---|
| Technique | Mamdani |
| Version | 2.0 |
| Rules Created | 17 |

**iii) Regression Tree**

The following steps were followed during regression modelling,

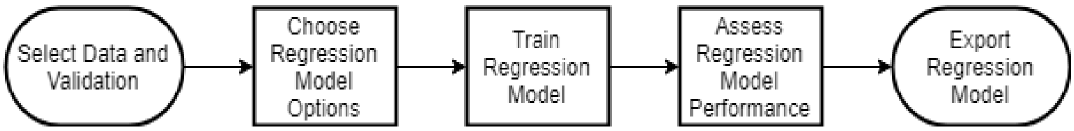


***Fig.8:**-Process of Regression Modelling*

The method of validation used here is Cross – Validation. It is a very useful technique in cases where overfitting is more. Three trees have been used. They are coarse, fine and medium trees. The minimum leaf size of the trees is 4, 36 and 12 respectively. The best model is chosen by comparing the performance criteria of Regression Value (R) and Mean Square Error (MSE). The number of folds considered is 5.

**PERFORMANCE MEASURE**

The forecast performance is evaluated using three goodness-of-fit measures, the root-mean-square-error (RMSE), the Correlation Coefficient (CC) and coefficient of Determination (CD) as defined below:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[(Q_m)_i - (Q_s)_i\right]^2}$$

$$\mathrm{CC} = \sum_{i=1}^{n}\frac{\left[(Q_m)_i - \left(\overline{Q_m}\right)\right]\left[(Q_s)_i - \left(\overline{Q_s}\right)\right]}{\sqrt{\sum_{i=1}^{n}\left[(Q_m)_i - \left(\overline{Q_m}\right)\right]^2}\cdot\sqrt{\sum_{i=1}^{n}\left[(Q_s)_i - \left(\overline{Q_s}\right)\right]^2}}$$

where Q is the discharge; the subscripts m and s represent the measured and simulated values; the average value of the associated variable is represented with a ‘bar’ above it; and n is the total number of training records [18].

CD is the square of CC. RMSE is the square of Mean Square Error (MSE). A perfect fit between the predicted values and the actual values of forecast is obtained when RMSE value is zero, CC and CD values are closer to one.

But being a very complex natural process, these ideal values can’t be attained. However it is possible to improve the values by better model calibration.

## RESULTS AND DISCUSSIONS

The comparison between observed and computed inflows in correspondence to training, testing and validation for ANN method is shown in Figures 9.

The comparison between observed and computed inflows for Regression and fuzzy logic method is shown in Figures 10 to 13. It can be observed that the forecast is better for lower and medium values of inflow when compared to higher values. Thus, we can state that our models predict well under normal conditions as compared to extreme conditions. Table 4 shows the computed performance measures for ANN method alone before and after converting zeroes to meagre values. Table 5 shows the performance measures of all the three methods.

The best Coefficient of Correlation value was found out to be 0.6875 from ANN method. When compared to other models in other papers, this ANN model may have lesser efficiency. But as the objective of the study is to compare the three methods of forecast, an even better model would only confirm to the already arrived result. Hence the ANN model was not needed to be improved any further.

