INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN: 2278 – 0211 (Online)

Identification And Prediction Of Pipe Line Hazards In Urban Water Distribution System By GIS And Neural Network Model

Shantanu Datta
National Institute Of Technology, Agartala, Tripura, India

Abstract:
Various physical, chemical and biological hazards associated with water distribution networks is a constant concern of the engineers and managers working in the water treatment and distribution sector. The uncertainties in the water distribution networks involve pressure drops, contaminations by harmful materials, leakages, corrosion etc. As the time and location of the hazard is hard to predict the spread of uncertainty remains undetected when and where it happens. To prevent such types of atrocities, experts are recommending automatic monitoring systems for water distribution network hazards. The present study is proposing a cognitive Multi Criteria Decision Making model (MCDM) to predict the related water parameters in real time and taking logical and scientific decisions about the intensity of the hazards and level of actions required to be undertaken. GIS framework is utilized to digitize the distribution network and to provide a spatial interactive display about the condition of the distribution network. The system utilizes the technical advancement of neural networks, mathematics of signal flow graph theory and decision making ability of Analytic Hierarchy Process to identify, analyse and predict the physical, chemical and biological hazards.

Key words: *Analytic hierarchy process (AHP), Artificial neural network (ANN), Geo graphic information system (GIS), Multi-criteria decision making model (MCDM), Pipeline hazards, Water distribution network, Water quality index(WQI).*

1.Introduction

Water supply systems are a structural part of public utilities. The water, as it leaves the treatment plant, is of desired quality. But the standard of this quality is to be maintained when the treated water is flowing through the network of the distribution system. The water is supplied in a way that is useful to the consumers but a considerable amount of filtered water is wasted because of various pipe line hazards. Physical hazard, chemical and biological hazards are the main threats to the water distribution system. Now a day's most water utilities worldwide suffer from the problem of water loss due to its large affects rather than on operational processes of the water system, but even on the financial, social and environmental aspects. So water losses can be classified to direct losses, which is real and physical losses evident in the water system due to the loss in the amount of treated water by reason of the leaks in pipes, as well as the damage that may affect the facilities of water system directly, and indirect losses, which is appearing as economic or commercial losses.

The present study is proposing a cognitive Multi Criteria Decision Making model to predict the related water parameters in real time and taking logical and scientific decisions about the intensity of the hazards and level of actions required to be undertaken. GIS framework is utilized to digitize the distribution network and to provide a spatial interactive display about the condition of the distribution network. The system utilizes the technical advancement of neural networks, mathematics of signal flow graph theory and decision making ability of Analytical Hierarchy Process to identify, analyse and predict the physical, chemical and biological hazards. The physical hazard is represented by pressure difference, chemical abnormalities are identified by AHP assisted water quality index and biological contaminations are monitored by colliform concentration. The software requires the data of necessary parameters in the initial and final point of the pipe network for predicting the same at each of the junctions of the distribution system. According to the results the software seems to display realistic results about its study area with which it was trained. The performance in real time situations may decide whether this tool can be utilized to prevent spreading of hazard in the water distribution system and save the hard earned money of the tax payers.

2.Previous Work

Previous work in water distribution system focused mostly on water leakage and leakage factor analysis. Actually the adoption of the ANN modelling technology began in the mid-1990s. Ho et.al (2009) developed an artificial neural network (ANN) model and a geographic information system (GIS) for assessing water leakage and to prioritize pipeline replacement. Where qualified pipeline break-event data were derived from the Taiwan Water Corporation . Of water distribution system the non-linear IVS algorithm is used for the development of ANN models to forecast water quality within two water distribution systems (May et al. 2008). Subsequently Aburawe et.al(2011) presented an initial perception of an innovative method for real-time leakage detection in water distribution networks depends on the use of SCADA system for providing a real-time pressure measurements at different points on the network. The failure rate and estimation of optimal replacement time for the individual pipes in an urban water distribution system was developed by Jafar et.al(2010) using Artificial Neural Networks (ANN). Mounce.et.al (2003) presents the analysis and data fusion for sensors measuring hydraulic parameters (flow and pressure) of the pipeline water flow in treated water distribution systems .An artificial neural network based system is used on time series data produced by sensors to construct an empirical model .

