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Smart Water Management

Pranav Pradhan
pranavpradhan00721@gmail.com
Pune Vidyarthi Griha's College of Engineering and Technology, Pune, Maharashtra

ABSTRACT

The shortage of water supplies has emerged as a pressing worldwide issue in a world that must contend with the twin problems of a growing population and climate change. The need of effective water management has grown, and it is all too easy to see the results of carelessness and human mistake in managing water resources. Artificial Intelligence (AI), however, is a promising solution in the realm of computer science. A developing area of computer science called artificial intelligence has the power to completely alter how we manage our water resources. Computers, as opposed to people, are known for their accuracy and dependability. Utilizing AI in water management could not only correct past mistakes but also save millions of litres of water each year, thereby helping the world's population, which is always expanding. At its foundation, smart water management comprises effectively managing water resources with the least amount of human involvement. Data-driven "intelligent" applications have already revolutionized many elements of our daily life in the digital age. Water utilities that are forward-thinking can greatly improve their operational performance by using this digital technology revolution. For water utilities starting their journey toward digital transformation, this abstract offers an introduction to the core AI ideas. It puts a strong emphasis on streamlining water distribution processes and dealing with the urgent problem of unaccounted-for water. Water utilities may use a wealth of data and information to improve service delivery, lower operating costs, and make better decisions by utilizing the power of AI algorithms and big data analytics. This succinct review describes the wide-ranging uses of big data analytics and AI-related algorithms in the water supply industry. It also explores how water utilities might use AI to predict and reduce unaccounted-for water, a problem that persists in the industry. Finally, actionable suggestions for implementing AI are offered, along with first cost projections.

Keywords: *Artificial Intelligence, Water management, Hydraulic Modelling 1.0, Hydraulic Modelling 2.0, big data*.

I. INTRODUCTION

Applications that use data to make them "intelligent" have disrupted ordinary life. This digital technological revolution can help innovative water utilities function better. By using the artificial intelligence algorithms and big data analytics, water utilities can maximize information and data available to make better decisions while enhancing service delivery and reducing costs. For water utilities beginning this digital transformation to improve their water distribution operation in general and to handle unaccounted-for water problems in particular, this brief outlines the fundamentals of artificial intelligence. The executive summary outlines some of the most extensive applications of big data analytics and AI-related algorithms in the water supply, discusses how water utilities can test AI for the prediction of unaccounted-for water, and offers implementation suggestions as well as rough cost estimates. With the help of data analytics, regression models, and algorithms, AI can simplify the process of managing water resources. The development of effective water networks and systems is facilitated by this cutting-edge technology. Building water facilities and determining the state of water supplies are both possible with AI. Government agencies and water managers can utilize AI to create a smart water system that can provide effective infrastructure for managing water and can adapt to changing circumstances. These technologies, which can maximize all water management options and foresee possible hazards, will be affordable and sustainable.

