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Design and Analysis of a Smart Water Distribution Network System in Jaipur, Rajasthan

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***Abstract*:- The primary goal of this research paper is to study and design requirements for a water distribution system using EPANET to allow a fair supply of water to customers at adequate pressure head to the required place in Jaipur, Rajasthan's Central Government colony. The design limitations include a water supply of at least 135 lpcd with adequate pressure head and budget constraint. To improvise the design service life span and distribution network reliability considerations, consideration has been given to high-grade cast iron pipe. To satisfy the demand requirement, the distribution network must be intended to decrease hydraulic losses. Different distribution network models have been simulated and analysed to meet the minimum 12 m pressure head and velocity in the range of 06 to 23 m / s and in some cases to meet the peak water demand hour for water supply. In addition, entropy tests of these tubes were carried out to determine the optimum positioning of sensors in the network.**

Keywords: Water distribution system, EPANET, network, constraints

1. INTRODUCTION

1.1 Importance of Water

Providing adequate amount of clean water has been one of the most important issues in human history. Most of ancient civilizations flourished near water sources. With increasing population needs, the challenges to demand the incremental water supply demand substantially increased. Ancient Romans used to deliver water over long distance using aquaducts (*Pitroda, 1993*).

New generation water supply system is essentially consisting of infrastructures such as collection centre, storage tanks and distribution network. With reducing & unpredictable pattern of rainfall and lack of perennial sources of water in India, there is an emerging need to design a distribution network with minimal hydraulic losses. Multiple studies were conducted in this domain; however, in most of the cases it has been found that they are site-specific in nature. Hence, it is need to conduct studies at the design phase of the project to eliminate any bottlenecks & validate the site-specific studies conducted by other eminent researchers, thereby effective meet the water supply demand.

1.2 Water Distribution Network

The main objective of WDN is to ensure that distribution network meets the flow rate and pressure requirement of water supply at the consumer need.

Good distribution system requirements

1) Water quality in the distribution tubes should not deteriorate.
2) It should be able to supply water with adequate pressure head at all planned locations.
3) It should be able to supply the required quantity of water during firefighting.
4) The design should be such that during the repair of any portion of the scheme no customer would be without water supply.
5) It is preferable to lay all distribution pipes one meter away or above the sewer lines.
6) It should be watertight enough to maintain losses to a minimum due to leakage.

1.2.1 EPANET

U.S Environmental Protection Agency (EPA) has developed an open source software EPANET to designing and analyze the water supply model across the globe. The main purpose of EPANET is as mentioned below (*EPANET, 2019*):

1. Determining diameters of pipes to be used.
2. Determining the improvements and extensions the network needs.
3. Determining the location for installation of tanks, valves and pumps.
4. Studying chlorine's behaviour and the necessity to establish second chlorination points.
5. Altering source utilization within multiple source systems
6. Use the formulas of Hazen-Williams, Darcy Weisbach, or Chezy-Manning to compute friction head loss.
7. Modelling the age of water throughout a network

1.2.1.1 *Steps in using EPANET*

In order to accurately mode the water supply distribution network in EPANET, hydraulic engineer across the globe uses following steps as mentioned below (*EPANET, 2019*);

1) Drawing a distribution system network representation or importing a fundamental network description placed in a text file.
2) Editing the characteristics of the system objects.
3) Description of the operation of the scheme.
4) Select a number of alternatives for assessment.
5) Select a number of alternatives for assessment. / water quality.
6) Looking at the analytical outcome.

1.2.2 Smart City

A smart city is an urban development project involving the integration of various ICT solutions in a safe manner to manage the assets of a city such as local information systems, schools, libraries, transport systems, hospitals, power plants, water supply networks, waste management, law enforcement, and other community facilities. The objective of building a smart city is to improve the quality of life through the use of technology to improve service efficiency and meet the needs of residents (*Guestrin et. al., 2005*).

The Smart Cities Mission is one of the latest central government initiatives of the BJP and aims to set examples that can be replicated within and outside the Smart City, catalyzing the development of similar Smart Cities in different regions and parts of the country (*Sathyanathan, 2016*).

The core infrastructure elements in a smart city would include:

- Adequate water supply,
- Secure energy supply,
- Sanitation, including solid waste management,
- Efficient urban mobility and government transport,
- Affordable housing, particularly for the poor,
- Robust IT connectivity and digitalization,
- Good governance, in particular e-governance and citizen involvement,
- Sustainable environment,
- Safety and security of citizens, particularly women, children and the elderly, and
- Health and education.
- Area-based urban development (Greenfield development) strategic elements plus a pan-city initiative in which Smart in the Smart.

1.2.3 Water Distribution Network Problems

It well conceived fact that risk of failure of existing WDN increases with over-aging of the components which invariably influences the magnitude of hydraulic losses. In reality, hundreds of kilometers of globe-wide tubes are upgraded or substituted every year in an effort to decrease water loss owing to pipe bursts. The proportion of drinking water placed in a WDN that does not find its way to paid clients or unbilled approved users can be described as water losses. Losses of water are widely categorized as: obvious loss of water and actual loss of water. The former category relates to non-physical losses in utilities that are consumed but not correctly measured, accounted for or paid for. Whereas the latter category relates to the distribution system's physical water losses, including pipe breaks and leaks (*Christodoulou, 2015*). Supervisory control and data acquisition systems (SCADA) and the use of sensors strategically situated across the network are now mainly used to monitor real-time. Such sensory placement's primary objective is to maximize their sensing efficiency and also to limit their deployment and operating costs.

1.2.4 Water Sensors

A water sensor is a transducer system which is essentially contact based sensor which measures the measurable such as presence of water in pipe and discharge, velocity & entropy using Active and Passive Water Sensor respectively.