There are various methodologies that have been used for pipe leakage analysis, IRA-WDS (Vairavamoorthy et al.2006), district metering area (Li et al.2011), Grey relational analysis(Jing et al.2012), comprehensive review of leakage assessment method (Puust et al.2010) are some remarkable methods.

3. Description Of The Study Area

Agartala (23.50^{0}N 91.5^{0}E) is the capital of princely state Tripura (India) and is second largest city in North-east India after Guwahati both in municipal area(58.84Km^2) population(399688) & density (6,251/km$^{2)}$. The city comes under west Tripura district and receives its water supply from 4MGD water treatment plant in Bordowali, south Agartala. The entire Pipe network that's starts from Bordowali WTP, located at the Southern bank of river Howrah(Agartala) is considered for the present study .

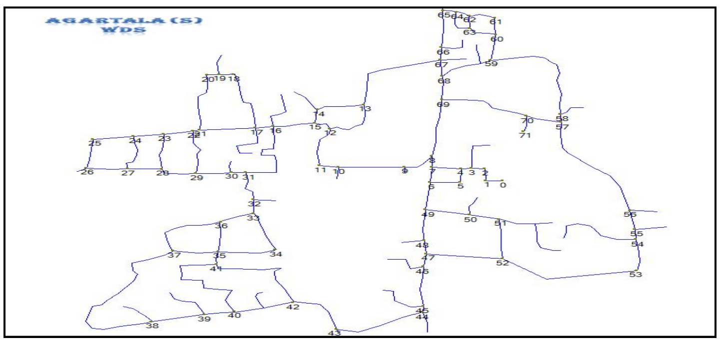


Figure 1: The Water Network Considered In The Study

4.Methodology

Undergoing the study in this research, the seven key stages as follows:

- Data collection.
- Digitization of distribution system by GIS.
- Development of the geo database.
- Conceptualization of hazard identification.
- Application of AHP for determination of importance for water quality parameters in WQI.
- Prediction of various hazards by neural network model.
- Preparation of the independent software model to be utilized as a decision support system.

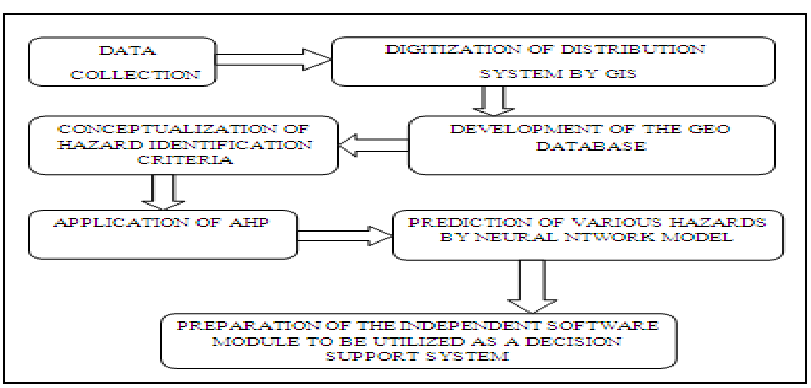
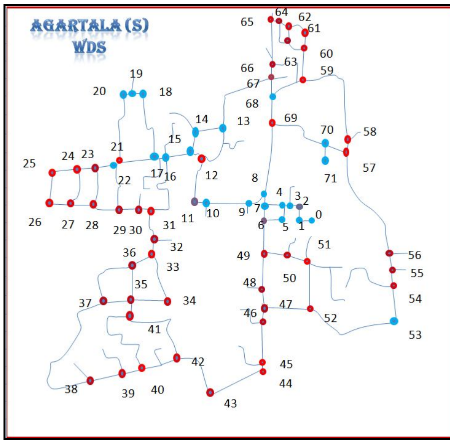


Figure 2: Fundamental Stages Of The Prediction Of Various Hazards

The initial stage of the work is to collect data from various junctions of the pipe network. This includes collection of pressure data at various junctions and water quality parameters at the same junctions. The second stage is to digitize the distribution system. In this research geographic information system has been utilized throughout the digitization process. With the help of Map window GIS we are digitizing the distribution network. Here 71 nodes have been taken. Depending on the parameters i.e. water quality and water pressure in pipes; we shall predict hazards in various nodes.

