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A Review on Comparison of Different Water Leak Detection Techniques Suitable for Indian Scenario

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Abstract

Effective management of water distribution is necessary for any country worldwide by reducing water losses during different utility operations. Also in India, water loss is the biggest challenge for the municipalities and local bodies of various states. Different researchers had tried to give attention to this issue and its effective solution through different techniques. In this research papera summarization of different methods used to identify and locate the leakage with its merits and demerits was given. A review of different leak detection techniques from randomly selected research papers in the form of a comparison table considering suitability, methodology, outcomes, and limitations by different researchers suitable for the Indian scenario was also presented.In the end, an effort was made to emphasize the selection of the appropriate method for leak detection and localization of leakage suitable for Indian conditions.

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Introduction

We know water is one of the important gifts given to mankind from nature. Water is the source of happiness, wealth, and prosperity in the daily life of mankind. There are limited available resources of water in the different parts of the world, India is one of them and a decrease in the quantity of it spreads scarcity to the users.[1] Developing countries like India, China, countries of Africa, and Bangladesh have expected more water scarcity as compared to other countries with the consideration of population growth and migration towards major cities of countries.[2] To fulfill this,every major city of India expands its distribution network concerning an increase in water supply demand due to the growth of population as well as the development of the new area in different directions of the cities. In India, around 19% of water is consumed by industries, while around 70% of water is utilized by farming or agriculture.[2] This will result in the need for effective distribution of water throughout the whole country. The demand of water is expected

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to increase in the future in India and the projected demand for water exceeds 50% by 2030 and around 600 million peoples of India face water shortage resulting in 2,00,000 loss of life every year from inadequate access to drinking water.[3] So, the gap between the demand of users to the sources of water supply increasing rapidly in India and in this situation, water conversation, and reduction of water leakage in distribution pipe networks need to be importantly studied.[4] India is one of the developing country and the loss of water in a domestic sector with consideration of leakage is nearly 30% to 40% of the total flow during distribution of water through pipe network.[5] Losses in the distribution of water have a great economic impact on the Gross Domestic Products (GDP) of the country. So, an effective methodology or solution for the better management of the water distribution of the network by minimizing losses will be a great relief to a nation like India, which faces the problems of losses of water from a large network of pipesand difficulties to maintain and operate the water distribution network efficiently withoutany loss of water. In India, the design of pipelines for distribution is based on Continuous Water Supply (CWS) guidelines, and the operational work for the distribution of water is done as per the Intermittent Water Supply (IWS).[6] The main cause of water losses is leakage developed in different components such as distribution pipes, transmission pipes, pipe connections, pipe joints, valves, hydrants as well as the whole distribution system during water distribution operations. The estimated loss due to leakage is considered 70% of total loss in water distribution networks, especially in underground pipelines.[7] Leakage is mainly due to pipe material defects, pipe aging, corrosion, design fault in installation, traffic movement above the pipeline,etc.[8] The basic economic loss due to leakage is the raw water treatment cost and its transportation costincluding erosion of bedding under pipe, pipe breakage, and the foundations of buildings and roads nearby pipes. Therefore, designing a cost-effective solution to identify and locate the leakage is quite needful for all the smart cities of India in the upcoming days for effective management of the distribution of water through a network of pipes. Here in this research paper, an effort was carried outto draw attention to the suitability and comparison of different leak detection techniques suitable forthe Indian scenario. In section 2, the classification, instrumentations, merits, and demerits of different leak detection techniques were presented. While in section 3, a review of different research in the form ofa comparison table with review methodology was given. At the end of a research paper, a discussion based on the literature studied was presented with a conclusion.

Different Leak Detection Methods

There are many different methods adopted by researchers to detect leakage in the water distribution pipe network are Underground Wireless Sensor Network (U.W.S.N.), intelligent sensing and use of Information and Communication Technology (ICT), acoustic detection with noise logger and leak noise correlator, use of hypothesis and algorithm, use of thermal image with Infrared (IR) high-resolution camera, use of Ground Penetrating Radar (GPR), geophysical technique, hydraulic modeling, fiber optic monitoring, tracer gas, multi-model systems and many more. Generally, all smart cities of the developed and developing country of the world have an underground piping network for the distribution of freshly treated water among the city to maintain the beautification the city. So, it is very difficult to find the position of leakage as well as do effective management in the distribution of water without making any losses. If any method is available to find the approximate location of leakage in the pipe network, that will be a great relief to the local municipalities bodies to do repair work in time as well as save the quantity of freshly treated water which is ultimately wasted due to leakage. In this review paper, different methods for the effective management of loss of water are listed and the merits and demerits of each technique are given in section 2. While in section 3, the summary of the research work from randomly selected research papers was presented. At the end, discussion based on the review papers with the concluding part for the suitability or selection of proper technique of leak identification was given for a developing country like India.