1.2.5 Types of Water Detection Sensors

1.2.5.1 Detectors of spot leakage

Spot leak detectors are often used in fields such as drip pans, floor drains, or where water tends to converge in confined fields. Two samples stretch towards the ground, generally with a support bracket adjustable to suit distinct concentrations of water detection. While spot detectors are economic for particular apps, they are less appropriate for tracking wide open spaces.

1.2.5.2 Hydroscopic Tape-Based Sensor

Hydroscopic tape-based (HTB) sensors often attach water-sensitive tape to constructions such as water containers and tubes that are susceptible. An alarm is activated when subjected to water or humidity. Providing highly sensitive and considerable coverage, these detectors require optimal environments as elements like condensation can trigger false alarms.

1.2.5.3 Rope-Style Sensor

Leak detection cables (rope-style sensors) are designed to cover very large open areas. These wires can also be directly attached to water supply and return lines, making them suitable for multi-leak point coverage of big rooms. Conceptually, all leak detection cables are based on two sensing wires running concentrically around the cable. Conductive fluid acts as a switch between both wires connecting the circuit between them.

These detection wires may have variable amounts of flexibility in bending, reactive reliability, and susceptibility to false alarms depending on material and quality, as dust and dirt may build up over time and act as an insulator. Individual wires are often put where they feed into a multi-zone control system, allowing users to identify the problem zone. Some devices allow reading over the cable map board along the pipeline, which enables us to identify the region of the leakage. Therefore, water sensors are mainly used to measure the extent of water leakage, water theft and unaccounted for water use.

1.2.6 Overview of the Site under Investigation

The site considered in this research study is situated alongside NH-8 in Chop close Jaipur (Rajasthan) about 40 kilometers from Jaipur. The weather of the site is warm and dry (*Smart Cities, 2019*).

The site consists of 2 types of quarters, namely Type-II and III quarters. There are about 50 and 20 rooms in Type-II and III quarters respectively. Hence, the former's water distribution network is relatively larger and more complex. Figure 1 demonstrates the site map and the network layout of the water allocation.

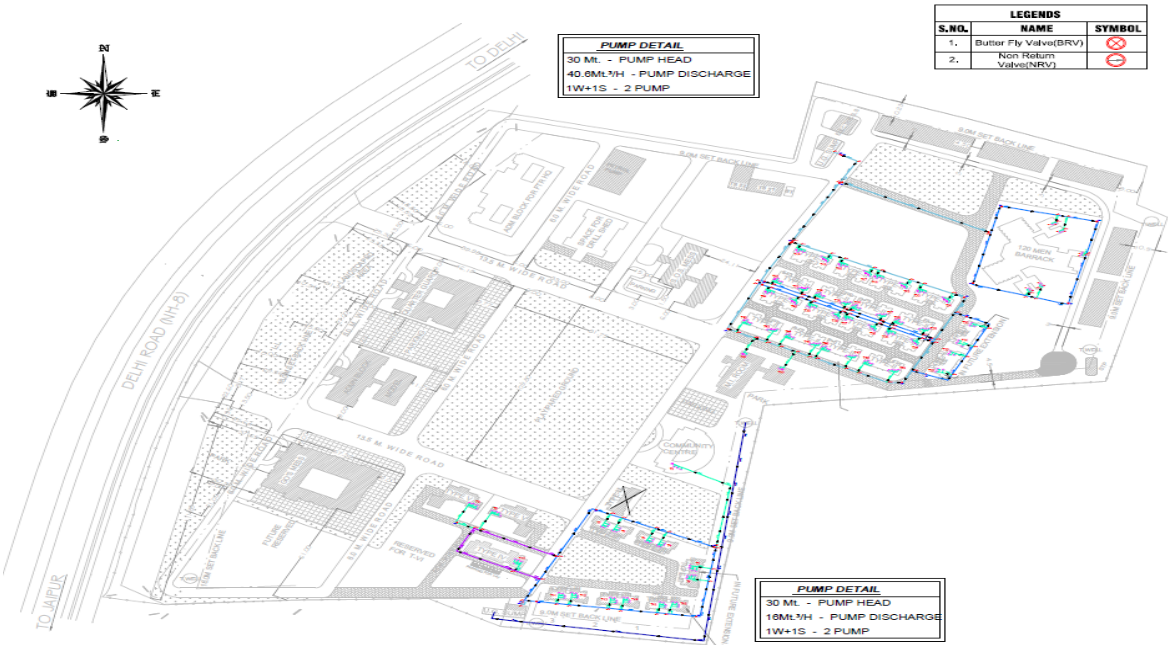

Fig. 1. Study Area

2. METHODOLOGY

The methodology adopted for the project is as shown below;

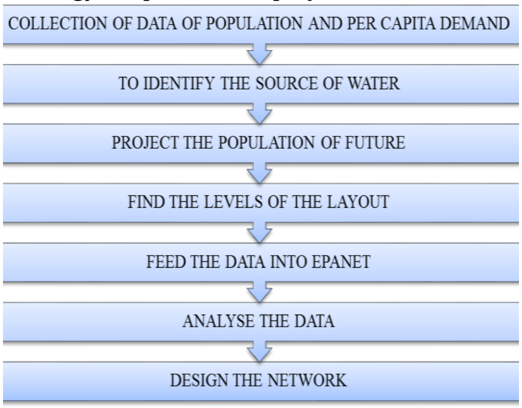

Fig. 2. Methodology for Designing WDN

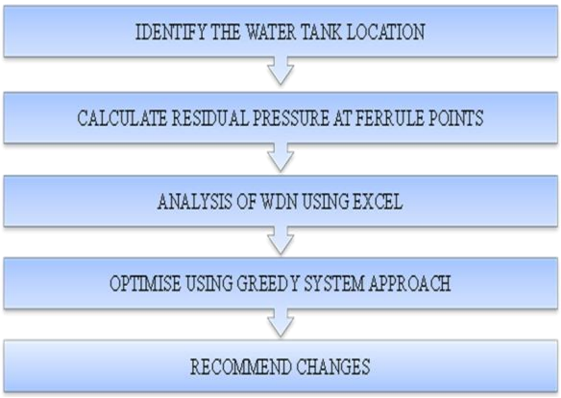

Fig. 3. The methodology adopted for conversion of WDN into Smart WDN

Realistic Design Constraints

In this project the following realistic design constraints are to be considered and work accordingly to overcome these constraints.