After the digitization of water distribution network a geo- database has been prepared by various parameters. This approach provides a formal model for storing and working with data.



node	PH	node	PH	node	PH	node	PH
1	6.87	23	6.89797	45	6.87067	67	6.87542
2	6.89815	24	6.89886	46	6.88345	68	6.88564
3	6.88648	25	6.87133	47	6.87425	69	6.89394
4	6.87188	26	6.88355	48	6.89724	70	6.87621
5	6.87645	27	6.89794	49	6.87093	71	6.88849
6	6.88621	28	6.89718	50	6.87687		
7	6.87346	29	6.88135	51	6.87475		
8	6.87234	30	6.89456	52	6.88335		
9	6.87849	31	6.89206	53	6.88921		
10	6.8924	32	6.89215	54	6.88545		
11	6.88225	33	6.88625	55	6.87052		
12	6.89949	34	6.89236	56	6.89935		
13	6.88551	35	6.88539	57	6.87903		
14	6.8779	36	6.89658	58	6.87521		
15	6.89046	37	6.87392	59	6.89396		
16	6.87476	38	6.88512	60	6.89006		
17	6.89087	39	6.89072	61	6.88021		
18	6.88981	40	6.88039	62	6.87495		
19	6.88161	41	6.88699	63	6.88338		
20	6.89164	42	6.87948	64	6.87879		
21	6.89547	43	6.87038	65	6.8931		
22	6.89722	44	6.89775	66	6.87857		

Figure 3: A Geo Database

The next stage is to conceptualize the various parameters. In this stage six parameters such as Pressure at various locations, Hardness of water, pH, Dissolved Oxygen, Turbidity, Colliform has been taken. But it is very difficult to identify the importance of hazards. Because colliform is a important hazard but variation of other parameters are also important. That is why we have to follow the next step i.e. analytic hierarchy process.

4.1.Application Of AHP

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Saaty (1980) and has been extensively studied and refined since then. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions [14]. It should be noted that the weightage of various parameters calculated by AHP will further use to getting Water quality index (WQI) at various junctions of pipe network.

4.2.Water Quality Index

Water Quality Index (WQI) is a very useful and efficient method for assessing the suitability of water quality. It is also a very useful tool for communicating the information on overall quality of water to the concerned citizens and policy makers.WQI is a dimensionless number that combines multiple water-quality factors into a single number by normalizing values to subjective rating curves. Factors to be included in WQI model could vary depending upon the designated water uses and local preferences [1].
The mathematics of the AHP and the calculation techniques are briefly explained:

	C1	C2	C3	C4	C5	A	W_n
C1	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	S_1	S_1/S
C2	W_{21}	W_{22}	W_{23}	W_{24}	W_{25}	S_2	S_2/S
C3	W_{31}	W_{32}	W_{33}	W_{34}	W_{35}	S_3	S_3/S
C4	W_{41}	W_{42}	W_{43}	W_{44}	W_{45}	S_4	S_4/S
C5	W_{51}	W_{52}	W_{53}	W_{54}	W_{55}	S_5	S_5/S
						S	

Table 1: Sample Metrics

4.3.MIC (Most Important Character)

Highest weitage achieved by a criteria from the AHP process after comparison with the other criteria. Where,$S= (S_1+S_2+S_3+S_4+S_5)$ & Hardness, pH, Turbidity, Dissolved oxygen and Colliform are represented by C_1 ,C_2,C_3,C_4,C_5.

