# Optimal Design of Water Distribution Network Using Neuro – Fuzzy Technique

**Abu Rashid**
National Institute of Technology Jamshedpur
**Sangeeta Kumari** (sangeeta.ce@nitjsr.ac.in)
National Institute of Technology Jamshedpur https://orcid.org/0000-0002-7920-3219

**Research Article**

**Keywords:** Water Distribution Network, Hydraulic Constraints, Water Gems, Optimization, ANFIS.

**Posted Date:** September 29th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-915481/v1

# Abstract

Present paper is intended to develop optimal policy for Water Distribution Network using Neuro- Fuzzy Technique in an effective manner. Hydraulic simulation of the Real Network is performed in Water Gems and is used for the evaluation of the system performance measure. The real network is revised by adding certain Hydraulic parameters such as PBV's (Pressure Break Valves) and Pumps and the results are found to be within standard limits for velocity and pressure specified by CPHEEO (Central Public Health and Environmental Engineering Organization). The networks are optimized using ANFIS (Adaptive Neuro Fuzzy Interactive System) to achieve the optimal cost and to obtain maximum reliability of the network. The pipe length and diameters are considered as fuzzy variables in the model and given as inputs to the model and pressure and velocities are outputs of the model. A comparison is made which marks the proposed network optimized using ANFIS is more reliable than the real network with slight increase in cost. Chota Govindpur – Baghbera Water Supply System is used as Case Study which is located in East Singhbhum District Jharkhand, India and the source of water is Subarnarekha river originated from Nagri village in Ranchi district of Jharkhand.

# 1. Introduction

For the development of any country it's very important to conserve and use the water in a most efficient way. From the population growth curve, it is clear that with the increase in population, demand of water supply on the public amenities including water supply for domestic purposes, irrigation, industry etc. has increased. Consequently, it's very important to identify such source of water supply, conserve it and optimally utilize the water. Various attempts have been made in the past to optimize the WDN (Water Distribution Network) using various Deterministic, Stochastic and Hybrid Techniques. From the previous literature review it was observed that during 1980s deterministic methods optimization work was carried out and in 1990s stochastic and hybrid methods work started.

In the past, around 45.5% papers have used Deterministic Approach, 49% papers used Stochastic Approach and around 5.5% used Hybrid Methods. The solution methodologies developed by previous authors for the optimal design of WDN can be broadly classified into three categories, namely Deterministic, Metaheuristic and Hybrid Techniques. The optimization of WDN started in 1980's as Deterministic optimization techniques such as Linear programming (LP), Non-linear programming (NLP) and Dynamic programming (DP). In the 1990's optimization was also developed using Metaheuristic and Hybrid Techniques.

Deterministic methods are categorized into Linear Programming, Non-Linear programming and Dynamic Programming. By using Linear Programming maxima or minima of a linear objective under linear constraints are found. It is an analytical or mathematical model which consist of objective function and set of constraints which can be either equality constraints or non- equality constraints.

Dynamic programming is additional deterministic optimization method used for solving multistage optimization problems, Dynamic Programming is based on decomposing a multi stage problem into single-stage problem. Basis fundamental of Dynamic Programming is the principle of optimality developed by Richard Bellman (1950). Its significance is that an optimal solution can be found using functional equation by relating optimal value for $(t + 1)$- stage problem to $t$ -stage problem (Martin 2003).

Non-linear programming techniques is also one of the Deterministic techniques used in WDS are based on the sequential LP or sequential quadratic programming and generalized methods of minimized gradient. NLP has certain limitations while handling and managing certain amount of constraints and variables therefore it can only manage less complex WDS.

Most of the real-world optimization's problems are extremely nonlinear and multimodal under certain complex constraints. Objectives are often found conflicting. Optimal solutions may not exist sometimes for a single objective also. In particular, finding an optimal solution is not an easy task. The heuristic means to find or to discover by trial and error and meta means beyond or higher level. Metaheuristic generally perform better than simple heuristic. Algorithm with stochastic components are mentioned as heuristic in the past but in recent literature it is referred as metaheuristics by Glover (1986) and Kochenberger (2003).

Randomization and Local search are used as a certain tradeoff in Metaheuristic algorithms. In Metaheuristic an excellent solution to difficult optimization problems can be found in a practical amount of time, but there is no assurance that optimal solutions can be reached. Almost all metaheuristic algorithms tend to be suitable for global optimization (Voss 2001).

Main components of metaheuristic algorithms are diversification and intensification (Blum and Roli, 2003). Diversification here identify to generate diverse solutions which explores the search space on a global scale, whereas intensification identify to emphasis the search in a local region. Therefore, it is very necessary to have a stability between intensification and diversification which should be found while selecting the best solutions to improve the rate of algorithm convergence.

In present study neuro fuzzy model for Water Distribution Network is developed with two input variables Length and Diameter and velocity and pressure as output variables in two different scenarios. The basic principle of neuro fuzzy model is that it can take multiple inputs but will generate only single output. The developed model is applied to the case study of the Real Water Distribution Network, East Singhbhum District, India.

## 2. Model Features

# 2.1 Artificial Neural Network

Artificial Neural Network (ANN) are so-called Neural Networks. Computational model was created by Warren McCulloch and Walter Pitts for neural networks which is based on algorithm called threshold logic. The ANN consists of connections, where each connection provides the output of one neuron as an input to another neuron. Weight is assigned to each connection which marks its relative importance. External data is received in the input layer. The ultimate result is generated in the output layer. In between the input & output layer are zero or more hidden layers.

The three major learning patterns of ANN are supervised learning, unsupervised learning and reinforcement learning. In supervised learning training of data is performed. Here both input & output is available which are further classified. Algorithm used in Supervised learning is Naire Bayes Algorithm. On the basis of input and output data we develop a model using Bayes Algorithm and once the model is developed, we provide new input data and get the output and validate whether the output generated after providing the new input data matches with the training output data or not. On the basis of that accuracy of the training output data is checked.

In Unsupervised learning there are only inputs. On the basis of input arbitrary clustering is made The algorithm followed in unsupervised learning is K-Mean. In K mean clustering the group is made or defined and the same type of individual is placed in that group. Reinforcement learning is based on reward and policy. Here an agent has to perform an action in environment and on the basis of the action agent will rewarded if found correct and penalized if found incorrect and a state change is noted and on the basis of reward or penalty, he develops a policy simultaneously and eventually the agent learns.

# 2.2 Fuzzy Logic Theory

Fuzzy Logic Theory approach is based on degree of truth rather than saying true or false (Boolean Logic). The inventor of the fuzzy logic was Lofti Zadeh in the year 1960’s. Instead of documenting degree of truth to be either true or false it is documented as something to be partially true or partially false with certain degree of membership. (Zimmermann 1991) defined the degree of membership to be set between 0 & 1. A fuzzy subset E of a universe of discourse U is characterized by a membership function $\mu E(x)$ in the range [0, 1] and represents the grade of membership in E.

Membership functions are curves of different forms which include triangular, trapezium, Gaussian, B-spline, sigmoid etc. that define how each point in the input space is plotted to a membership value (Mehta et al. 2005). Sharma (1985) provided methods to construct MF from statistical data. The fuzzy rule-based model works on an “IF–THEN” principle, where the “IF” is a vector of fuzzy descriptive variables and “THEN” is fuzzy significance.

# 2.3 Mamdani Fuzzy Inference System

Mamdani fuzzy inference system (FIS) is the most commonly used fuzzy methodology. In Mamdani approach the output generate through membership function. It’s a linguistic fuzzy modelling characterized by high inter- probability and low accuracy.

In this approach it is easy to frame the rules, interpretable, less accurate, follows Standard Centre of Sum Method and its Bit Expensive.

The IF−THEN control rules are given in the form:

$R_r$: If $x_1$ is $A_r^{(1)}$, $x_2$ is $A_r^{(2)}$ ……….$x_p$ is $A_r^{(p)}$ THEN $y_r$ = $f_r$( $x_1$, $x_2$, ……..$x_p$) (1)

where $A(p)_r$ is a fuzzy set corresponding to a partitioned domain of the input variable $x_p$ in the $r^{th}$ IF−THEN rule, *p* is the number of input variables, and $y_r$ is the output of the $r^{th}$ IF−THEN inference rule *Rr.*

## 2.4 Takagi-Sugeno (TS) Fuzzy Inference System

Takagi-Sugeno Fuzzy Inference System is similar to the Mamdani method in many respects. In Takagi-Sugeno output is on the basis of weighted sum of the linear equation. It follows the precise fuzzy modelling with high accuracy and low interpretability. It follows simple numerical calculation and difficult to interpret which is expressed as Mathematical Formula which needs some Co- efficient to be decided.

Considering m rules, the mathematical functioning of the TS model is:

$R_i$: If $x_1$ is $A_{i.1}$, AND ……….AND$x_K$ is $A_{i,k}$ THEN $y_i$ = ($a_i^T x$+ $b_i$) (2)

## 2.5 Neuro Fuzzy System

Neural Network are generally known good at recognizing patterns but are certainly not good at explaining how they reach their decisions whereas Fuzzy Logic is found good at explaining the decisions but cannot automatically attain the rules used for making the decision. These limitations of Neural Network and Fuzzy Logic hence act as a driving force for the formation of Hybrid Soft computing technique. A Hybrid Intelligent system is one that combines at least two intelligent technologies. Hybrid Optimization is aimed to build highly automated, intelligent machines for future generation. The main aim of the concept of Hybridization is to overcome the weakness in neural network and fuzzy logic and to bring out the strength by combining them.

