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## IoT-Based Water Quality Monitoring and Heat Mapping System for Aquaculture

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**ABSTRACT**: This paper introduces an IoT-based water quality measurement system, named 'waterQship,' designed for real-time monitoring of aquatic environments. The system integrates advanced sensor technology and heat mapping mechanisms to assess critical water quality parameters, including temperature, pH levels, dissolved oxygen, and turbidity. These parameters play a vital role in aquaculture, fisheries management, environmental conservation, and tourism. The research methodology involves developing a mathematical model that encapsulates these water quality indicators, followed by numerical techniques for accurate analysis and interpretation. The results demonstrate that the waterQship system efficiently provides real-time water quality insights, enabling early detection of potential issues that could impact aquatic life and water ecosystems. Furthermore, an Android application is developed to complement the system, allowing users to remotely access water quality data. The app offers real-time updates on the four key parameters, assesses water conditions, and provides actionable recommendations when necessary. This approach enhances decision-making for stakeholders, ensuring sustainable water management. The integration of IoT with water quality assessment not only improves accuracy but also ensures accessibility and ease of use. The waterQship system presents a novel and effective solution for maintaining optimal water conditions in aquaculture and related industries.

KEYWORDS: IoT, water quality monitoring, heat mapping, aquaculture, real-time analysis, environmental conservation

#### **I. INTRODUCTION**

Monitoring water quality is a critical concern for industries such as fisheries, tourism, and environmental conservation. The ability to access real-time water quality data is essential for ensuring safety and sustainability in these sectors. Traditional water quality assessment methods are often costly and time-consuming, creating a need for more efficient and immediate monitoring solutions. To address this gap, the 'waterQship' has been developed—an advanced Water Quality Detection Vessel integrated with a Heat Mapping System, designed to deliver accurate and real-time water quality insights [1].

A review of existing literature reveals that various water quality monitoring techniques are in use, including laboratorybased testing, remote sensing, and in-situ measurements. However, these approaches have limitations regarding cost, efficiency, and accuracy. The 'waterQship' is designed to overcome these challenges by providing a cost-effective, portable, and real-time monitoring solution. As illustrated in Figure 1, this system utilizes state-of-the-art sensors to measure key water quality parameters such as temperature, pH, dissolved oxygen, and turbidity. The collected data is transmitted to a central server, where it undergoes analysis through a heat mapping technique, offering comprehensive real-time insights into water conditions. The core principle of this system is based on the correlation between water quality parameters and the thermal properties of water. By assessing temperature variations influenced by different water quality factors, the system generates heat maps that provide a clear and immediate representation of water quality conditions [2].

Aquaculture encompasses the practices, knowledge, and techniques involved in cultivating various aquatic plant and animal species. This industry plays a crucial role in both food production and economic development. However, commercial aquaculture faces growing challenges due to climate fluctuations that directly impact water quality parameters. Traditionally, aqua farmers rely on manual testing methods to evaluate water quality, but these approaches are often time-intensive and prone to inaccuracies due to the dynamic nature of water conditions. Such inconsistencies underscore the necessity for more reliable and efficient monitoring solutions in aquaculture [3].



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Automating the monitoring process would significantly enhance accuracy and efficiency. The integration of modern technology in aquaculture can provide real-time water quality assessment, ensuring optimal conditions for aquatic life. Advanced technologies should be capable of addressing key areas such as aquatic health, environmental sustainability, and rural development. Therefore, when selecting suitable technological solutions for this sector, careful consideration is required to ensure their effectiveness and adaptability to changing environmental conditions [4].



Fig. 1. Automatic cruising boat for water quality monitoring

The introduction of IoT in various industries has revolutionized operations, and the water and aquaculture sectors are no exception. With the increasing demand for clean water, automated water quality monitoring solutions have become indispensable. These systems enable real-time monitoring of critical water parameters and provide instant alerts when abnormalities are detected. By minimizing the reliance on manual testing, IoT-based monitoring not only improves efficiency but also conserves time and resources [5].

An IoT-based water quality monitoring system consists of sensors, communication modules, and data analytics tools that continuously track key parameters such as pH, temperature, turbidity, dissolved oxygen, and conductivity. The collected data is transmitted to a centralized hub or cloud-based platform, where real-time analysis is performed. This ensures timely and precise evaluation of water conditions, allowing stakeholders to receive reports, visualizations, and alerts regarding water quality status. Designed for durability, these sensor systems can operate in harsh environments and are strategically placed in rivers, ponds, and lakes to provide continuous data collection at predefined intervals.

