

Intelligent Water Management System using IoT and Sensor-based Automation

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ABSTRACT

Water is a fundamental resource essential for human survival, economic development, and environmental stability. Rapid urbanization, industrial expansion, and climate change have intensified the challenges of water scarcity, contamination, and inefficient distribution[1]. The motivation behind this study is to address these pressing concerns by analyzing modern water management strategies and exploring the potential of emerging technologies.

This report reviews global water supply systems, treatment methods, and distribution networks[1],[3], focusing on efficiency, safety, and sustainability. It assesses water sources like surface water, groundwater, desalination, and rainwater harvesting, along with traditional and advanced treatment techniques, including AI-driven approaches.

Key challenges such as industrial contamination, aging infrastructure, and energy-intensive purification processes are highlighted,[5] along with case studies that demonstrate disparities in water management between developed and developing regions. Furthermore, the integration of cutting-edge technologies—including IoT-based smart monitoring systems, AI-driven automation, and renewable energy-powered purification—is examined for its potential to revolutionize water treatment and conservation[2],[3],[4]. The study also evaluates global regulatory frameworks and policy interventions, advocating for data-driven, sustainable solutions to modern water management challenges. In this paper, we describe the formatting guidelines for IJCA Journal Submission.

Keywords

IoT, Water Management System

1.INTRODUCTION

Water supply and treatment are fundamental to human health and environmental balance. With the increasing demand for clean water due to urbanization and industrialization, efficient water management is essential. Ensuring a continuous and safe water supply is a challenge due to pollution, climate change, and aging infrastructure.

Governments and organizations worldwide are investing in advanced treatment technologies to improve water quality and distribution systems [1].

Water is sourced from rivers, lakes, groundwater, and desalination plants, each requiring specific purification techniques to meet safety standards[4]. The **procedure for treating the condition** involves multiple stages, including filtration, sedimentation, and **decantation**, to remove contaminants and harmful microorganisms. Efficient water supply systems must also Water is sourced from rivers, lakes, groundwater, and desalination plants, each requiring specific purification techniques to meet safety standards.

2.WATER SUPPLY SYSTEMS

First Water supply systems collect, treat, store, and distribute water to consumers. The primary sources of water include:

Surface Water: This includes rivers, lakes, and reservoirs, which serve as major water sources for municipal supply. Surface water is vulnerable to contamination from industrial waste, agricultural runoff, and climate change, necessitating extensive treatment before use[3].

Groundwater: Extracted from wells and boreholes, groundwater is generally cleaner than surface water due to natural filtration through soil and rock layers.

Desalination: Used primarily in coastal regions, desalination involves removing salt from seawater through processes like reverse osmosis or distillation[1],[6]. Although effective, it is energy-intensive and produces brine waste, which can harm marine ecosystems if not managed properly.

Rainwater Harvesting: This method involves collecting and storing rainwater for domestic, agricultural, or industrial use. It is an eco-friendly solution that reduces dependency on conventional water sources.

2.1 WATER DISTRIBUTION NETWORK

Water distribution systems consist of pipelines, pumping stations, and reservoirs that ensure the continuous supply of safe.

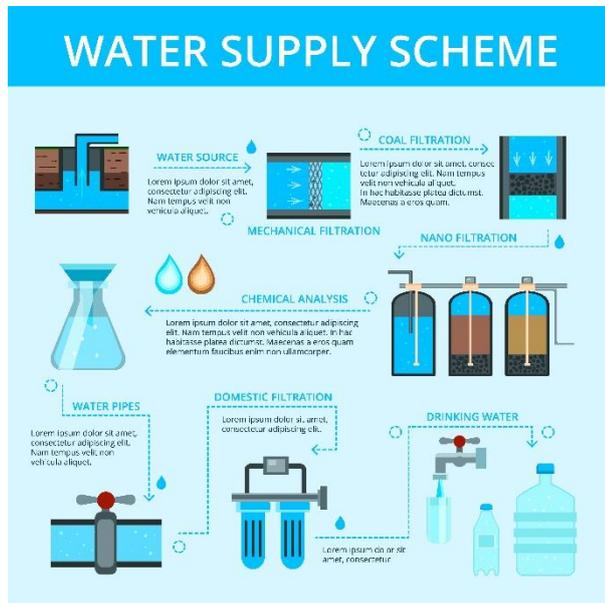


Fig 2.1 Water supply system

2.2 CASE STUDY: URBAN WATER SUPPLY

Pune and Bengaluru, two of India's rapidly growing metropolitan cities, face significant challenges in managing their water supply networks due to rising populations, urban expansion, and erratic monsoon patterns[5]. A study of these cities highlights key infrastructure issues, innovative solutions, and policy interventions aimed at ensuring sustainable water management.