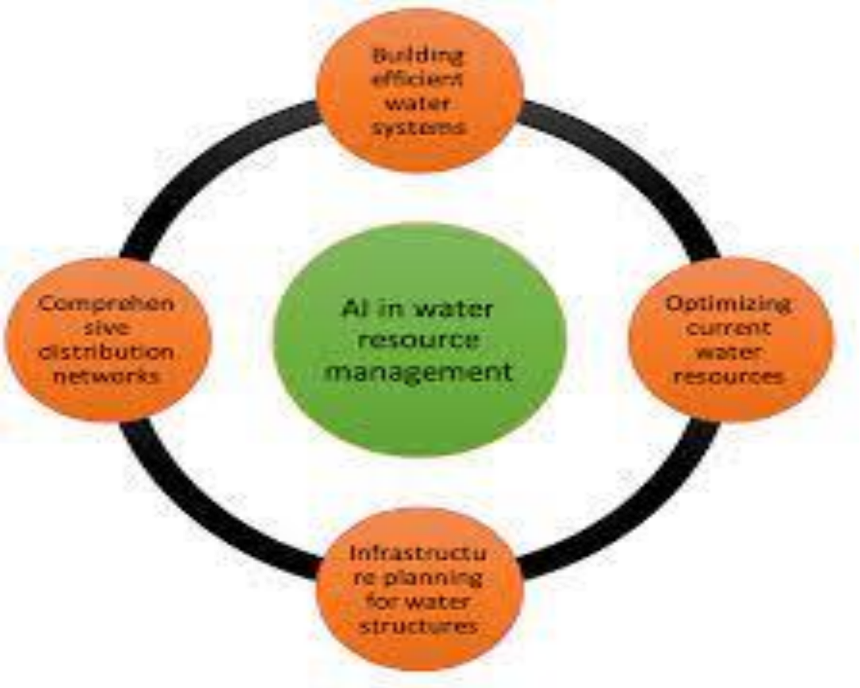

Figure 1.1 AI in water resource diagram chart

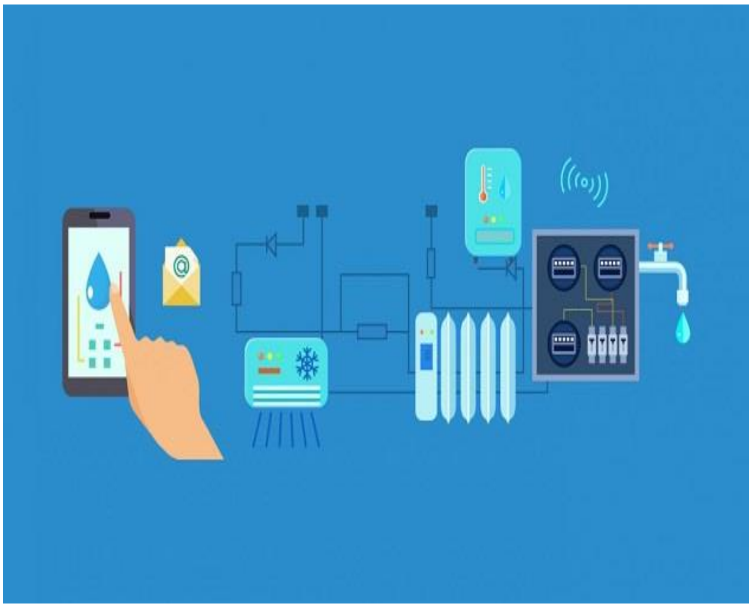

Figure 1.2 Using mobile interface for smart management of water

1.1 Managing Water Wastage

An India Today report states that it is estimated that around 40% of piped water in India is lost to leakage. According to a US EPA report, an average family can waste 180 gallons of water per week, or 9400 gallons of water annually, from household leaks, which is equivalent more than 300 loads of washing would use in terms of water. AI and IoT can help us use less water because of leaks, burst pipes, and other issues. The quantity of water wasted can be reduced by using AI to evaluate real-time water loss and automating pipes to shut off anytime there is a leak. AI can predict leaks in storage tanks and help in mending them before it is too late. Devices connected through IoT can communicate better and integrate various systems across a city or place.

1.2 Wastewater Treatment

AI can be used to reduce pollutants in the water which in turn decreases water contamination and scarcity of clean water. Since AI is based on optics, it may be used to detect the quantity and makeup of dangerous substances, improving the effectiveness of waste management systems. With the help of machine learning and big data, it is feasible to continuously monitor the quality of the water and to obtain real-time data. The energy expenditures that would normally rise while utilizing conventional methods will be decreased using neural networks and IoT.