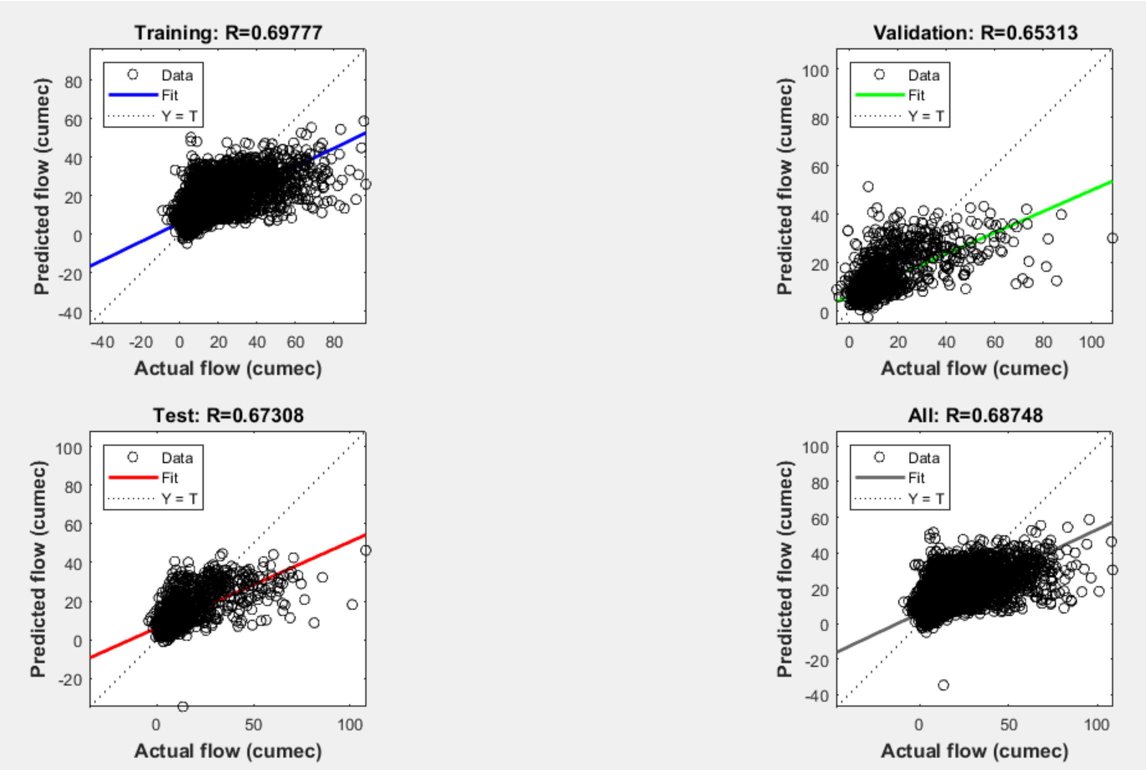


***Fig.9:***-*Plot showing Predicted flow vs Actual Flow for weekly forecast using pre-processed data in ANN method*

***Table 4:***-*Validation results for ANN method using actual and preprocessed data*

| Data Used | Forecast Period | Root Mean Square Error (RMSE) | Correlation Coefficient (CC) |
|---|---|---|---|
| Pre-Processed Data | Weekly | 8.5065 | 0.6875 |
| Raw Data | Weekly | 8.8659 | 0.6538 |

***Table 5:****-Performance Criteria when using All 3 Methods*

| **Method of Forecast** | **Root Mean Square Error (RMSE)** | **Correlation Coefficient (CC)** |
|---|---|---|
| ANN | 8.5065 | 0.6875 |
| Fuzzy Logic | 9.0376 | 0.5343 |
| Regression Tree | 8.7032 | 0.6083 |