Neuro – Fuzzy Proposed by J.S.R Jang in early 1990’s. Neuro Fuzzy is widely termed as Fuzzy Neural Network (FNN) or Neuro Fuzzy Systems (NFS). The Architecture of ANFIS is described in 5 layers as mentioned below:

Layer 1 is Fuzzification Layer, Layer 2 is Rule layer, Layer 3 is Normalization layer, Layer 4 is Defuzzification Layer and Layer 5 is Output layer.

In the first layer every node “i” in this layer is an adaptive node with a node membership function.

$O_i^1 = \mu_{Ai}$(x), i = 1,2,3, _ _ _ _ (3)

$O_i^1 = \mu_{Bi}$(x), i = 1,2,3, _ _ _ _ (4)

Fuzzy Membership function are of different shapes such as Gaussian, Triangular, Trapezoidal etc.

Layer 2: Calculates the firing strength of a rule via product operation.

$O_i^2$ = $W_i$ = $\mu_{Ai}$(x) * $\mu_{Bi}$(x), i = 1,2,3_ _ _ _ (5)

Layer 3: The role of third layer is to normalize the computed firing strength by dividing each value for the total firing strength.

= $\frac{W_i}{\sum W_i}$, i = 1,2,3,4_ _ _ (6)

Layer 4: Each node represents consequent part of fuzzy rule. The linear Co-efficient of rule consequent are trainable

$O_i^4$ = $w_i * f_1$ = $w_i$* ($P_k$* x + $q_k$* y + $r_k$) where i = 1,2 ….n (7)

Layer 5: Perform defuzzification of consequent part of rules by summing outputs of all the rules.

Final Output =$O_i^5 = \sum_i w_i * f_1$ = $w_i *$ ( $P_k$* x + $q_k$* y + $r_k$) (8)

# 3. Model Development

The optimization of a Water Distribution Network aims to design the least-cost network under different ranges of hydraulic constraints. The objective function is to minimize the cost and maximize the reliability of the Network.

**Objective Function**

Min Z = $\sum_{i=1}^{np} Ci(L, D)$ (9)

Where, $Ci$ is the cost of the network, L is the length of link and D is the diameter of the link.

**Constraint 1**:

$H_j \geq H_j^{min}$ j = 1,2,3________________nd (10)

Hydraulic head $H_j$ available should be greater than or equal to the minimum required value$H_j^{min}$

**Constraint 2**:

Pipe Diameter should be selected from commercially available discrete pipe sizes.

$D_i \in CD_k \forall ik = 1, 2,3$____________________________________$nc$ (11)

**Constraint 3**:

$V_{min} \leq V_i \leq V_{max}$ i = 1,2,3______________________n (12)

Where, $V_{min} and \leq V_{max}$ are the minimum and maximum velocity.

**Constraint 4**:

$P_{min} \leq P \leq P_{max}$ i = 1,2,3______________________n (13)

Where, $P_{min} and P_{max}$ are the minimum and maximum pressure.

**Nodal Mass Balance**

Flow that enters and leaves a node should be equal.

$q_j^{in}$ – ( $q_j^{out}$ + $q_j$ ) = 0 j = 1,2,3___________________nd (14)

**Loop Energy Balance**

Head Loss around any loop in a WDN should be zero.

$\left(\sum_{i=1}^{npL} HLi\right)_k$ = 0 k= 1,2,3___________________nL (15)

# 3.1 Operating Policy Implementation

Open Flow Water Gems is used as a decision tool for water distribution network and it also helps to act on operational strategies and how it should grow as population and operational strategies. Water Gems has several features such as to assess fire flow capacity, design water distribution system, Built and manage Hydraulic Models, identify water loss, develop flushing plans, pipe renewal prioritization, Real time simulation of water networks.

While designing the distribution network is should be kept in mind that it should satisfy all the constraints as specified in the standards of (Central Public Health and Environmental Engineering Organization (CPHEEO). The results obtained after hydraulic simulation in Watergems are imported in ANFIS.

The decision variable taken for ANFIS as an input in each case is Pipe Diameter and operational parameters such as valve settings for each loading conditions and we have only one output as per ANFIS rules. To satisfy the hydraulic constraints such as velocity and pressure as an output parameter. One parameter at a time is taken in ANFIS as an output and keeping the input as Pipe Diameter, Length, Elevation at nodes and operational parameters such as valve settings for each loading conditions in an ANFIS model.

Figure 1 shows the ANFIS layout structure which is split into 5 layers. In layer 1 it identifies input & output variables and decide descriptor for the same. In layer 2 membership function are defined for each input &

output variables. In layer 3 it forms a rule base. In layer 4 Rule Evaluation is done and in final layer 5 Defuzzification is carried out.

The parameters for optimization in an ANFIS are the premise parameters which describe the shape of the MFs, and the consequent parameters which describe the overall output of the system.

Rule1: IF $x$ is $A_1$ and $y$ is $B_1$, THEN $f_1 = p_1 x + q_1 y + r_1$ (16)

Rule2: IF $x$ is $A_2$ and $y$ is $B_2$, THEN $f_2 = p_2 x + q_2 y + r_2$ (17)

# 4. Model Applications

The proposed method is applied to a real WDN design problems. The Chota Govindpur Bagbera Water Supply network which lies in East Singhbhum District, Jharkhand, India is taken as my study area. Aim of these studies is to explain the ANFIS method precisely. To simulate the hydraulics of the networks in this real model, the Hardy–Cross method is used and the solver is verified by Water Gems.

It is a real WDN in East Singhbhum district under the government of Jharkhand. It covers rural areas of Chota Govindpur, Ghadara, Haludbani, Parsudih and Sarjamda. The case study for this research paper is DMA- 05 of Ghadara which covers 9.38 kms out of total 36.612 kms Ghadara as shown in Fig. 1. Pipe Diameter varies from 18 inch up to 4inches from the overhead tank up to the dead-end point of the distribution system. The material used is Ductile Iron (K-7) pipes and Co- efficient of Hazen Williams is taken as 140. As per the CPHEEO manual (Table 2- Serial no- 2), per capita demand is 135 liters per capita per day and UFW (Unaccounted Flow) is 15% as specified in CPHEEO manual which accounts to a total demand of 155.25 liter per capita per day. Usually highest population is forecasted to predict demand. From the Census of India 2011, District Census Handbook Purbi Singhbhum the initial population of entire Ghadara in 2011 was 18801 and the forecasted population in 2021 using GIM (Geometric Increase Method) is 22,749.

Figure 2 shows the location map of the study area which is drawn in Arc GIS. Figure 3(a) shows the Key plan of proposed distribution zone and Fig. 3(b) shows the proposed Ghadara Panchayat area which is split into 5 separate DMA's (District Metered Areas) such as DMA-1, DMA2, DMA-3, DMA-4 and DMA-5.

In this network the water flows from Over Head tank to entire distribution system under gravity flow. In this real pipe network of (DMA 5) Ghadara we have 68 Junctions and 72 pipes of diameter varying from 18 inches up to 4 inches. The Pressure at nodes should be in the range of [7,12] m to [12,17] m and Velocity should be in the range of [ 0.6, 2.3] m/s as specified by CPHEEO to obtain the safe performance of the network.

## 4.1 Data Availability

The network details such as pipe length, diameter, node elevation has been obtained from Drinking Water & Sanitation Department, Jharkhand Govt (East Singhbhum District). Figure 4 & Fig. 5 represents the real and proposed Water Distribution Network of Ghadara. The available data is partitioned in two parts nearly 70% used for calibration /training the model and 30% used for validation / checking of the model. Data Base have been prepared for two different scenarios. The decision variable taken for ANFIS as an input in each case is pipe diameter, length and has only one output in each scenario. For scenario 1, the output is pressure and for scenario 2, the output is velocity.The network details for Water Distribution Network for real network is shown in Table 1 and for revised network it is shown in Table. 2 mentioned in Appendix.

In Fig. 5, the proposed network is similar to real network as in Fig. 4 with two additional hydraulic parameters such as Pump and Pressure Break Valve as marked in Fig. 5. In Real Water Distribution Network flow is under gravity but since some nodes are not in the natural gradient of the flow therefore pressure and velocity at such nodes are not within the specified constraints of velocity and pressure. Therefore, to bring the velocity and pressure within the constraint 1 Pump and 1 PBV's have been added in the real network. In the proposed network 1 Pump and 1 (PBV) Pressure Break Valve used additionally in the entire network in comparison to the real network to satisfy the minimum and maximum pressure, minimum and maximum velocity as per the standards of CPHEEO. 1 Pump (Annotation- Pump 59) is installed in between Junction 142 and Junction 141 in the proposed network due to the nature of the reverse gradient from Junction 142 which recorded an elevation of 153.66 to Junction 120 which recorded an elevation of 157.97. 1 Pressure Break Valve (Annotation- PBV 2) is installed between AV-2 and J-113. The characteristics of pump definition type is defined as standard three point and its break-even point efficiency is set to 85% as marked by red curve and its corresponding head with respect to flow is marked by blue curve as in Fig. 6. Pump Definition is represented in terms of flow, efficiency and head as show in Fig. 6.