1.3 Smart Irrigation

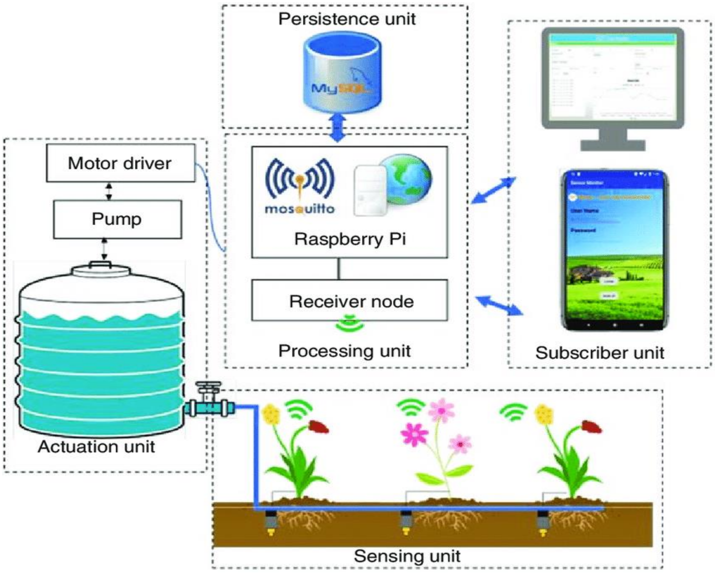

Figure 1.3 Smart irrigation

Agriculture is the biggest water-using sector and many lands use a good portion of groundwater for irrigation purposes. Smart Irrigation will leverage AI systems to minimize the use of water and also optimize the water resources without wastage. AI systems can predict agricultural demands to balance water use by directing sprinkler systems while also detecting the levels of groundwater. In order to improve agricultural management, more advanced precision-based AI systems can forecast weather, climate, and humidity. By integrating AI sensors, the smart farms will be able to decrease leaks and analyze the soil to identify the health of the plants and their water requirements.

II. MOTIVATION

Water scarcity will directly affect nearly 20% of the human population by 2025, according to several UN reports, and indirectly influence the rest of the planet's inhabitants as well as economies and the whole ecosystems. Smart water systems based on the combination of Internet of Things, big data and AI technologies can help stop these predictions from happening and undo the damage the imprudent usage of water resources has already caused. Due to climate change, there will be water scarcity in the whole world. Because of human errors many gallons of water are lost annually. This can be managed properly by a computer. That is why Artificial Intelligence is used for the management of things where humans make error because AI does not make much errors. Due to this this system can help manage water resources more accurately than any human can. Being an AI, it would work 24/7 365 days a year hence no water resource is mismanaged. This big motivation can help us to build an interconnected smart water management system. For future generations we have to manage our resources because resources that is natural resources are limited in this world. Water is one of the natural resources. Also, the population is ever increasing this means that there will be around 8 billion people by the end 2030. This is enough motivation for us to save water and manage it properly.

III. INTRODUCTION FOR PROPOSED MODEL OF SMART WATER MANAGEMENT

3.1 Physical based method-Physically based methods combine hydraulic modeling with statistical tools including state estimation techniques and pressure sensitivity studies. The fundamental physical principles (conservation of mass and momentum) that control water distribution networks can be fully utilized by the physical approaches. A "digital twin" or "digital mirror" of the actual water distribution network can eventually be created through the seamless integration of data and numerical models, allowing for the testing and verification of scenarios in real time. Other industries frequently use this strategy, such as when operating power distribution networks. Physically based solutions provide the foundation for water utilities' digital transformation from an operations perspective. Hydraulic Modeling 1.0 is the first phase, and it doesn't require sophisticated big data. Each water utility should have a standard hydraulic model that, when applied to deterministic (fixed) characteristics and consumption regulations, can accurately simulate the usual operating conditions of the water distribution network. It is only advised to switch to a more sophisticated strategy that takes into account the probabilistic, time-varying character of the various inputs and parameters once such a model is in place.

3.2 Data driven methods-Data-driven methods are based on the application of AI or machine learning algorithms as artificial neural networks (with their many variations generally known as deep learning methods), as well as support vector machines, classification trees, adaptive neuro-fuzzy inference systems, etc. These techniques, after being properly trained with large data sets, can extract information and detect patterns without use of network equations. Several data-driven approaches for pipe burst detection in water systems are summarized in the literature. For the hydraulic analysis of water networks (water leaks, pipe breaks, UFW, etc.), data-driven methods are not the natural approach for a variety of reasons. Among these is the fact that historical records are frequently too small to train the algorithms and discover novel anomalous events that haven't been observed before. Additionally, some aspects of a hydraulic model are complicated and not subject to general governing equations, making them inappropriate for physically based techniques. Aggregate human behavior, which is influenced by exogenous elements including the environment and socioeconomic conditions, determines patterns of water use, unauthorized connections, societal reactions to service incidents, etc. Meanwhile, complicated physicochemical interactions between soil, water, pipes, and external loads are what cause water leaks, pipe bursts, and roughness. Several phenomena such as pipe cracking, joint wearing, corrosion, bio filming, etc. are not yet fully understood and cannot be accurately modeled. It is when these factors come into play that data-driven methods can bring further benefits for the operations and management of the water utilities.