4.4.Prediction Of Hazards By Neural Network Model

The ANN approach constitutes an alternative computational approach inspired by the biological nervous systems process. The ANN can recognize patterns and learn from their interactions with the environment. The multilayer feed forward network is widely used. ANN are adaptive and can handle complex systems. The architecture of ANN includes a number of nodes (neurons) or units organized in input and output layers as well as a number of hidden layers. The ANN are flexible and ``learn" through an iterative process of adjusting their weights and biases. The most common learning is supervised learning, which provides a response value for every set of input values and requires a known (input) target value that the response is trying to ``guess". The difference between the response and the actual target gives the error value. The network weights are adjusted iteratively in accordance with the error value by a back-propagation technique (BPNN) in order to minimize the error [11].

4.5.Calculation Of "G"

From graph theory we are calculating "G". If N_1 is parameter at first node & N_2 is parameter at second node. Then G1 = (N_2/ N_1). Again overall G is average of G1 to $G_{n,}$ where "n" is the number of nodes or junctions.

4.6.Selection Of Topology

Selection of topology includes determination of number of hidden layer and nodes by trial and error or search algorithms like genetic algorithm.

Initially the input data is analysed. This analysis of data includes the data which are to be trained and which are to be validated & tested. In this study input is the parameters at various nodes and output is "G". After the analysis, these data will go for further process i.e. pre-processing & design.

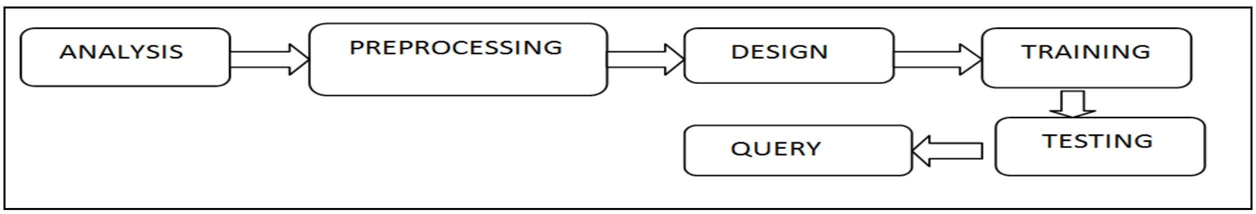


Figure 4: Flow Chart Of ANN Operation

4.7.Training Phase

In this phase updating of weightage takes place. This is for minimizing the difference between estimated results and actual output. The weightages are updated in different methods known as training methods like Quick Propagation, Conjugate Gradient Descent etc.

4.8.Testing Phase

The model output data is compared with the actual data not included in the training so that level of learning of the model can be estimated. This phase shows the level of accuracy acquired by the training of the model.

At the final step we are calculating the factor or ratio of predicted value and target value of 'G'. This factor will help to find the predicted values in future. The predicted value of node 2 i.e. P_2 can be calculated in the following ways:

P_2 ={(P_{1*} G_{p*}S)/100} Where G_p= Predicted 'G' & S={(G_1/G_t)*100} where G_t= G(Target).

So an independent software module has been created where prediction of pipeline hazards can be shown:

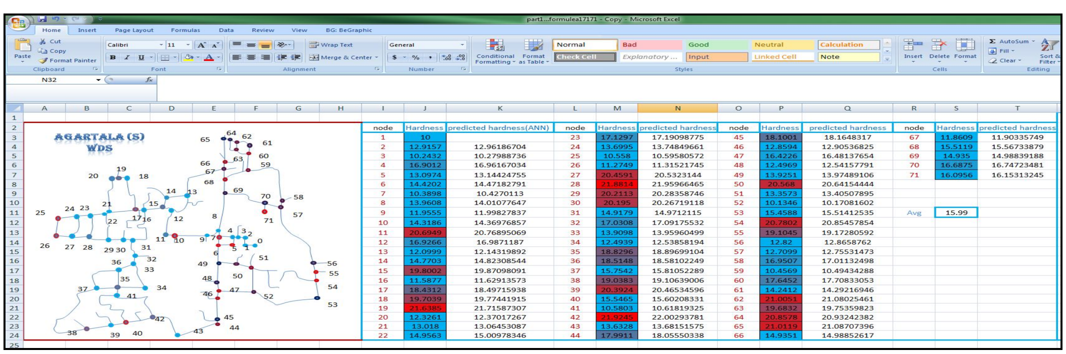


Figure 5: Figure Showing An Independent Software Model

5.Results And Discussion

5.1.Determination Of Importance For Water Quality Parameters By AHP

Importance of various water quality parameters has been determined by AHP process

