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IoT Oriented Approach for Rural and Urban Area Based on 'Smart Water Management Systems' through Sensors

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Abstract: Effective water management is crucial for both rural and urban areas, where water scarcity and pollution are pressing concerns. This paper explores an Internet of Things (IoT)-oriented approach to develop 'Smart Water Management Systems' through the integration of advanced sensors. The proposed system employs a network of sensors to monitor various water parameters, including flow rate, water quality, and leak detection, in real-time. By leveraging IoT technology, the system ensures continuous data collection and analysis, facilitating timely decision-making and resource allocation. In rural areas, the smart system aims to optimize irrigation practices, reduce water wastage, and enhance the reliability of water supply for agriculture. In urban environments, it focuses on efficient water distribution, early detection of leaks, and maintaining water quality standards. The paper also discusses the challenges and solutions related to the deployment of IoT-based systems, such as connectivity issues in remote areas and data security concerns. Through case studies and pilot projects, the effectiveness of the smart water management system is demonstrated, showcasing significant improvements in water use efficiency and sustainability. The findings indicate that IoT-enabled water management systems hold great potential in addressing the diverse water-related challenges faced by both rural and urban communities, paving the way for a more sustainable and resilient water management framework.

Keywords: *IoT, Smart water management, Sensors, Water sustainability, Monitoring, Water quality*

1. Introduction

India's population growth rate is high due to fast development and population of India is estimated nearly 17.51% of the world. Now India's population approximately 48% will live in the urban areas by the end of the year 2030 comparatively 33% population were living by the year of 2015 according to the population growth rate. [1]. Kevin Ashton explained the interconnecting network through the 'Internet of Things' [2]. Water is a very essential and natural resources for living beings. Now a days water shortage and deteriorated water resources is a major challenge [3]. So, the CPCB (Central Pollution Control Board) has implemented many stations for water monitoring to check and analyse water quality and water expenditure on yearly or monthly basis [3]. Shrinkage of the water resources is a major problem due to retrogression of fresh water reservoirs in the various regions of the world [4] [5]. To seeing the situation of Covid 19, Internet of Things is the best way to implement the 'Smart Water Management System' which will work with the minimal human interaction. IOT means 'less human interaction' with good quality work. The most critical situation is that urban and rural both areas are facing water related issues like water contamination, water shortage etc. With the help of IOT, information can be collecting anytime from anywhere within the time and with less human interaction [6]. Currently an estimated number of 0.6% of devices that can be part of IOT has been connected so far [7]. Internet of Things can be defined with 3 words see as in figure1.

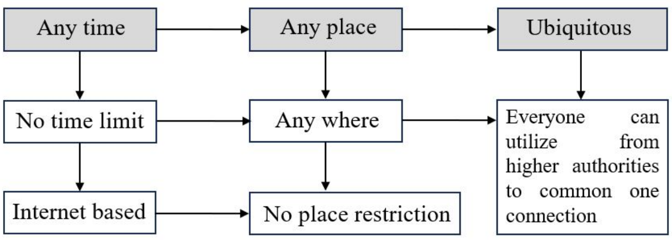

Fig 1: interactions between various connected networks, Source: Author

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IoT is a novel paradigm that is quickly gaining popularity in the modern technologies. Large number of applications can be utilized by the help of Iot system but currently in our society Iot system's uses are very less [8]. The IoT domain includes smart environment in the home, office, plant etc., health management area, transportation, logistics and many more [9].

This study aims to propose and implement an IoT-based approach for comprehensive water management in rural and urban areas of India. Specifically, it seeks to: (1) Develop a smart water management system leveraging IoT technology to enhance monitoring and efficiency; (2) Address water-related challenges by analysing issues such as contamination and shortages across diverse rural and urban contexts; and (3) Establish a unified framework for scalable water distribution and management, integrating IoT sensors and data systems to optimize decision-making and automation processes. Through these objectives, the study aims to demonstrate the transformative potential of IoT in addressing India's pressing water management needs effectively and sustainably.