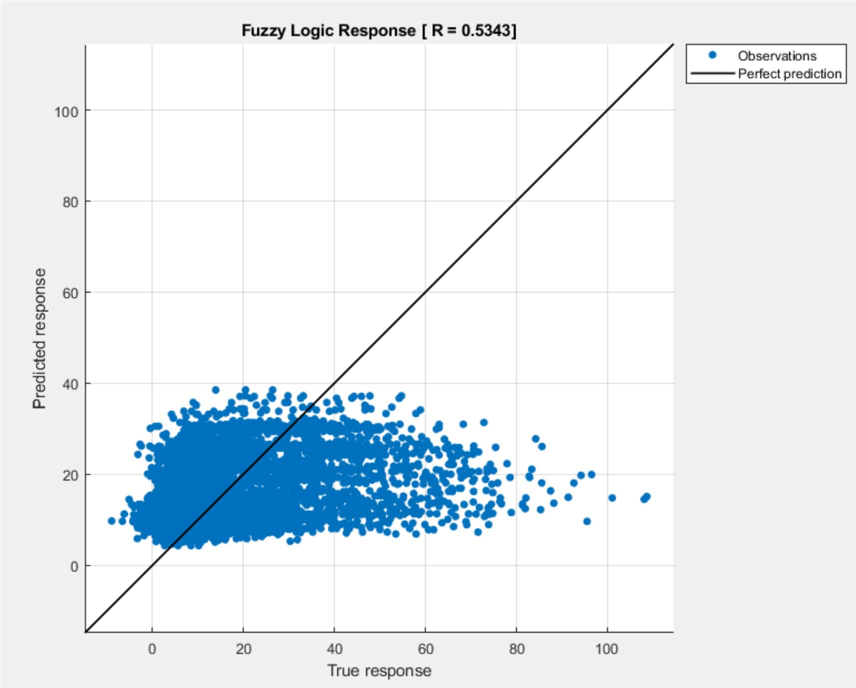


***Fig.10:****-Predicted flow vs Actual Flow for weekly forecast using fuzzy logic method*

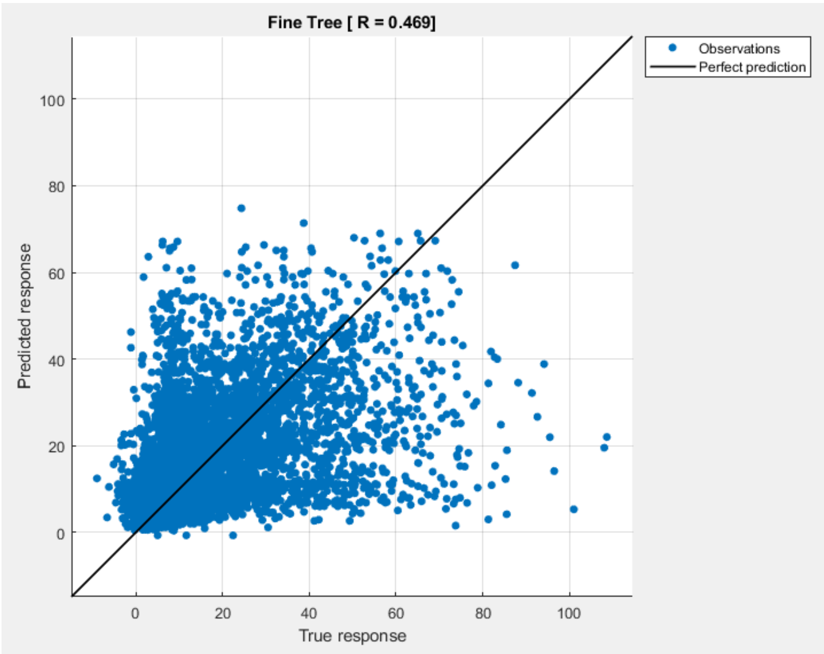


***Fig.11:****-Predicted flow vs Actual Flow for weekly forecast when using Fine tree in Regression Method*

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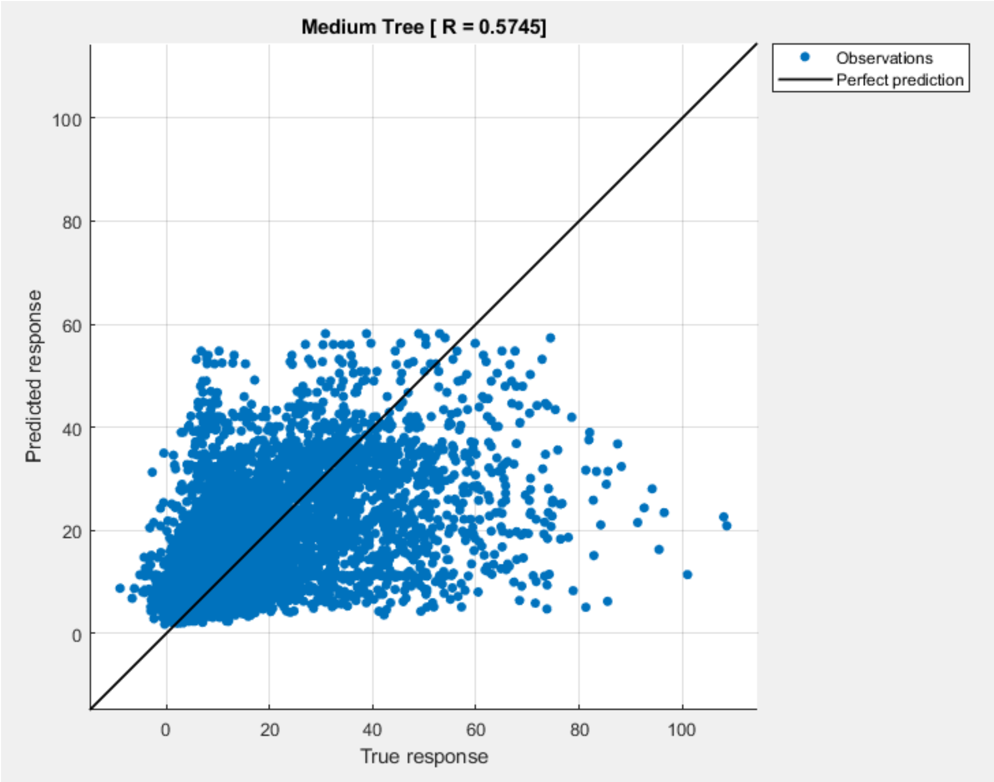


