Preface

Water is a valuable resource that both sustains life and propels social progress. A consistent supply of clean water is critical for communities throughout India. However, leaks can undermine the integrity of water pipelines, posing substantial problems to the water delivery system. This document emphasises the crucial necessity of pipeline leak detection in India's water sector and the need for creative solutions to this critical issue.

The fast expansion of the Internet of Things (IoT) in recent years has cleared the way for dramatic changes in the monitoring and management of critical infrastructure assets. IoT-based solutions have emerged as a game changer in the context of water pipes, providing unique capabilities for leak detection and prevention. This document investigates how IoT technology integration can revolutionise leak detection in water pipes, presenting a paradigm shift in maintaining the sustainability and efficiency of water delivery systems.

IoT-based systems offer real-time monitoring and early detection of leaks in water pipes by using the power of networked devices, advanced sensor technologies, and data analytics. This prologue explains the several benefits of IoT in water pipeline leak detection, such as increased accuracy, faster response times, lower water loss, and better resource management. The document also dives into the broader consequences of efficient leak detection, such as minimising environmental damage, protecting public health, and optimising overall water supply network performance.

This document describes a model constructed utilising IoT pressure sensors to demonstrate the possibilities of IoT-based leak detection systems. The model accurately forecasts the leaks in the water supply system, using the static pressure & velocity conditions generated from modelling the Hydraulic Network. This document demonstrates the model's effectiveness in detecting deviations from static circumstances, allowing for the early detection and localisation of leaks in water pipelines. The adoption of such models shows how IoT technology can be used to develop unique pipeline leak detection solutions, hence improving the resilience and dependability of water delivery infrastructure.

In conclusion, this document emphasises the important significance of pipeline leak detection in maintaining India's continuous and sustainable supply of clean water. It emphasises the benefits of IoT technologies and introduces a model-based solution based on pressure sensor readings to demonstrate how IoT-driven approaches have revolutionised leak detection in water pipes. By embracing these innovations, India can handle the issues posed by pipeline breaches in a proactive manner, protecting both the environment and the well-being of its population.

Acknowledgement

We would like to convey our heartfelt gratitude and appreciation to the individuals and organisations who helped us complete our research titled " Pipeline Leak detection using GIS, Remote sensing & IoT based techniques for Malkapur City of Satara District, Maharashtra, India." Their outstanding aid, direction, and support have been critical throughout our process.

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We also want to thank (Prof) Dr. TP Singh, Director at Symbiosis Institute of Geoinformatics, for giving us the opportunity to work on this project with Tech Mahindra. We are appreciative for his consistent support and encouragement, which inspired us to push ourselves and present a thorough work.

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Abbreviations & Units of Measure

Abbreviations

- DPR: Detailed Project Report
- ESR: Elevated Service Reservoir
- GIS: Geographic Information System
- GoM: Government of Maharashtra
- GoI: Government of India
- HGL: Hydraulic Grade Line
- MBR: Master Balancing Reservoir
- GSR: Ground Service Reservoir
- MS: Mild Steel
- DI: Ductile Iron
- CI: Cast Iron
- NRW: Non-Revenue Water
- WTP: Water Treatment Plant
- GSR: Ground Service Reservoir

Units of Measure

- Km: Kilometre
- LPCD: Litres per Capita per Day
- M: Meter
- m^2: Square Meter
- m^3: Cubic Meters
- MLD: Million Litres Per Day

A. Executive Summary

The Malkapur Nagarpanchayat has recived 8.00 MLD Reservation for Water Supply of a city. This water is required by Malkapur city for its daily drinking & usage purpose. The purpose of this document is to create a pilot model for leak detection system for Raw & Pure Water Transmission lines at Malkapur Nagarpanchayat.

The details of Scheme are shown in figure below

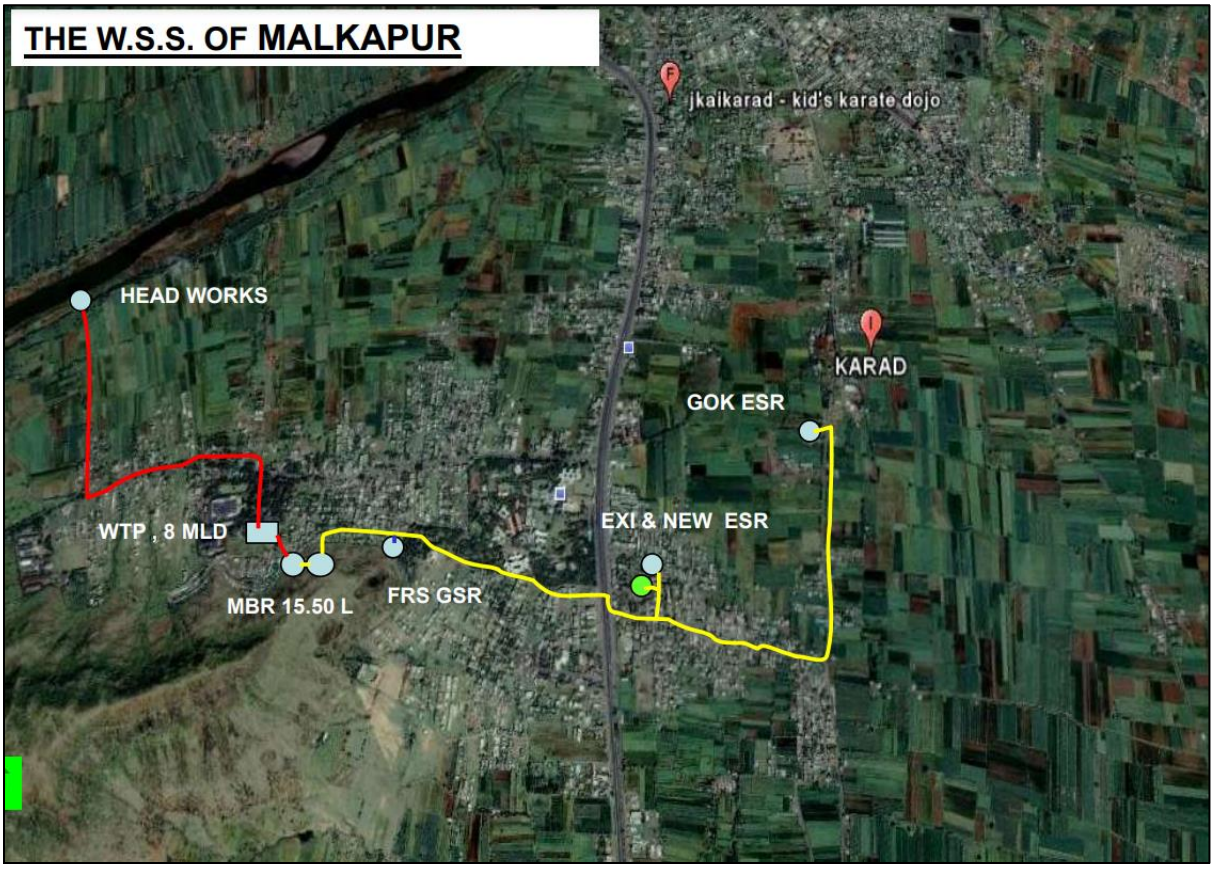


Figure 1: - Water Supply System at Malkapur Nagarpanchayat

In order to ascertain the pipe sizes of the network of the transmission mains, a GIS based hydraulic model is created using Bentley"s WaterGEMS software. ArcGIS Pro (a GIS software) is used to demarcate all the pipes and their alignments using the Satellite Images and then later converted into the shape files. These shape files are then used to create the GIS based hydraulic model. For this, the GIS software is integrated with Bentley"s WaterGEMS software.

The levels are assigned to all the nodes using elevation profile data from actual DEM extracted of 1m Spatial resolution from Google Earth Platform. The base scenario, simulating water supply of the entire network, is prepared as a first step. Child scenarios of the rising main and distribution system are created.

The GIS based hydraulic model is prepared for the 2 scenarios. The comprehensive model is created, and the 2 scenarios are analysed. In each scenarios the diameter of the pipes is validated. The model is run for all the 2 scenarios and the results are shown in "pipe results" as well as "junction results." In pipe results the various attributes of pipe such as pipe label, pipe material, Hazen William"s C value, lengths are indicated. Besides this the results of flow through pipes and velocities and head loss per km are shown. In junction tables, the junction label, ground elevation, demand, nodal pressures, and HGL are shown.

The leak Detection model was created using Static Pressure ranges of the complete scenario. The sample readings were generated for 6 hours and feeded to the model & accuracy of Model is tested for conditions. The real time sensor readings can be attached & the code can be converted into a real-world system. The approach has proven unique as it can achieve 100% accuracy.

The raw water and pure water are designed to suit the demand of 8 MLD. The pipe sizes that are being laid are validated. The recommendations are mentioned in conclusion chapter.

1. Introduction

India's water supply system is complex, diverse, and faces many challenges due to factors such as population growth, urbanization, climate change, and aging infrastructure & identification of leaks in the system

Typical Water System of a city

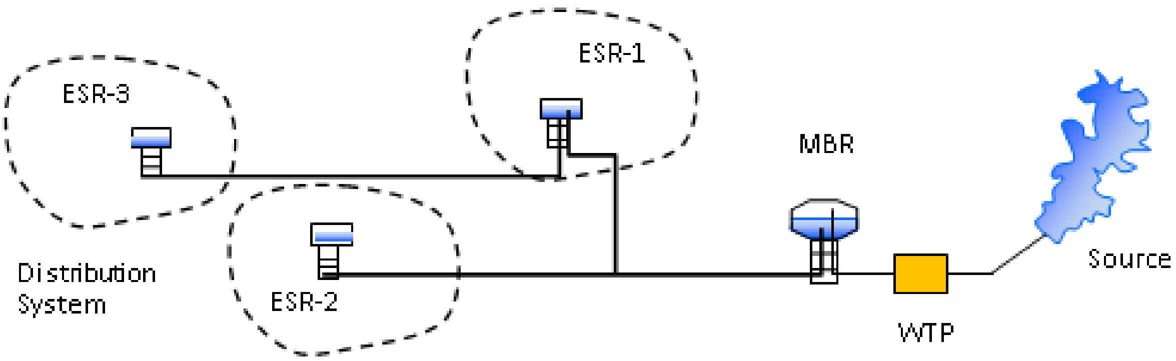


Figure 2: - Typical Water Supply System of a city

A typical water system of a city consists of several components that work together to ensure a continuous supply of safe drinking water to residents. These components include:

a) **Water source**: The source of water for a city can be from surface water (such as rivers, lakes, and reservoirs) or groundwater (aquifers).
b) **Water treatment plant:** Once the water is collected from the source, it undergoes various treatment processes to remove impurities, bacteria, and viruses. The treatment process includes coagulation, flocculation, sedimentation, filtration, disinfection, and distribution.
c) **Distribution system:** After the water is treated, it is transported through a network of pipes, pumps, and valves to various neighbourhoods and buildings in the city.
d) **Storage tanks:** Water storage tanks are strategically placed throughout the city to ensure a continuous supply of water during peak demand or emergencies.

Why no leak detection system in India?

- **Lack of electricity:** As you mentioned, electricity is not available on a 24/7 basis in many parts of India, which can make it difficult to continuously monitor leak detection systems that require electricity to operate.

- **Lack of maintenance:** Maintenance is crucial for the proper functioning of leak detection systems. However, in India, there is often a lack of proper maintenance systems in place, which can result in the failure of leak detection systems and other water infrastructure.

- **Inadequate water supply:** In many cities in India, the water supply is not continuous or pressurized, which can make it difficult to accurately detect leaks in the distribution system. Without a consistent and pressurized water supply, it can be challenging to pinpoint the location of leaks.

- **Cost:** Implementing a leak detection system can be expensive, and many municipalities in India may not have the financial resources to invest in this technology. This can be especially challenging in smaller cities and rural areas.

- **Lack of awareness:** There may be a lack of awareness among engineers, policymakers, and the general public about the benefits of leak detection systems and the importance of investing in water infrastructure.

In summary, some of the primary reasons why leak detection systems are not commonly employed in India are a lack of constant electrical supply, inadequate maintenance systems, restricted pressurised water supply, cost, and a lack of awareness. Addressing these issues is critical for increasing the efficiency and dependability of India's water supply system.

Need of Leak Detection system in India

Water leak detection systems are critical for increasing the efficiency and reliability of India's water supply infrastructure. Here are some of the reasons why leak detection systems are required:

1. **Preventing Water loss: -** Water distribution system leakage can result in significant water loss, which can be a huge issue in a country like India, where water is scarce. Cities may reduce water waste by identifying and repairing leaks, ensuring that more water is accessible for vital applications such as drinking, sanitation, and irrigation.
2. **Controlling waterborne diseases: -**Waterborne diseases such as cholera, typhoid, and dysentery have a long history in many Indian cities. Water distribution system leaks can contaminate the water supply and increase the risk of waterborne infections. Cities can lower the danger of contamination and provide a cleaner water supply for citizens by finding and correcting leaks.
3. **Improving infrastructure efficiency: -** Leak detection systems can assist in identifying inefficient portions of the water distribution system that require maintenance or repair. Cities can enhance the overall efficiency of their water delivery infrastructure and lower the cost of operating and maintaining the system by addressing these challenges.
4. **Meeting demand: -** Few Indian towns have pressurised 24-hour water supply systems, which can result in water scarcity and discomfort for inhabitants. Cities may ensure that more water is accessible to households by discovering and correcting leaks, especially during peak demand periods.