2.2.1 Water supply challenges:

Dependence on surface water: Both cities rely heavily on rivers as their primary water source— Pune sources water from the Khadakwasla Dam and Mula-Mutha rivers, while Bengaluru depends on the Cauvery River. Seasonal fluctuations and pollution severely impact water availability and quality.

Aging Infrastructure: Decades-old pipelines and treatment facilities result in significant water losses due to leakage, estimated at nearly 35-40% in Bengaluru and 30% in Pune.

Groundwater Depletion: Over-extraction of groundwater in urban areas leads to declining water tables, exacerbating the risk of scarcity. Unregulated borewell usage in Bengaluru has led to depletion concerns, while Pune faces similar issues in suburban areas[4].

Water Supply Inequality: While central parts of both cities receive treated piped water, many outskirts and slum areas depend on tanker water or borewells, leading to disparities in access.

2.3 INNOVATION SOLUTION AND SMART WATER MANAGEMENT

IoT-Based Leak Detection: The Bengaluru Water Supply and Sewerage Board (BWSSB) has introduced smart water metering and IoT-based leak detection systems to minimize losses and improve supply efficiency.

Rainwater Harvesting Mandates: Both cities have implemented strict regulations requiring rainwater harvesting in residential and commercial buildings to supplement water sources.

Recycled Wastewater Use: Pune has launched wastewater treatment initiatives to reuse treated water for industrial and landscaping purposes, reducing the demand for fresh water. Bengaluru has promoted large-scale reuse of treated water for non-drinking purposes.

Public Private Partnerships: Water conservation projects involving NGOs and private firms are helping improve efficiency. Initiatives like "Mission Paani" in Pune promote awareness and infrastructure development for water conservation.

3. METHODOLOGY

The methodology aims to design and implement an IoT-based intelligent water management system capable of real-time monitoring, automated control, and efficient resource utilization. The approach integrates sensors, microcontrollers, wireless communication, and cloud-based analytics to create a smart, data-driven water supply and treatment workflow. The following subsections describe the system architecture, components used, data flow, and overall operational process. are your own designated keywords which can be used for easy location of the manuscript using any search engines[3],[4].

3.1 SYSTEM ARCHITECTURE

The proposed Intelligent Water Management System is designed using a layered architecture that integrates IoT sensors, microcontrollers, wireless communication, and cloud-based analytics. The system consists of four major layers:

Sensing Layer: Measures water level, flow, turbidity, pH, pressure, and leakage using embedded sensors.

Processing Layer: A microcontroller (NodeMCU/ESP32 or Arduino) collects, cleans, and processes sensor data.

Communication Layer: Transfers data to the cloud using Wi-Fi or LoRaWAN for long-range usage.

Application Layer: Displays real-time water quality, leakage status, and tank levels through a dashboard or mobile application.

3.2 SENSORS AND MODULES USED

The system utilizes different sensors to automate water monitoring and supply regulation:[4]

Ultrasonic Sensor – Measures water level in tanks or reservoirs.

Flow Sensor (YF-S201) – Detects consumption rate and pipeline blockages.

pH Sensor – Monitors acidity/alkalinity of water to ensure safety.

Turbidity Sensor – Detects suspended particles and contamination.

Pressure Sensor – Identifies leakage or bursts in distribution pipelines.

NodeMCU/ESP32 Module – Processes sensor values and sends readings to the cloud.

Relay Module – Controls motors and valves based on automated decisions.

3.3 DATA FLOW & COMMUNICATION

The data communication workflow follows these steps:

- Sensors collect real-time data at regular intervals.
- The microcontroller receives raw readings and performs initial filtering.
- Data packets are transmitted to the cloud via MQTT/HTTP protocols.
- The cloud server processes, stores, and visualizes the data.
- If abnormal values are detected, the system triggers alerts.
- Automated actions (pump ON/OFF, valve regulation) are executed as required

This ensures reliable and continuous monitoring of the water system.

3.4 WORKFLOW OF THE IOT-BASED WATER MANAGEMENT SYSTEM

The overall operational workflow includes:[2],[3]

Sensing: Continuous monitoring of water level, quality, and flow rate.