	C1	C2	C3	C4	C5	A_n	$B_n(W)$
C1	1	5	2	3	0.5	2.30	0.27
C2	0.2	1	5	3	0.2	1.88	0.22
C3	0.5	0.2	1	2	0.5	0.84	0.10
C4	0.3	0.33	0.5	1	0.2	0.47	0.06
C5	2	5	2	5	1	3.00	0.35

Table 2: Calculated Weightage

With the help of Analytic hierarchy process we are comparing the importance of one parameter with another one. The final value comes after calculation is our required weightage. Although Satty (1980) scale is used, but the weitage is taken after discussion with experienced person related to the water quality field. After getting these weightages , the values is used for calculating water quality index.

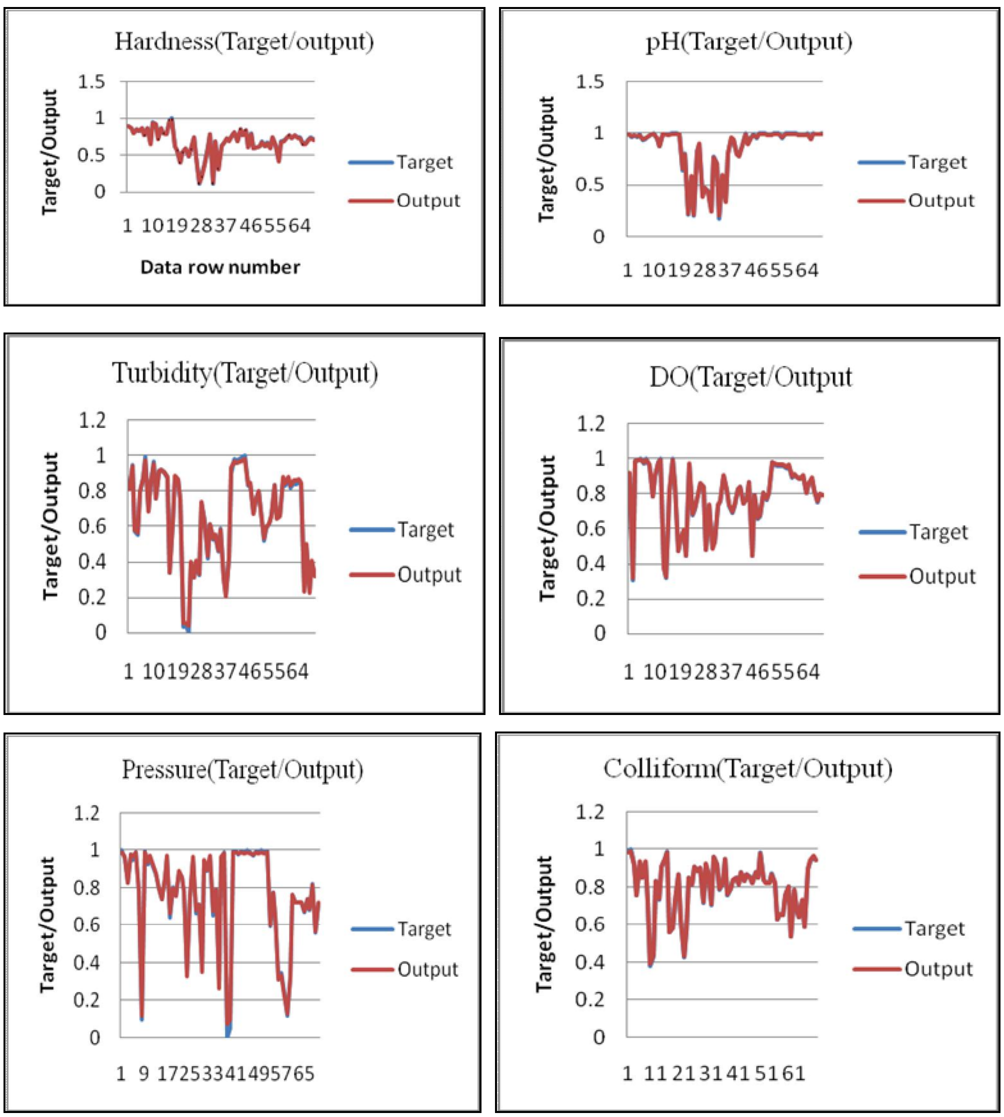
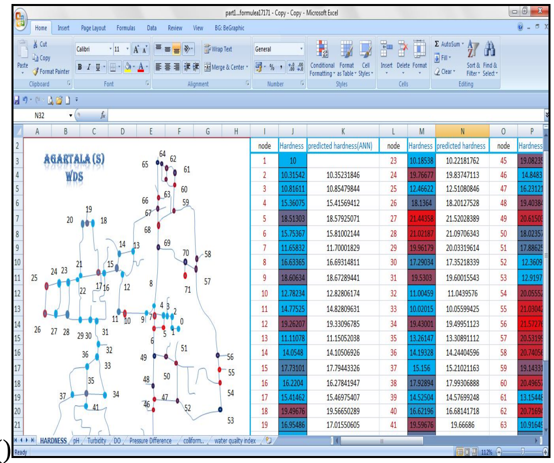
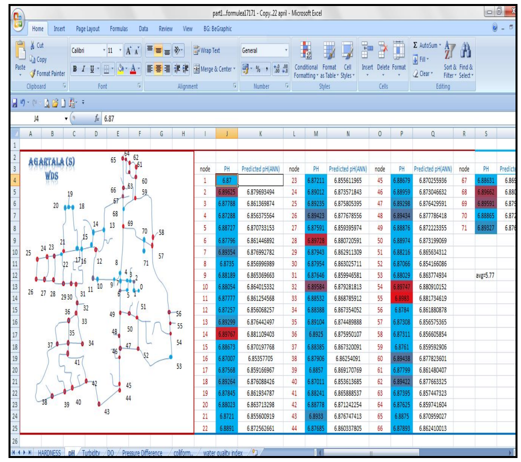