In summary, leak detection systems are required in Indian cities to avoid water loss, control waterborne infections, improve infrastructural efficiency, and meet water demand. Installing leak detection systems can be a critical step towards guaranteeing a safe, dependable, and long-term water supply for all people.

General Problem in Water Supply System (Context of India)

a) More Non-Revenue Water (NRW) (Generally > 50%)
b) Supply hours = few minutes to few hours / day
c) Low pressure
d) GI pipes (Low diameters)

e) Water not reaching all places (no equitable distribution)
f) AC pipelines- easily give rise to leakages
g) Low quality pipes
h) No Leakage Detection System
i) Very few cities have 24X7 Continuous Pressurized Water Supply.

Objectives

- Development of IoT based Pipeline Leak Detection for Water Utility Network.
- Assessing health of Water Supply System in Steady condition.
- Creating & recognizing anomalies to be feed in Machine learning Model in steady simulation of network.

2. Review of Literature

(Maroua Abdelhafidh, 2017) proposes an IoT-based Water Distribution Monitoring System approach to detect and locate leaks in a Water Pipeline System, with an assessment phase to evaluate its performance. (João Alves Coelho, 2020) observes a system based on a wireless sensor network to detect water leaks with a 75% accuracy, using an autonomous learning algorithm. The system is validated in a real-case implementation.

(Yang Liu, 2019) designs a leakage detection method based on machine learning and wireless sensor networks (WSNs) to address the lack of intelligent and low efficiency of conventional leakage detection methods. It employs wireless sensors, 4G network, and leakage triggered networking to reduce energy consumption and prolong system life cycle.

(Bin XU, 2011) applied Airborne laser remote sensing system is suitable for detecting gas leaks on plain, desert, hills, but unfit for large altitude diversification.

(A Ayad, 2021) Developed an integrated approach for water pipe network calibration and quantifying leaks using field measurements, linear programming, Genetic Algorithms (GA), GIS, a new constraint handling function, floating-point representation, and EPA net hydraulic modelling. Results prove the approach's accuracy and efficiency.

(Wilmer P. Cantos, 2020) Developed, tested, validated, and illustrated the application of a machine-learning-based risk assessment method for early detection of high likelihood leaks, their geolocation, and detection accuracy assessment in the water distribution system of the SUNRISE demonstration site.

(Ganjour Mazaev, 2023) Presented a microservice architecture for leak localization in WDNs, using heterogeneous sources of data to combine hybrid data-driven and model-based leak detection and localization methodologies.

(Irene Karathanasi, 2016) Developed a system DEYAP which is responsible for the Operation and Maintenance of the Water Supply system in Patras, Greece, covering a service area of 333 km2 and a population of 240.000. They are developing a permanent Leakage Control System according to the IWA methodology, which includes DMAs, Pressure Management, GIS-based decision support system, database aggregation, procurement of Leak detection equipment, and training personnel.

(Izabela Rojek, 2018) IT systems have been developed to support city management, such as water and sewage management. This paper focuses on the subsystem for detecting and locating leakages on the urban water supply network, including hidden leakages. An algorithm based on MLP and Kohonen was developed and tested on hydraulic models of several municipal water supply networks.

(Li, 2015) Developed and implemented a long-distance pipeline monitoring system is necessary to improve the security and stability of the system in the event of a natural catastrophe. The system should be completed using automatic control of the entire production process, leak monitoring, alarm, chain and other functions, including the pipeline network and the oil depot. It can also improve the pipeline’s operational efficiency, enhance the accident warning alarm and provide fault diagnosis analysis, and improve the level of safety management and enterprise.

(Marian Kwietniewsk, 2022) argues that continuous integrated monitoring of water supply networks using IT technologies is the most effective way to limit water losses. It proposes a classification of methods for detecting and estimating leakages, analysing their strengths and weaknesses in terms of leak detection efficiency.

(Sheng JIN, 2015) invests and establishes joint ventures with local water companies in China to improve their managerial and operational efficiencies. The success story of NRW reduction from 35 to 5 % in Tanzhou took 18 years due to Suez Environnement's global approach and expertise on NRW management. The successful actions included replacing customer meters, standardizing supplier selection, investing in a network rehabilitation, investigating production meters, applying Aqua Circle tool, and using advanced technologies and management systems.

(MOHAMED YAHIA, 2021) Proposed a digital image processing tool based on multitemporal IR to improve the detection and location accuracy of water leakage in distribution networks pipelines. A luminance transformation of the IRimages was used to determine the temporal temperature variation due to water leakage. Results showed that the proposed method is capable of accurately detecting and locating water leakage, an improvement to the false detections of spatial thermal IR analysis.

(M. Li, 2015) Introduces a real-time GIS platform for high-sulfur gas emergency response, combining real-time data from leak detection systems and meteorological monitoring stations. It provides the functions of simulating, evaluating and displaying spatial-temporal toxic gas distribution patterns and evaluation results. A well blow scenario is used to verify the system.

(Alaa Hawari, 2018) presented an automated tool to detect defects such as cracks, deformation, settled deposits and joint displacement in sewer pipelines. It is based on image-processing techniques and mathematical formulas to analyze output data from CCTV camera images. The proposed methodology was able to detect cracks, displaced joints, ovality and settled deposits, but could be improved with additional images.

(Hunaidi O, 2004) stated a new, low-cost and easy-to-use system can help water utilities locate leaks in all types of pipes, providing a solution to water shortages.

(Sungyong Park, 2020) explained Aerial thermal imaging (ATI) and ground-penetrating radar and closedcircuit television surveys were used to identify leakage points in sewer pipelines. The results showed that the depth of penetration at the leakage points was 35 cm, which is greater than other points. This suggests that ATI is an effective method to predict leakage in deteriorated underground sewer pipelines.

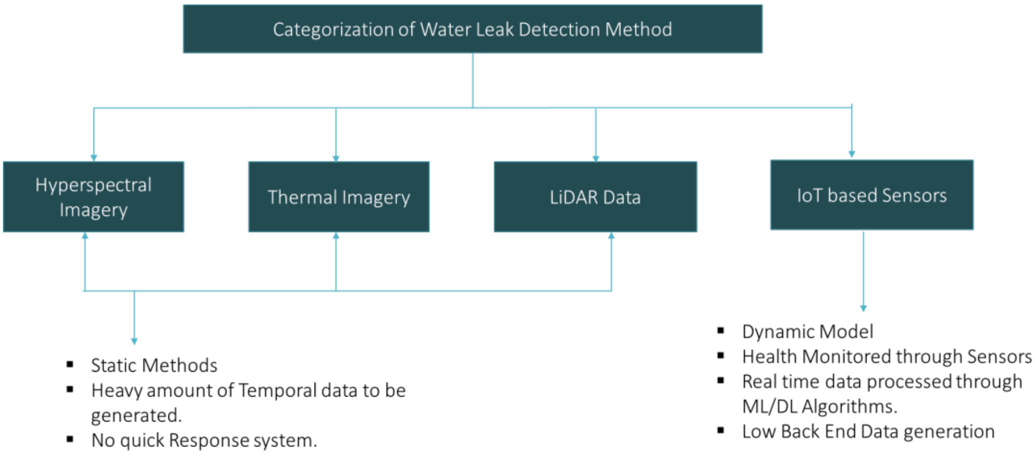


Figure 3: - Categorization of Water leak detection method

Preferable Approach

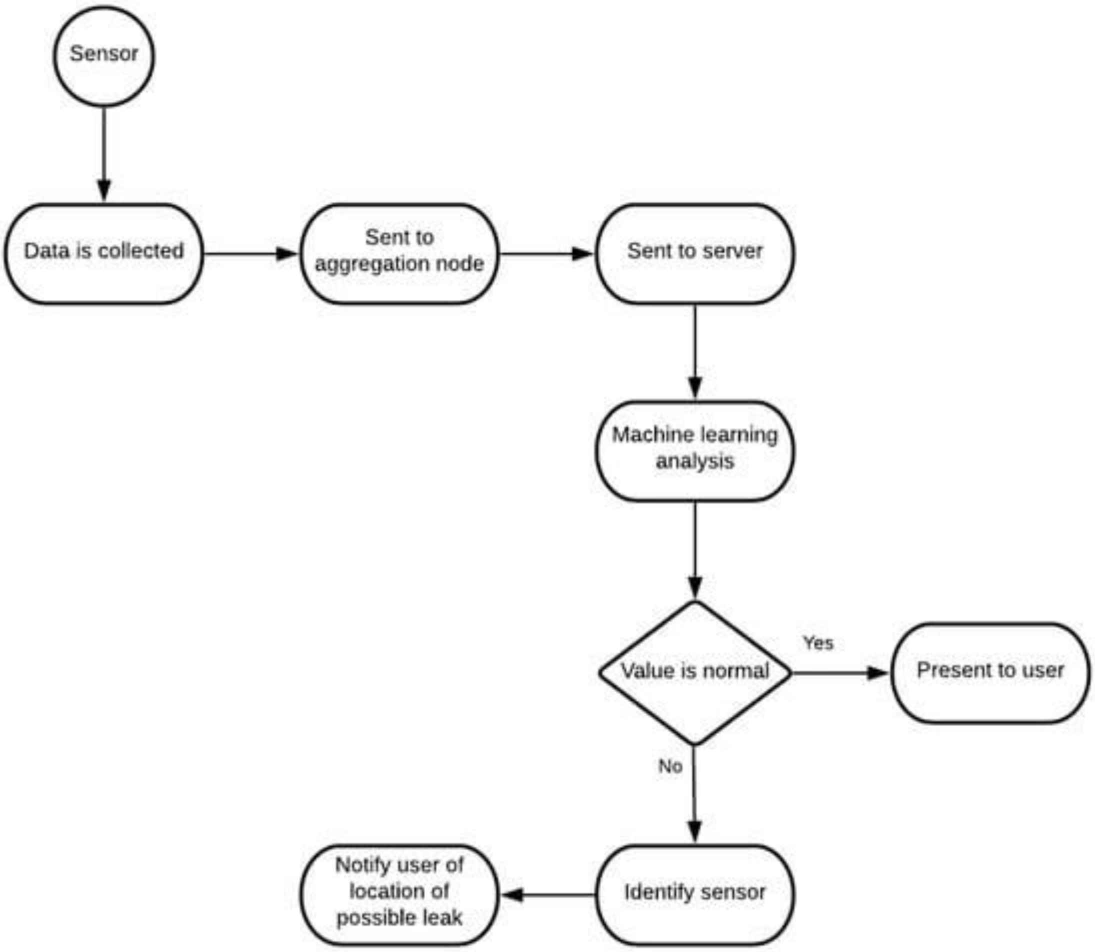


Figure 4: -Schematic Approach

Summarizing Literature Review

- Conditions or anomalies of fluctuation in Pressure & Velocities should be generated through Steady State Simulation in different Scenarios.
- Anomalies to be recorded & trained in Model of Machine learning for monitoring on Real time data.

Tools & Capabilities required

1. **ArcGIS Pro: -** Under the state of art deep learning model, Image Analysis, spatial analysis with imagery data, it is possible to prepare training data.
2. **Bentley Water GEMS: -** Creating a hydraulic model of the pipeline network and simulating water flow and pressure under normal and abnormal conditions, the software can help identify potential leak locations and estimate leak sizes. Water GEMS can also be used to test different leak detection methods, such as pressure sensors or acoustic sensors, to determine their effectiveness in different scenarios.
3. **Different types of sensors: -**
    a) **Pressure Sensors: -** a) Resolution of 0.1 bar.
    b) Can measure diff types of pressure (Absolute, Differential & Gauge Pressure).
    b) **Flow rate sensors: -** a) Accuracy of + or – 1%.
    b) Resolution of 0.1 mL/min.
    c) Response time limiting to 30 sec to 1 minutes.

3. Integrating GIS for Hydraulic Modelling

Hydraulic Terminologies

- **Pressure: -** The force exerted by water on the pipeline walls is referred to as pressure in a water pipeline. It is commonly measured in pounds per square inch (psi) or pascals (Pa). The resistance to flow, pipe friction, and changes in elevation within the pipeline system all contribute to pressure.

- **Velocity: -** The velocity of the water flowing through the pipeline is referred to as its velocity. It is commonly measured in metres per second (m/s) or feet per second (ft/s). The velocity of water in a pipeline is affected by a number of parameters, including pipeline diameter, water flow rate, and fluid characteristics.

- **Water Demand: -** The quantity of water required by individuals, households, communities, industries, or any other entity for diverse uses such as residential usage, irrigation, industrial processes, and commercial activities is referred to as water demand. It denotes the amount of water required to suit the needs of a specific population or area.