Data Transmission: Sensor values are sent to the cloud platform.

Analysis: AI-based analytics detect contamination events, leakage, and usage patterns.

Decision Making: The system determines whether to open valves, activate motors, or send alerts.

Actuation: Relays control pumps and valves automatically.

Notification: Alerts are sent to users or administrators through mobile/SMS.

Record Keeping: All data is stored for future optimization and analysis.

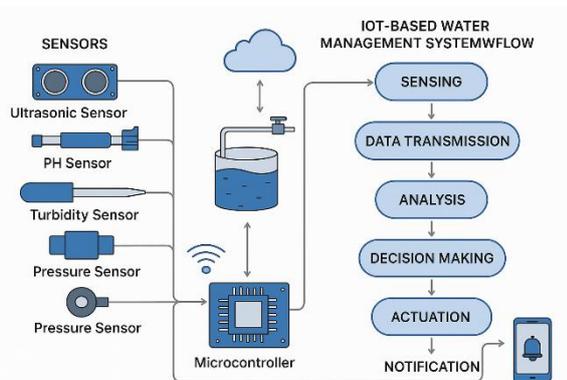


Fig 3.4 IoT-Based water management system work-flow

4. WATER TREATMENT PROCESSES

Water treatment is essential to ensure that water is safe for consumption, industrial use, and environmental sustainability[1]. The treatment process removes contaminants, sediments, microorganisms, and chemical impurities, ensuring compliance with health and safety standards. The key stages of water treatment include coagulation, sedimentation, filtration, and disinfection.

4.1 STAGES OF WATER TREATMENT

Coagulation and Flocculation: Involves the addition of chemicals like alum or ferric chloride to water. These chemicals neutralize charged particles, causing impurities to clump together into larger particles called flocs.

Sedimentation: The water is allowed to sit in large tanks where gravity helps settle heavy flocs at the bottom. The clear water above the sediment layer is then moved to the next treatment stage.

Filtration: Water passes through layers of sand, gravel, and activated carbon to remove fine particles. Activated carbon filtration is used to eliminate organic compounds, chlorine, and other chemicals.

Disinfection: Pathogens like bacteria and viruses are eliminated using disinfectants such as: Chlorine (most common but can produce harmful by-products). Ozone (effective against microbes but costly). Ultraviolet (UV) radiation (destroys genetic material of microorganisms without chemicals).

Advanced Treatment Methods:
Reverse Osmosis (RO): Uses a semipermeable membrane to remove dissolved solids and contaminants[6].
Nanotechnology Filtration: Uses nanoporous membranes to trap even the smallest pollutants.
Electrodialysis: Uses electrical potential to remove dissolved salts and ions.

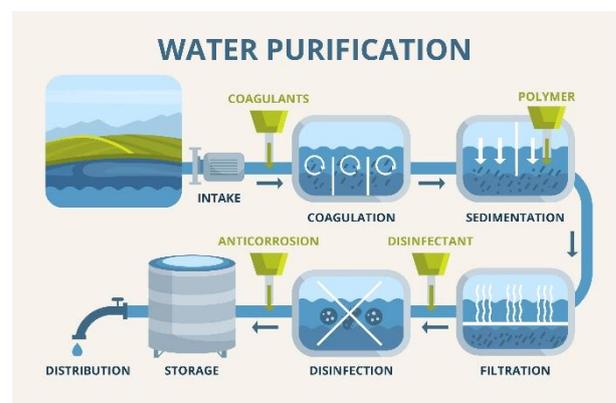


Fig 4.1 Stages of water treatment

4.3 CHEMICAL AND BIOLOGICAL TREATMENT

Chemical treatment involves adding substances such as chlorine, alum, or ozone to eliminate pathogens, neutralize impurities, and facilitate coagulation and flocculation. It is highly effective for rapid disinfection and purification but may produce chemical by-products that require careful monitoring.

Biological treatment uses microorganisms to naturally break down organic pollutants in water through processes such as microbial filtration, bioreactors, and bio-remediation. It is environmentally friendly and sustainable, though it typically requires longer processing time and controlled environmental conditions.