The Pressure Break Valve (Annotation- PBV 2) is installed between Air Valve (AV)- 2 to J- 113 having a diameter of 6 inches and the pressure settings is set to 5 meters to control the loss at downstream as the velocity will always be more at dead end point. The entire network details is shown in Table.1 and its elevation is shown in Table.2 (Appendix). The entire cost of WDN depends on the length of entire Network in DMA – 5 is shown in Table 4.

Table 3
Commercially available pipe diameters and their unit costs

| Sl. No | DIA (K-7) | Cost /m (Rs.) |
|---|---|---|
| 1 | 100 | 866.53 |
| 2 | 150 | 1274.35 |
| 3 | 200 | 1580.19 |
| 4 | 250 | 2078.61 |
| 5 | 300 | 2631.4 |
| 6 | 350 | 3126.43 |
| 7 | 400 | 3585.21 |
| 8 | 450 | 4361.14 |
| 9 | 500 | 5154.03 |
| 10 | 600 | 6810.18 |
| 11 | 700 | 9169.69 |
| 12 | 750 | 11442.03 |
| 13 | 800 | 11898.5 |
| 14 | 900 | 13561.35 |
| 15 | 1000 | 16798.05 |

Table 4
Estimated pipe diameters and their unit costs

| SL No. | Diameter Type (K-7) | Diameter/m Cost | Length (m) | Total Cost |
|---|---|---|---|---|
| 1 | 100 | 866.53 | 6539.48 | 5666655.604 |
| 2 | 150 | 1274.35 | 1773.02 | 2259448.037 |
| 3 | 200 | 1580.19 | 758.64 | 1198795.342 |
| 4 | 300 | 2631.4 | 233.17 | 613563.538 |
| 5 | 450 | 4361.14 | 78.02 | 340256.1428 |
| **Rs 10078718.66** | | | | |

Table 5
Scenarios for ANFIS as Input & Output

| Scenario No. | Input 1 | Input 2 | Output |
|---|---|---|---|
| 1 | Fuzzy Length | Fuzzy Diameter | Pressure |
| 2 | Fuzzy Length | Fuzzy Diameter | Velocity |

Table 5 shows the inputs and output used in corresponding network during Hybrid Optimization using Neuro Fuzzy or ANFIS. In Takagi Sugeno approach the inputs for length and Diameter are taken in terms of membership function ranging from 0 to 1 which are created in MATLAB for neuro fuzzy technique and the output is based on the weighted sum of the linear equation in neuro fuzzy.

## 4.2 Water Distribution Network Operating Policy

Before the construction of Water Distribution Network, the concerned authorities had formulated the water distribution operating policy. The release from the intake well to Hudco water treatment plant is carried out with the help of 6 raw water pumps (3 Operating and 3 Stand by) with a power rating of 37 KW and head is 142.82m. The discharge for each pump is 650 $\mathrm{m}^3$/hr. The water from treatment plant to overhead tank is supplied by gravity flow. In this present study the distribution network is considered from Overhead tank of Ghadara to entire distribution network of DMA 5.

1. The capacity of Ghadara over head tank is 13.1 lakh liters.
2. The pressure to be maintained in the entire distribution network should be in the range of 7metre up to 17 metre and it should not exceed 22 metre. (7 metre for single storey, 12 metre for double storey, 17 metre for triple storey) as specified by CPHEEO.
3. The velocity should be in the range of (0.6–2.3) m/s as specified by CPHEEO.
4. The per capita demand is 135 l/c/d with an unaccounted flow of 15% that is 156 l/c/d.
5. The population demand for 2021 is projected from the 2011 census of East Singhbhum District (Ghadara) using the Geometric Increase Method.
6. The basic principle on which WDN is based is Nodal mass and Loop Energy Balance.

Here in this network four constraints are taken maximum and minimum velocity and maximum and minimum pressure.

## 4.3 Membership Functions

There are several types of Membership Function (MF) such as Triangular, Trapezium, Sigmoid, Gaussian, etc. Membership functions for all inputs and outputs are chosen from the existing MF (Zimmermann 1991) as triangular type (which is simple and commonly used in water resources applications). In Table 7. flowchart is represented which marks the block diagram of Neuro Fuzzy Model. Here a network has been simulated in Water Gems. Input parameters in Water Gems for the Hydraulic Simulation are Pipe length, Pipe Diameter, Elevation, Air Valve, Orifice meter, Hazen William Co- efficient. Once the network is simulated and the results such as Velocity and Pressure obtained in the Flex Tables which are exported in MATLAB where it is Train, Tested and Fuzzy Inference System (FIS) is generated to develop a Neuro Fuzzy Model. From the FIS the results are exported to Excel where the Model Data is validated with the Observed Data to calculate the Root Mean Square Error and also the Co-relation Coefficient. Once the model gets simulated its optimal cost and Reliability of Network can be obtained.

# 5. Results & Discussion

The available data is partitioned in two parts. Around 70% of data is used for training / Calibration and the remaining 30% used for testing/validation. Here in the Water Distribution Network inputs taken are length, diameter and Pump as well as Valve settings with a single output reliability. Here the reliability means it should satisfy the minimum and maximum pressure constraints, minimum and maximum velocity constraints.

The Hydraulic parameters after simulation which are obtained in Water Gems are imported in MATLAB. Here, two scenarios separately have been developed to calculate velocity and pressure For **scenario 1** to calculate pressure as an output the input fuzzy parameters taken are diameter and length. Sugeno approach has been used as a fuzzy Inference System. In MATLAB Environment, Neuro Fuzzy Designer, from the observed data nearly seventy percent data is imported in MATLAB for training and nearly 30 percent of observed data for testing.

Now generate Fuzzy Inference System with Number of Membership Function in for two Inputs is set as three - three and Membership Type is selected as Triangular and in Output the Membership Type is set to constant in Takagi Sugeno Approach. The number of rules generated is nine which is based on based on number of membership function assigned. In Fuzzy Inference System training of FIS is done with optimization method as Hybrid. Here Epochs generated is 1.67611 when it is set to 100. Designated epoch number reached after ANFIS training completed at epoch from 1.6752 to 1.67611. Finally test the Fuzzy Inference System (FIS) for the training data, testing data for the scenario. 1 The Rule viewer for scenario – 01, for 2 inputs and 1 output is generated as shown in Fig. 8.

Now once the model has been trained and tested for velocity the results from Rule Viewer are extracted to find the Correlation and Root Mean Square Error. The Correlation was found to be 0.952 or 95.2 % and the RMSE (Root Mean Square Root) was found to be 0.164.

Table 6
Correlation for Scenario-01

| Observed Data | Model Data |
|---|---|
| 1 | 0.952 |
| 0.952 | 1 |

For **Scenario 2** to calculate velocity as an output the input fuzzy parameters taken are diameter and length of the pipe. Sugeno approach has been used as a fuzzy Inference System. In the Neuro Fuzzy Designer, from the observed data nearly seventy percent data from the observed data is imported in MATLAB for training and nearly thirty percent of observed data for testing.

Now generate Fuzzy Inference System (FIS) with Number of Membership Function in Input as 3 3 and Membership Type is selected as Triangular and in Output the Membership Type is set to constant in the Takagi Sugeno Approach. The number of rules generated is nine which is based on based on number of membership function assigned.

In Fuzzy Inference System training of FIS is done with optimization method as Hybrid. Here Epochs generated is 0.0610471 after it is set to 100. Designated epoch number reached after ANFIS training completed at epoch from 0.0609561 to 0.0610471. Finally test the FIS for the training data, testing data for the scenario. 2.

The Rule Viewer for scenario – 02, there are 2 inputs and 1 output shown in Fig. 10.

Now once the model has been trained and tested for velocity the results are exported from Rule Viewer to Excel to find the Correlation and Root Mean Square Error( RMSE). The correlation coefficient was found to be 0.813 or 81.3% and the RMSE was found to be 0.154.

Table 7
Correlation for Scenario-02

| Observed Data | Model Data |
|---|---|
| 1 | 0.8136 |
| 0.8136 | 1 |

Once the reliability of the network is satisfied such as maximum and minimum velocity constraints as well as maximum and minimum pressure constraints in the revised network using neuro fuzzy technique it is validated with the observed/real network to find Root Mean Square Error (RMSE) and Correlation Coefficient.

In the real /observed network the cost incurred along the network covering 9382.33 metre varying from 18 inches up to 4 inches from the Overhead tank of Ghadara to the entire Water Distribution Network of DMA-05 is Rs. 10078718.66 but as we observed from the real/observed data that some of the constraints are not within the specified range of CPHEEO therefore there is a need to revise the network by adding one pump and two pressure break valves. Though there is a marginal increase in cost in the proposed network as compared to the real network/Observed network by the addition of 1 pump and 1 PRV (Pressure Break Valve) but the Reliability of the network is satisfied to greater extent compared to real network. The cost details of Pump and PRV are found from SOR (Sequence of Rates) from the Jharkhand Government.

