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INTELLIGENT WATER MANAGEMENT SYSTEM FOR SMART URBAN DEVELOPMENT

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Abstract: The runaway path of global urbanization combined with unstable climate change has subjected municipal water infrastructure to record stress. Conventional reactive water management frameworks based on static regulations are inherently unsuitable for providing the required levels of efficiency and robustness to contemporary urban settings. One of the prime symptoms of this systemic failure is the existence of Non-Revenue Water (NRW), which undetermined the commercial feasibility of utilities and environmental abundance of portable water. Predictive flow control through Artificial Intelligence (AI) is a required technology transformation, redefining the fundamental operations of utility companies from passive monitoring to self-optimizing systems. This survey lays out the critical role of AI incorporation to enable sustainable urban water management, outlining its technical underpinnings in the Internet of Things (IoT) and Supervisory Control and Data Acquisition (SCADA) systems. The central application, Dynamic Pressure Management (DPM), delivers measurable worth by facilitating the reduction of NRW by large amounts estimated at 0.79 gallons per service connection per day for each PSI decrease and garnering enormous Operational Expenditure (OpEx) savings through optimized pumping.

In addition, AI improves the longevity of infrastructure by preventing pressure transients and extends its applications to crucial flood risk reduction, ensuring overall urban climate resilience. Strategic investment in such a transition requires careful financial planning using models such as Performance-Based Service Contracting (PBSC) and strict governance practices to take on the amplified cybersecurity threats, especially those to data integrity and autonomous control loops. Index Terms-Artificial Intelligence (AI), Dynamic Pressure Management (DPM), Non-Revenue Water (NRW), Internet of Things (IoT), SCADA, Urban Resilience, Cybersecurity.

Keywords: Internet of things (IoT) sensor, Real-time Monitoring, Artificial Intelligence, Smart Metering, Leak Detection, Predictive Maintenance.

I. INTRODUCTION

Water is a universally accepted luxury commodity that is fundamental to the survival of all Earth's species. Yet its management is increasingly being challenged globally and need impacts currently almost one-fifth of the world's total human population, a figure that is estimated to affect over 1.8 billion people by 2025, with agrarian labourers and peasant farmers being the most affected. This increasing demand, combined with increasing urbanization and unpredictable climate patterns has put unprecedented pressure on municipal water systems, much of which is old and operating well beyond the design life. Water shortage has been one of the most significant issues facing many communities and the world in the 21st century. In the past century, use of water increased at a rate greater than twice that of population growth. Although a common, global water crisis does not yet prevail and more and more locations are facing chronic shortages of water. In developing countries, this is a crisis based on a 2018 report released by India's NITI Aayog, 600 million individuals, or over half of the Nation's population face critical water shortages.

In addition, 21 key cities in India were competing to achieve harmful levels of groundwater by 2020, affecting 100 million individuals. These dismal figures confirm that the need for sophisticated water management technologies has transcended simple efficiency gains into being a key driver of public health and economic resilience. The convergence of aging systems and climate variability forms a critical risk nexus. Aging infrastructure introduces systematic vulnerability through leakage and pipe failure, while climate volatility manifests as unpredictable demand spikes during droughts or

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intense rainfall events leading to localized flooding. This demands distribution systems capable of rapid adaptation, requiring a shift away from reliance on stable historical averages toward real-time, predictive management capabilities.

II. FOUNDATIONAL TECHNOLOGIES FOR SMART WATER SYSTEM

A. The Widely Used IoT Sensor Layer

The very first requirement for any system that predicts or self-optimizes is having a dependable and wide-ranging data extraction network, which is predominantly through the Internet of Things (IoT). IoT systems are made up of a collection of real-world objects that can send and receive data and thus interact with their surroundings. In case of smart water systems, IoT devices are likened to the "eyes and ears" of the system, as they give us the finest and most up-to-date parameters. The smart water meters that are installed act as the main data collection points that help gather data of pressure, consumption, temperature, and flow. These gadgets make use of wireless technology to send data back to a central server for storage and analysis in the cloud. The types of sensors used differ according to the purpose: pressure sensors are most important for leak detection, flow meters keep track of usage, and quality sensors test pH, turbidity, and chlorine levels, amongst others. This constant stream of top-notch data is a necessity, because AI model performances solely depend on the quality and amount of field data provided to the control platform.