- **Elevation: -** The height or vertical distance of a site above or below a reference point, often the mean sea level, is referred to as elevation. It is a crucial geographic feature that is used to characterise and find locations on the Earth's surface. Elevation is commonly measured in metres (m), feet (ft), or miles (mi).

- **Flow Rate: -** The volume of water travelling through a certain point in a hydraulic system per unit of time is referred to as the flow rate. It is usually expressed in terms of cubic metres per second (m3/s) or gallons per minute (gpm).

- **Head: -** Head is a measure of the energy of water in a hydraulic system that is the vertical distance from a reference point (typically the water surface) to a specified location in the system. Head can be expressed in metres (m) or feet (ft).

Hydraulic Gradient Line & Total Energy Line

The concept of Hydraulic Grade Line & Total Energy line is very useful in the study of flow of fluids through pipes. They are defined as

Hydraulic Grade Line: - It is defined as the line which gives the sum of pressure head (ρ/w) and datum head (z) of a flowing fluid in a pipe with respect to some reference line or it is the line which is obtained by joining the top of all vertical ordinates, showing the pressure head (ρ/w) of a flowing fluid in a pipe from the centre of pipe. It is briefly written as H.G.L (Hydraulic Gradient Line)

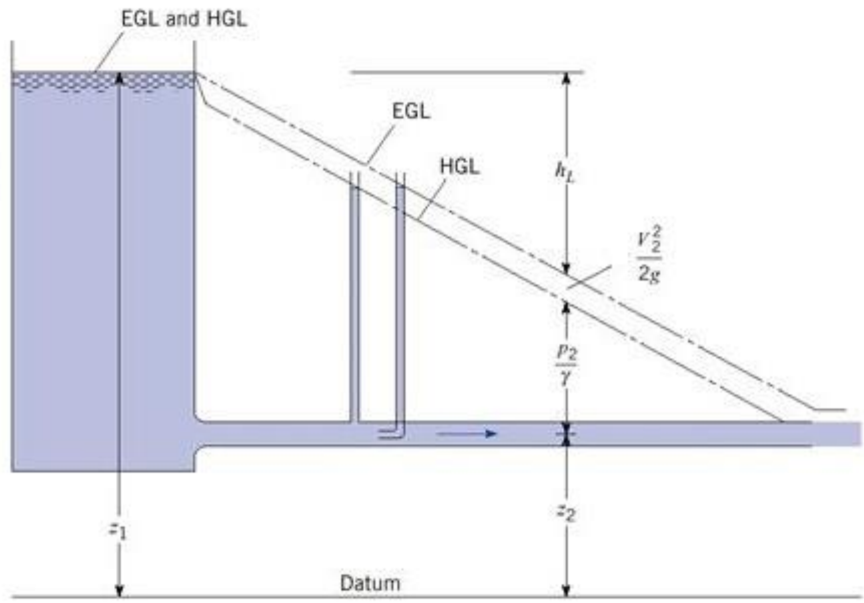


Figure 5: -Hydraulic Gradient Line & Energy Gradient Line

Total Energy Line: - It is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe with respect to some reference line. It is also defined as the line which is obtained by joining the tops of all vertical ordinates showing the sum of pressure head and kinetic head from the centre of pipe. It is briefly written as T.E.L (Total Energy Line)

Various Equations for Modelling Flow through Pipes

- **Hazen Williams Equation: -**This equation is used to calculate the head loss (pressure loss) in a pipe due to friction. It is expressed as:

$$\boldsymbol{Q = k * C * A * R^{0.63} * S^{0.54}}$$

Q= Discharge in cumec
C= Hazen Williams Roughness Coefficient
A=Flow Area
R= Hydraulic Radius
S=Friction Slope
k=Constant (0.85) for SI Units

- **Darcy Weisbach Equation: -** This equation is an alternative to the Hazen-Williams equation and is used to calculate head loss in a pipe due to friction. It is expressed as:

$$\boldsymbol{hl = f * \frac{L}{D} * \frac{V^2}{2g}}$$

hl= Head loss coefficient
f=Frictional loss coefficient
L=Length of Pipe
D=Diameter of Pipe
V=Velocity

g=Gravitaional Acceleration

- **Mannings Equation: -** Manning's equation, which is based on Chezy's equation, is one of the most popular methods in use today for free surface flow. For Manning's equation, the roughness coefficient in Chezy's equation is calculated as:

$$\boldsymbol{C = k * \frac{R^{\frac{1}{6}}}{n}}$$

C=Chezy's roughness coefficient
R=Hydraulic radius (m, ft.)
n=Manning's roughness
k=Constant

Substituting this roughness into Chezy's equation, you obtain the well-known Manning's equation:

$$\boldsymbol{Q = \frac{k}{n} * A * R^{\frac{2}{3}} * S^{\frac{1}{2}}}$$

Q=Discharge
k=Constant
n=Mannings Roughness
A=Flow area
R=Hydraulic radius (m, ft.)
S=Friction Slope

Integrating GIS & Water Network Technology

The size of India's water distribution system is significant. The distribution system is made up of hundreds of nodes and pipelines. It is incredibly difficult to design or analyse such a vast water distribution system manually. It necessitates the use of the Hydraulic Model. This model is created with software such as Epanet (free freeware) or another Network programme. However, simply creating a non-spatial hydraulic model is insufficient because the construction or analysis of vast networks necessitates data feeding to a large number of pipes and nodes. This necessitates the use of a robust tool capable of assigning data such as ground elevations and demands to each node and attributes to each pipe. GIS assists in feeding data to the network in order to develop a GIS-based hydraulic model for the big networks.

GIS provides a centralised platform for accessing all water business data, maintaining network information, locating customer information, and creating reports. It is able to assist network tracing as well as study development trends affecting future demand using the built-in spatial analysis capabilities. The visualisation and mapping features provide a comprehensive, integrated picture of the city's water or sewer network in connection to consumers and surrounding infrastructure.

Prior to the introduction of the hydraulic model, the distribution system was created using a simple excel sheet method that was approximate and inaccurate. There were many iterations in the design/analysis process. The distribution network was perceived in the same way that the seven blind men perceived the elephant.

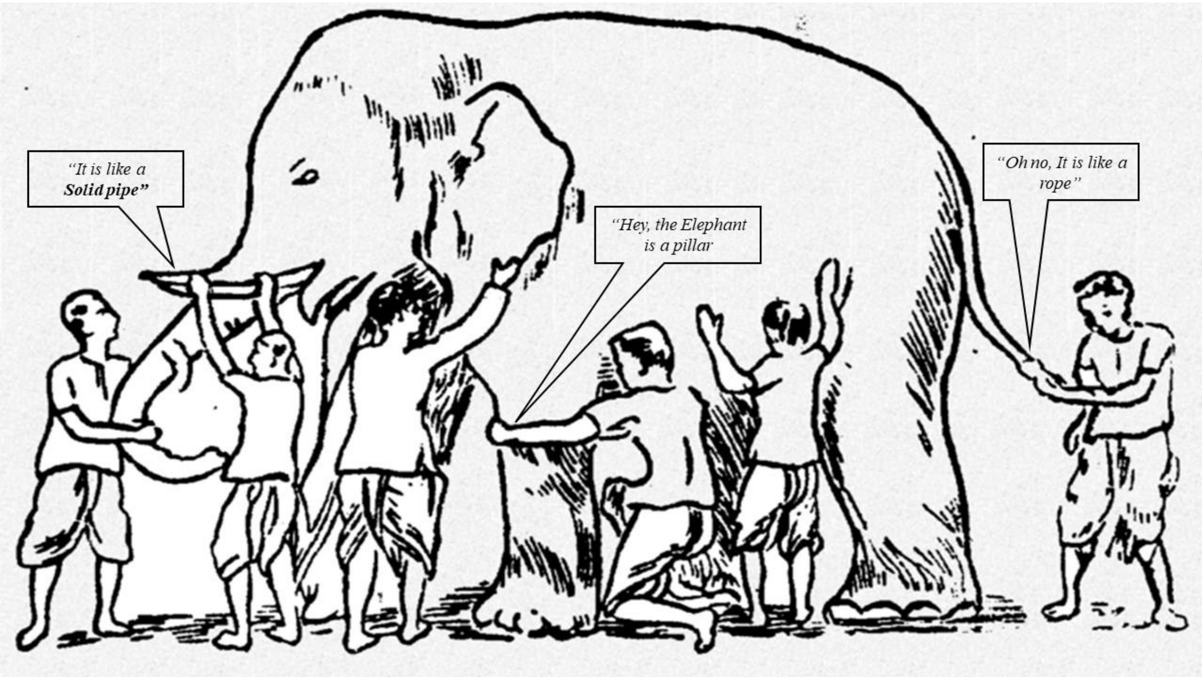


Figure 6: - Before Hydraulic Model

However, powerful software for constructing the distribution pipe network is available. When right data is fed into the models, they produce fast and accurate analysis and design outcomes. This has resulted in a more positive mindset.

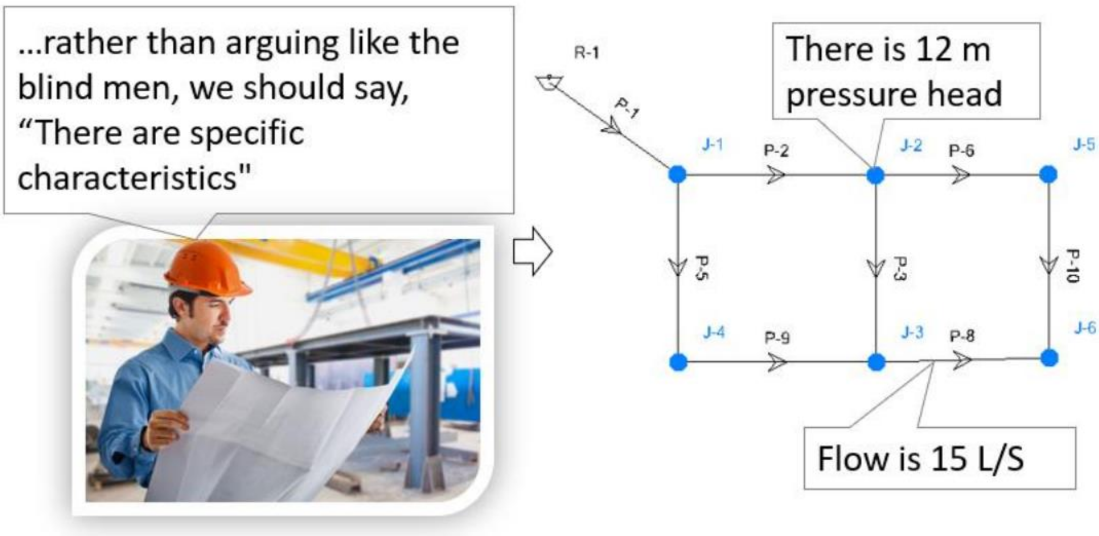


Figure 7: - After Hydraulic Model

We obtain a complete grasp of the hydraulic behaviour of a system by modelling it. A hydraulic model is used to plan infrastructure improvements, define operational and maintenance (O&M) strategies, and manage water systems proactively.

The process of constructing a representation of network modelling of a real water supply or sewerage system using computer software is referred to as hydraulic modelling.

Modelling with Network Software

Base maps are required for creating a hydraulic model. As a background layer in Network software, a GIS base map displaying the footprint of buildings and land use areas such as residential areas, commercial areas, parks, gardens, and roadways is added. The appropriate shapefiles add existing water infrastructure, such as existing tanks and pipelines, to the basic terrain.

- **Creation of Active topology: -** The active topology of current and proposed pipelines is generated using a pipe shapefile and the Model Builder tool of the Network programme. To provide complete coverage, new pipelines are being suggested.

- **Assigning data to nodes: -** Manually assigning data to any large network is highly complex, prone to errors, and may not be accurate. GIS assists in resolving this issue by integrating it with network software. GIS is used to provide figures for ground elevations and water demand to each node of the distribution system.