3.3 The best of both worlds must eventually be combined into a "hybrid methodology" called hydraulic modeling 2.0, which is the natural evolution of conventional water network analysis meeting big data and AI algorithms to breed a new generation of tools.

3.4 Artificial Intelligence for optimization and decision support tools in water supply-

There are several uses for hydraulic models, including:

(i) Explanation and prediction of what occurred in a specific location at a specific time in the water distribution network without the use of instruments or sensor data
(ii) Forecasting of "what if" scenarios for the planning and operation of the water distribution network
(iii) Prescriptive tools for decision support platforms, which are increasingly popular because they provide recommendations for the best possible solutions to a specific problem.

In its most basic form, optimization techniques are used in decision-making to identify the set of variables that maximizes or minimizes a numerical objective function. Networks for distributing water have been subject to optimization strategies since the beginning of hydraulic modeling. With the ascent of fast processors and cost-effective sensors resulting in cheaper computer power, optimization techniques are now mainstreamed into the operation of most water utilities. One method involves using observability analysis, or optimizing the placement of a small number of sensors to get the most data possible about the water supply system. Another way is through operational analysis, which involves real-time and optimized control of certain water distribution network components, particularly pumping stations and pressure or flow control valves, to cut down on energy use or monitor water quality. Big data produced by social media, mobile devices, and the Internet of Things (IoT) directly feed into AI, providing a big data ecosystem in addition to the improved computer and graphics processing capabilities. Any algorithm that can process data and learn, improving over time as it is better trained, is referred to as AI. The foundation of machine learning tools, fueled by large data, is made up of numerous statistical models such decision trees, nonhierarchical classification techniques, and Bayesian networks. Recent developments in a single set of algorithms, referred to as "deep learning" or multilayered artificial neural networks, have achieved outstanding outcomes for numerous well-known applications, including image classification, voice recognition, and autonomous cars. It's not yet apparent whether deep learning will transform consumer interactions and corporate procedures in the same way it is doing with water network analyses. Although it is true that AI-based algorithms for water demand predictions are growing more powerful than the conventional ones, deep learning and other data-driven techniques do not now appear to be a feasible substitute to physically based models for network analysis. On this basis, a “hybrid” approach, encapsulated in Hydraulic Modeling 2.0, is the preferred strategy.

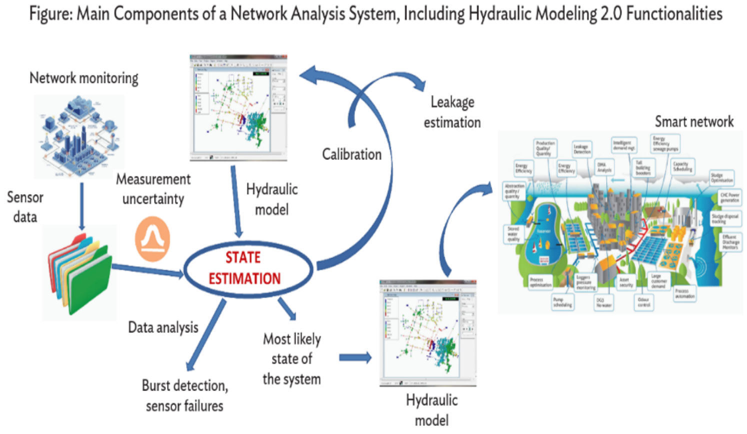

Figure 3.1 hydraulic modeling 2.0

3.5 On this basis, a “hybrid” approach called Hydraulic Modeling 2.0, is the preferred strategy. With access to big data, AI algorithms provide the following functionalities:

(i) optimal network configuration for monitoring and control. The shift of water utilities to the digital information era was made possible by monitoring and control networks, which are the digital equivalent of the physical pipes. In order to extract the most data about the entire system with the lowest CAPEX, the AI algorithms offer objective information-based criteria to specify the location of a specific number of sensors in a given network. This suggests installing pressure gauges in preference to pricey flowmeters, as well as reducing the number of control points. This quantitative method to network instrumentation also establishes a clear connection between ICT investments and the anticipated operational advantages, providing a frequently lacking cost-benefit analysis with a realistic framework.

(ii) Numerical detection of physical and apparent water losses. Using state estimation and stochastic optimization techniques, AI algorithms can provide spatial information on the amount and type of water losses. The AI algorithms then try to find the most likely status of the network after assigning a certain degree of uncertainty to the existing data. They essentially perform a continuous and probabilistic calibration of the network (instead of the standard onetime, deterministic calibration), which allows analyzing the structure of the errors (difference between the measurements and the model predictions) at each control point, and extracting information from the error patterns. Depending on the density and frequency of measurement in each sector of the network, it may be feasible to distinguish between various types of water losses (for example, pipe leaks versus unauthorized consumption). This numerical location of losses does not replace the use of field equipment to locate water leaks or connections, but it does save time and money by eliminating the need to send out teams to find leaks, sectorize the distribution networks to the best advantage, and prioritize pipe replacement projects. It would also be feasible to identify aberrant measurements, such as those caused by equipment malfunction, etc. By calculating the most probable pipe roughness coefficients, the probabilistic calibration enhances the hydraulic model representation.

(iii) Energy savings. The AI algorithms can guide energy savings in network operations using stochastic optimization techniques with two different approaches: first, by defining the most efficient operating procedures complying with minimum service levels given a predetermined configuration of pumping facilities, storage tanks, and energy tariffs; and second, identifying the most cost-efficient investment in a given system (pump replacement, increased storage capacity, change of energy contract, etc.) for energy savings.
(iv) Definitions of protocols and contingency plans. Water utilities plan for emergencies in order to manage them and lessen the effects on their consumers. Additionally, incidents like pipe bursts, malfunctions, electricity blackouts, water shortages, and contamination might result in anomalous circumstances. Based on the amount of danger (from service disruptions to health threats), the AI algorithms help to optimize a response. Such emergency procedures may be predetermined (for instance, in response to algae blooms in reservoirs) or selected in the moment (for example, which valves to close to lessen the effect of a burst pipe on consumers).
(v) anticipating demand and classification of consumption habits. The AI algorithms adapt and develop as more data become available to anticipate water consumption for a node or a set of nodes based on past data and sophisticated statistical methods. To help with capacity expansion plans, forecasts can be created in real time for the upcoming 24 hours or for the longer term (years). Based on the quantity of historical data available to calibrate the hydraulic model, all forecasts contain the level of uncertainty. Future socioeconomic and climatic situations are connected to long-term predictions (user-defined).

(vi) Network expansion design with optimal configuration. Advanced AI optimization tools give insight on the most efficient configurations based on cost minimization (CAPEX plus discounted OPEX) or any other selected target. Dedicated AI algorithms can identify optimal alternatives for network expansions. In order to provide a more reliable approach to decision making, they take into account the uncertainty of some design elements, such as population forecast and spatial urban expansion.

(vii) Active asset management programs. In order to ensure ideal service levels and reduce costs, the majority of water utilities have a clear strategy for combining maintenance and replacement. Acting proactively rather than responding to unforeseen external occurrences is the goal of active asset management. Based on the statistical description of an asset's useful life, criticality, and other criteria, algorithms can establish optimal schedules for monitoring and replacing assets.