B. The Dual Scale of IoT Application: Utility vs Domestic Conservation

1) Utility-Scale Deployment

At the utility scale, the deployment strategy focuses on maximizing the immediate return on investment by strategically targeting high-value data acquisition points. For example, the Bangalore Water Supply and Sewerage Board (BWSSB) have made the first rollouts of AI-enabled smart meters for large consumers. This method detects large differences in both the physical flow (leakage across zones) and commercial losses (billing inaccuracies) where the financial impact is the greatest.

2) Domestic/Localized Systems (The Micro-Scale)

Household water systems aim to be low-cost and convenient and promote water saving. A small-scale system can be constructed for approximately Rs. 500 by using basic components such as a NODEMCU (Rs. 300) and an ultrasonic sensor (Rs. 120). The NODEMCU, which is driven by the ESP8266 Wi-Fi chip, links sensors to the internet. It employs an ultrasonic sensor to detect water levels sending sound waves and a water level sensor as a backup. The information is transferred to a cloud system such as Firebase, where a web application (for instance, created with React) displays water usage, provides notifications, and proposes methods of saving water. To enhance reliability, the system has redundancy if one of the ultrasonic sensors fails, the water level sensor switches off the motor automatically. It guarantees constant monitoring, showing that low-cost systems can be reliable and efficient for smart water management as shown in the figure.