The reason for installing the pump is difference in elevation along the nodes as the water flows in the reverse gradient requires extra head to allow water to flow in that particular gradient and the reason for Pressure Break Valve is to check the pressure at dead end nodes due to high velocity and to make the pressure within the specified limits. The rates of Pump and Pressure Break valve are found in the Sequence of Rates (S.O.R) of the Jharkhand Government which increases the cost of proposed network compared to the real/observed network. The size of Diameter and Length of Link remained unchanged in both the real as well as proposed network.

# 6. Conclusions

The entire Hydraulic simulation of the study area is performed using Water GEMS and Neuro Fuzzy Technique to get the Rule viewer output. The correlation coefficient and Root Mean Square Error between the real and revised model are calculated. the The reliability and cost of observed /real and proposed networks are compared. The ANFIS or Neuro Fuzzy is a Hybrid model having Properties of artificial neural network and fuzzy logic which has proven to be a powerful tool for variety of application in engineering domain.

The following observations are made during this study of optimal design:

1. Based on the Reliability it is more reliable to select the proposed network as it satisfies all the four constraints (mimimum and maximum pressure, minimum and maximum velocity) when compared to the real network.
2. Based on Economy the cost incurred in the real network is less when compared to the proposed network by the installation of 1 Pump and 1 Pressure Break Valve .

It is preferable to use proposed network as it is more reliable and satisfies the demand in that Ghadara (DMA 05) while following all the CPHEEO standards.

# Abbreviations

PBV’s : Pressure Break Valves

CPHEEO : Central Public Health and Environmental Engineering Organization

ANFIS : Adaptive Neuro Fuzzy Interactive System

MATLAB : Matrix Laboratory

FIS : Fuzzy Inference System

UFW : Unaccounted Flow

TS : Takagi-Sugeno

CPHEEO : Central Public Health and Environmental Engineering Organization

DMA : District Metered Areas.

# Declarations

**Acknowledgement** The authors gratefully thank the Administration of Drinking Water & Sanitation (DW&S) Department, Jharkhand Govt for providing the data of Chota Govindpur Bagbera Water Supply Project.

**Author Contribution** All authors contributed to the study conception and design. Data collection were performed by Abu Rashid and Sangeeta Kumari. Analysis and Optimization were performed by Abu Rashid and Sangeeta Kumari. The first draft of the manuscript was written by Abu Rashid. All authors read and approved the final manuscript.

**Funding** No Funding by any agency.

**Data Availability** Data are not available at the free domain.

**Code Availability** All analyses were made by licesnsed software Water GEMS and MATLAB.

**Declarations**

**Ethics Approval** Not applicable.

**Consent to Participate** Authors give their permission.

**Consent to Publish** Authors give their permission.

**Competing Interests** The authors declare no conflicts of interest.

# References

1. Alvisi, S., & Franchini, M. (2015). A linearization approach for improving the computational efficiency of water distribution system ranking-based optimization algorithms. Procedia Engineering, 119, 516-525.
2. Abkenar, S. M. S., Stanley, S. D., Miller, C. J., Chase, D. V., & Mc Elmurry, S. P. (2015). Evaluation of genetic algorithms using discrete and continuous methods for pump optimization of water distribution systems. Sustainable Computing: Informatics and Systems, 8, 18-23.
3. Blum and Roli (2003) Metaheuristics in Combinatorial Optimization: Overview and Conceptual Comparison, January 2001 (DOI:10.1145/937503.937505)
4. Cunha, M., & Savi, D.A (2015). Environmental Modelling & Software Multi-objective optimization of water distribution systems based on a real options approach, 63, 1–13.
5. Dongre, A. (2016). Optimization of Water Distribution Network - A Review, 2(09), 269– 272.
6. Do, N., Simpson, A., Deuerlein, J., & Piller, O. (2017). Demand estimation in water distribution systems: solving underdetermined problems using genetic algorithms. *Procedia Engineering*, 186, 193-201.
7. F.Glover and G. Kochenberger, eds. (2003) Handbook of Metaheuristics (International Series in Operations Research & Management Science) Volume 1, Kluwer Academic Publishers, Springer, Boston
8. Fracasso, P. T., Barnes, F. S., & Costa, A. H. R. (2014). Optimized Control for Water Utilities. Procedia Engineering, 70, 678–687.
9. Fayomi, O.S.I. Olukanni, D.O. Fayomi G.U. And Joseph, O.O. 2017. In situ assessment of degradable carbon effusion for industrial waste water treatment, Cogent Engineering 2017, 4: 1291151 http://dx.doi.org/10.1080/23311916.2017.1291151
10. Fayomi G.U, Wusu O, Mini S.E, Fayomi O.S.I, Kilanko O. Data analysis on the level of exposure to pollutions in industrial zone: A case study of Ewekoro and Ota Township Data in Brief, 2018, 19, 859-864.
11. Giacomello, C., Kapelan, Z., Nicolini, M., 2013. Fast hybrid optimization method for effective pump scheduling. J. Water Resour.Plan. Manag. ASCE 139(2), 175e183
12. Giustolisi, O., Berardi, L., Laucelli, D., Savic, D., & Kapelan, Z. (2015). Operational and tactical management of water and energy resources in pressurized systems: Competition at WDSA 2014. Journal of Water Resources Planning and Management, 142(5), C4015002
13. Hsu, N. S., Cheng, W. C., Cheng, W. M., Wei, C. C., & Yeh, W. W. G. (2008). Optimization and capacity expansion of a water distribution system. Advances in Water Resources, 31(5), 776-786
14. Jetmarova, H., and Sultanova, N. (2018). History of Optimization in Water Distribution System Analysis.
15. Kim, M., Choi, T., Kim, M., Han, S., and Koo, J. (2015). Optimal operation efficiency and control of water pumps in multiple water reservoir system: Case study in Korea. Water Science and Technology: Water Supply, 15(1), 59–65.

16. Kurian, V., Chinnusamy, S., Natarajan, A., Narasimhan, S., & Narasimhan, S. (2018). Optimal operation of water distribution networks with intermediate storage facilities. Computers and Chemical Engineering, 119, 215–227.
17. Lejano, R. P. (2006). Optimizing the layout and design of branched pipeline water distribution systems. Irrigation and Drainage Systems, 20(1), 125–137.
18. Martin L. Puterman, in Encyclopedia of Physical Science and Technology (Third Edition), 2003.
19. Mala-Jetmarova, H., Sultanova, N., & Savic, D. (2017). Loss in optimization of water distribution systems. A literature review of system operation. Environmental modelling & software, 93, 209-254.
20. Mehta, R., & Jain, S. K. (2009). Optimal operation of a multi-purpose reservoir using neuro-fuzzy technique. Water Resources Management, 23(3), 509-529.
21. Nicklow, J., Reed, P., Savic, D., Dessalegne, T., Harrell, L., Chan-Hilton, A.& Zechman, E. ASCE Task Committee on Evolutionary Computation in Environmental and Water Resources Engineering (2010) State of the art for genetic algorithms and beyond in water resources planning and management. Journal of Water Resources Planning and Management, 136(4), 412-432.
22. Ostfeld, A., (2001). "Reliability Analysis of Regional Water Distribution Systems.", Elsevier Science Ltd., Urban Water.
23. Voss (2001) Metaheuristics: The state of the art. Lecture Nodes in Computer Science, 2148
24. Zimmermann, H.-J. (1991) Fuzzy Set Theory and Its Applications. Kluwer Academic Publishers, Boston. https://doi.org/10.1007/978-94-015-7949-0

# Figures

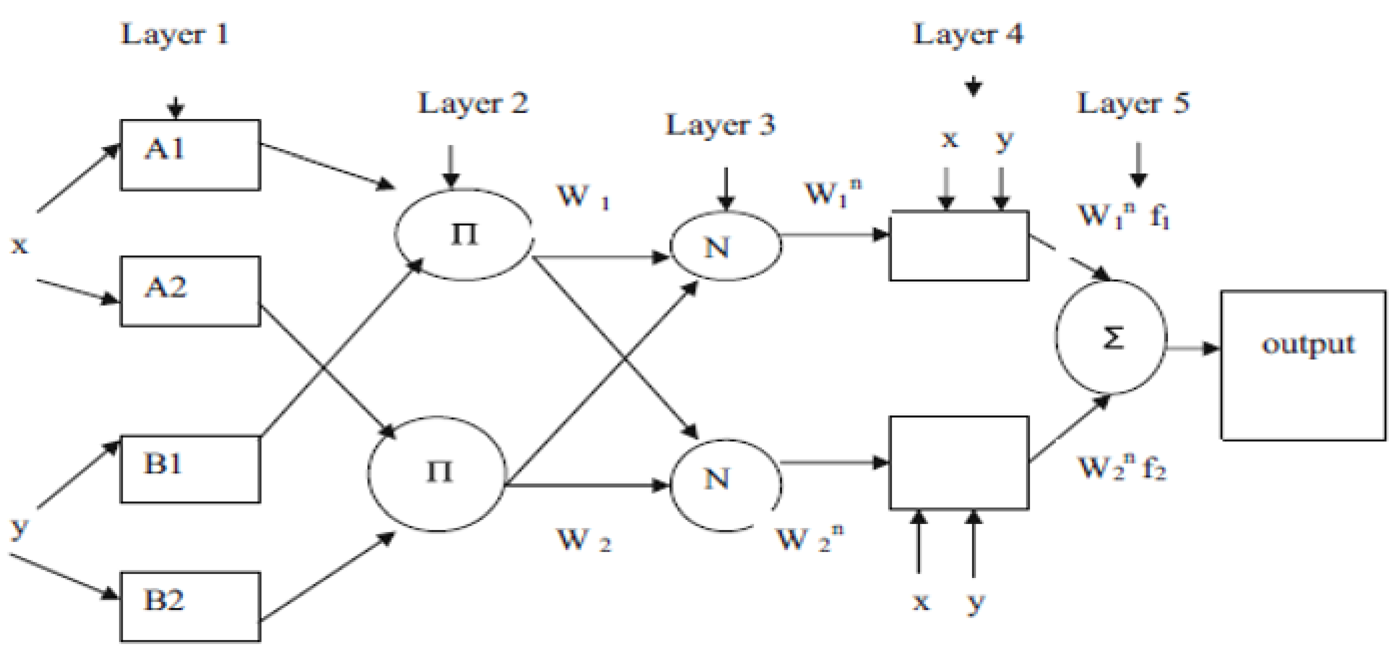



Figure 1

ANFIS Layout Structure (Source: Mehta and Jain 2009)