- **Economic Constraints:** The design of the WDN should be done in such a way that the estimation of the system should satisfy the budget.
- **Environmental Constraints:** The particular site considered in this project is located near Jaipur, Rajasthan. Hence, system should be efficient and no water loss should take place. We have to keep in mind that sensors should be heat resistant due to very hot climate.
- **Sustainability Constraints:** The design of the system should be done in such a way that it has minimal effect on the environment and reduces water losses.
- **Health and Safety Constraints:**
  Pure and hygienic water is supplied to the entire colony and thereby improving the health status of the colony.

3. DESIGN ANALYSIS

3.1 System Information for the Network

In order to carry out the analysis and simulation of WDN, the information required are water demand of each building, nodal elevation and digitalized plan of the colony.

3.1.1 Obtaining Water Demand

The building's water requirement was reached in accordance with IS 1172:1993 (Pitroda, 1993). Water usage per construction in terms of liters per head per day (l / h / d) is as follows:

- Houses- 135 l/h/d
- Office- 45 l/h/d

The product of population of each block with the per capita demand gives the water demand for that respective building.

Water Demand= Population × Per Capita Demand (1)

The water demand calculated for each nodes of the tanks of each building in terms of cubic meters per hour (m^3/hour) & elevation data for all the nodes in the layout is shown in Annexure-I & II and same is not shown for sake of brevity

3.2 HYDRAULIC MODELLING AND SIMULATION

In QGIS 2.8.7, the facility shape files, pipeline sketches and system boundaries are opened for the entire campus. The*.shp file is transformed to the picture bitmap (.bmp) file used in EPANET Software as a background. This allows us to assign prefixes to the junctions and pipes and obtain a working model of the system in EPANET. The intersections are established with their corresponding base requirements in front of each construction. These junctions are combined with variable length tubes. The length of the pipe lines between the nodes was determined and integrated in EPANET using Google Earth. The pumps were mounted in the network scheme with adequate pressure head to fulfill the necessary water requirement. The next step is to assign water requirement and elevation to the distinct nodes along with pipe features such as pipe length, pipe diameter and roughness coefficients to the corresponding tubes after a working model of the WDN scheme is produced in EPANET. (*Santiago, 2011*).

The pumps were mounted in the network scheme with adequate pressure head to fulfill the necessary water requirement. The next step is to assign water requirement and elevation to the distinct nodes along with pipe features such as pipe length, pipe diameter and roughness coefficients to the corresponding tubes after a working model of the WDN scheme is produced in EPANET. The maximum demand for water happens twice a day, from 6–9am and 6–9pm, and is especially pronounced in university hostels (*Strategies for smart cities mission, 2019*).

- The next steps are to model the water distribution network using EPANET:
- Draw a distribution system network representation or import a fundamental network description.
- Edit the characteristics of the system component objects. It involves editing the characteristics and entering the necessary information in different objects such as reservoirs, pipes, nodes and intersections.
- Describe the operation of the scheme.
- Choose a number of options for assessment.
- Analysis of hydraulic / water quality.
- See the evaluation outcomes.

3.3 Findings of EPANET Analysis:

During the simulation, changes were noted at different nodes at each hour in the chosen parameters such as flow, velocities, head and water pressure. The water distribution network comprises of 111 tubes with 1 pump and 1 source reservoir and 110 intersections. The tubes used were 32 mm, 50 mm, 65 mm, 80 mm in diameters that were best suited after approaching the solution heuristically for elevated head values.

3.3.1 Junction Report

Junctions are network points where connections come together and where water enters or leaves the network. The fundamental input information needed for intersection are:

- Higher than a reference (generally mean sea level)
- Water demand

The output results computed for junctions at all time periods of a simulation are:

- Hydraulic head
- Actual Demand
- Pressure

The following Fig 4. shows the proposed WDN plotted in EPANET 2.0

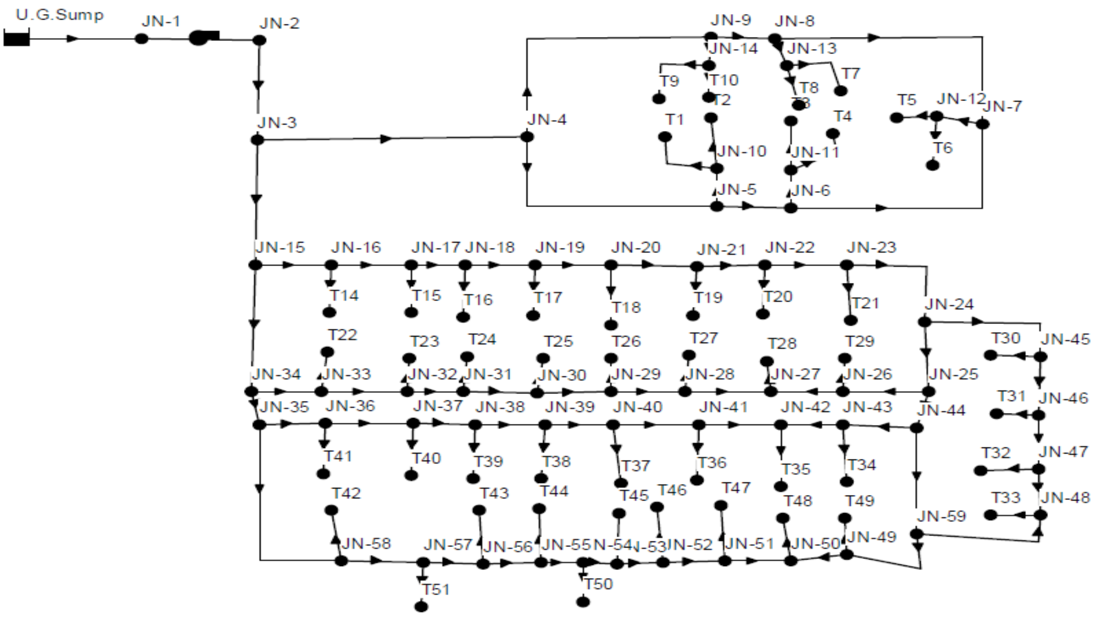

Fig 4. Proposed Water Distribution Network

The result of the simulation in form of Actual demand, Head & Pressure in Node-ID manner & base demand to actual demand ratio of the end nodes is given in the following Annexure-III & IV and same is not shown for sake of brevity.

3.4 PLANNING FOR CONVERSION OF WDN INTO SMART WDN

The description of the methods of optimization and deployment of sensors are given below:

3.4.1 Entropy

Entropy (normal symbol S) in thermodynamics is a measure of the amount of particular realizations or microstates that can represent a thermodynamic system in a defined state set by macroscopic factors. Most individuals know entropy within a macroscopic scheme as a measure of molecular disorder.

Second Thermodynamics Law says that entropy will either boost or stay the same in any cyclic process. (*Christodoulou, 2015*)

Change in entropy can be defined as equation (2)

$$\Delta S = \int \frac{\partial Q}{T} \qquad (2)$$

Mathematically, entropy can be expressed as the product of the probability mass function (*Px*) of a variable *x*, times the natural logarithm of the inverse of the probability (*Christodoulou and Deligianni, 2010*).

It is expressed by the following Equation (3),

$$H = \sum \text{Px} \ln \left(\frac{1}{Px}\right) \qquad (3)$$

Where,

Px- Probability Mass Function

Three are of specific significance among the main characteristics of entropy: sub-additivity, maximum, and equivocation.

- **Sub-additivity** denotes that the value of a function for the sum of two components is always equal to or below the sum of the orders of the function for each component.
- **Maximality** The entropy function, H (p1, p2, ..., pn), requires the highest value when all admissible results have equal probabilities (p1 = p2 = ... = pn). In other words, for the equi-probability distribution of possible results, maximum uncertainty is achieved.
- **Equivocation** In impact, is the conditional entropy of one random variable against another, and quantifies the remaining entropy (i.e., uncertainty) of the random Y variable, since the value of another random X variable is known.

3.4.2 A Closer Look at Equivocation

Mathematically speaking, misunderstanding is called Y entropy conditional on X. It is written in the manner in which the following equation sequence can be used (Eqn. 4,5,6)

$$H(Y|X) = \sum[P(x)H(Y|X = x) \qquad (4)$$

$$= \sum P(x) \sum [P(y|x) ln \frac{1}{P(y|x)} \qquad (5)$$

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$$= \sum[P(x,y) ln \frac{p(x)}{p(x,y)}] \quad (6)$$

3.5 Sensor Placement and Optimization

Since entropy is deemed a good measure of the order and stability of a system, maximizing its importance when a system is in a state of "equiprobability," a greater degree of entropy should also show a more balanced system with regard to sensed data. The issue of sensor-placement optimization could therefore be re-stated as one in which sensor locations are sought as to maximize system entropy (*Saminu et. Al., 2013*).

The entropy equation (2) describes the word of likelihood (px) as a statistical measure of the sensing radius ratio of a sensor over the network's complete length. Therefore, for a single-type sensor, the complete network entropy, Ht, would become

$$Ht = -\sum[\frac{ri}{Lt} \ln\left(\frac{ri}{Lt}\right)] \quad (7)$$

It should be noted that although the px = r / LT definition above is consistent with classical probability properties when the sensors cover the entire length of the network. On the contrary, if they don't and so it's not mathematically correct, it doesn't comply. A alternative to this issue is to redefine the size of the previous ratio as r / L based on the length of the arc and not the length of the network. The value of Px is now taken as the proportion of the sensor radius over the length of the detected network arc, and the complete entropy of the structure can be calculated by summing the entropy values for each arc. This definition also adheres to the reality that sensors at junctions have numerous arcs and the same add to the entropy concentrations of these arcs, thus helping to avoid clustering detectors in just a few areas of the network. Furthermore, in order to take into account the overlap in sensing radii of sensors placed at the end nodes of an arc and/or segment lengths shorter than the sensor radius, the value of ri used in equation (6) is taken as the minimum between the segment length (Li) and the sensor radius (xi) (for one sensor) of the sensor., or the combined sensing radii (in the case of two sensors) using equation (8, 9)

$$ri=\min\{xi;Li\} \quad (8)$$

$$Ht = -\sum[\frac{ri}{Lt} \ln\left(\frac{ri}{Li}\right)] \quad (9)$$

Where j is the index of the sensor type ; nr is the number of different types of sensors used in the project ; ri, j is the number of sensor type units j used on node I ;nt is the total number of sensors in the network and rT, j is the total number of sensor type j units used in the network. The main objective is therefore to maximize the entropy of the network, subject to an allowable maximum number of sensors (of a specified sensing radius) or to maximize entropy equivalently while minimizing the number of sensors used.