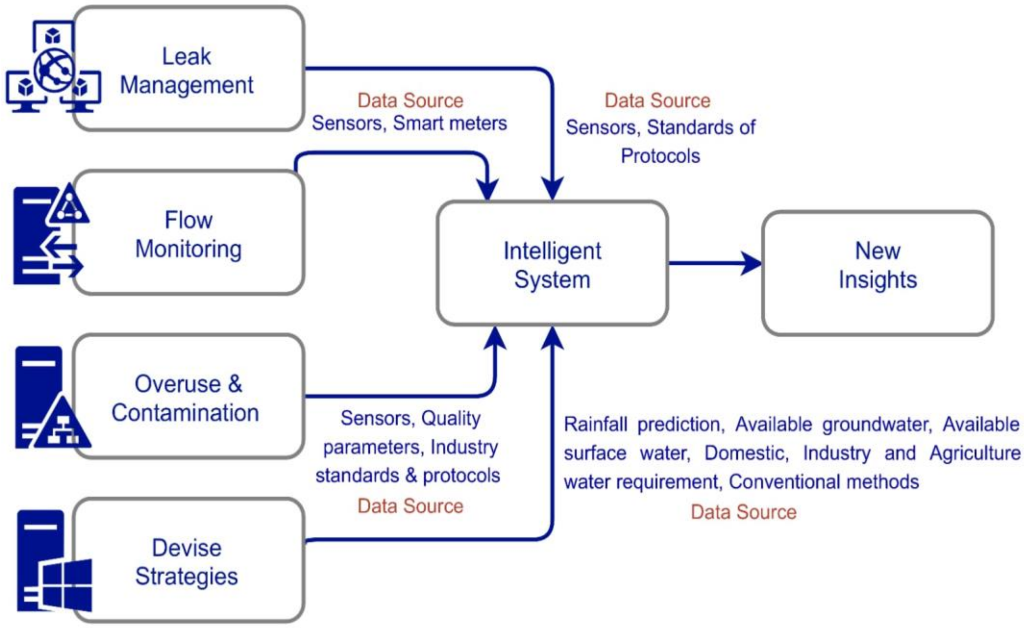

Figure: Smart water resource management using Artificial Intelligence

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III. LITERATURE REVIEW

SL NO	YEAR OF PUBLICATION	TITLE	DESCRIPTION
1.	2025[1]	IoT-Enabled Water Conservation And Leakage Control System	The IoT-Based Water Saving and Leakage Management System is a revolutionary way of tackling wastage of water and promoting sustainable use of the precious resource. It incorporates Internet of Things (IoT) technology through components like flow sensors, Arduino Uno, relay modules, and Wi-Fi connectivity to track and manage water distribution in real time. The system constantly monitors water movement using sensors and identifies abnormalities like leakage or illegal siphoning. Upon the detection of abnormality, it automatically cuts off the supply of water and sends notifications using an IoT platform, allowing for timely response and minimizing wastage. The automation reduces manual intervention to the barest minimum, enhances efficiency, and enables remote monitoring through mobile or web apps. The designed system reflects a noteworthy decline in water loss reducing leakage rates and maximizing water use. Through the use of real-time data gathering and cloud-based analytics, it fosters water sustainability in residential, industrial, as well as municipal sectors. Comparative analysis within the study indicates better maintenance, less wastage, and increased operational reliability following deployment. Real-time leak monitoring and immediate leak detection. Reduced human effort and operational expenses through automated control enables remote monitoring and intelligent alerts based on IoT connectivity. Needs stable internet connection for proper functioning. High installation and sensor setup expenses in the beginning. Electronics maintenance can be difficult in extreme environments.
2.	2024[2]	Intelligent Water Faucet for Real-Time Water Conservation In Smart Cities	The Smart Water Faucet for Real-Time Water Conservation in cities introduces a novel solution that combines embedded systems, Machine Learning, and the Internet of Things (IoT) to encourage efficient use of water. The project converts traditional faucets into intelligent ones that can sense user behaviour in real-time. Utilizing a Raspberry Pi with a camera and a GPU-powered server, the system uses the YOLOv7 Deep-Learning model to detect if a user's hands have SOAP (Simple Object Access Protocol). Upon detection, it automatically controls water flow operating on demand to avoid wastage. With an impressive performance score (F1 = 99%, mAP@0.5 = 0.991), this smart faucet showcases accuracy and efficiency appropriate for contemporary urban life. The data exchange between the faucet and server runs through the low-weight MQTT (Message Queuing Telemetry Transport) protocol to guarantee effective, real-time data transfer. This development supports the smart city's resilience objectives through a synergy of automation and eco-awareness. The system

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			minimizes unnecessary water flow by detecting usage patterns, significantly reducing wastage and hardware components sensors uses periodic calibration and cleaning.
3.	2023[3]	An Intelligent Wireless Water Conservation System	This paper explores a smart IoT-based system used to avoid water overflow and wastage by automation and wireless communication. It utilizes ultrasonic sensors and NODEMCU (Node Micro Controller Unit) modules to sense and track the water level in tanks or reservoirs. When the water level achieves a predetermined level, the system automatically turns the water pump on or off. This saves cost on installation of the system complexity. Moreover, there is an integrated mobile application for real-time updates, alerts, and remote control for the management of the water pump. This intelligent system can be particularly applied in residential homes, commercial establishments, and agricultural irrigation systems where efficient water management is crucial. Through automation, it saves time, cuts down manual labour, and allows for precise operation without human intervention. NODEMCU-based design permits easy scalability and modification to suit any environment. In addition, it enhances global water conservation through water wastage minimization and optimization of water utilization. Generally, the system promotes feasibility development by integrating contemporary wireless technology, automation, and environmental stewardship. Prevents water overflow and minimizes wastage that operates wirelessly, eliminating the need for long and costly cabling. Provides real-time monitoring and remote control via a mobile app. Dependent on a stable Wi-Fi network for communication. Sensors may malfunction under harsh or humid conditions.
4.	2023[4]	Design And Study of Smart Irrigation System Using Photovoltaic Cells Based Smart IoT System And Weather Prediction System For Energy And Water Conservation In India	The research is aimed at designing a smart irrigation system with the integration of IoT technology, PV solar energy, and weather forecasting to facilitate water and energy conservation in Indian agriculture. With agriculture continuing to be the source of India's economy, overuse of groundwater and fossil fuel dependency have created severe sustainability issues. The suggested system uses automated irrigation through soil moisture sensors and weather forecasts to apply optimum watering only when necessary. It is driven mainly by solar-powered PV modules, thus qualifying as an environmentally friendly and economical option for rural farmers. The system uses a NODEMCU ESP8266 microcontroller, soil moisture sensors, DC (Direct Current) pumps, and weather APIs (Application Programming Interface) to track environmental conditions in real time. If soil moisture falls below a predetermined threshold, the controller looks for rain forecasts before turning on the irrigation pump. This smart function avoids over-irrigation, saves water, and reduces energy. Simulation outcomes with MATLAB