2. Literature Review

2.1 Overview of Water Management Challenges

The urban and rural areas are uniquely affected by such issues. Municipalities face significant water loss due to leaks, inefficient workforce performance, and over-abstraction. Additionally, increasing demands from urbanization and business strain an aging infrastructure, where many city pipelines have exceeded their intended lifespan. Furthermore, the demand and pressures on existing systems that contribute to these problems are amplified through rapid urbanization. On other hand, rural habitations have to face lack of infrastructure; no access to clean drinking water & inadequate monitoring provisions [10]. In these settings, they typically have insufficient human and financial capacity as well as poor technology for water management resulting in high levels of contamination and continuous issue with the consistency of clean drinking-water [11]. Environmental problems incorporated as over water consumption tends to water scarcity, decreasing water and air quality, poor water drainage system, increasing flood frequency, and poor work quality due to increase in development cost of the organization [12]. This has driven the requirements for systematic urbanization which in turn has expanded the request for smart cities in India so the key 'smart' segment incorporates water, energy, transport, waste management, and healthcare [13]. Climate change further exacerbates these challenges by altering precipitation patterns, affecting water availability and quality [14]. Erratic rainfall and prolonged droughts impact water reservoir levels and groundwater recharge rates, exacerbating water scarcity issues in both rural and urban areas [15]. Rising temperatures also increase water demand for agricultural irrigation and urban cooling, placing additional stress on already limited water resources [16].

2.2 Existing Water Management Solutions

2.2.1 Review of Traditional Water Management Methods

Traditional water management methods have historically relied on community-based practices and local knowledge to sustain water resources. In rural areas, techniques such as rainwater harvesting, community wells, and small-scale irrigation systems have been crucial for meeting agricultural and domestic water needs [17]. These methods emphasize local participation and sustainable use of water resources, often integrating cultural practices with ecological stewardship. In urban environments, traditional water management involves centralized systems where water is sourced from distant reservoirs or rivers, treated at facilities to meet quality standards, and distributed through extensive networks of pipes [18]. These systems ensure mass water supply to urban populations but face challenges like aging infrastructure, inefficiencies, and water losses due to leaks and evaporation.

2.2.2 Examination of Modern Technologies Used in Water Management

Modern technologies are transforming water management practices by enhancing efficiency, reliability, and sustainability. IoT technologies, for instance, enable real-time monitoring of water quality, flow rates, and infrastructure conditions. Sensors deployed in water systems provide continuous data streams that facilitate early leak detection, optimize distribution networks, and improve operational efficiency [19]. Advanced treatment technologies such as membrane filtration and reverse osmosis enable the purification of wastewater and brackish water, expanding freshwater supply options in water-stressed regions [20]. These technologies play a vital role in mitigating water scarcity and enhancing resilience against climate-induced challenges. Integration of modern technologies with traditional practices offers a comprehensive approach to sustainable water management. By leveraging IoT for real-time monitoring and data-driven decision-making, alongside innovative treatment and conservation methods, communities and governments can enhance water resource resilience, ensure equitable access to clean water, and mitigate the impacts of urbanization and climate change on water availability [21].

2.2.3 Smart Water Management Framework and Water Distribution

Smart water management can be separated basically into three parts 'Forecasting demand', 'Water quality monitoring', and 'Anomaly detection'. These are dealt with the machine learning technologies utilized for the same [22]. Conventional water distribution is carried out zone wise. If the new area is developing around the city, a new water distribution zone is developed with a new municipal water tank in that zone. Indeed, within the particular region, or society wise manual water control valves are utilized for water distribution among the different zones of the society. These manual water control valves are utilized because of the confinement of the specified water pressure to supply water to all regions inside that particular zone [23]. Another critical thing is that the water quality is watched only at the Municipal water tanks which are found zone-wise and subsequently water quality isn't been checked at endpoints where chances of water defilement are on display due to rust and gap within the pipeline, and also few other reasons. Indeed, in case, water quality is checked at endpoints, it is time-consuming, labour-intensive and all endpoints are not aiming to cover. Subsequently, there's a requirement for a smart water distribution framework with persistent water quality checks [24]