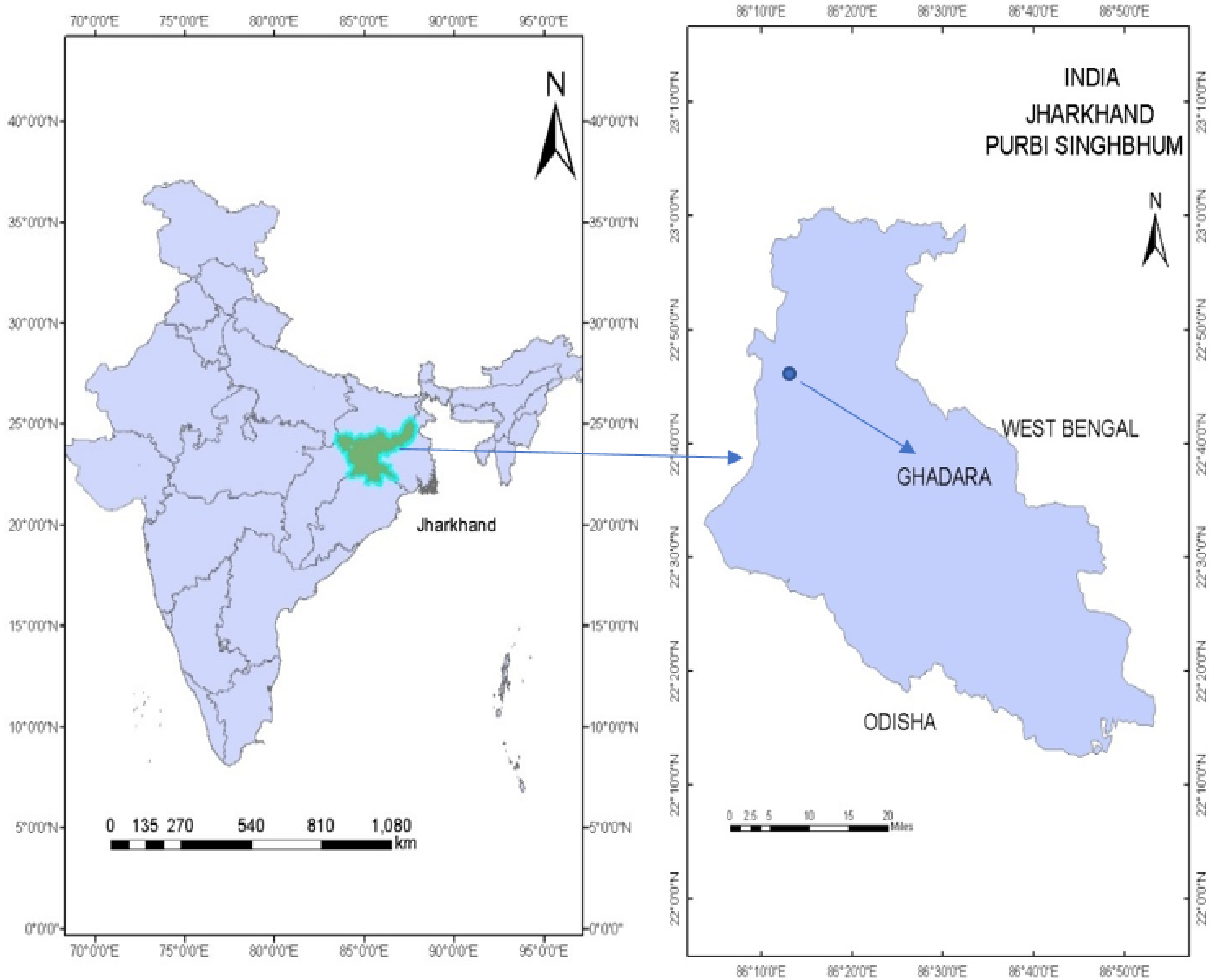
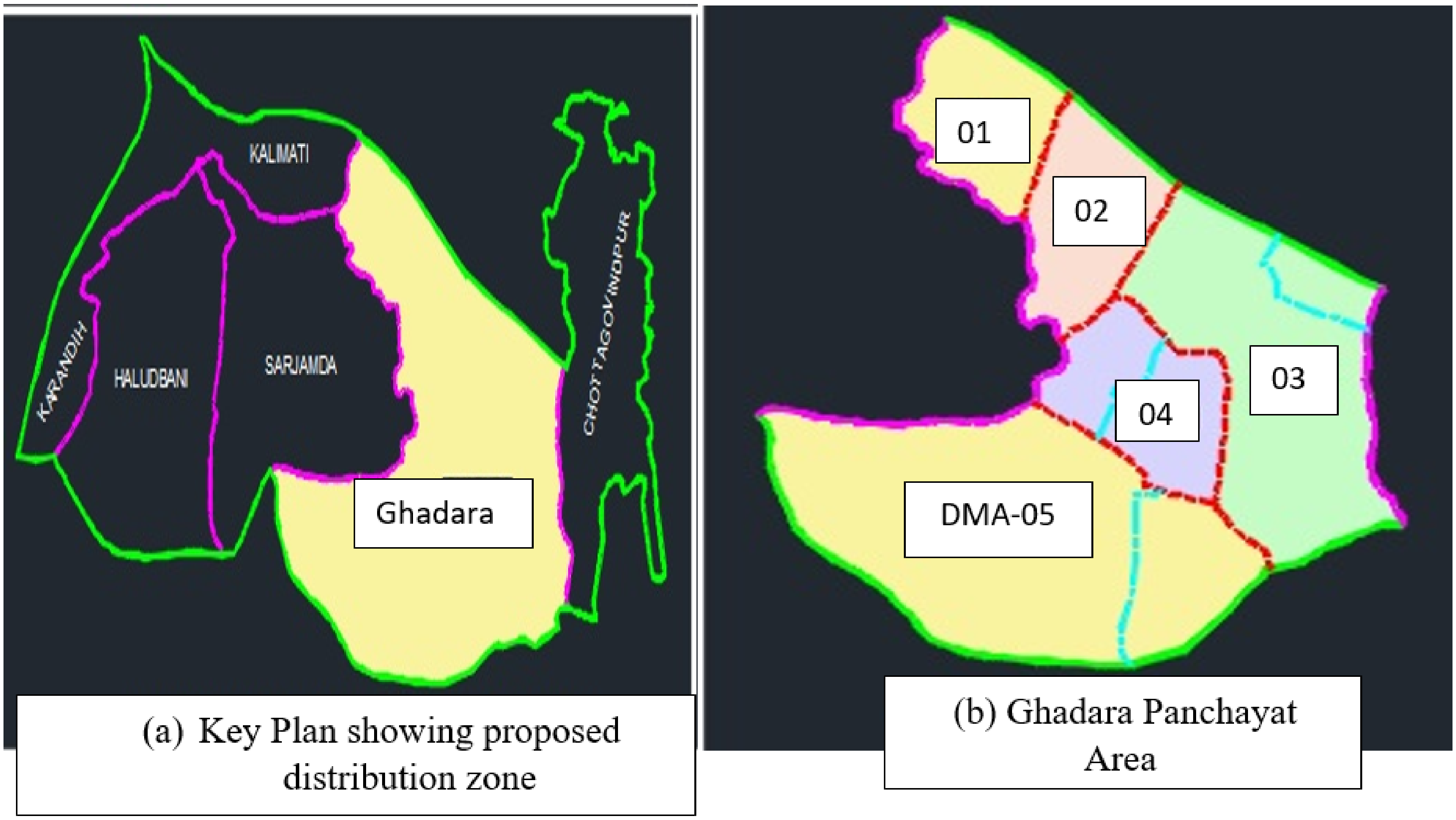