IV. ARTIFICIAL INTELLIGENCE IN HYDRAULIC MODEL 2.0

For water utilities to integrate AI at the core of their planning and operations, hydraulic modeling 2.0 is the way forward. Compared to the standard Hydraulic Modeling 1.0 now employed by the water utilities, Hydraulic Modeling 2.0 provides a qualitative improvement. The traditional Hydraulic Modeling 1.0 models serve as the foundation for the new paradigm for water distribution network analysis portrayed in Hydraulic Modeling 2.0. Consequently, based on the knowledge they have learned from using traditional hydraulic models, water utilities are anticipated to progress toward the more sophisticated Hydraulic Modeling 2.0. Before transitioning to Hydraulic Modeling 2.0, water utilities should first understand the deterministic version of their hydraulic model and explicitly define its limitations as a constraint in their operations. A set of mathematical equations known as "hydraulic modeling" 1.0 provides estimates of the flow, water level, and velocity in river channels, pipe networks, tidal systems, and floodplains. Hydraulic modeling version 1.0 uses average values for the state variables to depict a deterministic model. The 2.0 model, on the other hand, is a probabilistic model in which every variable is dependent on every other variable and is cross-related. Although it can only handle a small amount of data, the hydraulic model 1.0 can handle enormous data. This model does not take anomalies into account since it does not account for measurement mistakes, such as inaccuracies in flow and pressure. Artificial intelligence is used by the hydraulic model 2.0 to model the water utilities system. The model learns from the continuously generated data. The model attempts to give and predict the model's future by learning from the past and present data. Error is taken into account together with the measurement of all uncertainties. If a mistake does occur, it is fixed. Errors have minimal to no effect on the final model because the model makes use of vast data to model. This model categorizes and separates all the various field data and model findings. Different fields are classified using pattern recognition.

Table 4.1 comparison between hydraulic model 1.0 and hydraulic model 2.0

Hydraulic Modelling 1.0 (Conventional)	**Hydraulic Modelling 2.0 (High-Level Technology)**
Deterministic System represented by average values of the state variables (flows and pressures)	Probabilistic All variables treated as probabilistic with their density functions and cross-correlations.
One-off calibration Hydraulic model calibrated once a year (at best) based on aggregate error functions. Model parameters are usually fixed.	Continuous learning Hydraulic model real-time learning with new data generated: calibration constantly updated with past and current data.
Limited data Hydraulic model set up with limited data without the need for Realtime data, except to update water consumption. More data does not imply better model.	Big data Hydraulic model maximizes all data available (the more data, the better): well suited to a data-rich and real-time environment.
Simplification Uncertainty in water demand at the nodes not quantified and not considered.	Uncertainties Water demand reflects the uncertainty from the meters' errors and the aggregation of nodes when no meter is available
Shortcut Measurements' errors for flows and pressures not considered.	Holistic Measurement errors from sensors introduced into the model with a non-negligible impact on the results.
Anomalies Anomalies mostly not detected or if so, not characterized, nor classified.	Classification and sorting The algorithm analyses the residuals values (differences between field data and model results) and classifies them into categories: illegal connections, water leaks, pipe bursts, malfunctioning sensors, abnormal water consumption patterns, etc.

V. CONCLUSION

The internet, big data, and AI algorithms are causing a digital change in water utilities all around the world. Water utilities must transition from a "old school" operation—hydraulic modeling 1.0—that results from operating a monopoly with minimal outside pressure to a new era of efficiency and accountability, or hydraulic modeling 2.0, in order to stay competitive and improve customer service delivery. This revolution is being driven by the accessible big data from customers, employees, and sensors. This vast data is used by artificial intelligence to create a model for small losses in water networks or any other form of water utility system. Smart water management system is another name for the application of artificial intelligence in this modeling. Practically speaking, the hydraulic model 2.0 is more expensive than the hydraulic model 1.0 since it requires more educated personnel, new hardware, new sensors, and new pipelining. For that reason, the department of water management needs to be reorganized. As a result, water management needs to be improved.

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GLOSSARY

AI: Artificial Intelligence.
ICT: Information technology.
CAPEX: Capital Expenditure.

Capital expenditures (CAPEX) are funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment. CAPEX is often used to undertake new projects or investments by a company.

OPEX: Operating Expenses.

Operating expenses (OPEX) are the day-to-day expenses a company incurs to keep its business operational.

Old school: Conventional.