In the sample arc shown in Fig, for instance. 5. Suppose we denote a sensed node by a filled circle and a node without a sensor as an empty circle, the proposed entropy-based sensor positioning technique with a length higher than the total of the sensing radii, the complete entropy generated by the arc setup can then be calculated on the basis of the above definition of entropy.

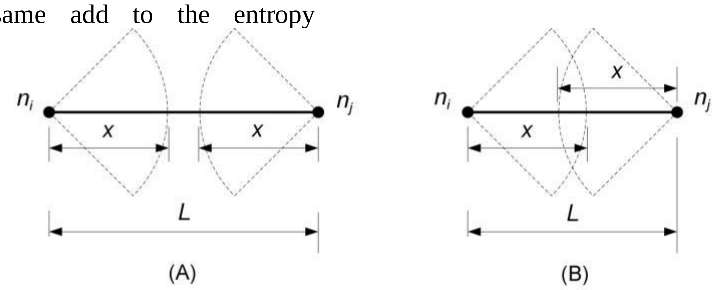

Fig. 5. Proposed entropy-based sensor placement method

$$= -\frac{\min(2x;L)}{L} \times \ln\left(\frac{\min(2x;L)}{L}\right) = -2x \times \ln\left(\frac{2x}{L}\right) \quad (10)$$

In the case of an arc length shorter than the sum of the sensing radii of the two nodal sensors, the total pipe entropy is taken as

$$= -\frac{\min(2x;L)}{L} \times \ln\left(\frac{\min(2x;L)}{L}\right) = -L \times \ln\left(\frac{L}{L}\right) = 0 \quad (11)$$

Suppose, for a pipe of length 300 meters, one sensor be used (at node *ni*) with an assumed sensing radius of 200 meters, then the entropy for pipe(n_i, n_j) is computed as seen in Fig. 6.

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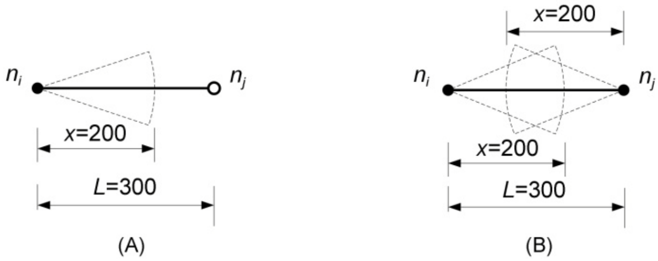

Fig. 6. Proposed numerical entropy-based sensor placement method

$$= -\frac{200}{300}\ln\left(\frac{200}{300}\right) = 0.270 \tag{12}$$

If two sensors are used (at nodes *ni* and *nj*) then the entropy is computed to be

$$= -\frac{300}{300}\ln\left(\frac{300}{300}\right) = 0.00 \tag{13}$$

It should be observed that the technique demonstrates preference in both end-nodes for a single sensor relative to sensors, and that the suggested entropy-maximization strategy is great in more complex sensor schemes. One in which is of equal value the data produced and/or distributed among its components. Therefore, the issue of sensor-placement optimization could be restated as one in which sensor locations are attempted to maximize the entropy of the scheme.

Sensors are to be placed in the network which will have to satisfy both uniformity and efficiency during deployment. The sensors will have to cover maximum area and they must not overlap at any place because makes them inefficient and complicates the coding as two sensors are covering the same node.

The data is fed into Microsoft Excel and the entropy is calculated accordingly, the data is then compiled and thereafter the network is heuristically approached in order to find the uniformity in deployment of the sensors to increase the efficiency. The efficiency of a water distribution network is thus calculated mathematically without the need of educated guesses thus eliminating the trial and error method usually practiced.