The system uses cellular networks or Wi-Fi to ensure reliable data transmission, even in remote locations. A crucial component of these systems is data analytics, where machine learning algorithms analyze sensor data to identify trends and anomalies. This allows stakeholders to make informed decisions and take immediate corrective action when necessary. One key advantage of IoT-based monitoring is its ability to generate real-time alerts. For instance, sudden changes in pH or dissolved oxygen levels trigger instant notifications, ensuring prompt intervention—critical for drinking water facilities and wastewater treatment plants [6].

Compared to conventional monitoring methods that rely on labour-intensive sample collection and laboratory analysis, IoT-based solutions offer a cost-effective and highly efficient alternative. Automated monitoring ensures continuous tracking, reduces human error, and lowers operational costs. In conclusion, IoT-driven water quality monitoring systems provide a transformative solution, allowing for real-time assessment, proactive issue detection, and sustainable water management. As clean water demand rises and pollution challenges intensify, these automated solutions are becoming essential for maintaining water quality and regulatory compliance [7].

#### **II. LITERATURE SURVEY**

Sobri et el. developed an automated system utilizing IoT technology to monitor water quality parameters such as temperature, pH, and dissolved oxygen in Vannamei shrimp farming. The system employs sensors connected to a microcontroller, transmitting real-time data to a cloud platform accessible via mobile devices. This approach enables continuous monitoring and timely interventions, enhancing shrimp health and yield [8].



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Gupta et al. designed an IoT-enabled underwater robot equipped with sensors to measure parameters like pH, turbidity, and temperature. The robot uses an ESP32 microcontroller for data processing and Wi-Fi communication to transmit real-time data. Implementing machine learning algorithms, specifically K-Means clustering, the system analyses water quality, facilitating efficient monitoring and management in aquaculture environments [9].

Huan et al. developed a system utilizing Narrow Band Internet of Things (NB-IoT) technology to monitor parameters such as temperature, pH, and dissolved oxygen in aquaculture ponds. The system employs an STM32L151C8 microcontroller to collect real-time data, which is transmitted to a cloud platform for remote monitoring. Field tests demonstrated high accuracy, with temperature control within  $\pm 0.12$ °C, dissolved oxygen within  $\pm 0.55$  mg/L, and pH within  $\pm 0.09$ , indicating the system's reliability for aquaculture applications [10].

Nasir and Mumtazah designed a system integrating sensors to measure water temperature, pH, turbidity, air temperature, and ambient light in aquaculture environments. Connected to an Arduino board, the sensors transmit data via GSM to the Thing Speak cloud platform, enabling 24/7 monitoring. The system effectively detected slight fluctuations in water parameters during feeding times, ensuring fish health and demonstrating cost-effectiveness for aquaculture farmers[11]. A study presented in Procedia Computer Science introduced a sensor-based system employing Wireless Sensor Networks (WSN) to monitor river water quality parameters such as pH, temperature, and dissolved oxygen. The system leverages IoT technology for real-time data transmission and analysis using Spark streaming and machine learning models. Upon detecting anomalies exceeding threshold values, automated SMS alerts are dispatched, facilitating prompt responses to water quality issues [12].

A study proposed a portable water quality monitoring system based on Wireless Sensor Networks (WSN) and IoT platforms. The system was designed to monitor parameters such as pH, dissolved oxygen (DO), and temperature. It included a power management system supplied by solar panels. The collected data was transmitted to users through an IoT-based system, enabling real-time monitoring and management of water quality in aquaculture environments [13]. A study developed an IoT-based water quality monitoring system utilizing wireless sensor networks equipped with sensors for parameters like turbidity, conductivity, temperature, pH, and oxidation-reduction potential. The system implemented fuzzy logic to predict water contamination risks in distribution pipelines at the local level. This approach facilitated real-time monitoring and proactive management of water quality, enhancing the efficiency and sustainability of aquaculture operations [14].

#### **III. METHODOLOGY**

An IoT-based water quality monitoring system is increasingly essential as it enables real-time data collection and analysis from remote locations. Implementing such a system involves selecting key water quality parameters, integrating appropriate sensors, establishing an IoT framework, configuring both hardware and software components, visualizing and analyzing the collected data, and taking necessary corrective measures. The proposed model incorporates an Arduino Mega microcontroller, along with multiple sensors, including TDS, pH, DS18B20 temperature sensor, and a dissolved oxygen (DO) sensor. Additionally, a GPS GSM GPRS SIM808 module is utilized for seamless data transmission. The following figure illustrates the system architecture, its summary, and the corresponding field deployment diagram.

The system's operational framework is divided into multiple layers for efficient processing. The first step involves identifying the essential water quality parameters that need monitoring, such as pH, dissolved oxygen, temperature, turbidity, conductivity, and total dissolved solids. Once these parameters are determined, suitable sensors are selected for accurate measurement. For example, pH sensors measure acidity or alkalinity, while dissolved oxygen sensors assess oxygen levels in the water. The collected sensor data is transmitted to the microcontroller, where it undergoes processing before being sent to the cloud for storage and further analysis. Figure 3 illustrates the system's flowchart.