**Figure 2**

Location of study area

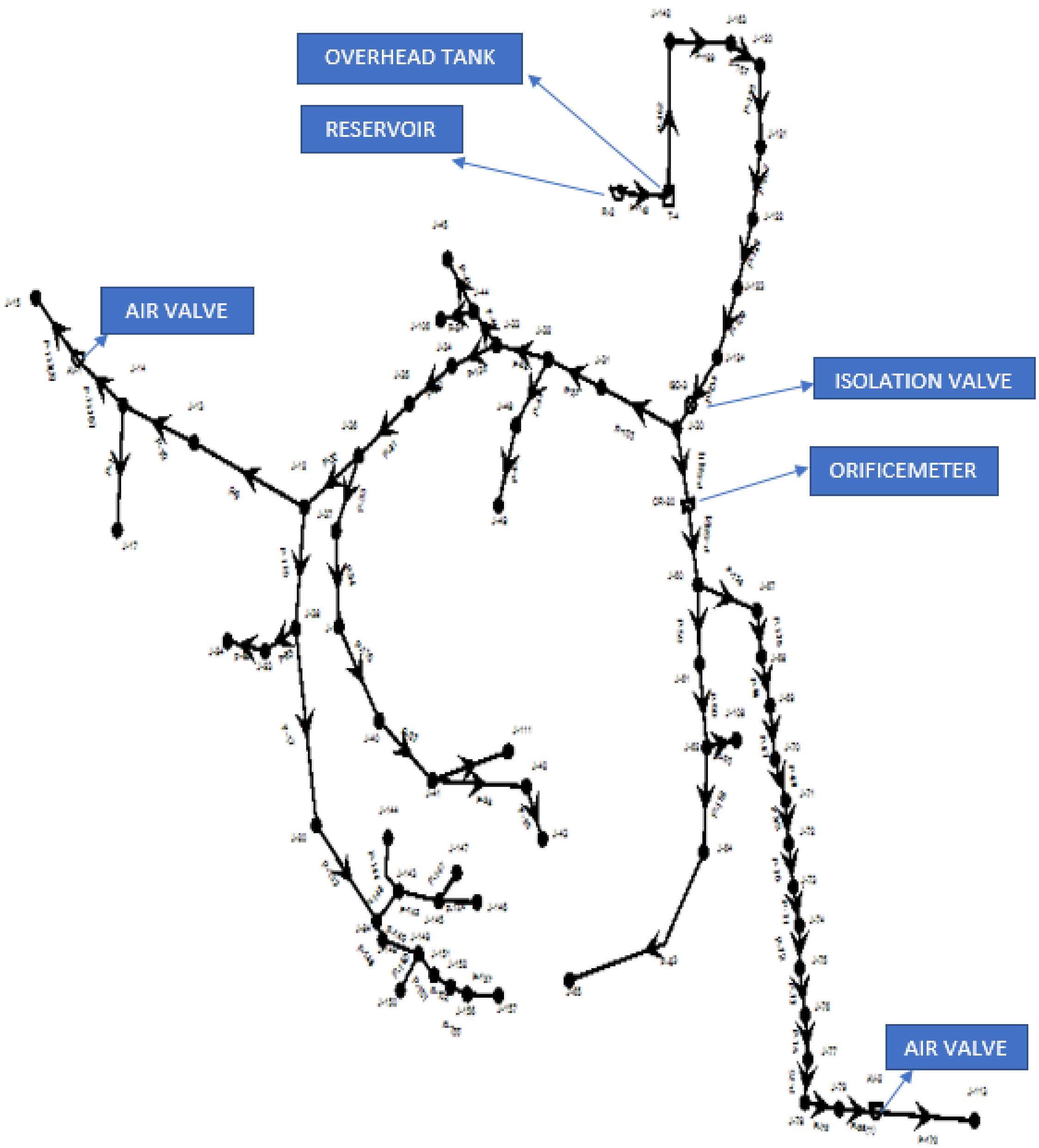



(a) Key Plan showing proposed distribution zone

(b) Ghadara Panchayat Area

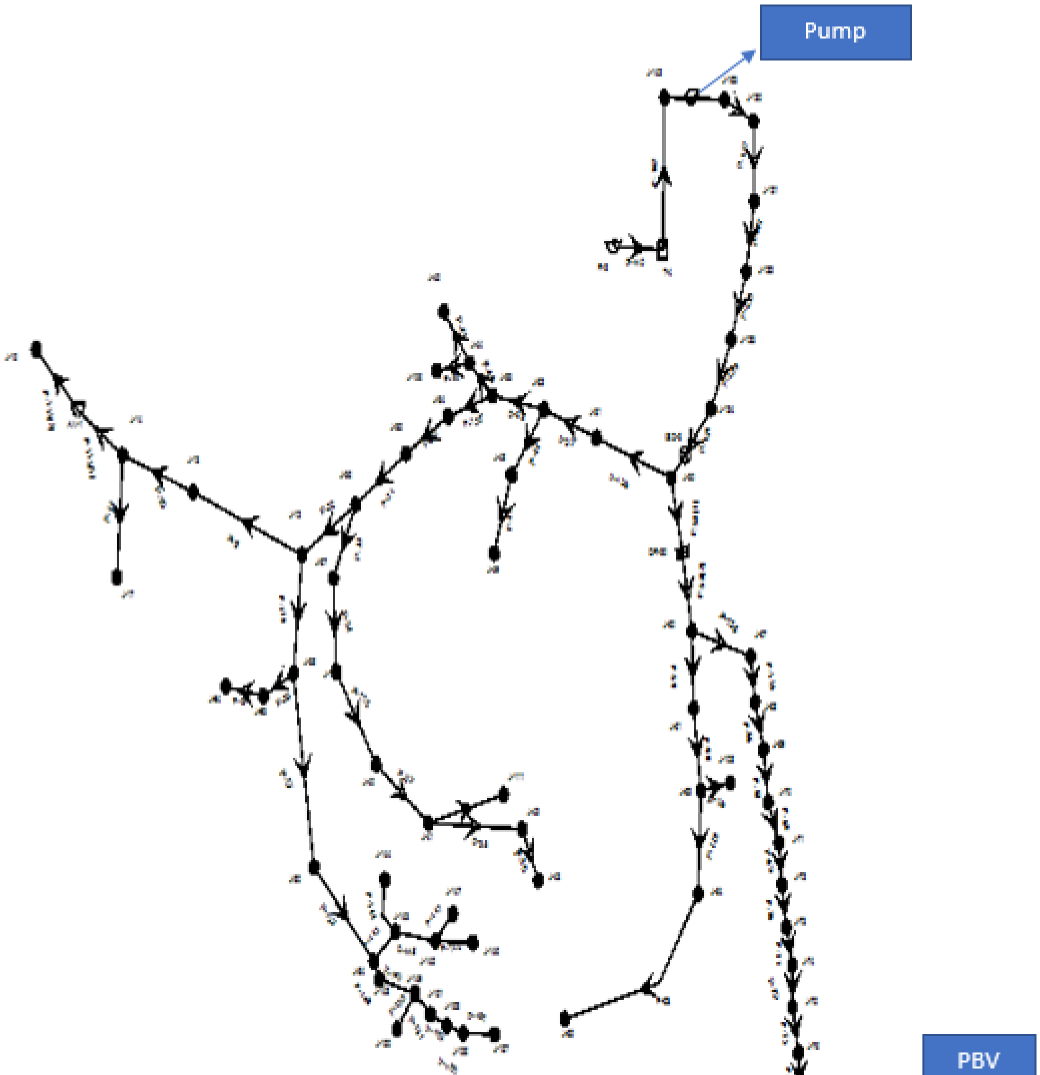
**Figure 3**

Proposed Water Distribution Network




## Figure 4

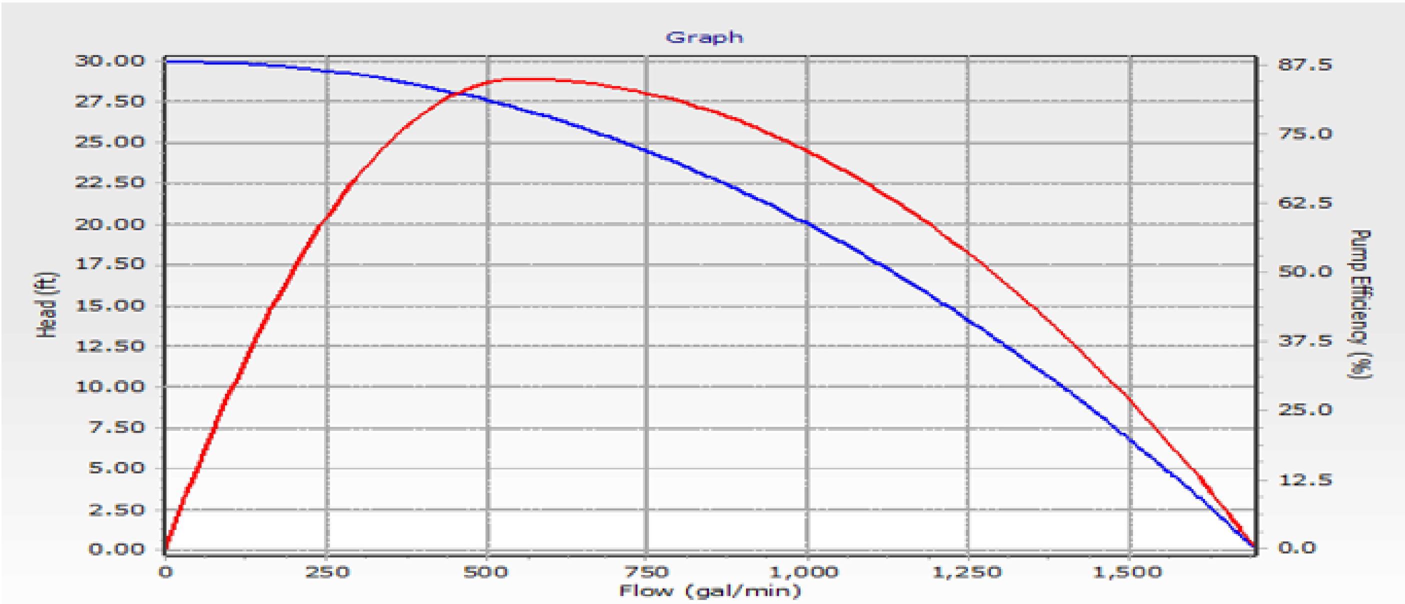
Real WDN – DMA-05 (GHADARA)