Classification of Methods

Leak detection methods can be classified based on instrumentations, objectives, sensors, techniques, flow parameters, and analysis with modeling from the collected data.

Static & Dynamic Method of Leak Detection

In a static method ofleak detection, there is a use of different data collectors and different sensors that are placed within the water distribution network to collect different flow parameters. From the analysis of this data, there is a prediction of leakage from any remote place. These systems are said to static leak detection because all the instrumentation is static and on the predefined location of the network. While in dynamic method of leak detection, we have to depend on the dynamic leak devices that can be moved throughout the entire possible leakage zone. Movement of such devices depend on any previous data of leakage. The main difference between static and dynamic leak detection systems is that in static method of leak detection, it is based on analysis of data and leakage identified immediately with some accuracy. While in dynamic method of leak detection, we have to rely on the information of leak possibilities or past data of leakage. Also, the dynamic method give approximation location of leakage as well as it is time-consuming as compared to static method of leak detection.[9]

Acoustic & Non-Acoustic Leak Detection

In the acoustic leak detection system, measures the sound generated by leakage with the use of different acoustic devices such as listing rods, ground microphones, noise loggers, aqua phones, geophones, etc. In this method, heavy instrumentation is required and placement of such devices in the pipeline is another issue. Also, the small leakage in the pipe, which generates very little noise has not been detected effectively. Localization of the leak is also difficult with the use of this type of devices, which are placed far from the actual position of leakage. While, in the non-acoustic method there is a use of different sensors to monitor flow, pressure, temperature, vibration, etc., to collect the data, and then after different modelling and algorithms techniques have been used to analyze such data. As there is a collection of different flow parameters with the help of sensors in this method, small or minor leakage is also identified and localization of leakage can also be done by the analysis of such data.

Traditional & Modern Leak Detection

Traditional methods used for decades to find leakage such as physical monitoring of pipes, use of robots in the pipeline, acoustic methods, use of thermal images, etc. Heavy instrumentation is required in these methods and very difficult to use in the case of underground pipe networks. While in modern techniques, there is a use of different types of sensors to collect data with the platform of ICT or Internet of Thing (IoT), and analysis of the collected data has been done using different algorithms and modeling techniques. In modern techniques, leakage can be identified and localized from any remote place while with the use of traditional methods there may be physical visits made through a complex pipe network before or after.Use of traditional methods required more man power as compared to modern technique.

Table 1: List of Different Leak Detection Techniques

Leak detection method	Instrumentation	Merits	Demerits
Wireless Sensor Network method (W.S.N)[10]	Flow Sensor, Pressure Sensor, Temperature Sensor, Humidity Sensor, Vibration Sensor, pH Sensor Microcontroller, . Cloud network, etc	• Very effective in leakage identification from real-time data. • Effective in localization of leakage. • Remote monitoring. • Required less manpower. • Also, able to monitor by the end-user.	• Optimization of several sensors and placement of sensors is very difficult. • After collection of all data, to analyze and prediction of leakage from collected data there is a need for an algorithm or modeling or machine learning technique. • Based on internet connectivity

		• With the use of different types of sensors all flow parameters observed and contamination can also predict if a pH sensor is included. • Effectively used in all-weather conditions as well as in all types of topographic conditions.	so better network required • Power consumption is more in some types of sensors. • Sometimes give false alarm. • Initial implementation cost is high. • Skill required for initial setup of sensor technology.
Acoustic method[11]	listing rods, ground microphones, noise loggers, aqua phones, Electrical & Mechanical Geophones, and Hydrophones.	• Accurate leakage identification and localization with in the range of devices. • Cheap to purchase. • Easy in installation. • Most suitable in metallic pipelines. • Provide fast onsite leak detection. • Low maintenance and low replacement battery cost.	• Hydrophones are costlier than geophones. • Heavily rely on human sense. • For real-time monitoring cost is very high. • Unable to identify the exact location of the leak without correlators. • Less accurate while pipelines are placed on a surface with a noisy environment.
Thermal Images with Infrared camera[9]	Thermography Camara/ Infrared Camara	• Effective in the case of surface pipelines. • Not affect the traffic and population. • Independent of pipe material, size of pipe, and network of pipelines. • Can be used day or night time.	• Not reliable in the case of damaged pipelines • Not all-weather techniques as on rainy days it is not useful. • Groundwater table influences the use of IR cameras. • Rotating the speed of the camera and the speed of the vehicle affects the actual result.
Ground Penetration Radar (GPR)[9]	Radar system	• Detect leakage independently irrespective of type of material used for pipe, and the size of the pipe. • Does not require a skilled person	• Require access for the road, which is above the pipeline. • Disturbance for traffic while the inspection is going on. • Depend upon pipeline bedding and surrounding condition • Instrumentation is costly.