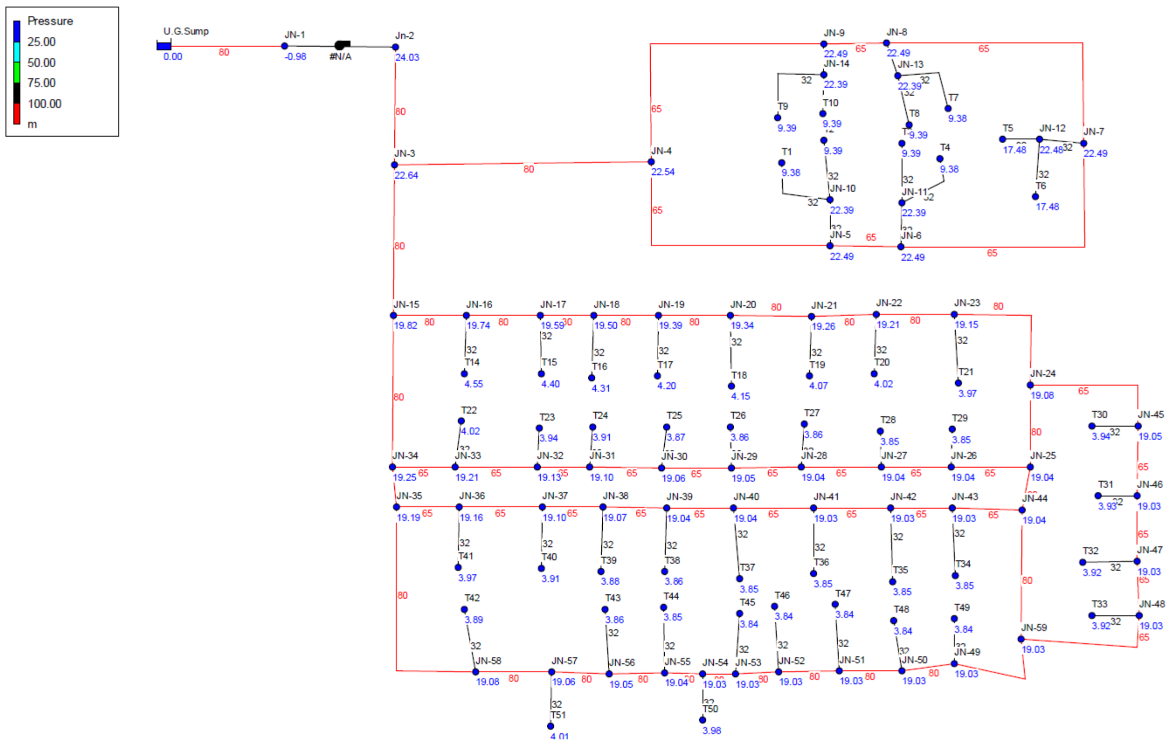

Fig. 7. EPANET layout of the water distribution network with diameter and pipe length

This method was applied using Microsoft Office Excel for the water distribution network of the site. Two sensor types (Arc length 10 m, 20 m) were used and the best possible sensor configuration was adapted on the basis of highest entropy received. Annexure-V shows the calculation of entropy for all the pipe configurations in the water

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distribution network. Entropies of the pipelines were calculated and optimized; it was found that deployment of 7 sensors would be ideal for managing the water distribution network. The following nodes as shown in Table 1 were selected based on the entropy parameters and location of the nodes:

Table 1: Nodes selected for placement of sensors in the WDN

S. No	Node Number
1	1
2	4
3	6
4	24
5	34
6	56
7	59

At node 4, sensor of arc radius of 20 m has to be placed. All the other nodes are to be fitted with sensors of arc radius of 10 m. The sensors have been optimised as necessary and have been evenly spread out as well. The sensors deployed can trigger alarm in case of an anomaly noted in the working of the network in real time and it can pin point the nodes which is malfunctioning. This greatly simplifies the maintenance activities in the future and cuts down the cost significantly in a long run. The sensors will have to cover maximum area and they must not overlap at any place as it will be rendered inefficient and complicates the coding as two sensors are covering the same node.

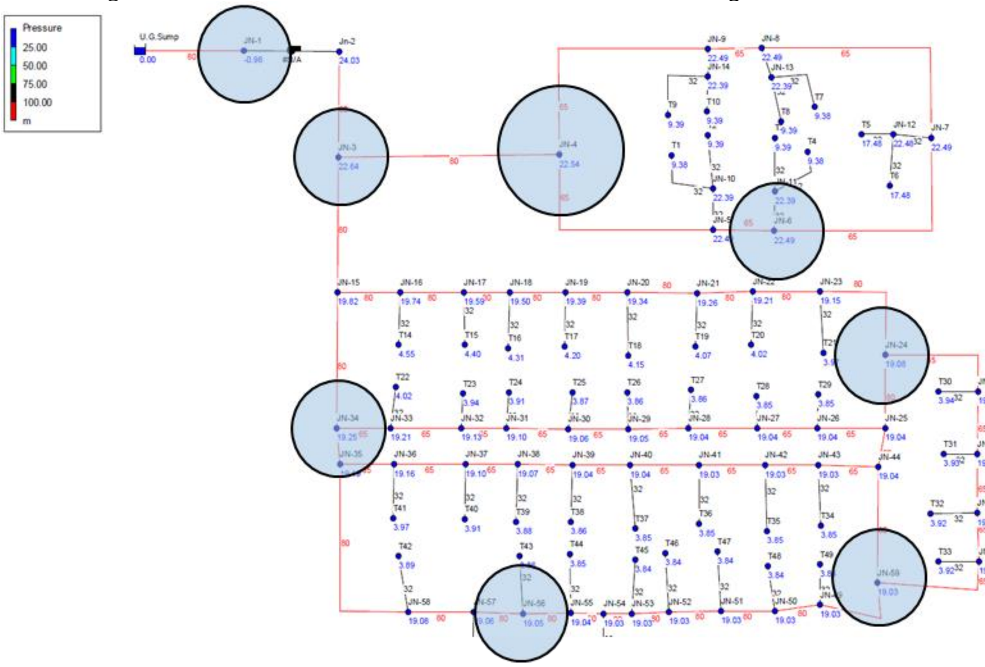

Fig. 8. Schematic layout of the proposed sensor placement in the water distribution network

4. CONCLUSION

This research study focused on analysing the water distribution network and identifying deficiencies in design, execution and use, as well as converting the current network into an intelligent water distribution network. At the end of the analysis, all factors such as water pressure, velocity, flow rate across all intersections were discovered to be good enough in the study region to provide sufficient equitable supply. One of the biggest issues in the distribution scheme is the existence of dead ends. Looping to link the dead ends is a suggested technique for increasing system reliability and providing steady water flow in pipes. System simulations disclosed that few pumps need to be installed to provide the water distribution system with adequate pressure head and velocity. All of the distribution system's hydraulic limitations were minimized to a maximum extent. For the supply of the required quantity of water, the minimum pressure head and water demand are ensured even during the peak hour. Using mathematical entropy approached using greedy search algorithm, the scheme was optimized for sensor deployment. The sensors were implemented in regions with important entropy and optimized throughout the network for standardized deployment. The assessment demonstrates that it is possible to provide sufficient water to the entire study area network at all intersections and speeds in all tubes. For brevity purposes, all the relevant data required for the analysis were collected in Annex I to V.

The following conclusions can be drawn from the study:

- The supplied quantity of water is sufficient enough to easily satisfy the water demand of the entire colony as seen in Annexure-IV, where the Actual Demand to Base Demand ratio remains more than 1 in all the end nodes.
- The residual pressure at all the nodes is found to be greater than 12 m. Hence, the flow can occur

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easily and the water reaches the tank present at height of 10 m.