Table 4.3 Advantages and Disadvantages of Chemical and Biological Treatment

Treatment	Advantages	Disadvantages
Chemical Treatment (Chlorination, Ozonation)	Kills bacteria effectively, widely used, cost-effective	Can create harmful by-products, requires careful handling
Biological Treatment (Microbial Filtration, Bioreactors)	Environmentally friendly, reduces organic pollutants naturally	Slower process, needs specific conditions to be effective

5. GLOBAL WATER SCARCITY TRENDS

Water scarcity is an increasing global challenge affecting billions of people. With rising populations, climate change, and inefficient water management, many regions are experiencing severe shortages. According to the UN, over 2 billion people live in areas with high water stress, and this number is expected to grow[2].

5.1 Cause of water scarcity

Several factors contribute to global water scarcity, including:

Climate change: Rising temperatures, irregular rainfall, and prolonged droughts reduce water availability.

Overconsumption: Urbanization, industrial use, and agricultural demands are straining water supplies.

Pollution: Industrial waste, chemicals, and plastic contamination make water sources unsafe.

Poor Infrastructure: Aging pipelines and inefficient management lead to significant water losses.

5.2 Regional water scarcity trends:

India & South Asia : Rapid urbanization and inefficient groundwater use are depleting resources.

Middle East & North Africa : Arid climates and limited freshwater sources make this region highly vulnerable.

Sub-Saharan Africa : Many communities lack access to clean water due to inadequate infrastructure.

North America & Europe : While generally water-secure, droughts and overuse in agricultural regions create localized shortages.

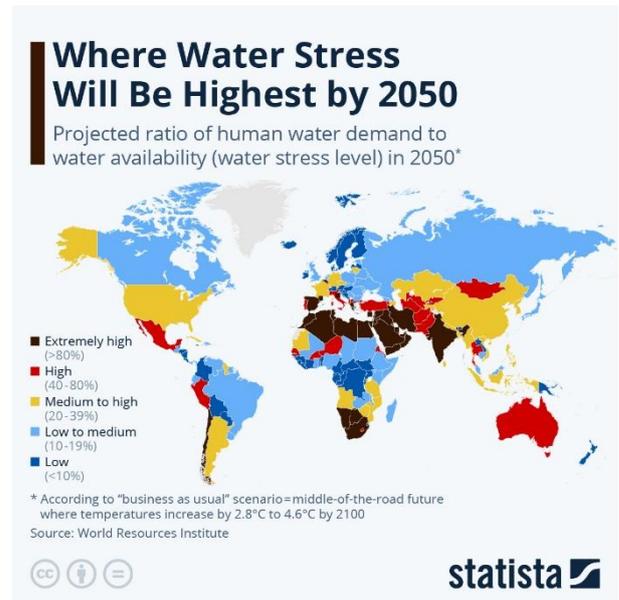


Fig 5.2 Projected ratio of human water demand

5.3 Solution to water scarcity

Desalination Plants : Converting seawater into drinking water, particularly in coastal cities.

Water Recycling : Reusing wastewater for irrigation and industrial purposes.

Smart Water Management : AI and IoT-driven monitoring to reduce wastage.

Rainwater Harvesting: Capturing and storing rainwater for various uses.

5.4 Future Outlook

If sustainable water management practices are not implemented, global water demand could exceed supply by 40% by 2030. Governments and industries must collaborate to develop innovative solutions, invest in infrastructure, and promote water conservation.

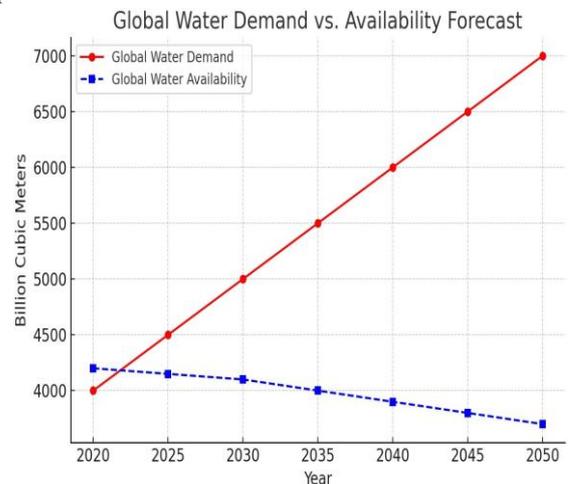


Fig 5.4 Global water demand vs availability forecast

5.5 IoT in water resource management

IoT is revolutionizing water management through real-time monitoring, smart distribution, and automated quality control[3],[4].

Key Applications of IOT in Water Management:

- Water Quality Monitoring: Sensors detect contamination instantly.
- Leakage detection: Smart meters identify and prevent water loss.
- Automated Distribution: IoT optimizes water supply based on demand.