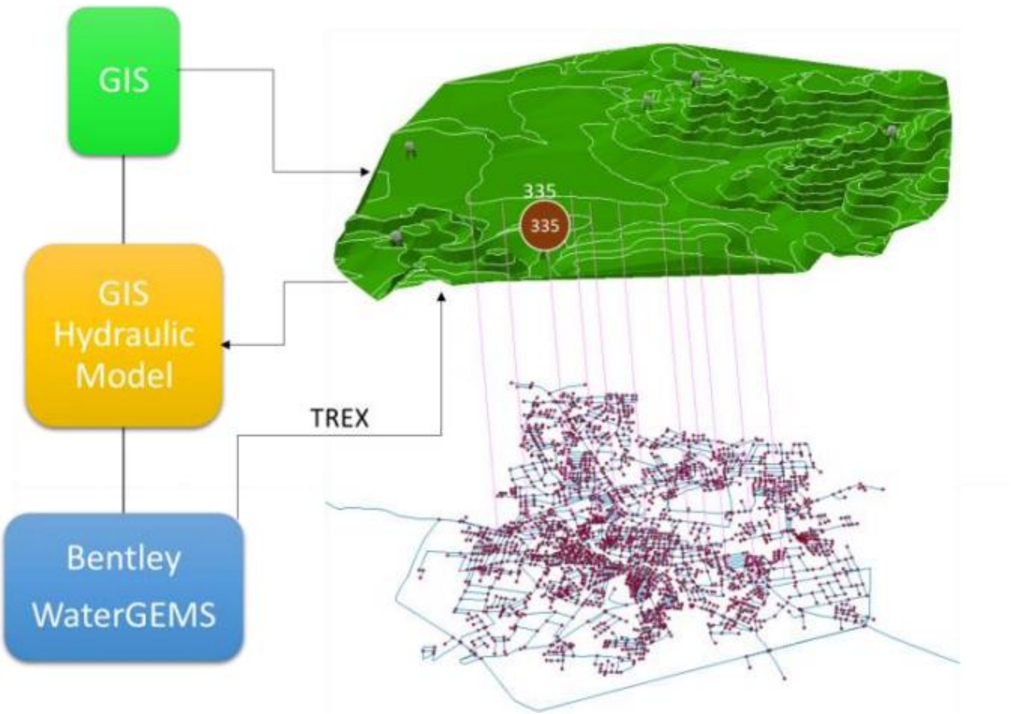


Figure 8: - Integration of Network Software with GIS

Assigning Ground Elevation to Nodes

The Network software's 'Terrain Extractor' (TRex) function automatically assigns ground elevations to each node. The computation is based on the closest elevation value from the GIS contours. The only need is that the GIS contour map lie directly over the geo-referenced base map containing the layer of pipe nodes. This necessitates the use of the same coordinate system for both the contour layers and the pipe nodes. The procedure of allotment of ground elevations to nodes is explained as below: -

Open Network software. In Tools select TRex Wizard. Select 'Data Source Type' as Shapefiles. In 'Elevation Dataset,' select the contour layer and select 'Elevation Field' as "Elevation" (this field stores values of elevations) from the contour layer. After selecting units, the ground elevations are assigned to all the nodes.

Alternately, the ground elevations to the node can be assigned by a shapefile of the geo-referenced points surveyed along the roads.

Assigning Demand to Nodes

The Network software's 'Load Builder' tool assigns demand (Load) values to nodes automatically. The 'Thiessen polygon' and the 'Future Population Density' layers are used in the computation. Each node of the pipe network is surrounded by a Thiessen polygon.

Polygons are generated by network software by a succession of perpendicular bisectors of a line connecting two neighbouring nodes, generating polygons surrounding each node.

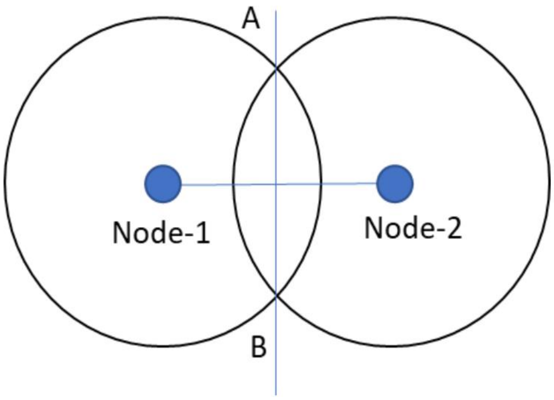


Figure 9: -Perpendicular bisector of a line joining the two adjacent nodes

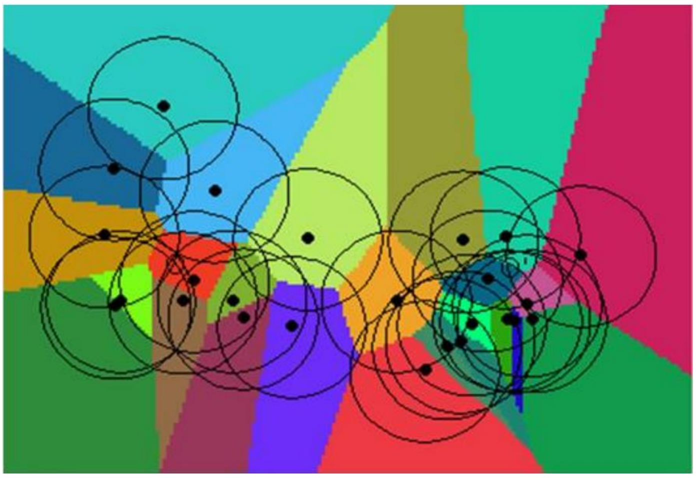


Figure 10: - Polygons formed around each node

The second critical duty is to allocate demands to each node. It is done performed through a tool known as Load Builder. Load Builder interpolates the population density in each of the Thiessen polygons and then assigns a value to the node within that polygon (based on the land use).

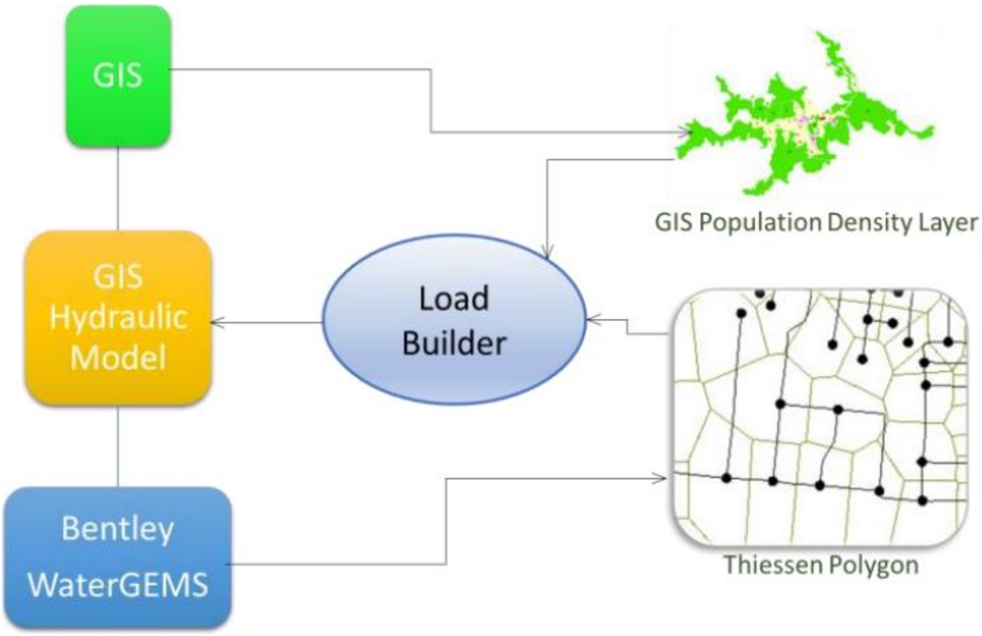


Figure 11: - Assigning Demand to Nodes

Demand data can be processed in three ways: point load, area load, and population/land use data. If customer data obtained from a survey is to be used, the method would be Point Load. The Population/Land Use Data technique is utilised in this publication. The following is an explanation of the procedure: -

Open Network programme and pick Load Builder Wizard from the 'Tools' menu. In the 'Service Area' layer, select the Thiessen polygon layer. Select the population layer as the Future Population Density Layer in 'Population Data', as mentioned in Chapter 4. Select the "PD" population density field (which was previously generated in the Population Density Layer). Choose Population/Hectare as the unit, and then enter a Load Density of 135 (or 150 for metro cities) Litre Per Capita Per Day (LPCD) for each ward name inside the 'Load Use Type' field.

Hydraulic Modelling

GIS (Geographic Information System) has transformed hydraulic modelling by revolutionising how we analyse and simulate water distribution networks. GIS improves the efficiency and accuracy of hydraulic modelling operations by integrating spatial data management and analytical capabilities. This research investigates the different applications of geographic information systems (GIS) in hydraulic modelling, emphasising its role in data administration, geographical analysis, network design and editing, and visualisation.

Data management is a critical application of GIS in hydraulic modelling. GIS allows for the storing, retrieval, and management of a wide range of geographic data essential to hydraulic modelling, including pipe network topology, land use data, elevation data, water demand data, and water quality data. It becomes easier to integrate and organise datasets required for hydraulic modelling by centralising this information in GIS databases. GIS efficiently streamlines crucial data management, resulting in better data quality and accessibility.

GIS software provides extensive spatial analytic tools that aid in accurate hydraulic modelling. It analyses topographical parameters, land use patterns, and hydrological factors, all of which are important inputs for hydraulic simulations. Engineers can use GIS to find optimal infrastructure deployment locations, estimate flood risk zones, and analyse the influence of various factors on water distribution systems. Spatial analysis in GIS allows for more informed decision-making and aids in the optimisation of hydraulic modelling processes.

GIS provides an easy-to-use platform for developing and editing water distribution network models. Engineers may readily build spatially accurate pipe networks, connections, valves, pumps, and other network components using GIS software. GIS makes it possible to modify and update network properties such as pipe diameters, lengths, and connectivity in real time. This capacity allows for more effective network design, system growth, and maintenance, resulting in better hydraulic modelling results.

GIS provides powerful visualisation and mapping capabilities, allowing hydraulic modelling findings to be shown. Engineers can construct thematic maps that visually illustrate numerous characteristics such as pressure, flow, water quality, and network performance by merging hydraulic model outputs with GIS data. GIS visualisation improves understanding of modelling results, allowing stakeholders to readily analyse and share complex hydraulic data.

The incorporation of GIS into hydraulic modelling has transformed the water sector by easing data management, enabling spatial analysis, making network building and editing easier, and improving visualisation capabilities. Engineers and decision-makers can make more informed decisions, optimise system performance, and improve water distribution network operations by employing GIS technology. GIS applications in hydraulic modelling are advancing, providing considerable benefits for efficient and sustainable water management.

4. Internet of Things (IoT)

The Internet of Things (IoT) refers to physical devices embedded with sensors and actuators that connect with computing systems over wired or wireless networks, allowing the physical world to be monitored or even controlled digitally.

IoT connects the digital and physical worlds through a range of technologies. Sensors placed in physical items can monitor things. Temperature, motion, or any other change in the environment—as well as actuators, which receive inputs from sensors and then perform something in reaction to those changes. Sensors and actuators interface with computing systems that can monitor or manage the health and actions of linked objects and machines via wired (for example, Ethernet) or wireless (for example, WiFi, cellular) networks.

Physical items being monitored do not have to be made; they might be natural objects, as well as people and animals. While some organisations may have a broader definition of IoT, our definition excludes systems in which all of the embedded sensors are used solely to receive intentional human input, such as smartphone apps that receive data input primarily through a touchscreen, or other networked computer software in which the sensors consist of a standard keyboard and mouse.

The constant connectivity enabled by IoT, when paired with data and analytics, opens up new options for businesses to create products and services while also increasing operational efficiency. Indeed, since the 2010s, IoT has emerged as one of the most significant developments in the digital transformation of business and the economy.

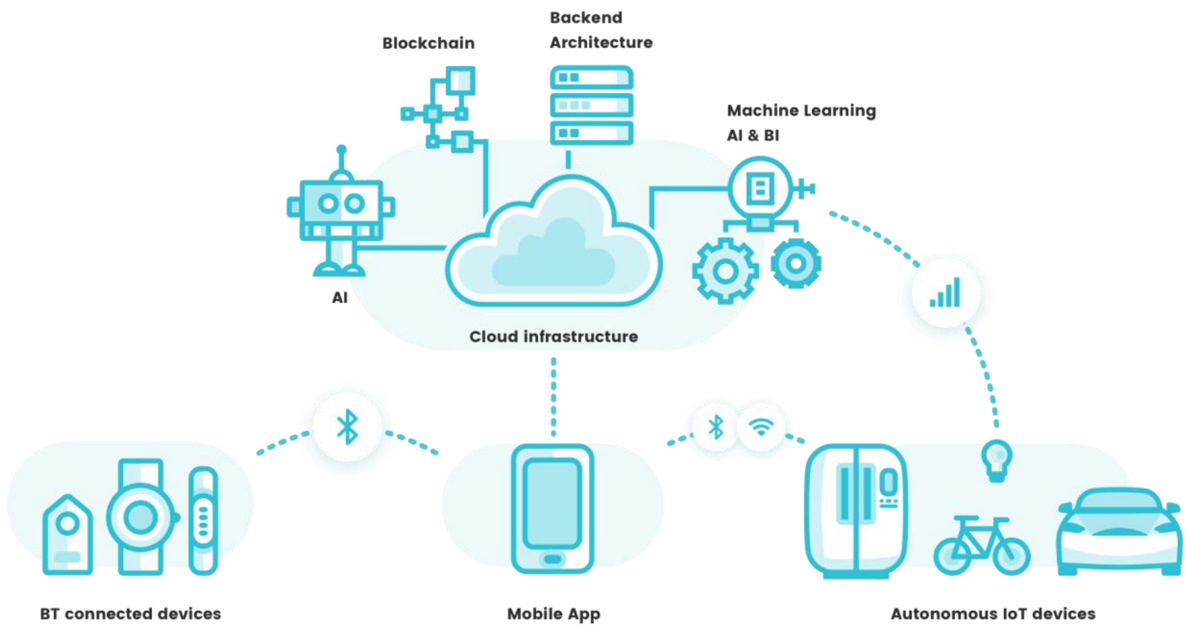


Figure 12: - IoT Architecture

Applications of IoT

Looking at IoT applications, also known as use cases, can help ground the discussion about what IoT is. IoT applications might be found in one of nine different contexts.