## Figure 5

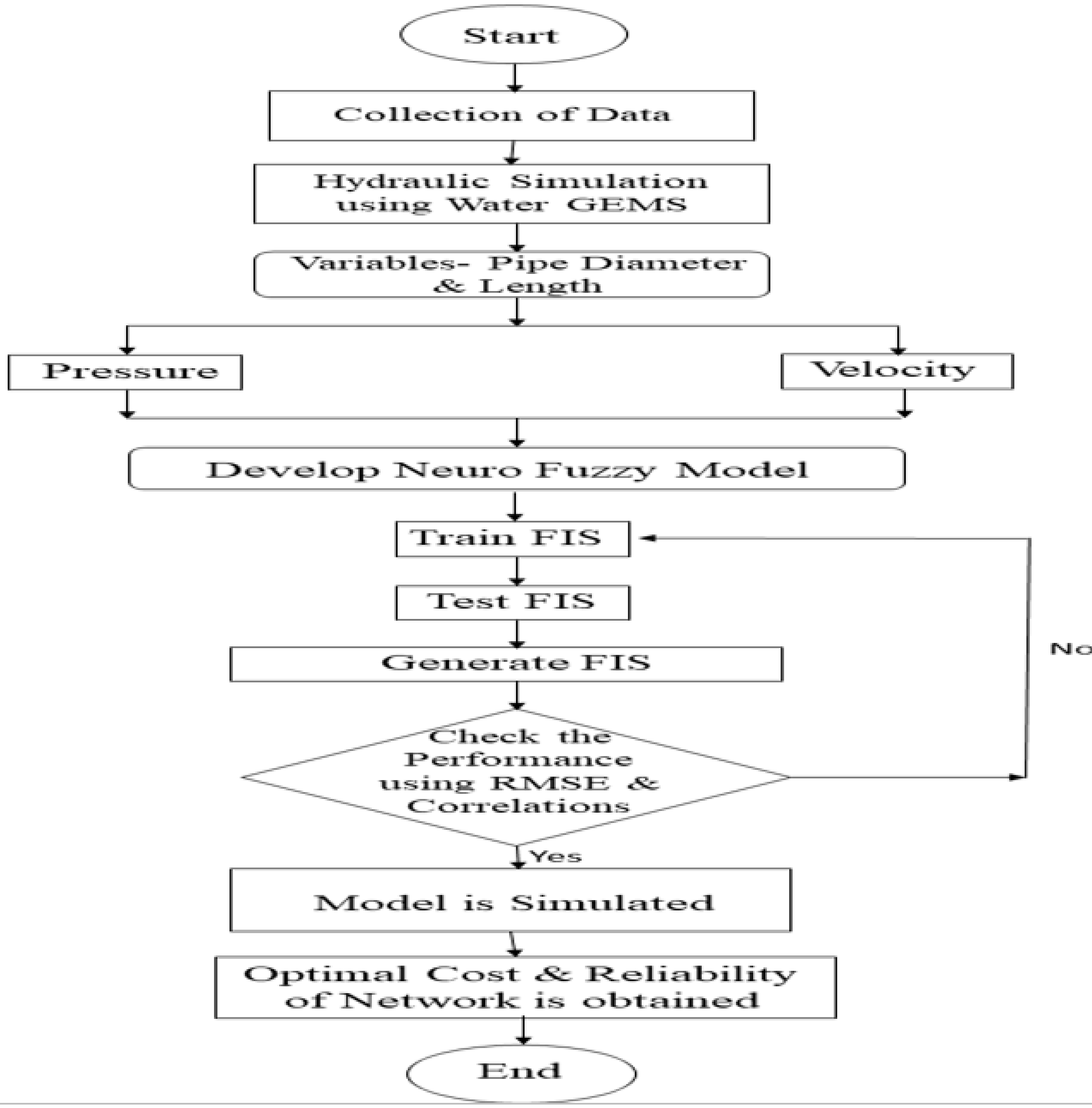
Proposed WDN – DMA-5 (GHADARA)