- The assumed pipe diameters are sufficient to withstand for the pressure for the entire network.
- The velocity in the pipe network is sufficient, i.e., in the range of 0.6 m/s to 2.5 m/s as prescribed in BIS (IS 2065:1983).
- The system can be converted into a smart water distribution network by deploying the sensors.
- The location of sensor deployment was pin pointed using a mathematical approach that led to an effective way to find the location of maximum efficiency.

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ANNEXURE-I

Node ID	Base Demand (m^3/hour)	Node ID	Base Demand (m^3/hour)	Node ID	Base Demand (m^3/hour)
JN-2	0	T23	0.278	T24	0.278
JN-3	0	T17	0.278	T22	0.278
JN-1	0	T18	0.278	T34	0.278
JN-15	0	T19	0.278	T35	0.278
JN-4	0	T20	0.278	T36	0.278
JN-14	0	T21	0.278	T37	0.278
JN-13	0	JN-45	0	T38	0.278
JN-9	0	JN-48	0	T39	0.278
JN-8	0	JN-59	0	T40	0.278
JN-10	0	JN-46	0	T41	0.278
JN-11	0	JN-47	0	T30	0.208
JN-5	0	JN-25	0	T31	0.208
JN-6	0	JN-44	0	T32	0.208
JN-7	0	JN-26	0	T33	0.208
JN-12	0	JN-27	0	JN-49	0
T1	0.139	JN-28	0	JN-50	0
T2	0.139	JN-29	0	JN-51	0
T3	0.139	JN-30	0	JN-52	0
T4	0.139	JN-31	0	JN-53	0
T5	0.069	JN-32	0	JN-55	0
T6	0.069	JN-33	0	JN-56	0
T10	0.139	JN-34	0	JN-57	0
T9	0.139	JN-43	0	JN-58	0
T8	0.139	JN-42	0	T42	0.278
T7	0.139	JN-41	0	T43	0.278
JN-16	0	JN-40	0	T44	0.278
JN-18	0	JN-39	0	T45	0.278
JN-17	0	JN-38	0	T46	0.278
JN-19	0	JN-37	0	T47	0.278
JN-20	0	JN-36	0	T48	0.278
JN-21	0	JN-35	0	T49	0.278
JN-22	0	T29	0.278	JN-54	0
JN-23	0	T28	0.278	T50	0.139
JN-24	0	T27	0.278	T51	0.139
T14	0.278	T26	0.278	T16	0.278
T15	0.278	T25	0.278	U.G. Sump	N/A

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ANNEXURE-II

Node ID	Elevation (m)	Node ID	Elevation (m)	Node ID	Elevation (m)
Jn-2	100	T23	115	T24	115
JN-3	100	T17	115	T22	115
JN-1	100	T18	115	T34	115
JN-15	100	T19	115	T35	115
JN-4	100	T20	115	T36	115
JN-14	100	T21	115	T37	115
JN-13	100	JN-45	100	T38	115
JN-9	100	JN-48	100	T39	115
JN-8	100	JN-59	100	T40	115
JN-10	100	JN-46	100	T41	115
JN-11	100	JN-47	100	T30	115
JN-5	100	JN-25	100	T31	115
JN-6	100	JN-44	100	T32	115
JN-7	100	JN-26	100	T33	115
JN-12	100	JN-27	100	JN-49	100
T1	113	JN-28	100	JN-50	100
T2	113	JN-29	100	JN-51	100
T3	113	JN-30	100	JN-52	100
T4	113	JN-31	100	JN-53	100
T5	105	JN-32	100	JN-55	100
T6	105	JN-33	100	JN-56	100
T10	113	JN-34	100	JN-57	100
T9	113	JN-43	100	JN-58	100
T8	113	JN-42	100	T42	115
T7	113	JN-41	100	T43	115
JN-16	100	JN-40	100	T44	115
JN-18	100	JN-39	100	T45	115
JN-17	100	JN-38	100	T46	115
JN-19	100	JN-37	100	T47	115
JN-20	100	JN-36	100	T48	115
JN-21	100	JN-35	100	T49	115
JN-22	100	T29	115	JN-54	100
JN-23	100	T28	115	T50	115
JN-24	100	T27	115	T51	115
T14	115	T26	115	T16	115
T15	115	T25	115	U.G.Sump	100

ANNEXURE- III

Node ID	Actual Demand	Base Demand	Actual Demand/ Base Demand Ratio	Node ID	Actual Demand	Base Demand	Actual Demand/ Base Demand Ratio
T1	0.14	0.139	1.01	T22	0.28	0.278	1.01
T2	0.14	0.139	1.01	T34	0.28	0.278	1.01
T3	0.14	0.139	1.01	T35	0.28	0.278	1.01
T4	0.14	0.139	1.01	T36	0.28	0.278	1.01
T5	0.07	0.069	1.01	T37	0.28	0.278	1.01
T6	0.07	0.069	1.01	T38	0.28	0.278	1.01
T10	0.14	0.139	1.01	T39	0.28	0.278	1.01
T9	0.14	0.139	1.01	T40	0.28	0.278	1.01
T8	0.14	0.139	1.01	T41	0.28	0.278	1.01
T7	0.14	0.139	1.01	T30	0.21	0.208	1.01
T14	0.28	0.278	1.01	T31	0.21	0.208	1.01
T15	0.28	0.278	1.01	T32	0.21	0.208	1.01
T23	0.28	0.278	1.01	T33	0.21	0.208	1.01
T17	0.28	0.278	1.01	T42	0.28	0.208	1.35
T18	0.28	0.278	1.01	T43	0.28	0.208	1.35
T19	0.28	0.278	1.01	T44	0.28	0.208	1.35
T20	0.28	0.278	1.01	T45	0.28	0.278	1.01
T21	0.28	0.278	1.01	T46	0.28	0.278	1.01
T29	0.28	0.278	1.01	T47	0.28	0.278	1.01
T28	0.28	0.278	1.01	T48	0.28	0.278	1.01
T27	0.28	0.278	1.01	T49	0.28	0.278	1.01
T26	0.28	0.278	1.01	T50	0.14	0.139	1.01
T25	0.28	0.278	1.01	T51	0.14	0.139	1.01
T24	0.28	0.278	1.01	T16	0.28	0.278	1.01