Figure 6: Comparison Between Target And Predicted Values For The ANN Model

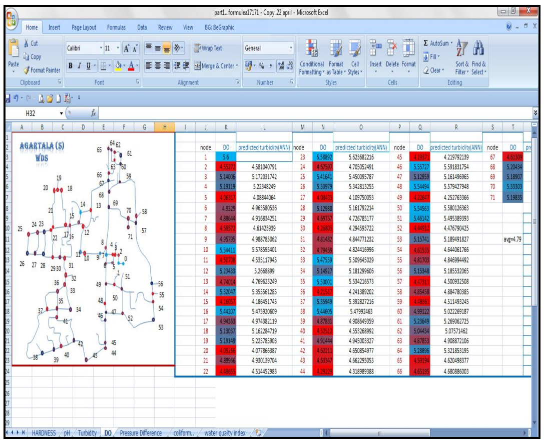
After calculation of all parameters by Neural network, the predicted values are use for the preparation of new model, where target values, predicted values are shown. The changes of these values are shown by changing colours.



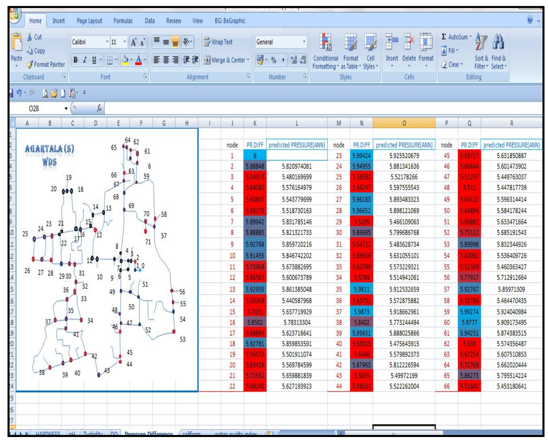
()
A) Final Model (Ph)



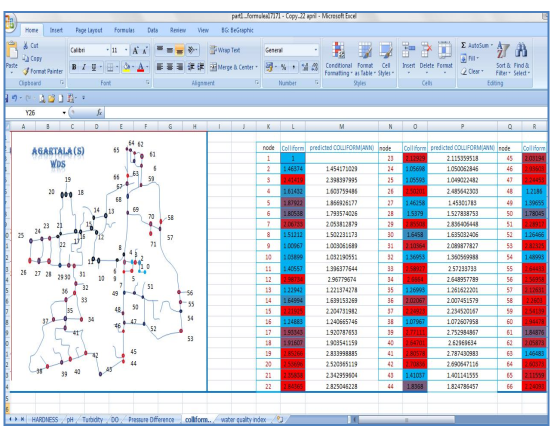
B) Final Model



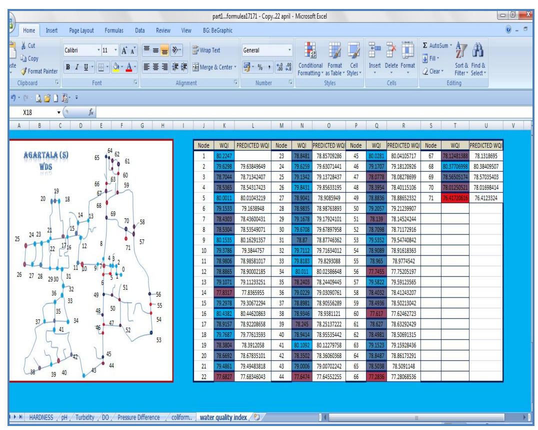
C) Final model (DO)



D) Final model (Pressure)



E) Final Model (Colliform)



F) Final Model (WQI)

Figure 7: Final Models For Various Parameters

6.Conclusion

The present investigation tries to develop an interactive software to monitor and locate the time and location of hazards in the water distribution systems. Three kind of hazards were monitored: Mechanical, Chemical and Biological. The advanced tools like neural networks and Geographical Information Systems are utilized to monitor the hazards in the said water distribution. The study utilized the GIS frameworks to digitize the entire water distribution system. The modelling framework was prepared with the help of neural networks.The graph theory was utilized to model the network dynamics. The AHP is used to take cognitive decisions about the chemical hazards. On entering the value of the parameters in the software; it can successfully predict the value of the same parameters in the entire network.

With the help of these values anyone can easily identify the location of the hazards. The time at which the data is entered can also spot the occurrence of uncertainty in any moment of the day. The training data of the distribution system was collected from the historical and sample collection from the junctions. The dataset was not enough for neural network training. That is why it was expanded with the help of stochastic interpolations.

In future, consideration of more parameters will give more accurate result. This MCDM model will be useful for automatic monitoring of water treatment plant. Finally we can say that the results of the study will help water companies to professionalize the active control of hazards in their pipelines.

7.Acknowledgement

The authors gratefully acknowledge the considerable support of DWS Sub-Division-II, Milon- sangha, Agartala.