***Fig.12:-****Predicted flow vs Actual Flow for weekly forecast when using Medium tree in Regression Method*

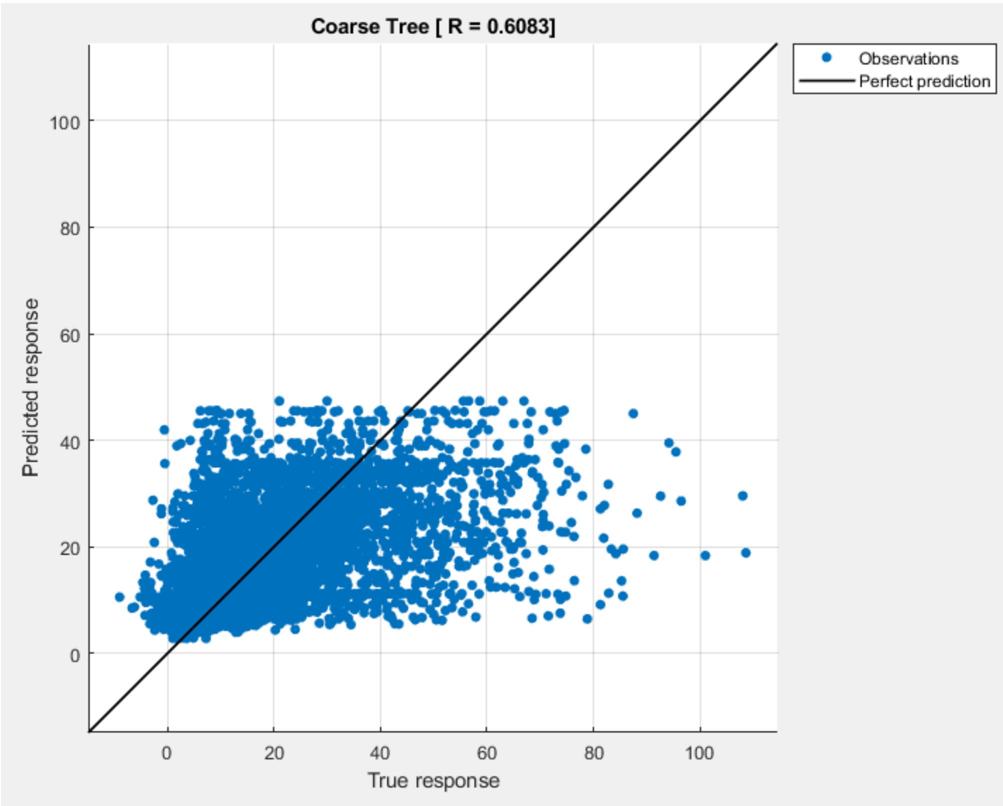


***Fig.13:-****Predicted flow vs Actual Flow for weekly forecast when using Coarse tree in Regression Method*

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To evaluate the importance input parameters on the output a sensitivity analysis was conducted. This was done by analyzing the actual inflow versus the predicted inflow plot obtained for the different inputs.

The closer he points are with the line of fit, the more accurate is the forecast. Hence, the group of parameters which produce the graph wherein the points are much closer to the line of fit are the parameters to be considered. In other words, the parameters which were left out have little or no significance in predicting the future data. By referring the plots we can understand that, in our system of forecasting the grater the parameters considered the better is the result, (i.e.) predicted output is of greater accuracy.

However, when a junk parameter (parameter not relating to inflow) like hydropower generated every day is included with the total parameter set the output is drastically affected. This proves that only when all the eleven parameters considered are chosen we will get the best output. Those sensitivity analysis plots are shown in Figure 14 to 16.