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			(Matrix Laboratory) indicated that this system could minimize energy consumption by 30% and save 64.7 trillion litres of groundwater per annum in case of extensive implementation. Additionally, solar systems which replaces diesel-operated pumps would save 1.72 billion litres of diesel and 2 billion dollars per annum, leading to environmental as well as economic sustainability.
5.	2022[5]	IoT And Cloud Based Water Conservation And Monitoring System	Internet of Things (IoT) and Cloud-Based Water Monitoring and Conservation System are a technological innovation meant to efficiently use water and eliminate wastage. It employs intelligent technologies like ultrasonic and water-level sensors tied to a NODEMCU microcontroller to record real-time water usage. The information gathered is transferred to a cloud database (Firebase), making it possible for users to observe their daily consumption of water via an online application developed using React. The system gives real-time alerts if water levels decrease or increase above the defined levels and gives customized suggestions to save water. The use of cloud computing guarantees data scalability, accessibility, and reliability. Based on analysis of past data, future usage patterns are forecasted by the system, enabling users to plan consumption well and prevent shortages. Ongoing monitoring of water consumption enables leaks and wastage to be identified immediately. The cloud platform keeps record of historical data and provides predictive information for effective water management. Although backup sensors are included, malfunction or calibration errors can affect accuracy. Periodic cleaning and calibration of sensors are essential for reliable performance.
6.	2022[6]	Application and Research of UAV Remote Sensing Technology In Soil And Water Conservation	Unmanned Aerial Vehicle (UAV) remote sensing technology integrates drone operations with remote sensing devices to obtain process, and evaluate environmental information. UAV remote sensing technology is essential in soil and water conservation as it offers high-resolution imagery and real-time data on landforms, vegetation cover, and erosion patterns. Conventional soil and water conservation technologies are mostly restricted by terrain, weather, and human errors. UAVs, on the other hand, are able to capture detailed information rapidly over vast regions, with more efficiency and accuracy. Applications of UAVs are extensive across planning, monitoring, and assessment phases of soil and water conservation projects. During the planning stage, UAVs offer accurate terrain and vegetation information that aid in project design. For dynamic monitoring, UAVs take time-series photos to monitor soil erosion, vegetation restoration, and land use change. Throughout project assessment, UAV remote sensing provides unbiased and data-based evaluation by eliminating human intervention. The technology is also beneficial in water resource planning as well as

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			environmental monitoring system which determines water distribution and achieve sustainable land use. UAV remote sensing provides high-resolution, cost-effective, and rapid data collection, adaptable to terrains, enhancing monitoring efficiency and environmental decision-making. The cost of initial equipment and subsequent maintenance may be expensive. UAVs need trained operators and the right licenses, and their operation is often restricted by flying duration, battery life, and government regulations.
7.	2022 [7]	A Real-time Online Monitoring System for Soil and Water Conservation Based on Transmission Cloud	The research introduces an online real-time monitoring system with the aim of improving soil and water conservation based on transmission cloud technology. So far, soil and water monitoring in China has been carried out traditionally through manual, inefficient means that were sometimes not real-time. To address this limitation, the system brings sensors, a 4G router, and an online-based management platform together to capture, transmit, and present environmental information including rain, wind speed, temperature, humidity, noise, and soil erosion. The essential hardware employs a photosensitive chain pin, which enhances the accuracy of measurements by capturing soil surface changes while immune to temperature and humidity. Sensor data are communicated via a USR-G776 4G router to a cloud server, enabling remote users to view site conditions in real time. The software interface enables data visualization, video monitoring, and early warning systems, facilitating proactive environmental management. Its performance was proven in the Shanbei-Hubei ultra-high voltage transmission project where it accurately depicted rainfall and soil erosion trends. Data can be viewed and analyzed from any location via the cloud platform also uses solar photovoltaic panels for power, making it sustainable. Requires stable 4G connectivity for real-time data transfer. Cloud-based systems are potentially vulnerable to cyber attacks or data breaches.
8.	2020[8]	The Effectiveness Of Reclaimed Condensed Water Used For An Evaporative Cooling Tower In Water Conservation And Energy Saving	The research examines the application of reclaimed condensed water collected as a by-product from air conditioning systems as a substitute for traditional water sources for evaporative cooling towers. Condensed water is generally clean and mineral-free and therefore can be directly used without any further treatment. The research at the L'Arc Hotel in Macao proves that diversion of air-conditioning condensate to the cooling tower minimizes water consumption and enhances system performance. By blending the low Total Dissolved Solids (TDS) condensed water with mineral-rich circulating water, dissolved solids concentration is reduced, resulting in increased Cycle of Concentration (CoC) and reduced bleed-off water requirement. Upto 85% bleed-off volume reduction and more than 3% enhancement of the Coefficient of Performance (CoP) of the chillers system was