Comparison of Different Leak Detection Methods

Many methods are available to detect leakage in pipe networks but practically before implementation of any method in the real scenario the laboratory experiments, analysis of data, and validation of the output must be carried out to check the effectiveness of the method in particular conditions. With the above consideration, the advantages and disadvantages of different methods with the instrumentation are summarized below in table 1 for the comparison and appropriate choice of leak identification method in the related case.

Table 1: List of Different Leak Detection Techniques

Leak detection method	Instrumentation	Merits	Demerits
Tracer Gas[9]	-	• Suitable for all types of pipe material. • Effective in the surface pipeline because the gas which is lighter than air is used. • Good for small-size pipelines.	• Not conventionally used in larger pipelines • For detection of leakage in a particular pipeline, the flow of water in another pipeline should be blocked. Hence, interruption of service. • Not suited for buried pipelines.
Hydraulic Modeling	-	• All flow parameters can be a measure • Effective in leak identification • Different scenarios can be created	• Calibration of the model is required • Collection of real data required for validation.
Fiber Optic Monitoring[12]	-	• A large number of nodes can be covered with a single fiber • Less maintenance and operating cost • Effectively used in less power zone or industrial zone. • Used in all-weather conditions.	• Physical parameters like temperature and pressure can affect the performance of fiber optic.
Genetic Algorithms (GA)	Algorithm model	• Less time consuming • More efficient than the conventional method • Once the system is established very cost-effective. • Simulation of different cases is possible.	• Different algorithm models used by different researchers. • Validation of model required before implementation in a real scenario. • Depend on the data given by sensors.
Artificial Neural Network (ANN) method	-	• Quick identification of leakage possible from the collected data. • Accuracy can be increased by adopting different approaches in ANN	• Without accurate simulation, it gives a false result • Skill person required to develop the neural network as per the case.

Table 2: Summary of review papers

Reference	Area for case study	Objectives	Methodology used	Suitability	Outcomes after the research work done	Limitations	Research Gap
[4]	Mandya (Karnataka, India)	Detection of a leak in water. pipelines	A Particle Filter (PF) algorithm was used in the simulation.	Suitable in the area where a branching pipe network is used for water distribution.	PF algorithm effectively used for flow estimation in a tree type distribution network of pipe. From the simulation, a leak is identified.	Not applicable to loop network Only flow parameters were simulated while pressure parameters were oscillating hence not included in the study. Use of many flow measurements will result in overall increase in the cost of system instrumentations.	Further research is required to apply in the looped network of pipes and study is also required to optimize the ratio of flow measurements to pressure measurements
[13]	-	Detection of leakage & localization of leakage	Mathematical model used with multi-sensor fusion data as well as Internet of things (IoT).	In all types of networks for water distribution.	Elaboration given for different mathematical modeling with the use of fusion concept for leakage detection. Concept wise fuzzy logic is more suitable for this type of. modeling With respect to Indian framework there is a need for an Automatic and Intelligent Integrated System (AIIS)	Research based on modelling technique no real case study with real distribution network included.	There is a different case scenario in real physical infrastructure for Water Distribution Network (WDN) in terms of material of pipelines, type of soil around pipe, population of area, topography of area, etc.