- **Human well-being: -** Wearable or ingestible gadgets that monitor or maintain health and wellness, assist in the management of diseases such as diabetes, and other devices can be attached to or implanted into the human body.
- **Home: -** Devices such as home voice assistants, robot vacuums, and security systems can be installed by homeowners.
- **Retail establishments: -** Devices can be deployed in stores, banks, restaurants, and arenas to ease self-checkout, extend in-store offerings, and assist in inventory optimisation.
- **Offices: -** IoT applications in offices could include energy management or building security.
- **Standardised manufacturing settings: -** IoT applications frequently try to acquire information in such contexts, such as manufacturing plants, hospitals, or farms. Increasing operational efficiencies or optimising equipment utilisation and inventories.
- **Environments for custom production: -** IoT applications may be utilised in predictive maintenance or health and safety activities in customised contexts such as mining, construction, or oil and gas exploration and production.
- **Vehicles: -** IoT can aid in condition-based maintenance, usage-based design, and presales analytics for automobiles and trucks, ships, aeroplanes, and railways.
- **Cities: -** IoT applications can be used for adaptive traffic management, smart metres, environmental monitoring, and resource management.
- **Outside: -** IoT applications in urban or other outdoor contexts, such as railway tracks, autonomous cars, or flight navigation, could include real-time routing, connected navigation, or shipment tracking.
- **Real World Applications: -** IoT solutions are being deployed in a variety of scenarios, including refrigerators to assist restaurants in optimising their food-compliance operations, fields to track livestock, workplaces to measure how many and how frequently meeting rooms are used, and beyond.

IoT based Sensor Architecture for Leak Detection System

The architecture of LPWAN networks is straightforward: the last nodes collect data from sensors and link directly to the base station to transmit the information and store it in a cloud database, where the data is analysed and then transferred to be visualised by internet-connected devices. (Computers, tablets, or mobile phones). Because of its architecture, the system is modular. Because the data gathering nodes operate independently, increasing the number of nodes has no effect on the system's behaviour. Another advantage is that each node consumes less power, which increases the autonomy of the connected devices. This type of communication network allows for limited information bytes transmission, yet it is sufficient to identify water leaks. This type of Architecture has four levels: -

Data Collection Level (DCL): - This is the system's fundamental level. The sensors on this level convert hydraulic variables into electrical impulses. The water level in tanks, the pressure and flow inside pipelines, the state of valves, the number of operational pumps in a pumping station, and so on can all be measured. The collection data nodes, where information is recorded and delivered, are self-contained.

Communication Level (CL): - The communication system used must be appropriate for the application of the sensor data. LPWAN networks are designed to communicate with distant elements across a small band. This has the advantage of consuming extremely little energy during gearbox. Based on IoT technology, each device creates an autonomous node. As a result, the inaccuracy of one node has no effect on the correct operation of the others.

Cloud Database & Analysis Level (CDAL): - At this level, the aspects of data storage and interpretation overlap. Cloud data storage enables for remote access to the data collected.

Visualisation Level: - Computers and smartphones/tablets can access the information.

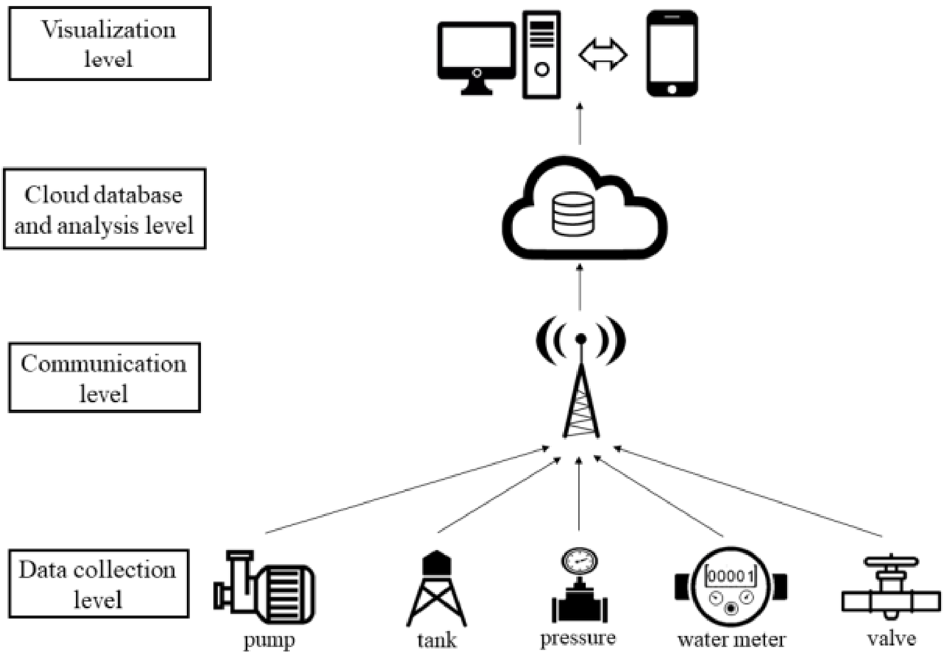


Figure 13: -Typical low-power wide-area (LPWAN) network architecture for water supply systems

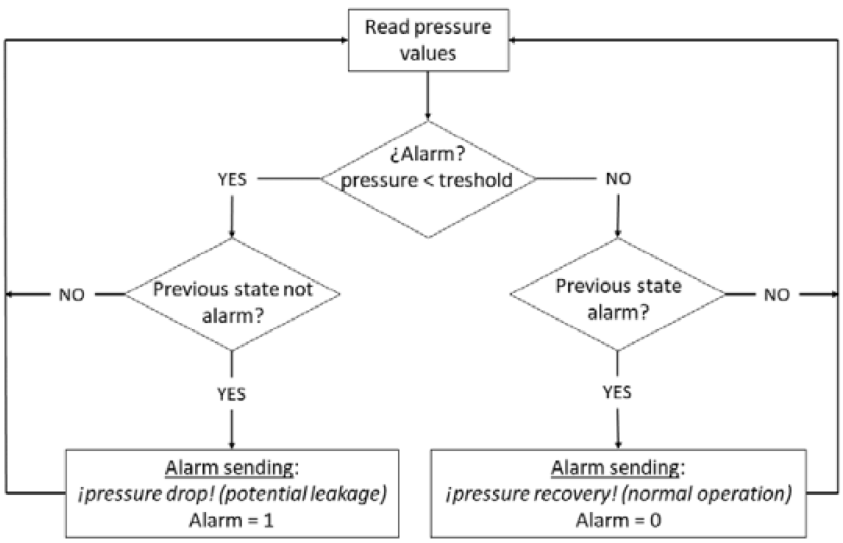
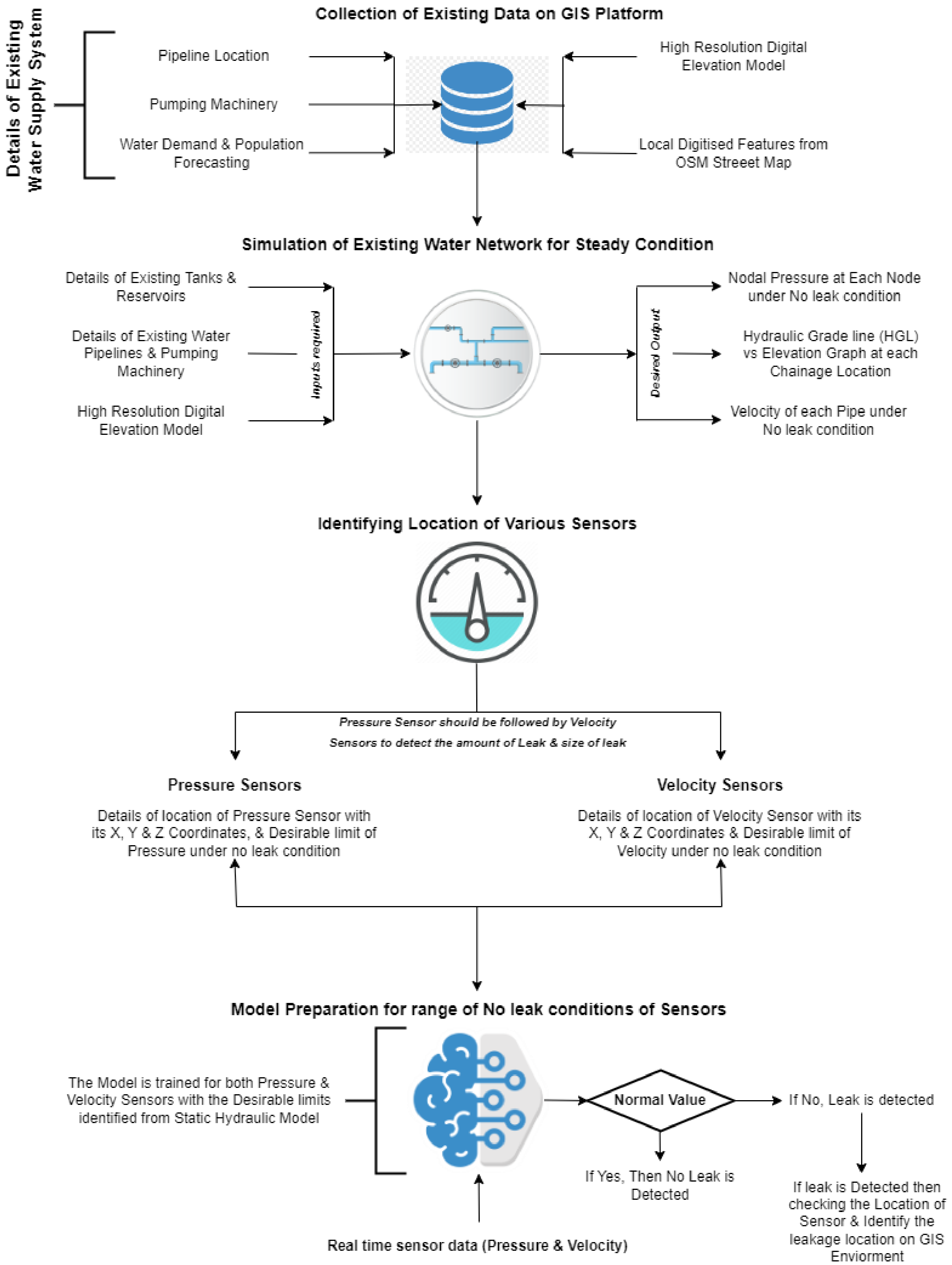


Figure 14: -Analysis of Pressure Deflection

5. Methodology



The network is then statically simulated using software such as Watergems. A geospatial technique is used to identify optimal sensor sites. Based on sensor measurements, a model is created for no-leak situations. To detect leaks, real-time sensor data is analysed and compared to the model. Ongoing monitoring and maintenance assure the correctness and dependability of the system.

i. **Data Collection and Conversion:** The first step is to collect existing pipeline network data. Hardcopy maps, engineering drawings, and any other applicable information may be included. The acquired data is subsequently digitally formatted for Geographic Information System (GIS) analysis. This entails digitising the data and constructing shapefiles that represent the pipeline network's geographical properties.
ii. **Watergems simulation:** Once the data is in the GIS platform, the next step is to simulate the existing network data under static conditions using software such as Watergems. Watergems is a hydraulic modelling software for simulating water distribution networks. The software builds a hydraulic model depicting the static conditions of the pipeline network by inputting essential characteristics such as pipe diameters, altitudes, and flow rates.
iii. **Using a Geospatial Approach to Identify Sensor Locations:** With the simulated static network in place, the next step is to determine the best sites for IoT sensor installation. To analyse criteria such as closeness to vital pipeline sections, high-risk zones, and accessibility, a geospatial technique is used. GIS tools can assist in visualising and analysing the spatial linkages between the pipeline network and prospective sensor locations, assisting in the selection of the most appropriate sensor deployment sites.
iv. **Model Preparation for No-Leak Conditions:** A baseline or reference range for sensor data under no-leak conditions is generated in order to develop the leak detection model. This entails gathering and analysing data from sensors when the pipeline is working normally and without leaks. A model is created using statistical approaches or machine learning algorithms by estimating the predicted range of sensor data under no-leak conditions.
v. **Analysis of Sensor Data and Leak Detection**: Once the IoT sensors are deployed and operational, real-time sensor data is collected and analysed. The data collected is compared to the existing model for no-leak situations. If the sensor values are within the intended range, there are no leaks. If the values differ from the baseline range, it indicates the presence of a leak and raises an alert for further study and action.
vi. **Validation and Continuous Improvement:** Field testing and validation should be performed to validate the effectiveness of the leak detection model. This entails comparing the detection results of the model to known leak cases or generated leak scenarios. Any inconsistencies or restrictions in the model can be recognised and rectified in order to achieve continual improvement.
vii. **Ongoing Monitoring and Maintenance:** Once the system is in place, the IoT sensors and the GIS platform should be monitored and maintained on an ongoing basis. Sensor calibration, data quality checks, and system updates must be performed on a regular basis to ensure accurate and reliable leak detection.