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			achieved after maintenance and scaling control using this technique. As a whole, incorporation of condensed water helps with both water and energy saving in big commercial buildings. Decreases the volume of chemical agents needed for water treatment. Lowers carbon emissions and supports sustainable building practices. The amount of condensate water varies with humidity and cooling load requires re-routing of drainage and additional storage systems.

IV. CONCLUSION

Artificial Intelligence (AI)–powered predictive water flow control is a revolutionary strategy for attaining sustainable urban development. By combining sophisticated data analytics, Machine Learning algorithms, and real-time monitoring systems, the technology allows effective regulation of water distribution networks. It foretells patterns of demand, detects possible leakages, and streamlines water use to reduce wastage. The application of AI guarantees that urban water infrastructure is able to dynamically respond to shifting consumption patterns, seasonal changes, and unanticipated disruptions, hence enhancing reliability as well as resilience.

In addition, predictive control systems enable preventive maintenance and minimize energy usage related to water treatment and pumping activities. This not only helps to conserve water but also decreases the overall environmental impact of urban infrastructure. The ability of the system to process vast amounts of data from IoT sensors supports better decision-making for policymakers and urban planners, fostering fair distribution and sustainable use of resources.

Finally, AI-predictive water flow control illustrates the capabilities of technological breakthroughs to solve immediate environmental issues in urban areas. By uniting Artificial Intelligence and smart water management, it opens the door to sustainable, data-driven urban environments that emphasize efficiency, resilience, and long-term ecological equilibrium.

V. SUSTAINABLE DEVELOPMENT GOALS

SDG Goals	Goal Description	Justification
SDG 15: Life on Land	Protect, restore and promote, sustainable use of terrestrial ecosystems.	Efficient water management supports sustainable land use by preventing over extraction of lawn water and reducing the environmental degradation caused by water wastage.
SDG 13: Climate action	Take immediate action to combat climate change and its impacts.	Predictive systems helps mitigate climate induced water creases by managing droughts and flood risks. The AI driven approach reduces carbon footprint by lowering energy use in pumping and treatment.
SDG 12: Responsible consumption and production	Ensure sustainable consumption and production patterns.	By optimizing water flow and monitoring consumption, the system encourages responsible water use among citizens and industries, reducing non-revenue water and promoting sustainability.
SDG 11: Sustainable cities and communities	Make cities and humans settlements inclusive, safe, resilient and sustainable.	The system supports smart urban development by improving resource efficiency and resilience. Predictive water management helps cities adapt to rapid

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		urbanisation and climate variability.
SDG 9: Industry, Innovation and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.	Incorporating AI, IoT and SCADA systems strengthens urban water infrastructure by introducing smart, data driven innovations. It supports modernisation and promotes sustainable technological development.
SDG 6: Clean water and Sanitisation	Ensure availability and sustainable management of water and sanitisation for all.	The project directly addresses water conservation through real-time monitoring, AI-driven predictive control and IoT based leak detection. It ensures efficient water usage, minimizes wastage and supports equitable water distribution in urban settings.

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