2.3 Role of Iot in Water Management

IoT has revolutionized various industries by interconnecting devices and enabling real-time data exchange and automation. In water management, IoT plays a crucial role in enhancing efficiency, sustainability, and resilience of water systems. IoT devices, equipped with sensors and actuators, collect and transmit data on water quality, consumption patterns, and infrastructure conditions, enabling informed decision-making and proactive management strategies [19].Table 1, shows the IoT technologies in water management across different regions of India. The integration of IoT technology fosters a more resilient and adaptive water management framework, promoting environmental sustainability and enhancing the quality of life. For instance, in urban areas like Hyderabad, smart water meters provide real-time consumption data, identify leaks, and improve billing accuracy. In Delhi, IoT sensors continuously monitor water quality, ensuring compliance and timely responses to contamination. In Maharashtra, precision irrigation systems optimize water usage based on soil moisture levels and weather conditions, while in Assam, flood monitoring systems provide early warnings, facilitating timely evacuations.

Table 1: implementations of IoT technologies in water management across different regions in India

Location	Installation	Implementation Details	Source
Telangana	Smart Water Meters	IoT-enabled smart water meters provide real-time data on consumption patterns, aiding in leak detection, reducing water losses, and improving billing accuracy.	[46]
Delhi	IoT-Based Water Quality Monitoring	IoT sensors in water treatment plants and distribution networks monitor turbidity, pH levels, and chlorine levels in real-time, ensuring water quality compliance.	[47]
Maharashtra	Precision Irrigation Systems	IoT-based precision irrigation systems optimize water usage by monitoring soil moisture and weather conditions, providing data-driven insights for irrigation scheduling.	[48]
Assam	Flood Monitoring and Early Warning Systems	IoT sensors in river basins provide early warning alerts during floods by measuring water levels and rainfall intensity, aiding in timely evacuation and disaster response.	[49]

2.3.1 Advantages of Using IoT for Water Monitoring and Management

The advantages of IoT in water management are manifold. Firstly, IoT enables real-time monitoring of water parameters, allowing prompt detection of leaks, contamination events, and infrastructure failures [19]. Secondly, IoT-driven data analytics provide actionable insights for optimizing water distribution, reducing operational costs, and improving resource allocation efficiency. Thirdly, remote monitoring capabilities of IoT systems enable authorities to manage water systems from a central location, enhancing operational flexibility and responsiveness to dynamic water demand patterns [50].

3. Applications

3.1 Iot Based Water Distribution System

Water Distribution System (WDS) based on many frameworks designed by different authors based on their types and security levels which is necessary according the various applications [25] [26]. Figure 2 explain about the basic framework contains 3 layers of WDS, which are the Perception layer, Network layer, and Application layer so this system will be utilized for water distribution framework based on IoT. A water distribution system operates with a perception layer using sensors to monitor flow, pressure, and quality. The network layer comprises communication infrastructure for data transmission. The application layer processes this data, providing user interfaces for real-time monitoring, analysis, and management, ensuring efficient and responsive water distribution.

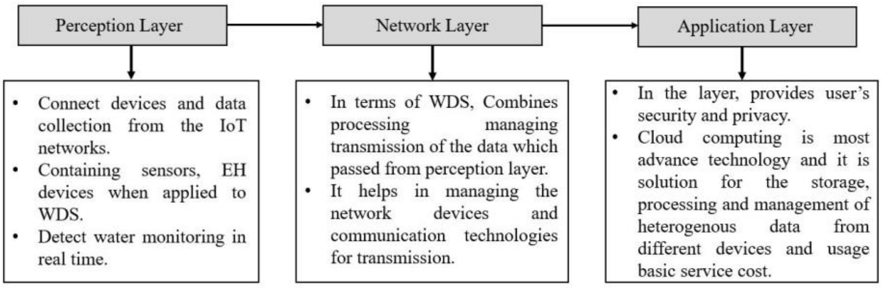

Fig 2: Layers of WDS, Source: [26]

a) Parameters of Smart Water System [27]:

- Quality Factors
- Quantity Factors
- Technology Factors
- Topology Factors

b) IoT based Application in 'Smart Water Management System:

- Smart Water System
- Smart Irrigation System
- Smart Gardening System
- Aquaculture System

c) Benefits: People have to consider IOT based system of water management in the aspect of technical, commercial and social aspect. After that people can take full benefits of this system with advance technology. These are some main benefits which is provided by advance technology system.