6. TECHNOOGICAL ADVANCEMENT IN WATER SUPPLY TREATMENT

Advancements in technology have significantly improved the efficiency, reliability, and sustainability of water supply and treatment processes. With the growing demand for clean water and the challenges posed by pollution and climate change, the integration of modern technologies is essential for water resource management.

6.1 Smart water management system

The implementation of Internet of Things (IoT) and Artificial Intelligence (AI) in water management allows real-time monitoring, predictive analysis, and automation of water distribution and treatment plants. These technologies help detect leaks, optimize resource usage, and enhance efficiency.

KEY FEATURES:-

Smart Sensors: Monitor water quality parameters like pH, turbidity, and contamination levels.

AI-driven Leak Detection: Identifies pipeline leaks and reduces water loss.

Automated Control Systems: Adjust chemical dosing and filtration based on real-time data.

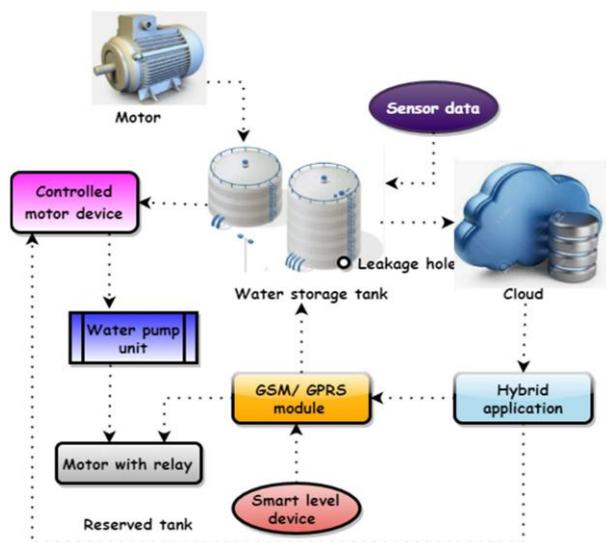


Fig 6.1 Smart water management system

6.2 Advanced water treatment technologies

New treatment techniques aim to improve water purification, reduce energy consumption, and minimize harmful by-products.

Key Innovations:

Nanotechnology-based Filtration: Removes micro-pollutants and heavy metals with high efficiency.

Membrane Bioreactors (MBRs): Combines biological treatment with membrane filtration for superior purification.

Electrocoagulation: Uses electrical currents to remove contaminants without excessive chemical use.

Table 6.2 :Traditional vs Advanced Treatment

Treatment Method	Traditional Methods	Advanced Methods
Filtration	Sand filtration, slow and less effective	Nanofiltration, membrane bioreactors (MBRs)
Disinfection	Chlorination, UV light	Ozonation, advanced oxidation
Coagulation & Flocculation	Alum-based coagulants	Electrocoagulation, polymer-based flocculants
Desalination	Multi-stage flash distillation	Reverse osmosis (RO), solar desalination
Water Recycling	Minimal reuse	Greywater recycling, wastewater

6.3 Renewable energy in water treatment

The integration of solar, wind, and hydroelectric power in water treatment plants helps reduce dependency on fossil fuels and promotes sustainability.

Examples:

•Solar-powered Desalination: Converts seawater into drinking water using solar energy.

•Hydropower-driven Filtration: Uses river flow energy to operate treatment units.

•Wind-powered Water Pumps: Ideal for rural and off-grid areas.

6.4 Water Recycling and Reuse

With increasing water scarcity, water recycling plays a crucial role in sustainability. Greywater treatment systems enable reuse of household wastewater for irrigation, toilet flushing, and industrial purposes.

Types of Recycled Water:

•Potable Reuse: Treated wastewater purified to drinking standards.

•Non-Potable Reuse: Used for irrigation, industrial cooling, and cleaning.

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Lastly, we acknowledge all the resources and references that contributed to our research, helping us gain a deeper perspective on the subject.

8. CONCLUSION

The water supply and treatment system has provided valuable insights into its efficiency, compliance, and overall effectiveness[1],[5]. While the system demonstrates strengths in [mention key strengths, e.g., infrastructure, water quality standards, treatment efficiency], there are areas that require attention, particularly in [mention key issues, e.g., leakage control, maintenance, regulatory compliance]. Addressing these concerns through recommended improvements will enhance service reliability, water quality, and operational efficiency. Ensuring continuous monitoring and timely corrective actions will be crucial for sustainable and safe water management.

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