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ANNEXURE-V

Start Node Number	End Node Number	Length	Minimum length (x,10)	Minimum length (x,20)	Entropy for 10 m arc sensor	Entropy for 20 m arc sensor
Sump	1	12	10	12	0.1519	0
2	3	17	10	17	0.3121	0
3	15	43	10	20	0.3392	0.356
3	4	72	10	20	0.2741	0.3558
4	9	42	10	20	0.3416	0.3533
9	8	4	4	4	0	0
9	14	13	10	13	0.2018	0
4	5	58	10	20	0.303	0.3671
5	6	4	4	4	0	0
5	10	13	10	13	0.2018	0
6	11	34	10	20	0.3599	0.3121
8	7	47	10	20	0.3292	0.3635
6	12	4	4	4	0	0
7	T1	3	3	3	0	0
10	T2	1	1	1	0	0
10	T4	3	3	3	0	0
11	T3	1	1	1	0	0
11	T6	3	3	3	0	0
12	T5	1	1	1	0	0
14	T10	1	1	1	0	0
14	T9	3	3	3	0	0
13	T8	1	1	1	0	0
13	T7	3	3	3	0	0
8	13	13	10	13	0.2018	0
23	24	21	10	20	0.3533	0.0464
15	16	6	6	6	0	0
16	17	12	10	12	0.1519	0
17	18	8	8	8	0	0
18	19	12	10	12	0.1519	0
19	20	6	6	6	0	0
20	21	12	10	12	0.1519	0
21	22	8	8	8	0	0
22	23	12	10	12	0.1519	0
24	45	20	10	20	0.3465	0
48	59	20	10	20	0.3465	0
45	46	12	10	12	0.1519	0
46	47	8	8	8	0	0
7	48	12	10	12	0.1519	0
25	26	6	6	6	0	0
26	27	12	10	12	0.1519	0
27	28	8	8	8	0	0
28	29	12	10	12	0.1519	0
29	30	6	6	6	0	0
30	31	12	10	12	0.1519	0
31	32	8	8	8	0	0
32	33	12	10	12	0.1519	0
33	34	5	5	5	0	0
44	43	6	6	6	0	0
43	42	12	10	12	0.1519	0
42	41	8	8	8	0	0
41	40	12	10	12	0.1519	0
40	39	6	6	6	0	0
39	38	12	10	12	0.1519	0
38	37	8	8	8	0	0
37	36	12	10	12	0.1519	0
36	35	5	5	5	0	0
45	T30	25	10	20	0.3665	0.1785
46	T31	25	10	20	0.3665	0.1785
47	T32	25	10	20	0.3665	0.1785
48	T33	25	10	20	0.3665	0.1785
59	49	16	10	16	0.2937	0
49	50	12	10	12	0.1519	0
50	51	6	6	6	0	0
51	T47	25	10	20	0.3665	0.1785
50	T48	25	10	20	0.3665	0.1785
51	52	12	10	12	0.1519	0
52	T46	25	10	20	0.3665	0.1785

49	T49	25	10	20	0.3665	0.1785
52	53	3	3	3	0	0
53	54	6	6	6	0	0
54	50	25	10	20	0.3665	0.1785
54	55	6	6	6	0	0
55	56	6	6	6	0	0
56	57	6	6	6	0	0
57	58	6	6	6	0	0
53	T45	25	10	20	0.3665	0.1785
55	T44	25	10	20	0.3665	0.1785
58	T42	25	10	20	0.3665	0.1785
57	T51	25	10	20	0.3665	0.1785
T43	56	25	10	20	0.3665	0.1785
35	58	35	10	20	0.3579	0.3197
15	34	25	10	20	0.3665	0.1785
34	35	5	5	5	0	0
24	25	20	10	20	0.3465	0
25	44	5	5	5	0	0
44	59	20	10	20	0.3465	0
43	T34	25	10	20	0.3665	0.1785
42	T35	25	10	20	0.3665	0.1785
41	T36	25	10	20	0.3665	0.1785
40	T37	25	10	20	0.3665	0.1785
39	T38	25	10	20	0.3665	0.1785
38	T39	25	10	20	0.3665	0.1785
37	T40	25	10	20	0.3665	0.1785
36	T41	25	10	20	0.3665	0.1785
26	T29	25	10	20	0.3665	0.1785
27	T28	25	10	20	0.3665	0.1785
28	T27	25	10	20	0.3665	0.1785
29	T2	25	10	20	0.3665	0.1785
30	T25	25	10	20	0.3665	0.1785
31	T24	25	10	20	0.3665	0.1785
32	T23	25	10	20	0.3665	0.1785
33	T22	25	10	20	0.3665	0.1785
6	T14	25	10	20	0.3665	0.1785
17	T15	25	10	20	0.3665	0.1785
18	T16	25	10	20	0.3665	0.1785
19	T17	25	10	20	0.3665	0.1785
20	T18	25	10	20	0.3665	0.1785
21	T19	25	10	20	0.3665	0.1785
22	T20	25	10	20	0.3665	0.1785