- Integration of Technology
- Data Storage, Management and computation
- Energy Management
- Economical
- Asset Utilization
- Increase Productivity

3.2 Iot Based Drinking Water System

To conserve water, IOT based sensor system can be installed in different surroundings or propose for installation where water can be saved with smart ways like Cloud computing [28].

3.2.1 Drinking water management model

To conserve the water, now it is necessary to have to install IOT based sensors. So, water management model can be discussed in terms of: IOT based drinking water management model based on following five things [29].

- Main Tank
- Sub Tank T1, T2, T3…
- Controlling Unit
- Cloud Computing
- Warning System

A comprehensive drinking water management model involves key components to ensure efficient water distribution and safety. The Main Tank serves as the primary storage, supplying water to Sub Tanks T1, T2, T3, and more, which distribute water to various areas. A Controlling Unit manages the flow and quality of water between tanks, utilizing sensors and automated systems for precise control. Cloud Computing facilitates real-time data analysis and storage, enabling remote monitoring and decision-making. A Warning System alerts authorities and users of any anomalies or contamination, ensuring timely interventions and maintaining the quality and safety of the drinking water supply

3.2.2 Algorithm of functions

According to function of system, algorithm can be divided into 3 steps following as [30]:

Step I: Ultrasonic sensor's analogue data have to understand first.

Step II: Manipulate all data into distance.

Step III: When get result accordingly, then can be control the solenoid valve.

The system's algorithm operates in three distinct steps to manage drinking water effectively. First, it interprets the analog data from ultrasonic sensors, crucial for assessing water levels in tanks. Second, it converts this data into measurable distances, providing precise information about the water volume. Finally, based on the calculated distances, the system controls the solenoid valve, adjusting the water flow between the main and sub tanks. This automation ensures optimal water distribution, maintaining efficiency and preventing overflows or shortages, ultimately enhancing the reliability of the drinking water management system.

3.3 Iot based water management for irrigation system

Irrigation System is a major source of livelihood for human beings in our country. Approximately 78% population is depending on agriculture business and their daily livelihoods. IOT plays very important role in the agribusiness during farming's because IOT based implementation methods reduce risk level and also increase work efficiency and productivity of crops [31]. Global System Mobile Communication (GSM) technology widely used in agribusiness which is contactless and wireless advance technology. Irrigation base technology designed with the soil moisture, water level and ph. value which is analysed by the designed application and used for irrigation water management system in the fields. So, it can be controlled by the sensors. These technologies will cover lacking information of existing soil structure and climatic conditions for the production of the crops. IOT based irrigation system based on the advance technology like sensors, PIC 16F877A Microcontroller, GSM, IOT and LCD [32]. Figure 3 explain about a block diagram for irrigation-based sensor technology typically includes the following components: soil moisture sensors, temperature sensors, and humidity sensors in the perception layer. Data from these sensors is transmitted via a wireless network layer to a central processing unit. The application layer then analyses the data, optimizing irrigation schedules and water usage through user interfaces and automated controls.

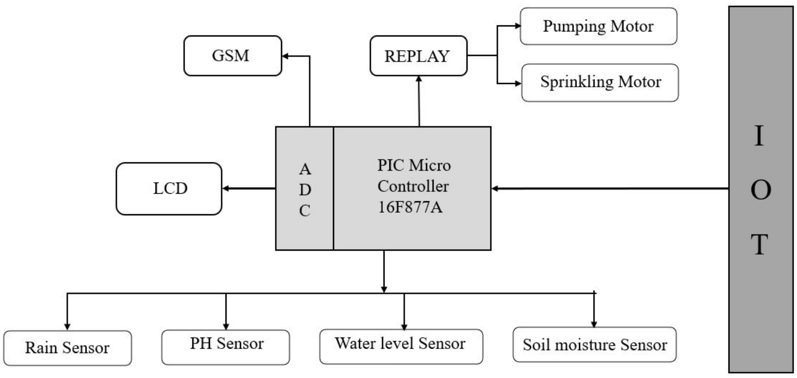

Fig 3: Block Diagram for irrigation-based sensors technology, Source: [33]

