ANALYSIS ON POLLUTANT INTRUSION IN A WATER DISTRIBUTION SYSTEM USING ARTIFICIAL NEURAL NETWORKS

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Abstract - *Water distribution systems are spatially diverse which are vulnerable to a variety of threats of which one of the most serious one is the chemical contaminant injection within the distribution system. The present study aims at analysis of a typical water distribution system to obtain concentration at the sources affected by typical pollutants utilizing water quality at monitoring points as inputs to artificial neural network (ANN) model. Development of model using modern computer techniques can prove to be a helpful tool for quality analysis and prediction in water distribution system. This will not only save time, but will also prove to be efficient in application, through constant monitoring by a simulation model. The water distribution system opted for analysis was Manvila zone in Trivandrum district, Kerala. The methodology includes hydraulic analysis, water quality analysis and water age analysis of the system using EPANET. ANN model was developed for prediction of source quality. The result shows that model efficiency was high which was greater than 80 percent and performance evaluation was found to be satisfactory. ANN based quality prediction methodology has potential applicability for simple as well as complex networks for predicting source quality magnitude.*

Key Words: **EPANET, Simulation, Modelling, ANN.**

1.INTRODUCTION

In India, where the population is massive, providing water in required quantity and maintaining quality of water distribution system is a challenging job. The quality of drinking water provided to the people is of great concern. Although quality tests on water are performed when it leaves the treatment plant, its quality may deteriorate substantially during its transport to the consumers, as a consequence of processes occurring inside pipes such as corrosion, growth or decay of non-conservative constituents or by external intrusion of pollutants [1]. Identification of contaminant sources in a distribution system is not an easy task. At present, there are many cost-effective sensors for real-time monitoring of water quality. Artificial Neural Networks are good alternatives to traditional modelling techniques in the solution of large scale complex problems [2]. To better control a specific distribution system, a robust mathematical tool for predicting the performance must be developed based on past observations of certain key parameters. Modelling a distribution system is highly difficult due to the complexity and nonlinear behaviour that are difficult to describe by linear mathematical models [5]. As an alternative to physical models, artificial neural networks (ANN) are a valuable forecast tool in environmental sciences.

1.1 Objectives of the Study

The specific objectives of present study were summarized as follows:

1. Hydraulic analysis of the selected water distribution system using EPANET
2. Quality analysis of the typical water distribution system
3. Water age analysis of the distribution system
4. Artificial Neural Network based approach for quality prediction of the distribution network.

1.2 Study Area

The water distribution system opted for analysis is the distribution system of Manvila zone in Trivandrum City. In Monvila distribution system, there are three tanks, among them the distribution line from Pongumoodu tank which is independent was considered. The distribution system covers an area of about 4 sq.km and it feeds a population of around 57,460. For analysis the data was collected from Kerala Water Authority, Trivandrum which includes Auto CAD drawing of the distribution system, data on demand and elevation for the area under study.

2. METHODOLOGY

A water distribution system is a network of pipes, pumps, reservoirs, valves etc. The structure of the network is branched. Initially hydraulic analysis of the system was done using EPANET so as to prove that the system is stable. It was developed by the United States Environment Protection Agency (USEPA). For the analysis, AutoCAD drawing of distribution system was converted to EPANET drawing consisting of nodes and links. Thereafter the node properties were determined which include elevation and water demand. Link properties were then defined which includes pipe length and diameter.

2.1 Hydraulic Analysis of the System

The hydraulic simulation model computes junction heads and link flows. The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of flow equation for each junction and the head loss relationship across each link in the network. This process is known as "hydraulically balancing" the network which requires an iterative technique to solve the nonlinear equations involved. EPANET employs the "Gradient Algorithm" for this purpose.

2.2 Water Age Analysis

Water age refers to the time it takes for water to travel from sources to consumers. It depends on flow velocities and pipe lengths in the distribution system and is completely a hydraulic parameter, that does not dependent on reactions that occur within the pipe network. Lower water age indicates better water quality. In order to make the network more realistic for analysis, an extended period of simulation for 72 hrs was done. In addition to chemical transport, EPANET can also model the changes in the age of water throughout a distribution system.Water coming into the network from reservoirs or source nodes enters with age of zero. EPANET can also perform source tracing. It tracks over time what percent of water reaching any node in the network had its origin at a particular node. In the present study it is assumed that fluoride tracer is injected at a node and water age analysis was carried out.