8.References

1) Ahmad I. Khwakaram, Salih N. Majid, Nzar Y. Hama(2012) **“**Determination of water quality index (wqi) for qalyasan stream in sulaimani city/ kurdistan region of Iraq” International Journal of Plant, Animal and Environmental Sciences,2(4) , 148-157.
2) Cheng-I Ho · Min-Der Lin · Shang-Lien Lo(2009) “Use of a GIS-based hybrid artificial neural network to prioritize the order of pipe replacement in a water distribution network”, pp.177–189.
3) C. Vipulanandan, W. Qiao and H. Hovsepian (2012)“ water pipeline failures in the active zone”.
4) Daniel P. Ames, Christopher Michaelis, and Ted Dunsford (2007) "Introducing the MapWindow GIS project." OS Geo Journal ,v.2, pp.1-5.
5) Holger R. Maier, Ashu Jain, Graeme C. Dandy, K.P. Sudheer,(2010) “Methods used for the development of neural networks for the prediction of water resource variables in river systems: Current status and future directions”,pp.891- 909.
6) I. Bentes, L. Afonso, H. Varum, J. Pinto, J. Varajão, A. Duarte, J. Agarwal, (2011) “A new tool to assess water pipe networks vulnerability and robustness”, pp.1637–1644.
7) K. Vairavamoorthy , Jimin Yan , Harshal M. Galgale, Sunil D. Gorantiwar(2007)“IRA- WDS: A GIS-based risk analysis tool for water distribution systems” Environmental Modelling & Software ,pp. 951-965.
8) Kang Jing , Zou Zhi-Hong, (2012) “Time Prediction Model for Pipeline Leakage Based on Grey Relational Analysis”pp.2019 – 2024.
9) Lai-bin Zhang, Xian-Yong Qin, Zhao-hui Wang, Wei Liang, November 2009 “Designing a reliable leak detection system for West Products Pipeline” Journal of Loss Prevention in the Process Industries, 22(6), 981-989.
10) LeChevallier, Mark W., William Schulz, and Ramon G. Lee(1991) "Bacterial nutrients in drinking water." Applied and Environmental Microbiology ,vol. 3,pp. 857-862.
11) R. Puust , Z. Kapelan , D. A. Savic , T. Koppel, , February 2010 “ A review of methods for leakage management in pipenetworks” Urban Water Journal , 7, pp.25–45.
12) Raed Jafar, Isam Shahrour, Ilan Juran, (2010)“Application of Artificial Neural Networks (ANN) to model the failure of urban water mains”, Mathematical and Computer Modelling , 51, 1170-1180.
13) Robert J. May, Graeme C. Dandy, Holger R. Maier, John B. Nixon(2008) “Application of partial mutual information variable selection to ANN forecasting of water quality in water distribution systems” Environmental Modelling & Software, 23 , 1289–1299.
14) Salah Muamer Aburawe, Ahmed Rodzi Mahmud(2011)“water loss control and real-time leakage detection using GIS Technology**”**.
15) Saaty, Thomas L. (1987)"Risk—Its priority and probability: The analytic hierarchy process." Risk Analysis, 7, pp.159-172.
16) Stephen R. Mounce, Asar Khan, Alastair S. Wood, Andrew J. Day, Peter D. Widdop, John Machell(2003)“Sensor-fusion of hydraulic data for burst detection and location in a treated water distribution system”,pp.217–229.
17) Symeon Christodoulou, Alexandra Deligianni, Pooyan Aslani, Agathoklis Agathokleous (2009)“Risk-based asset management of water piping networks using neurofuzzy systems” Computers, Environment and Urban Systems,pp.138–149.
18) Thomas Kistemann, Susanne Herbst, Friederike Dangendorf, Martin Exner, (2001) “GIS based analysis of drinking-water supply structures: a module for microbial risk assessment “,International Journal of Hygiene and Environmental Health, pp.301-310.
19) Weifeng Li, Wencui Ling, Suoxiang Liu, Jing Zhao, Ruiping Liu, Qiuwen Chen, Zhimin Qiang, Jiuhui Qu, (November 2011)“Development of systems for detection early warning, and control of pipeline leakage in drinking water distribution: A case study” Journal of Environmental Sciences, 23, 1816-1822.
20) West, Douglas Brent(2001) “ Introduction to graph theory”. Englewood Cliffs: Prentice hall .
21) Zell Andreas, Niels Mache, Ralf Huebner, Günter Mamier, Michael Vogt, Michael Schmalzl, and Kai-Uwe Herrmann. Snns(1994) “Stuttgart neural network simulator”. Springer US.