3.4 Water Utility and Monitoring and Control

Internet of Things based system will approach to improve 'Water Management System' with low cost and less human power. It will save energy and time. Figure 4 explain about Water supply management systems can address water management problems through two primary solutions: implementing advanced IoT-based monitoring for real-time data on usage and quality, and utilizing smart infrastructure to optimize distribution, reduce leaks, and ensure efficient, sustainable water use across urban and rural areas. Water supply management system can be divided into two most possible solution of all water management problems [34].

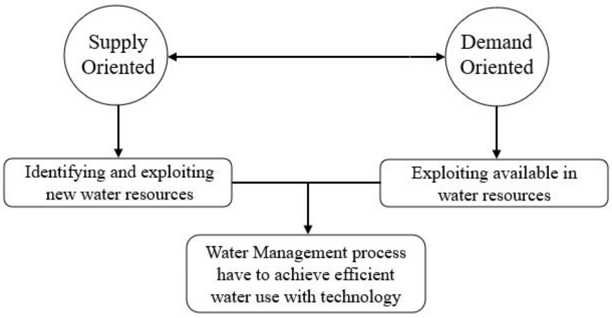

Fig 4: Water supply management system, Source: Author

Water Utility Monitoring and Control System works on these two types of devices [35].

- Dispersed Devices ⟶ Covers a large area
- Concentrated Devices ⟶ Closely connected

Above mentioned devices can be movable or immovable. Immovable devices have wireless internet connections in such areas and movable devices can also be connected wirelessly with internet. Architecture of 'water utility monitoring and control system' based on IoT can be divided into several levels [36] [37]. Figure 5 explain about an IoT-based architecture model for utility-based water monitoring and control integrates five key levels: the sensor level employs devices to monitor flow, pressure, and quality; the communication level ensures data transmission through wireless networks like LoRaWAN or cellular networks; the management of application level processes this data, providing real-time analytics for optimizing water usage and detecting issues; the terminal level interfaces, such as dashboards and mobile apps, present the data for user interaction; and the user level empowers utility managers and consumers to make informed decisions based on real-time insights, enhancing efficiency and ensuring sustainable water management.

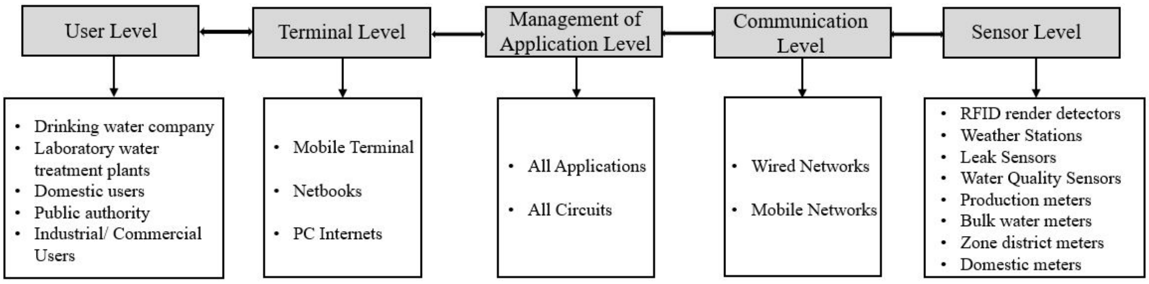

Fig 5: Architecture Model on the utility-based water monitoring and control system, Source: [38] [39]

The source of water quantity depletion based on the utilities of consumers and providers. So, they have these following two characterisations.

- Functional Integration
- Geographical Distribution

Water quantity depletion is influenced by both consumer usage and provider utilities, characterized by two main factors. *Functional Integration* involves the coordination of various water use functions, such as residential, industrial, and agricultural needs, ensuring that each sector's demand is met efficiently without excessive waste. *Geographical Distribution* addresses the spatial allocation of water resources, recognizing that different regions may have varying availability and demand. Efficiently managing these aspects ensures balanced water distribution, mitigates depletion, and supports sustainable use. By integrating functions and considering geographical factors, water providers can better address consumption patterns and resource limitations.