2.3 Water quality analysis of the distribution system

EPANET's water quality simulator uses a Lagrangian time-based approach to track the fate of discrete parcels of water as they move along pipes and mix together at junctions between fixed-length time steps. New node concentrations are calculated which include the contributions from any external sources. Finally, a new segment will be created at the end of each link that receives inflow from a node if the new node quality differs by a user-specified tolerance from that of the link's last segment. The demand pattern was loaded and simulation was done for 72 hrs. Then the optimal monitoring point for intrusion was identified by water age analysis.

2.4 ANN based methodology for quality prediction of distribution network

The ANN based pollutant intrusion modelling was implemented using MATLAB. A feed forward network was created and trained using Levenberg Marquardt algorithm. It was used to predict the fluoride concentration using the concentration from observation point. The required data for training and testing was generated using EPANET for randomly generated magnitudes of contaminant at the source within a specified range. For water distribution network under study, following steps were done for the development of ANN model in order to predict source quality by monitoring water quality at an arbitrary node in the network:

(i) Specification of node and link characteristics, demand pattern for the network and pump station outflow pattern
(ii) Randomly generated magnitudes of pollutant at specified intrusion point
(iii) For a given magnitude of pollutant concentration at the source , the concentration of fluoride at monitoring point was determined using EPANET
(iv) An ANN model was created with concentration at monitoring points as the input and magnitudes of source concentration as the output
(v) Model was trained using back propagation algorithm.

3. RESULTS AND DISCUSSION

On running hydraulic analysis, it was found to be successful which proves that the system is hydraulically stable. The percent of tracer at different nodes were obtained. Water age analysis was done for 72 hrs and the time taken by parcel of water to reach each node was obtained. The optimal monitoring point was found to be node 1154 as there is significant variation in water quality.

3.1 Results of ANN Model

The node quality was selected as the input and source quality as the output. Back propagation algorithm was used for training of multilayer perceptron using gradient descent, applied to sum of squares error function. It involves an iterative procedure for minimization of error function, with adjustments to weights being in series of sequence steps. The size of training data and testing data was 41 and 12 respectively.

3.2 Properties of the Monitoring Node

Results of simulation include various parameters of monitoring node like pressure, demand, flow and fluoride tracer concentration as shown in Chart 1 to 4.