6. Malkapur Nagarpanchayat

Malkapur Nagarpanchayat is located in the Maharashtra district of Satara, which is in western India. The village is located at an elevation of 704 metres (2,310 feet) above sea level. The town is situated on the banks of the Koyana River, one of India's major rivers. The river runs through town and provides water for a variety of uses, including irrigation, drinking, and industrial use.

Malkapur Nagarpanchayat has a tropical climate with hot summers and mild winters. During the monsoon season, which lasts from June to September, the town receives moderate to high rainfall.

Malkapur Nagarpanchayat and its surrounding surroundings are characterised by hills, rivers, and lush green landscapes, making it a lovely place to reside.

The first integrated water delivery infrastructure for Malkapur and Nandlapur villages was completed in 1988, with a predicted population of 14000 in 2010 by utilising the Koyana Riveras perennial source. In addition, the expanding Malkapur town area was supplied with water via 11 borewells. The water delivery rate was 40 LPCD.

The above-mentioned existing water supply scheme was found insufficient to cater the increased water supply need. Hence as per the demand of people of Malkapur Grampanchayat, it was decided to plan and execute 24x7 Water Supply Scheme by adopting Koyana River as perennial source and accordingly the proposal was framed for a projected population of 67196 for year 2037 and submitted to Govt for approval.

Figure 15: -Geographic Location of Malkapur town

Scheme Details		
1	**Cost**	
	Original	Rs 947.54 lakh (Adm. Approval dt. 9/6/1999)
	Revise	Rs. 1225.13 lakh (Adm. Approval dt. 3/8/2008)
	Re-revise	Rs. 1402.92 lakh (with Govt.)
2	**Financial Pattern**	
	Govt. share	90%
	Popular contribution	10% (122.00 lakh collected till date)
3	**Population**	
	Year 2011	31713
	Year 2037	67196 (ultimate)
4	**Rate of water supply**	70 LPCD
5	**Pumping hours**	12 (daily)
6	**Work executed**	
	A) Head works	
	Intake well	3.00 m dia (RCC)
	Inspection well	3.00 m dia (RCC)
	Connecting Pipe	750 mm dia (CI) L-55m
	Approach Bridge	45 m. Length (RCC)
	B) Pumping Machinery	
	Raw water	150 HP (VT) Discharge- 3.25 Lakh Ltr./Hr
	Pure water	75 HP (VT) Discharge- 3.08 Lakh Ltr./Hr
	C) Rising main	
	Raw water	400 m.m. DI L-1840 m.
	Pure water	400 m.m. DI L-155 m
	D) Water Treatment Plant	Capacity -8.00 MLD
	E) Gravity Main	400 to 250 mm DI L-3520 m
	F) ESR/GSR	Total-06 nos, Cap- 36.75 Lakh Ltrs.
	G) Distribution System	
	300 To 150 mm D.I.	L-8.06 km
	140 To 75 mm HDPE	L- 67.17 km
	Domestic water connection (MDPE pipe & with AMR water meter)	Nos - 5997

Sustainable Water Infrastructure at Malkapur Nagarpanchayat

The initiative is sustainable both physically and financially. The water availability in the source "River Koyna" is sufficient for all 365 days of year and years together for the small quantity required by this town. As per the historical data and as per the water release schedule of Koyna Dam which is one of the major dams in the high rainfall zone of Sahyadri's there will be no constraint in availability of water. The system capacity is also sufficient to take care of fluctuation in demand for another 10-15 years. The present requirement can be met by 12-13 hrs pumping. Thus, water resource and system capacity point of view the initiative is sustainable. Financially the initiative is sustainable as the operation cost and the revenue are closely matching and the Municipal Council has decided to increase the rates every year and to keep the sustainable rate. In fact, they have constituted a committee of ruling party, opposition party, experts and those who were opposing the initiative or requesting for lower rates. The committee is given task to propose the rates in such a manner that there will be no loss in operating the system. The recovery levels are also increasing. 60% of the connection holders have tried successfully to keep their consumption within limit so that the water is affordable to them. Some of the big houses who have rented their premises to many families have now started charging them for water in addition to rent just like electricity bills. Thus, the consumption that is charged in higher slab for such houses rented to many families is offloaded to the hirers of the premises. All these minutest planning and convincing the Municipal Council by the nominee and positive orientation of Municipal Council has made the initiative physically and financially sustainable.

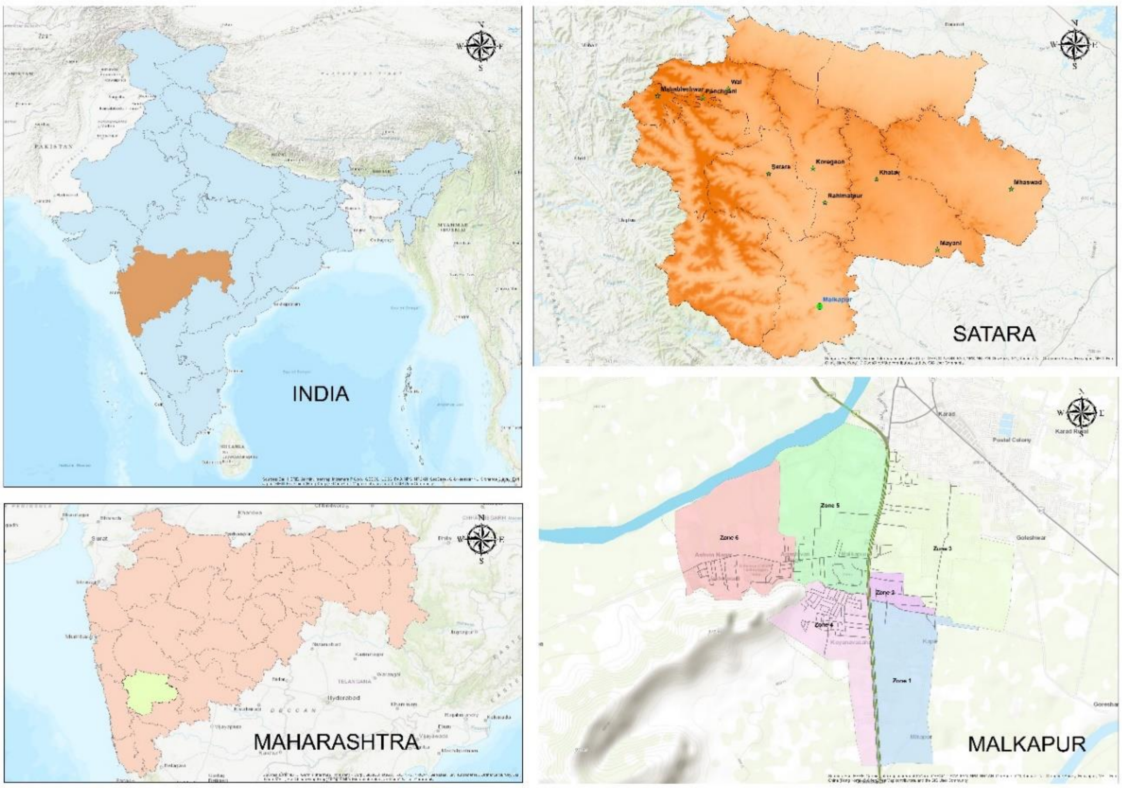


Figure 16: - Study Area Map

Systematic Water Supply at Malkapur Nagarpanchayat

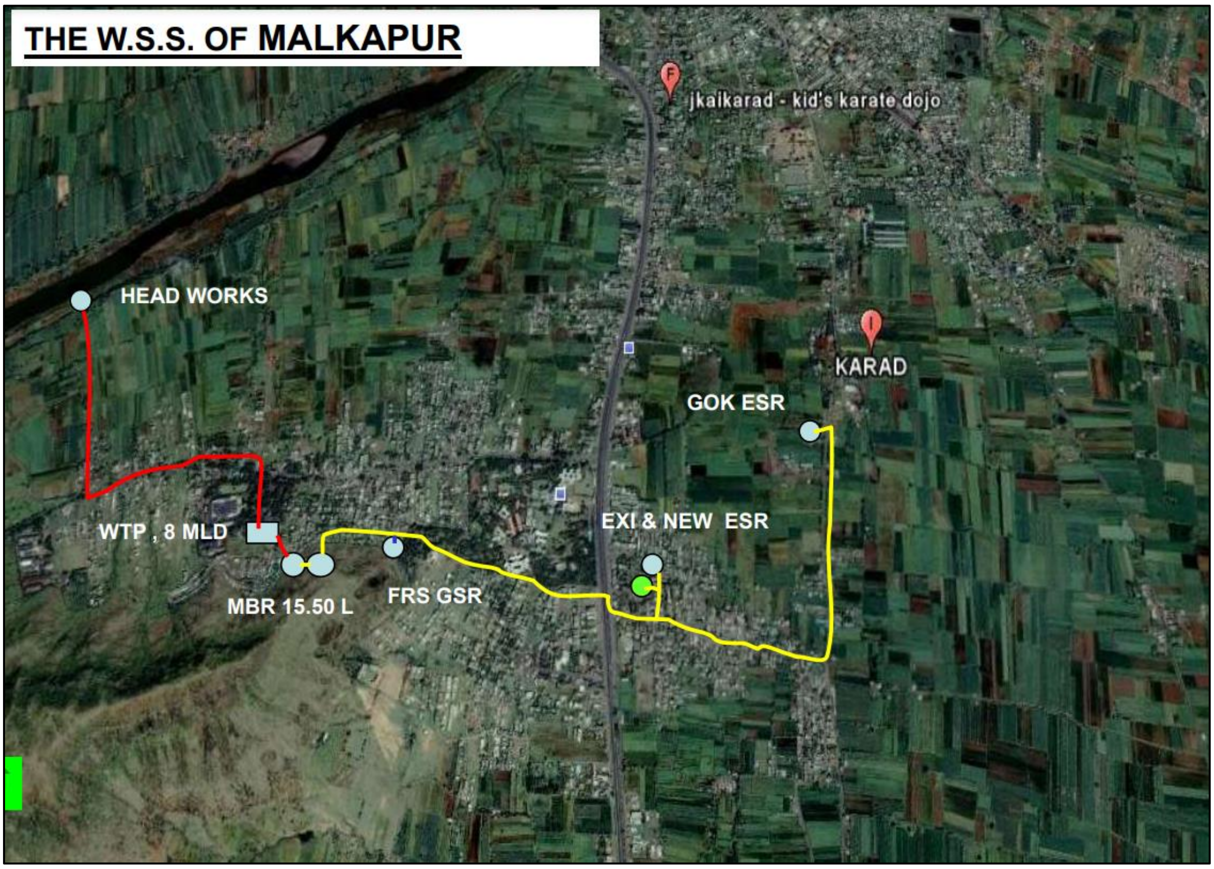


Figure 17: - WSS of Malkapur

- **Water Source: -** The Water Source for Malkapur nagarpanchayat is at Koyana River which originates from Sahyadri Mountain Range and lastly meets at Krishna River near Historic town Karad. The total daily intake for Malkaour Nagarpanchayat is around 8.00 MLD.

Figure 18: - Koyana River

❖ **Raw Water Transmission line: -** Raw Water Transmission line consists of 1840m length having 400 mm dia with Ductile Iron as material. The pipeline is completely underground and has pumping arrangement near Jackwell itself.

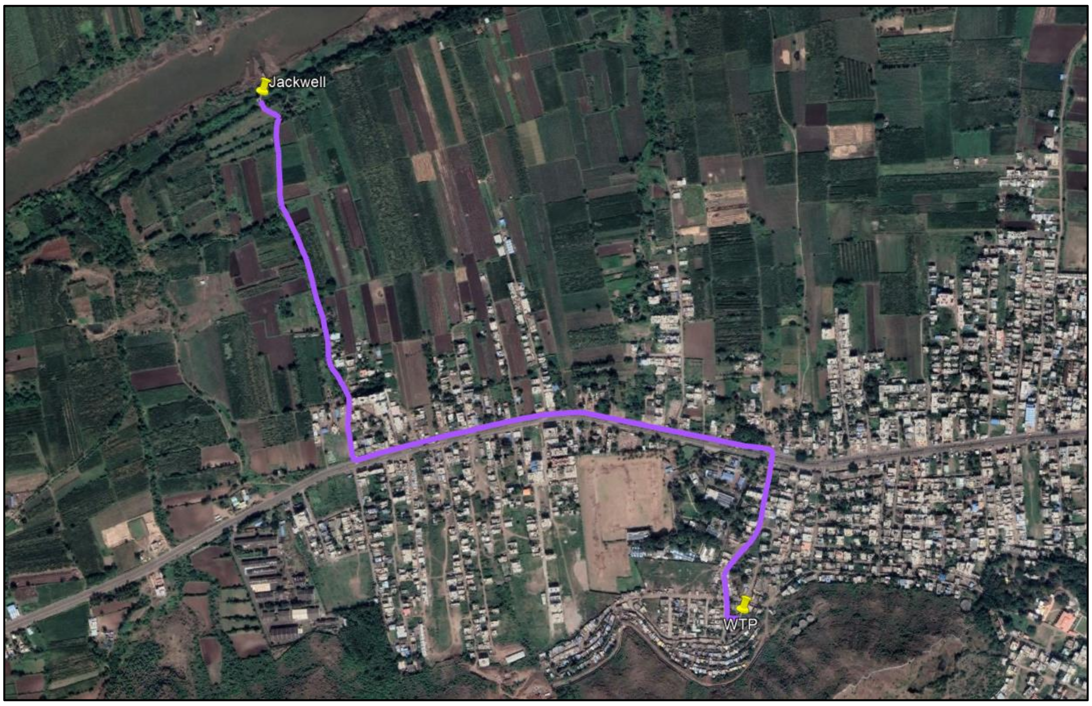


Figure 19: - Raw Water Transmission Line

❖ **Water Treatment Plant: -** Water treatment plant has the capacity of 8.00 MLD with traditional arrangement & sump house outside the premises.