3.5 SCADA System (Supervisory Control and Data Acquisition system)

IOT based SCADA system focused to monitor and control the equipment. So, the process of the SCADA system is based on the following three things.

Infrastructure Process: This involves overseeing critical infrastructure such as water distribution networks, power grids, and transportation systems. Sensors and IoT devices collect real-time data, enabling efficient management and rapid response to issues.

Industrial Process: In manufacturing and production environments, the SCADA system monitors machinery and production lines, ensuring optimal performance, minimizing downtime, and enhancing safety through automated controls and alerts.

Facilities Process: This includes managing building systems such as HVAC, lighting, and security. IoT-enabled SCADA systems ensure energy efficiency, comfort, and security by integrating and automating facility operations.

3.6 Advance Implementation Based Enable Technology [40]

a) *Internet of Things:* Combination of all sensors, devices and technology etc. Called an 'Internet of Things'. The word 'Thing' can be defined in terms of objects as sensors, peoples, machines, technology, Advancements etc. so the word IOT can be varying according to the contexts, effects and their conditions.

b) *RFID Technology* (Radio Frequency Identification Technology): RFID is a key which enable to develop the concept of IOT. Authentication of RFID System with their both features as characteristics and functionalities.

- RFID Technology has 2 components. First is Contactless Electronic Tags and second is RFID Reader and permitting storage of data on RFID Tags.
- Giving access to the integration of RFID with sensor-based technology.
- RFID equipment's has unique Identification number of the things
- Automatic Identification and Data Capture (AIDC) wireless Technology
- It has low-cost solutions and power efficiency for the users.
- It is used for water utility monitoring and controlling.
- Contactless and nonlinear functionalities which enables data handling in severe environmental conditions and through various substances.

c) Multi-Agent Technology: MAT Technology used to solve various problems by the use of this MAT Technology, users can understand that how it is cost effective and resourceful. MAT Technology meaning can be defined as a 'Changing of information between multiple things', and Agent term defining to the 'software components' which means well-organized role of the operating system. So, the benefits could be getting by the implementation of Multi-Agent Technology.

- High Performance
- High Flexibility
- High Modularity

d) IOT Based Approach

- SCADA requires advance applications which will be used for water monitoring and controlling the system. So, these are as follows:
- Instant Monitoring allows real-time tracking of water levels, flow rates, and quality, ensuring immediate detection and response to anomalies.
- Scalability/ Measurement ensures that the system can expand and adapt to growing needs, accurately measuring various parameters across multiple sites.
- Connectivity (to permit all sensors to the enterprise IT systems) is crucial, linking all sensors to enterprise IT systems, facilitating seamless data exchange and centralized control. This connectivity ensures comprehensive oversight and efficient management.
- The system is designed to aid vigorous environments, capable of functioning in harsh conditions and adapting to fluctuating demands
- Safety and reliability are paramount, with IoT applications enhancing system integrity, preventing failures, and ensuring continuous, safe water supply.
- This comprehensive approach not only optimizes water management but also ensures sustainability and resilience in water infrastructure.

3.7 Iot Based Water Quality Monitoring System

Water is required in every field as: agriculture, industrial uses, domestic uses, commercial uses etc. Major open resources of water, mainly rivers are getting polluted by the domestic and industrial wastages. Contaminated water is major source of health degradation via drinking water or agricultural products. So, the Central Pollution Control Board has planned to implement IOT based sensors system (water quality) to monitor the current quality of water and showing all data at any time. It also has been implemented on the river ganga basin by CPCB [41].