Table 2: Summary of review papers

Reference	Area for case study	Objectives	Methodology used	Suitability	Outcomes after the research work done	Limitations	Research Gap
[14]	-	Flow control &Quality Measurement	Wireless sensors using IoT	Only Flow control is there. No discussion in the case of leakage.	Flow can be controlled by the distribution team at remote places resulting in reducing manpower. Water quality can be observed by a pH sensor.	Chances of false prediction if the proper data from the sensor is not transmitted properly. No matter discusses the output received from sensors in the case of leakage.	Methodology suggested but no clear idea is given on which flow parameters it depends. Any real case scenario not included in the research.
[15]	-	To find more accurate prediction techniques for leakage detection and leakage localization.	Optimization algorithm and mathematical process using a hybrid Artificial Neural Network Model	Suitable for linear pipe distribution network.	Improvement in leak detection capability by introducing a modern fluid flow simulator by replacing a simple model.	Toor detects leakage in the pipe only pressure fluctuations have been studied. Consideration of only linear pipelines without considering other pipelines.	Tree and branching network of the pipeline not included in the study. Only pressure fluctuations have been studied instead of all flow parameters,
[16]	Simulated data used of water distribution network of CSIR-CEERI, Pilani into EPANET Tool	Leakage identification and locate the leakage in a water network.	Support Vector Machine (SVM) Technique.	More suitable where large size pipes were used for distribution.	With the use of the SVM technique on the data generated of pressure and flow, it detects leakageand non-leakage points and also predicts the size of the leakage as well as location of leakage.	Accuracy is more in the case of large sizes of leakages but at the same time accuracy is decreased up to 50% in the case of the small sizes of leakage. Sometimes the actual leakage node and predicted nodes may be different or nearby.	Application of data from sensors should be incorporated to use this prediction model from any remote place with any internet-connected device.

Table 2: Summary of review papers

Reference	Area for case study	Objectives	Methodology used	Suitability	Outcomes after the research work done	Limitations	Research Gap
[17]	-	Introduce a sensor placement method for Contamination Detection in Water Distribution Network	The review is given on available methodologies for sensor placement	Method is given for contamination detection.	Comparison is given of single objective sensor location and multi-objective sensor location methodologies.	No consensus amongst researchers on sensor location problems, so not finalized any method for sensor placement in the water distribution network for contamination detection.	No discussion on which type of sensors has been effectively used for contamination of water.
[5]	A prototype of various scenarios has been used.	Leakage Detection	Introduce a wireless cloud base data logging with a GPRS module.	Suitable in the identification of leakage in different types of work but fail to give the exact location of leakage	Prototype designed in this research is an effective solution for monitoring the flow rate and leak detection for pipes.	Developed system in this research only capable to detect leaks between any sensor nodes rather than the pin point the location of leakage	Leakage identified between places of two sensors. Hence it is not localized or rather difficult if the distance between sensors is more.
[18]	-	Billing of water supply to user, Quality Monitoring of supplied water, and automation of distribution line.	Wireless Sensor Network Method is used.	From observing Quantity parameters amount of loss of water can be observed but fail to pinpoint the leakage.	Optimization of pump speed, of electric power and overflow from elevated storage. Various quality and quantity parameters collected with the use of a wireless sensor network.	Only Monitor Quality and Quantity parameters.	No discussion or methodology suggested for loss of water i.e., leakage detection and localization of leak.

Table 2: Summary of review papers

Refe-rence	Area for case study	Objectives	Methodology used	Suitability	Outcomes after the research work done	Limitations	Research Gap
10	-	Detection of Leak and exact location of leakage.	Wireless Sensor Network method with the use of different types of sensors like pressure, flow rate acoustic, and tempe-rature.	Suitable in Major distribution cases.	Leakage identification with the help of profile of relative pressure change. Suggested method reducing in the help of losses of water during utility operations.	-	No real case study was taken.
19	-	Leak Detection	The wireless sensor network method	Location of leakage was not possible but identification of leakage through the distribution system was possible.	Leakage identification methodology suggested with different parameters	High consuming power equipment has been used.	Only Variation of data captured by sensors was presented but no Modelling technique or algorithm was presented for the analysis and prediction of leakage from collected data.
20	-	Gas leakage detection in the industrial sectors.	The wireless sensor network method	Suitable for gas pipeline network.	Gas leakage identification was done with the help of a gas sensor using the LabView tool.	-	Effectiveness in the case of water leakage is not included.
21	-	To detect the leakage	Wireless sensor Network Method	Suitable in pressure pipe	Leakage detection using water pressure	-	Not all flow parameters included.

		in the pipe-line in real-time.	with Zig-bee Module	distribution network.	sensor by comparing median and threshold value of pressure using MATLAB software.		
Refe-rence	**Area for case study**	**Objectives**	**Methodology used**	**Suitability**	**Outcomes after the research work done**	**Limitations**	**Research Gap**
[22]	Laboratory model developed	Leakage detection in pipe-line and blockage detection for the hilly regions.	Wireless sensor Network using the capture of vibrations of pipes.	Suitable for the hilly regions	Leakage detection in plastic pipes for water supply with the analysis on vibration on the surface of pipe with the use of high Signal-to-noise ratio Accelerometer.	Suggested method depend on the vibration of the pipe's surface, so a small leak that creates no vibration may not be identified.	Research study does not include the effect of vibration sensors for flat or plain regions.
[23]	-	Tracking of water level in reservoir and conta-mination Monitoring of Leakage	Use of IoT with LabVIEW software.	Suitable for all types of networks.	IOT based method suggested	Validation of method not included	Yet to be tested and validated before implementation in the real scenario.