**Pump Definition Detailed Report: Pump Definition - 1**
**Licensed for Academic Use Only**



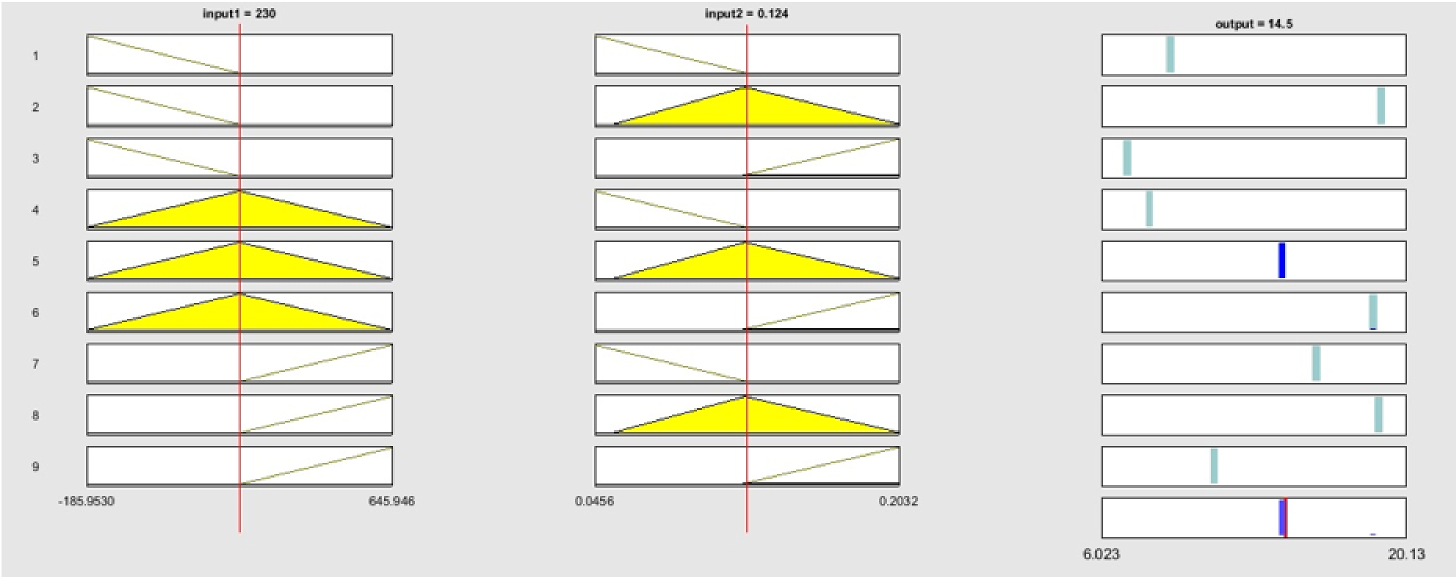

## Figure 6

Pump Definition



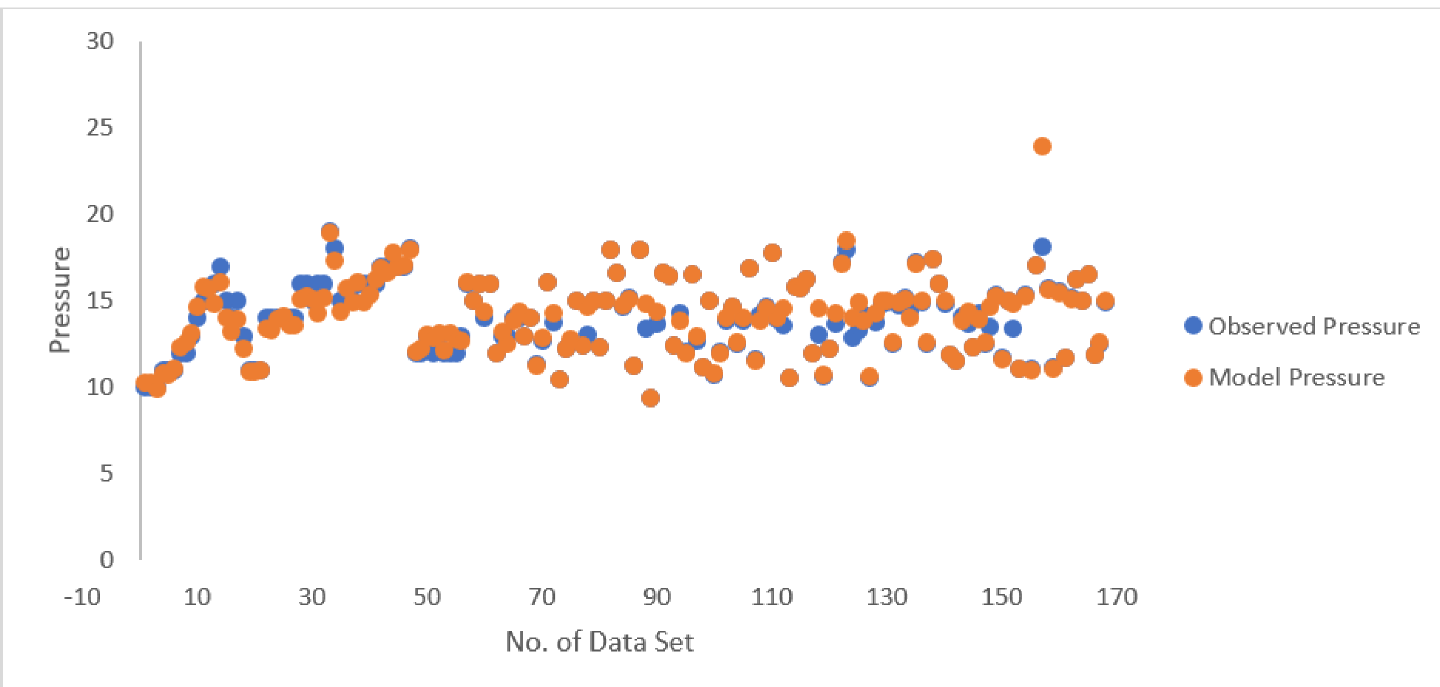

## Figure 7

Block Diagram of Neuro Fuzzy Model



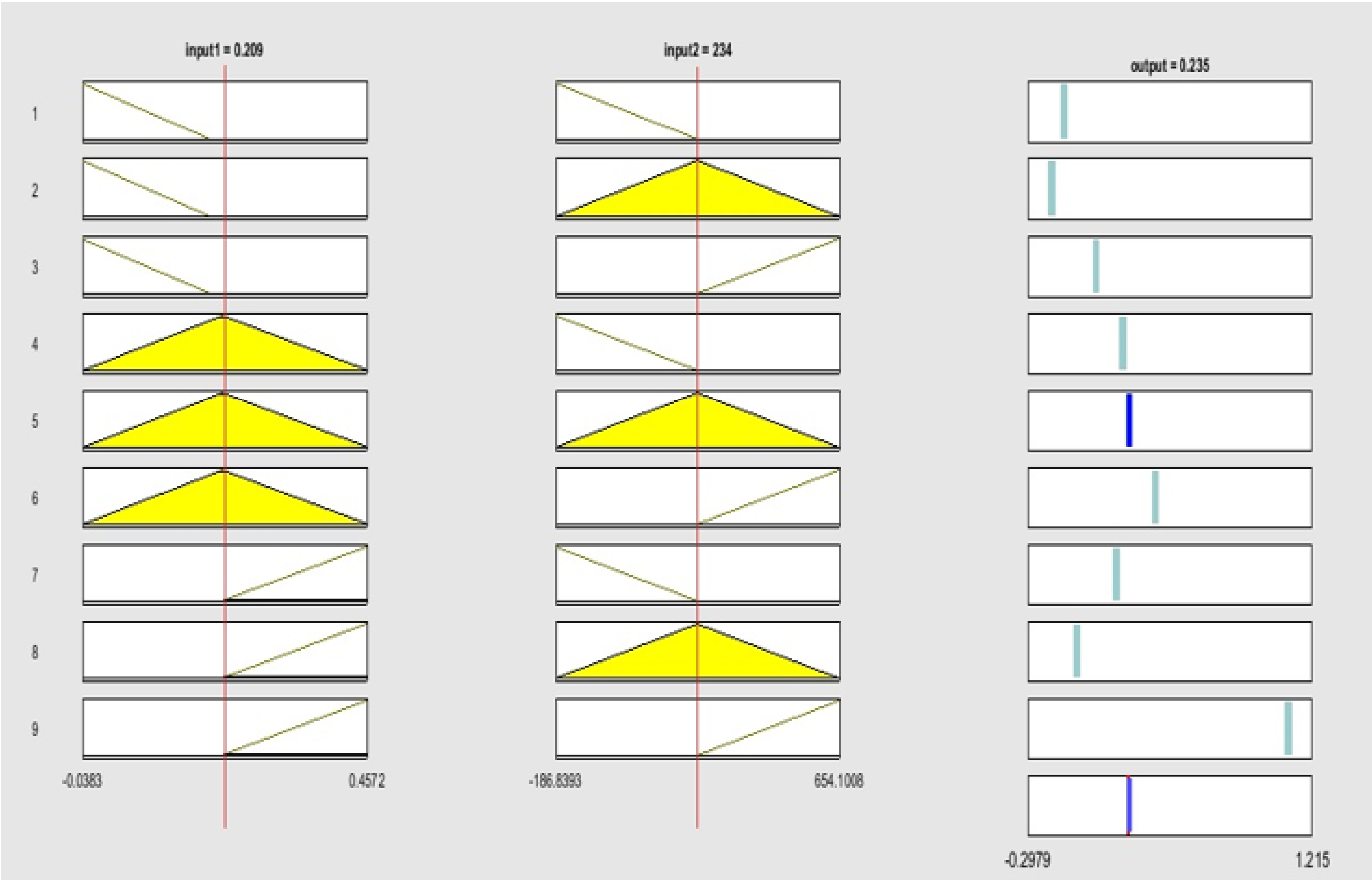

## Figure 8

Rule Viewer for Scenario 1




## Figure 9

Observed Vs Model Data @ Pressure for Scenario – 01




## Figure 10

Rule Viewer for Scenario 2

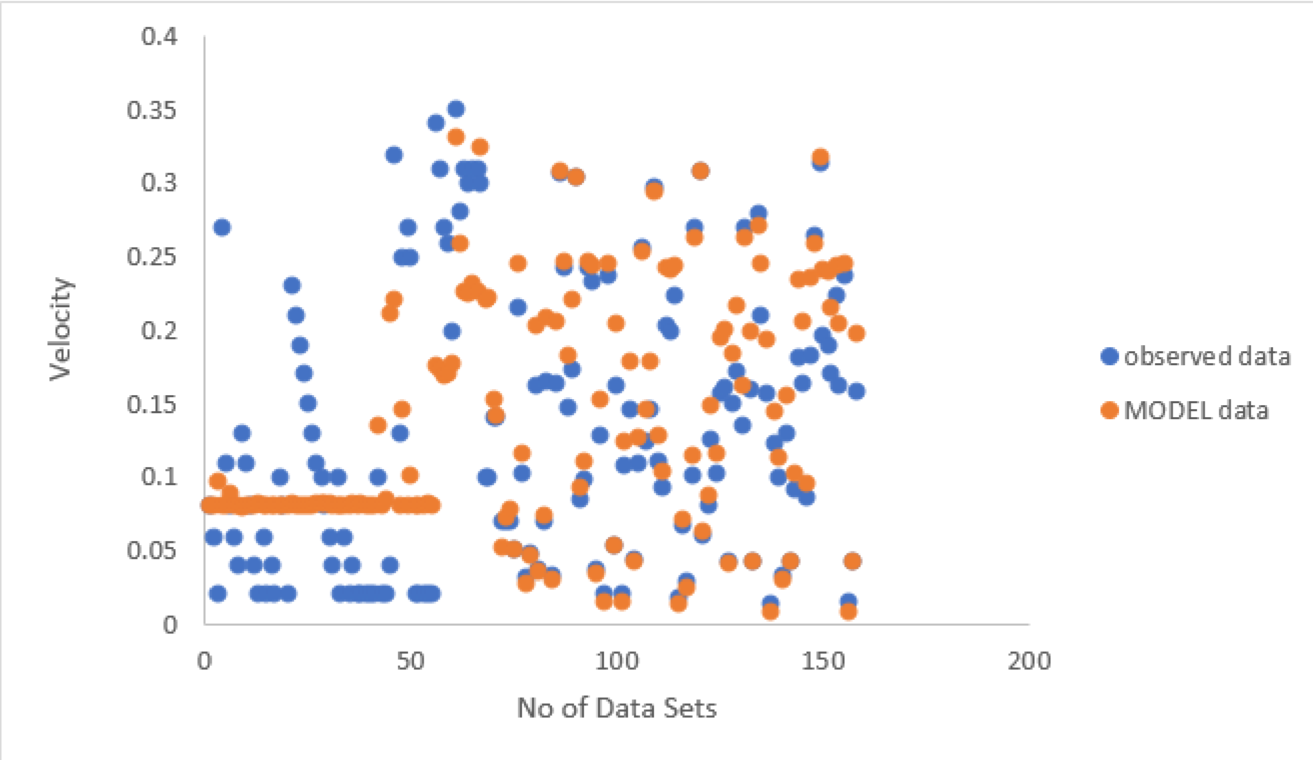



**Figure 11**

Observed Vs Model Data @ velocity for Scenario – 02

# Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AppendixA.docx