Figure 20: - Water Treatment Plant premises

❖ **Pure Water Rising Main: -** Raw Water Transmission line consists of 2500 m length having 400 mm dia with Ductile Iron as material. The pipeline is completely underground and has pumping arrangement near Sump house itself.

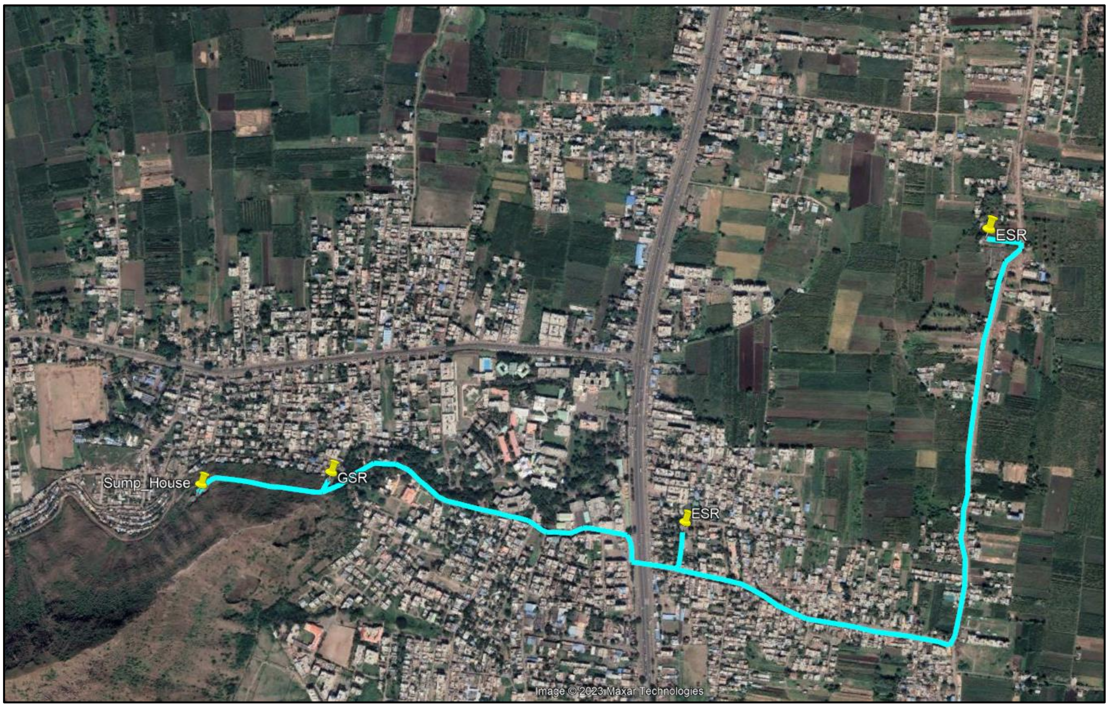


Figure 21: - Pure Water Rising Main

7. GIS based Hydraulic Model

Headworks

The existing Jackwell is shown in Figure 9. From the jackwell water will be pumped to the WTP

Figure 22: - Headworks on Koyna River

Existing Pumps

The details of existing pumps are shown in Table 1

Table 1:- Details of Existing Pumps

Pump Definition	Status	Design Flow (ML/day)	Design Pump head	Working no	Power	Discharge
Raw Water	Existing	8 MLD	12.00m	1	150 HP	3.25 Lakh/Ltr
Pure Water	Existing	8 MLD	10.00 m	2	75 HP	3.08 Lakh/ Lt

Hydraulic Modelling

Modelling of the water supply system is a critical part of designing and operating water networks. It helps the system to serve reliably, safely, and efficiently in daily operations. Hydraulic model gives commanding knowledge of the water infrastructure and help to take informed decisions. Modelling is defined as a mathematical description of a real-world system.

The Modelling Process: - Main objective of any water utility is to deliver safe and potable water to its customers uninterruptedly. The first step in preparation of the model for water supply project is a creation of maps and records.

System Maps: - The hydraulic model in Water GEMS is prepared. Junction levels have been given from the GIS based contours.

Scenarios

One base scenario is created for entire water supply scheme. Two child scenarios are created-for (1) Rising main and (2) Distribution system as shown in

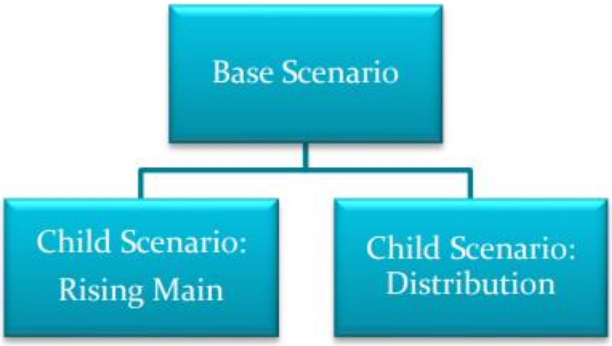


Figure 23: - Scenarios for Hydraulic Model

- **Raw Water Rising Main: -** The steady state simulation was carried out for the complete RWRM for computing Pressure at each nodes & velocity at corresponding pipes. The results are tabulated as follows.

Table 2:- Pipe Results of RWRM

Diameter (mm)	Discharge (cumec)	C Factor	Length (m)	Material	Start Node	Stop Node	Velocity (m/s)
400	0.36	120	100	DI	J20	J-2	0
400	0.36	120	100	DI	R-1	J1	0
400	0.36	120	100	DI	J-2	J20	0
400	0.36	120	100	DI	J1	R-1	0
400	92.59	120	100	DI	R-1	PMP-1	0.74
400	92.59	120	100	DI	J14	J15	0.74
400	92.59	120	100	DI	J15	J16	0.74
400	92.59	120	100	DI	J16	J17	0.74
400	92.59	120	100	DI	J17	J18	0.74
400	92.59	120	100	DI	J18	J19	0.74
400	92.59	120	100	DI	J19	J-2	0.74
400	92.59	120	100	DI	J13	J14	0.74
400	92.59	120	100	DI	J7	J8	0.74
400	92.59	120	100	DI	J6	J7	0.74
400	92.59	120	100	DI	J3	J4	0.74
400	92.59	120	100	DI	J8	J9	0.74
400	92.59	120	100	DI	PMP-1	J2	0.74
400	92.59	120	100	DI	J2	J3	0.74
400	92.59	120	100	DI	J4	J5	0.74
400	92.59	120	100	DI	J5	J6	0.74

400	92.59	120	100	DI	J9	J10	0.74
400	92.59	120	100	DI	J12	J13	0.74
400	92.59	120	100	DI	J10	J11	0.74
400	92.59	120	100	DI	J11	J12	0.74

Table 3:- Results of Junction for RWRM

Node	Demand (MLD)	Elevation (m)	HGL	Pressure (m of H2O)
J1	0	563.63	563.63	0
J-2	92.59	613.33	623.3	10
J20	0	613.33	623.3	10
J19	0	609.04	623.46	14
J18	0	600.04	623.62	24
J17	0	595.49	623.78	28
J16	0	589.05	623.94	35
J15	0	588.12	624.1	36
J14	0	586.77	624.26	37
J13	0	586.4	624.42	38
J12	0	585.5	624.57	39
J9	0	584.19	625.05	41
J10	0	583.74	624.89	41
J8	0	583.96	625.21	41
J11	0	582.78	624.73	42
J7	0	579.01	625.37	46
J6	0	575.57	625.53	50
J5	0	573.38	625.69	52
J4	0	569.94	625.85	56
J3	0	569.15	626.01	57
J2	0	568.43	626.17	58

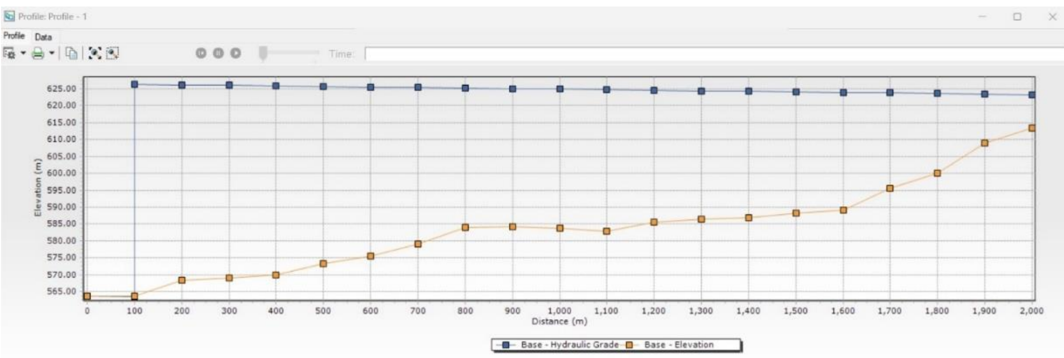


Figure 24: - HGL Graph of RWRM

- **Pure Water Rising Main: -** The steady state simulation was carried out for the complete PWRM for computing Pressure at each nodes & velocity at corresponding pipes. The results are tabulated as follows.

Table 4: - Pipe Result of PWRM

Diameter (mm)	Discharge (cumec)	C Factor	Length (m)	Material	Start Node	Stop Node	Velocity
300	29	120	132	DI	J-3	J-4	0.41
300	93	120	100	DI	R-1	J2	1.31
300	58	120	100	DI	J12	J13	0.82
300	58	120	78	DI	J13	J-3	0.82
300	93	120	100	DI	J2	J3	1.31
300	93	120	9	DI	J3	J-1	1.31
300	29	120	100	DI	J21	J22	0.41
300	58	120	100	DI	J10	J11	0.82
300	58	120	100	DI	J11	J12	0.82
300	29	120	100	DI	J15	J16	0.41
300	29	120	100	DI	J18	J19	0.41
300	58	120	91	DI	J-1	J4	0.82
300	29	120	100	DI	J30	J31	0.41
300	29	120	60	DI	J31	J32	0.41
300	29	120	100	DI	J16	J17	0.41
300	29	120	100	DI	J17	J18	0.41
300	29	120	100	DI	J19	J20	0.41
300	29	120	100	DI	J20	J21	0.41
300	29	120	22	DI	J-3	J14	0.41
300	29	120	100	DI	J14	J15	0.41
300	29	120	100	DI	J28	J29	0.41
300	29	120	100	DI	J29	J30	0.41
300	58	120	100	DI	J4	J5	0.82
300	58	120	100	DI	J5	J6	0.82
300	58	120	100	DI	J6	J7	0.82
300	29	120	100	DI	J22	J23	0.41
300	29	120	100	DI	J23	J24	0.41
300	29	120	100	DI	J24	J25	0.41
300	58	120	100	DI	J7	J8	0.82
300	29	120	100	DI	J27	J28	0.41
300	58	120	100	DI	J8	J9	0.82
300	58	120	100	DI	J9	J10	0.82
300	29	120	100	DI	J25	J26	0.41
300	29	120	100	DI	J26	J27	0.41

Table 5: - Junction Results of PWRM

Node	Elevation (m)	HGL	Pressure (m of H2O)
J3	628.17	633.71	6
J-1	625.67	633.65	8
J2	626	634.35	8
J4	621.47	633.4	12
J-3	609.29	630.75	21
J5	602.63	633.13	30
J7	598.85	632.59	34
J6	597.63	632.86	35
J8	596.75	632.32	35
J9	594.32	632.05	38
J10	591.1	631.78	41
J11	589.49	631.51	42
J15	587.89	630.66	43
J16	586.65	630.59	44
J14	586.49	630.74	44
J12	586.56	631.24	45
J13	585.64	630.97	45
J17	584.87	630.51	46
J28	583.93	629.69	46
J25	584.13	629.91	46
J27	583.76	629.76	46
J19	584.35	630.36	46
J18	584.39	630.44	46
J26	583.36	629.84	46
J31	582.57	629.46	47
J29	582.66	629.61	47
J30	582.29	629.54	47
J32	582	629.42	47
J24	581.69	629.99	48
J20	581.52	630.29	49
J23	580.54	630.06	49
J22	580.2	630.14	50
J21	578.32	630.21	52

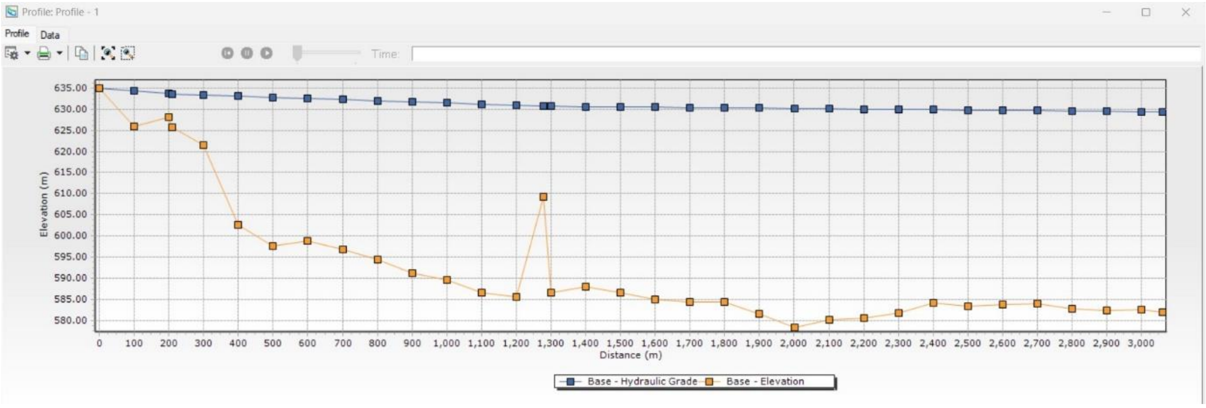


Figure 25: - HGL Graph of PWRM

8. Leak Detection Model

The pipeline leak detection system is based on a steady-state simulated Water Supply network. Bently WaterGEMS, a software package typically used for modelling and analysing water distribution systems, was used to simulate the network.