Literature review

The literature review presented here was based on the research papers published in peer-reviewed journal in the field of effective management of water losses, observation or monitoring of different flow parameters during distribution of water in pipe network, leakage detection in the water distribution network, and some cases studies of leakage identification. Different search strings were used to search research articles like “Losses in the water distribution network in India”,“Leakage identification in the distribution network in Indian condition” and “Water scarcity in India”. Numbers of papers were found addressing the losses of water and leakage detection methods inthe Indian scenario as well as in other developing countriesas the problem was an older one. In this review paper, recent research papers published from the year 2014 to 2021 were considered. A detailed reading of the abstract and conclusion was done to classify and compare the articles based on analysis, method, and instrumentation used, Suitability in a particular condition, outcomes, and limitation of the research work. A detailed comparison of the above-stated points of the most recent research work randomly selected from the collected research papers was presentedhere in table 2. The limitations of the research work also presented to select the appropriate methods among the available methods in particular conditions. India has a wide range of variations in the distribution network of pipes based on topographical conditions, geographical conditions, the layout of the pipenetwork, different water supply systems, water source location, water demand in different sectors, and pipe size. So, the choice of a leakage detection system may be different in different conditions. A detailed discussion on this was given after this section for better implementation of a suitable method of leakage detection to minimize the losses of water.

Discussion

The Government of India (GOI) launched the mission ‘Smart Cities in India’ in 2015 for 100 cities within the country. To become a smart city GOI decided on many parameters, adequate water supply is one of them. So, there is a great chance to implement or introduce any techniques which result in effective management of loss of water during distribution through a complex and huge piping network. As found from the review of research papers there are many methods to identify the leakage and localize the leakage to reduce losses resulting in better management of water distribution. Water leakage is found using acoustic devices in developed countries based on vibration or sounds generated by the pressurized pipe, While in developing countries major leaks are found only when they appear on the surface of roads in case of underground pipe network which is resulting in a considerable amount of wastage of water.[5] From the review of research papers, it was found that in earlier days acoustic method is mostly used in developed countries for leak detection but nowadays the use of IoT, wireless sensors, machine algorithms, and neural network techniques have increased as compared to the traditional method. As there are many existing leak detection techniques the selection of a proper leakage identification method will depend on many parameters such as flow parameters, pipe aging, the distribution network of pipes, pipe material, full supply or intermittent supply, size of pipe, underground network, surface network, water source, fund allocation, awareness of local bodies, etc. It is very difficult to select and rely on any method because effectiveness in individual cases may be different from case to case. Different research work is carried out by many researchers in this direction and as a result, the implementation of any leakage detection method depends on many parameters as each method has its own merits and demerits. The comparison of different research work carried out recently shows there is different instrumentation is needed for each method. In India, most of the cities supply the water with IWS systems that means less than 24 hours per day resulting in distribution with pressure. So, major parts of India have underground pressurized pipe networks for the distribution of drinking water. In this situation, the leakage detection method which dependsupon the flow parameters that are flow and pressure give better result as compared to the methods which are used for the CWS system. Also, we have to see the feasibility of the implementation of different instrumentation for different methods in the already developed underground water distribution network of the city without disturbing the supply of water.

Conclusion

From the study and comparison of different methods and looking at the fact that in the Indian

scenario most of the cities have IWS systems with pressurized pipes in underground water distribution networks, the Wireless Sensor Network(WSN) technique is more suitable with the use of IoT in most of the cases for identification of leakage. WSN technique is the latest and most modern technology to detect leakage in the pipelines as compared to the traditional method and it has many advantages which overcome the limitations of other methods. To locate the leakage, we have to use mathematical modeling or machine learning algorithms or use of any artificial intelligence technique from the collected data by wireless sensors. The advantage of using a wireless sensor network is its suitability in any situation, fewer instrumentations require, the system once established can be used for a long time, and collection of data from sensors can be done from any remote place. This system could be easily implemented in the already established water distribution network. However, more research work should be carried out to implement WSN technique effectively in terms of an optimum number of sensors, cost of the sensor, the accuracy of the sensor, placement of the sensor, method for analysis of data received by sensors, effectiveness in a real scenario, and validation of simulation of the model.

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Conflict of Interest

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