Figure 6 explain about a water quality monitoring system utilizing GPRS/GSM techniques enables real-time, online monitoring by transmitting data from sensors to central servers via mobile networks. This system measures parameters such as pH, turbidity, and contaminant levels, ensuring immediate detection of water quality issues. The continuous data flow allows for instant analysis and prompt action, improving the management of water resources. By leveraging the widespread availability of GSM networks, this approach offers a reliable and scalable solution for both urban and rural areas, facilitating efficient water quality control and ensuring the safety of water supplies. Figure 7 shows a block model of a data network includes the information layer, GPRS network, and water quality platform (WQP). The information layer gathers data from sensors, the GPRS network transmits this data, and the WQP processes and analyses it, providing insights for water quality management and decision-making.

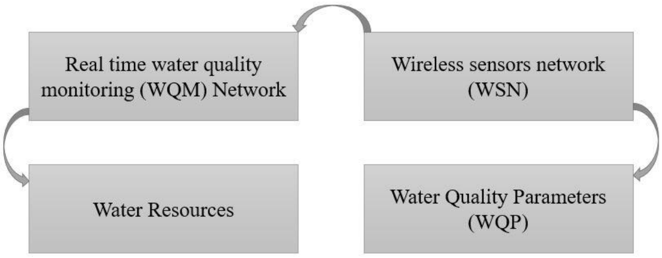

Fig 6: Water Quality Monitoring system based on GPRS/GSM techniques via online, Source: [42]

Fig 7: Block model of data network, Sources: [43]

Modern Technology (IOT) is able to observe, check and connect with the prevailing infrastructure of internet. To capture real time data each device, have unique identification. Cell phone is very good platform for both communication and computing. So, it can be connected with IOT to measure water quality system and cell phone will work as a remote control or display. Figure 8 shows a block diagram for monitoring water quality typically includes several interconnected components: sensors, data acquisition systems, communication networks, data processing units, and user interfaces. Sensors measure parameters such as pH, turbidity, and contaminant levels, transmitting data via communication networks like GPRS/GSM to central processing units. These units Analyse the data, generating real-time insights displayed through user interfaces, enabling efficient monitoring and management of water quality. This structured approach ensures continuous, accurate assessment of water resources, facilitating timely interventions and maintaining safe water standards in various environments.

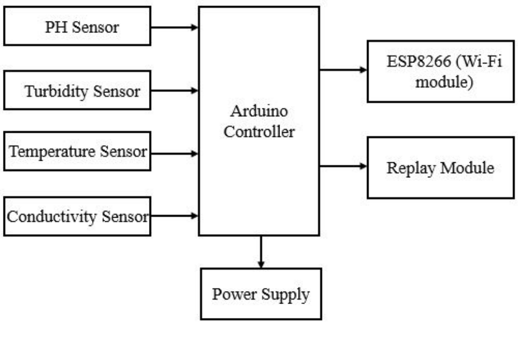

Fig 8: Block Diagram of monitoring water quality, source: [44] [45]

5. Conclusion

Overpopulation is a major driver of water resource exploitation, necessitating innovative solutions for water conservation. In response, scientists are prioritizing economical and efficient methods to secure our precious water resources. IoT emerges as a particularly beneficial approach for diverse users, facilitating effective water management through advanced technologies. These IoT-based applications have been successfully implemented across various sectors, including industrial, domestic, commercial, and agricultural fields. The systems, which are user-friendly and require minimal disruption during installation, provide an efficient means to conserve water and manage water resources. The IoT-oriented approach for smart water management systems, leveraging sensors, offers transformative potential for both rural and urban areas. This technology enables real-time monitoring and precise management of water resources, addressing critical challenges such as water scarcity, pollution, and inefficient distribution. In urban settings, smart water systems optimize water usage, reduce wastage, and ensure better quality control, contributing to sustainable city living. For rural areas, these systems provide essential data for improving irrigation practices, enhancing crop yields, and ensuring reliable access to clean water. Overall, the deployment of smart water management systems signifies a significant advancement towards achieving global water security and resource efficiency. By leveraging IoT, we can create more sustainable and resilient water management practices that ensure communities have access to safe and reliable water resources. This approach aligns with the broader goals of sustainable development and technological innovation, offering a path to a more secure and efficient water future. Continued collaboration between policymakers, researchers, and industry stakeholders will be essential in driving the adoption and enhancement of IoT technologies, ultimately leading to more effective water management strategies that can be scaled globally.

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