The pressure and velocity ranges for each sensor in the network were identified during the simulation. These ranges are used to determine whether a leak exists in a given segment of the pipeline. The pressure ranges in the supplied code are manually defined based on the simulation findings.

Bently WaterGEMS' steady-state simulation assists in establishing a baseline for normal operating circumstances in the water distribution system. The expected pressure and velocity values at various sites in the network can be determined by analysing the simulated data. When the system is operational, this information is critical for detecting anomalies like as leaks.

The model then compares the simulated pressure and velocity ranges to the actual sensor measurements. Any reading that falls outside the predefined range is marked as a possible leak. This data is used to build map markers that visually depict the location of the leaks.

Overall, by including the Bently WaterGEMS simulated steady state model into the Python code, the pipeline leak detection system becomes more robust and accurate. It uses the simulation findings to create typical operating conditions, allowing anomalous readings to be identified and offering significant insights for water distribution system maintenance and repair.

WaterGEMS steady-state simulation can analyse the complete water supply network, including pipe networks, pumps, valves, and other hydraulic components. It provides a thorough understanding of the system's pressure and velocity distributions. This data is critical for identifying potential weak points or leak-prone regions. Operators and engineers may effectively monitor the system's health and discover any deviations from the predicted operating conditions by combining the simulation results from WaterGEMS with the real-time sensor readings in the Python code.

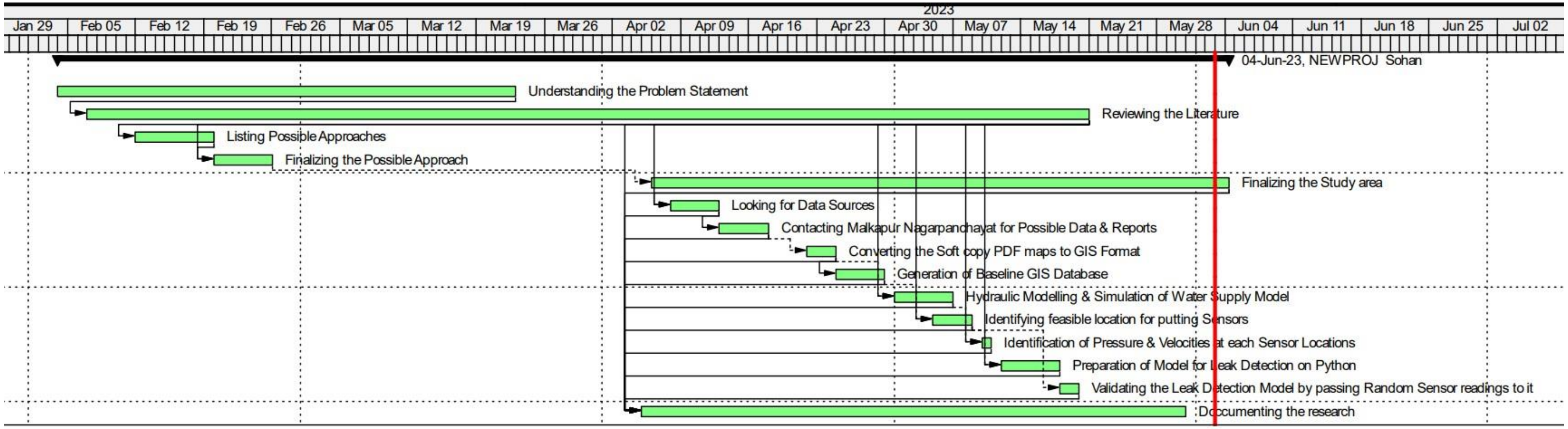
The Python code's visualisation feature, which makes use of Folium and Geopandas, improves the presentation of the pipeline leak detection system. Stakeholders may quickly understand the spatial distribution of leaks and make educated decisions about maintenance and repair activities by plotting sensor locations, pressure ranges, and identified leaks on an interactive map. The map has an easy-to-use interface that allows users to zoom in and out, click on markers for more information, and browse the full pipeline network. This visualisation feature simplifies the comprehension of the results and enhances communication among the various parties engaged in the water supply system management.

9. Project Management

Project management is the practise of planning, organising, and coordinating resources in order to achieve certain goals and objectives within a timeline. It entails effectively managing and executing projects by applying knowledge, skills, tools, and processes.

Activity ID	Activity Name	Start Date	End Date	Predecessors
A-1	Understanding the Problem Statement	3rd Feb 2023	7th Feb 2023	
A-2	Reviewing the Literature	7th Feb 2023	21st May 2023	A-1
A-3	Listing Possible Approaches	12th Feb 2023	20th Feb 2023	A-2
A-4	Finalizing the Possible Approach	20th Feb 2023	26th Feb 2023	A-2, A-3
A-5	Finalizing the Study area	5th April 2023	10th April 2023	A-4
A-6	Looking for Data Sources	8th April 2023	13th April 2023	A-2, A-5
A-7	Contacting Malkapur Nagarpanchayat for Possible Data & Reports	13th April 2023	18th April 2023	A-6
A-8	Converting the Soft copy PDF maps to GIS Format	22nd April 2023	25th April 2023	A-7
A-9	Generation of Baseline GIS Database	25th April 2023	30th April 2023	A-8
A-10	Hydraulic Modelling & Simulation of Water Supply Model	01st May 2023	07th May 2023	A-2, A-8
A-11	Identifying feasible location for putting Sensors	05th May 2023	09th May 2023	A-2, A-9
A-12	Identification of Pressure & Velocities at each Sensor Locations	10th May 2023	11th May 2023	A-2, A-10
A-13	Prepration of Model for Leak Detection on Python	12th May 2023	18th May 2023	A-2, A-11
A-14	Validating the Leak Detection Model by passing Random Sensor readings to it	18th May 2023	20th May 2023	11
A-15	Doccumenting the research	5th April 2023	31st May 2023	A-2, A-5, A-6, A-7, A-8, A-9, A-10, A-11, A-12, A-13, A-14

Gantt Chart for Visualization



10. Uniqueness of our Project

The proposal described in our report stands out in several unique aspects:

i. **IoT Sensor Integration**: Our approach incorporates IoT sensors to collect real-time data on pressure and flow rate within the pipeline network. We enable continuous monitoring of pipeline conditions by embedding IoT sensors, ensuring that any potential leaks are discovered as soon as possible.
ii. **Predefined Pressure and Flow Rate Range**: The pressure and flow rate range is derived using static hydraulic modelling. This method establishes a standard against which real-time sensor readings can be compared. If the readings are inside the set range, there is no leak in the pipeline.
iii. **Python Code for Leak Detection**: A Python code is created and implemented to process sensor data and detect the presence or absence of a leak. The algorithm compares the current values to a preset range derived from static modelling. If the readings differ from the predicted range, there is a leak present.
iv. **Static Modelling for Leak Detection:** Using static hydraulic modelling to determine the pressure and flow rate ranges adds a new dimension to the concept. Using this modelling method, the system can distinguish between typical changes in pressure and flow rate and those induced by leaks, improving leak detection accuracy.
v. **Simplicity and efficiency:** The recommended approach is straightforward but effective. We design a streamlined pipeline leak detection system by combining IoT sensors, static hydraulic modelling, and Python programming. The technology is effective in detecting leaks and reducing false positives, resulting in more accurate and dependable results.
vi. **Cost-Effective option:** The utilisation of IoT sensors, along with static modelling, provides a low-cost option for pipeline leak detection. The approach reduces the requirement for extra complicated equipment or extensive pipeline network upgrades by utilising current infrastructure and modelling methodologies.

Overall, the integration of IoT sensors, the use of specified ranges from static modelling, the use of a Python code for leak detection, and the approach's simplicity and cost-effectiveness distinguish our solution. These features make our concept realistic, efficient, and capable of producing accurate pipeline leak detection results.

11.Conclusion & Recommendations

Study concentrated on the use of GIS (Geographic Information System), Remote Sensing, and IoT (Internet of Things) in pipeline leak detection, specifically in the context of Malkapur Nagarpanchayat's transmission lines. The study simulated the network under static conditions and recorded the leak detection threshold pressures and velocities. Based on sample sensor data, a leak detection model was created that successfully detected leaks.

This study's findings show the potential for using GIS, remote sensing, and IoT technologies in pipeline leak detection. Continuous and proactive leak detection is feasible by using real-time sensor information and executing the established model in the background.

Recommendations

Based on the study conducted, the following recommendations can be made: -

a) **Real-time Implementation:** To enable continuous monitoring and detection of pipeline leaks, the established leak detection model should be coupled with real-time sensor readings. This necessitates the establishment of a dependable and efficient data gathering system capable of transmitting sensor data in real-time to the leak detection model.

b) **Enhanced Sensor Deployment:** Future study should concentrate on optimising sensor deployment along the pipeline network. This includes selecting appropriate sensor types, finding optimal sensor positions, and taking environmental conditions and maintenance requirements into account. The accuracy and efficiency of leak detection can be increased by strategically installing sensors.

c) **Integration of Machine Learning and AI Techniques:** The leak detection model can be improved further by using machine learning and artificial intelligence techniques. The model can grow more precise and capable of distinguishing between true leaks and false alarms by regularly analysing sensor data patterns and including algorithms that learn and adapt.

d) **Expansion to Dynamic settings:** Although the current study concentrated on static settings, pipelines are exposed to dynamic changes in pressure, flow rates, and environmental influences. To confirm the model's usefulness in real-world circumstances, future work should consider simulating and evaluating it under dynamic conditions.

e) **GIS and remote sensing integration:** GIS and remote sensing technologies provide vital spatial and contextual information that can improve pipeline leak detection. Future research should look into integrating GIS data, such as land cover information and proximity to sensitive areas, with the leak detection model to increase leak detection accuracy and prioritise response measures.

f) **Field Validation and Performance Evaluation:** Field validation and performance evaluation should be performed to ensure the feasibility and dependability of the produced model. Installing the IoT sensors and monitoring their operation in a real-world pipeline network is required. The accuracy and effectiveness of the system can be evaluated by comparing the model's detection results with actual leaks.

g) **Cost-Benefit Analysis:** Future work should include a full cost-benefit analysis of adopting the pipeline leak detection system based on GIS, remote sensing, and IoT. This study should take into account the costs of sensor deployment, data collecting, and system maintenance, as well as the possible benefits of leak prevention, environmental protection, and economic savings.

Implementing these recommendations will broaden the scope and effectiveness of the GIS, remote sensing, and IoT-based pipeline leak detection system, resulting in improved leak detection, faster reaction times, and lower environmental and economic hazards.

While our approach aims for high accuracy in pipeline leak detection, it is crucial to highlight that claiming 100% accuracy in any detection system, including pipeline leak detection, is difficult due to factors such as ambient conditions, sensor limits, and system complexities.

Although our concept combines established ranges and static modelling to increase accuracy, external influences or unforeseen events may still result in inaccuracies or false positives/negatives.

Our idea, on the other hand, aims to achieve the maximum possible accuracy in pipeline leak detection by utilising IoT sensors, applying static hydraulic modelling, and employing a well-designed Python code. The combination of these factors allows reliable and quick leak detection, saving response time and lowering the risks connected with pipeline breakdowns.

To improve accuracy, it is critical to regularly validate and modify the system, undertake extensive testing, and adopt quality control procedures. While perfect accuracy is an attainable goal, it is critical to recognise and handle the inherent limitations and uncertainties of any detection system.

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