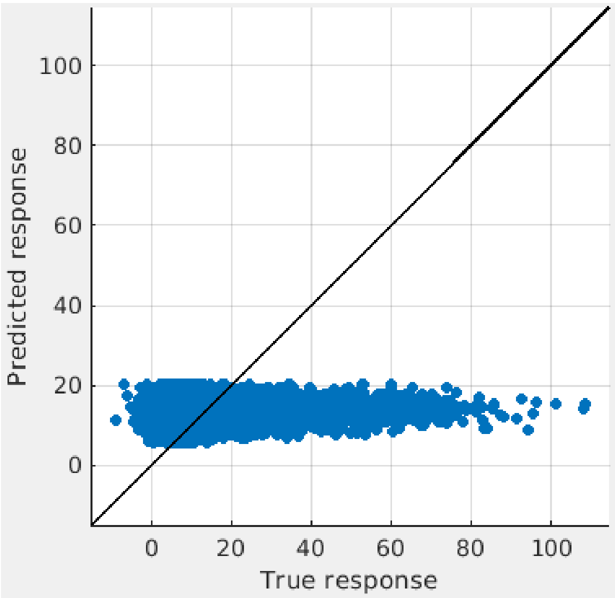


***Fig.14:-****Plot of Fit considering only snow parameter*

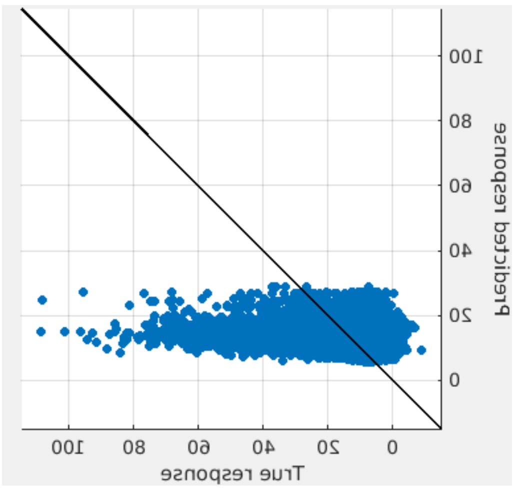

***Fig.15:-****Plot of Fit considering only snow parameter, CDD, HDD & Precipitation*

 

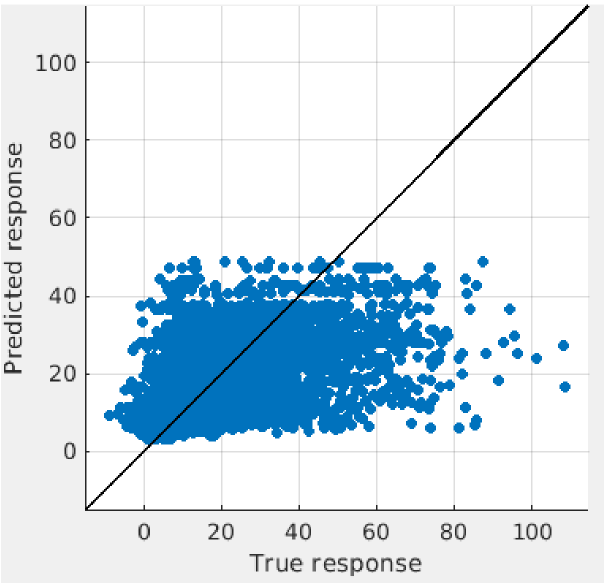


***Fig.16:-****Plot of Fit considering all the chosen parameters*

## SUMMARY AND CONCLUSIONS

The objective of this study was to assess the potential application of three forecasting techniques, namely ANN, fuzzy logic and regression tree, in attaining the reservoir inflow.

Three different models were created for weekly forecast of Deer Creek Reservoir, Utah, United States. To compare the performance of the models the following performance evaluation criteria were used. They are Root Mean Square Error (RMSE), Correlation Coefficient (CC) and Coefficient of Determination (CD).

They were generated for the three methods for the last seven and half years which were not used in model fitting and training.

The correlation coefficients for the models were 0.6875, 0.5343 and 0.6083 for ANN, fuzzy logic and Regression tree method respectively. For sixty years of data, the errors with the ANN model are less than those from other methods. Thus, it is concluded that ANN is the most effective tool among the three for reservoir weekly inflow forecasting for the Deer Creek Reservoir.

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