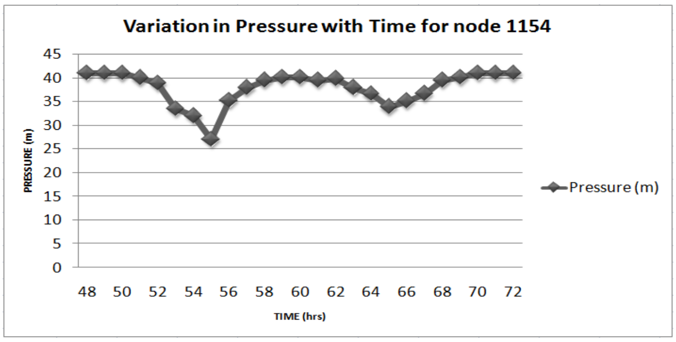


Chart - 1: Variation in Pressure with time for node 1154

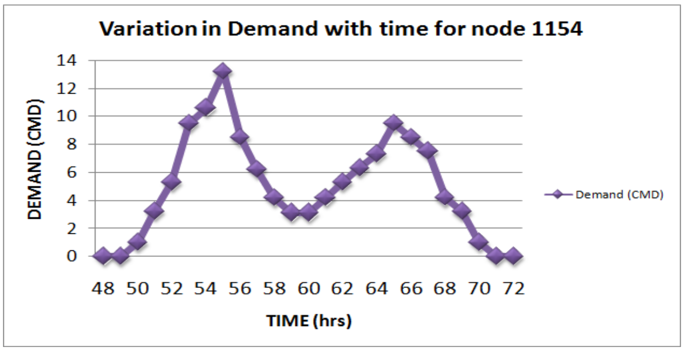


Chart- 2: Variation in Demand with time for node 1154

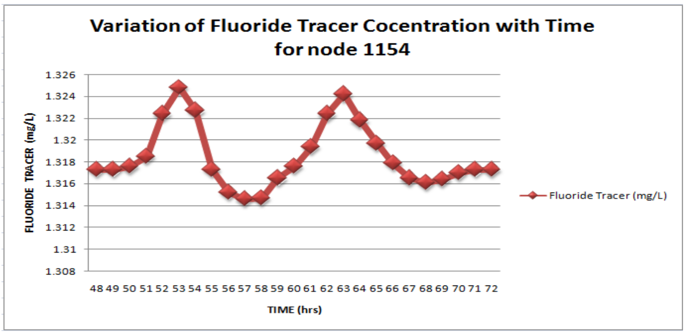


Chart- 3: Variation in Fluoride tracer concentration

3.3 Performance Evaluation of the model

The following statistical techniques were used for the performance evaluation of the network.

Percentage Error (E) was calculated from equation (1)

$$E = \frac{|Xa - Xc|}{Xa} \text{ x } 100 \text{ ---------------------------------------} \quad (1)$$

where, X_a = actual value; X_c = calculated value

Normalized Percentage Error can be found out by the equation (2);

$$NE = \frac{\sum_{i=1}^{n} |Xa - Xc|}{\sum_{i=1}^{n} Xa} \text{ x } 100 \text{ --------------------------------} \quad (2)$$

i=index for observation; n= total number of observation

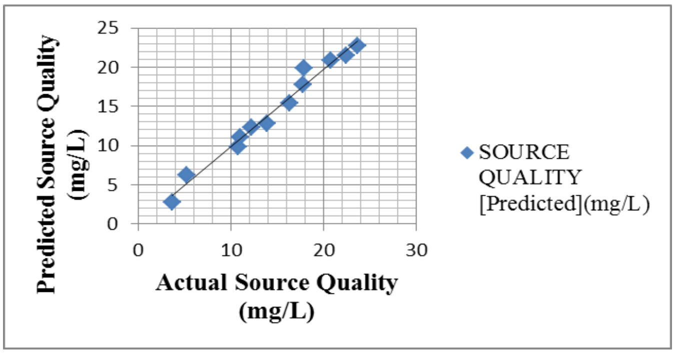
Model Efficiency was obtained using the equation (3);

$$ME = 1 - \frac{\sum_{i=1}^{n} (Xa - Xc)^2}{\sum_{i=1}^{n} (Xa - \bar{X})^2} \text{ x } 100 \text{ ------------------------------} \quad (3)$$

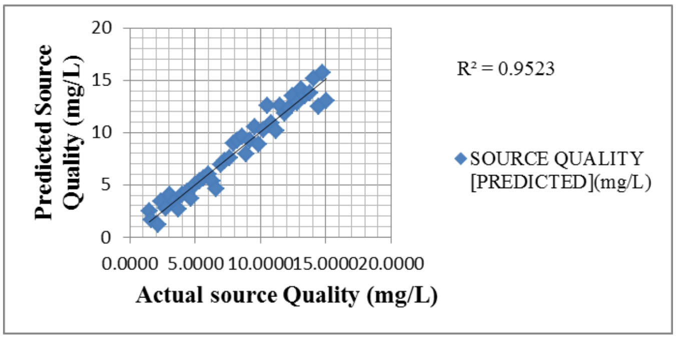
where $\bar{X}$ = mean of actual values

Table-1. Performance of ANN model

ANN Models	Normalized Error	Model Efficiency (%)
Training	0.0009	85.93
Testing	0.0464	85.98



Chart–4: Plot for Training Data



Chart–5: Plot for Testing Data

The plots show high coefficient of determination (R^2) values in both training and testing data sets. Thus the performance evaluation was satisfactory.

4. CONCLUSION

Present work discuss the methodology for development of pollutant intrusion model using ANN. Hydraulic and water quality analysis were accomplished by using simulation model EPANET. The results show close matching between actual and predicted values in both training and testing mode. However, normalised percentage error for training and testing is considerably low, which shows the level of accuracy delivered by the model. The model efficiency in all cases was high (greater than 80 percent). Also the performance evaluation was found to be satisfactory.

ANN based quality prediction methodology has potential applicability for simple as well as complex networks for predicting source quality magnitude. However the extensive evaluation of the methodology is required with more complex networks with different tracers for fully establishing the applicability of the methodology.

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