At the data processing stage, the microcontroller filters, calibrates, and converts the collected data as necessary. Sensors are strategically placed in the water source and configured to communicate data to an IoT platform via a cellular network (GPS GSM GPRS SIM808). The IoT platform is structured to receive, store, and manage this data efficiently. Additionally, automated alerts are generated if any water quality parameter surpasses predefined thresholds. A visualization tool or dashboard displays real-time sensor data, allowing users to monitor trends and detect anomalies. A heat map of a specific water region is generated using the temperature sensor, providing a visual representation of temperature variations. This feature aids in quickly identifying critical changes in water conditions, enabling timely interventions.



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Fig. 3. Flowchart for the proposed system

Utilizing advanced analytics tools to evaluate the collected data over time enables the identification of patterns and trends, offering valuable insights into water quality. Based on these insights, necessary measures can be implemented to maintain or improve water conditions, such as adjusting chemical levels, switching water sources, or installing filtration systems. Additionally, regular maintenance of both the sensors and the IoT platform is essential to ensure optimal functionality. This includes cleaning sensors, updating software, and replacing faulty components when required.

An IoT-based water quality monitoring system follows a structured process: data collection from sensors, transmission to the cloud, real-time processing and storage, continuous monitoring with alert notifications, visualization of key parameters, data analysis for pattern detection, and taking corrective actions as needed.

The system design for an Internet of Things (IoT)-enabled automated water quality monitoring system encompasses the careful selection of sensors, the establishment of communication protocols, networking infrastructure, and data storage solutions. This design is adapted to ensure real- time observation and analysis of water quality metrics, produce timely alerts and detailed reports, and possess the flexibility to support future expansions and enhancements. Below is a summary of the system's design framework and the simulation methodology:



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Sensor Selection: The key step is to select sensors that can measure various water quality parameters such as pH, temperature, turbidity, dissolved oxygen, and conductivity. The sensors must be durable, consistent, and capable of withstanding harsh environmental conditions. For example, pH sensors must have a robust membrane that can withstand fouling, and turbidity sensors must be capable of measuring low turbidity levels accurately. The selected sensors must also be compatible with the communication protocols used in the system.

#### **IV. PROPOSED SYSTEM DESIGN AND SIMULATION**

The design of an IoT-enabled automated water quality monitoring system involves the strategic selection of sensors, implementation of reliable communication protocols, establishment of a robust networking framework, and integration of efficient data storage solutions. This system is structured to facilitate real-time monitoring and analysis of water quality parameters, ensuring prompt alerts and comprehensive reporting. Additionally, it is designed with scalability in mind, allowing for future upgrades and expansions. Below is an overview of the system's design architecture and the methodology used for simulation and performance evaluation.

**Sensor Selection:** The key step is to select sensors that can measure various water quality parameters such as pH, temperature, turbidity, dissolved oxygen, and conductivity. The sensors must be durable, consistent, and capable of withstanding harsh environmental conditions. For example, pH sensors must have a robust membrane that can withstand fouling, and turbidity sensors must be capable of measuring low turbidity levels accurately. The selected sensors must also be compatible with the communication protocols used in the system [15].

**Communication Protocols:** The second step is to select transmission protocols that allow the sensors to transmit data to the proper platform. Standard protocols such as MQTT, CoAP, and HTTP can be used to ensure interoperability and compatibility with existing systems. The communication protocols must also be secure, providing data encryption in transit and at rest.

**Networking:** The third step is to design the networking architecture that connects the sensors to the central hub or cloudbased platform. Wired and wireless networking technologies can be used, depending on the system's requirements. For example, Wi-Fi, Zigbee, and LoRa WAN can be used for wireless networking, while Ethernet and RS485 can be used for wired networking. The networking design must ensure high availability, low latency, and scalability [16].

**Data Storage:** The fourth step is to select the appropriate data storage technologies to store the collected data. The data storage technology must be scalable, secure, and compatible with the communication protocols used in the system. Cloud based platforms such as AWS, Azure, and Google Cloud can be used for data storage, providing a scalable and secure solution.

**Simulation:** Once the system design is complete, the system can be simulated to test its performance and identify any issues. The simulation can include testing the system under different environmental conditions, such as changes in temperature and pH levels, to determine its accuracy and reliability. The simulation can also test the system's scalability by increasing the number of sensors and monitoring points[17].

**Implementation:** After the system design and simulation are complete, the system can be implemented. The implementation process includes installing the sensors, configuring the communication protocols and networking, and deploying the data storage technologies. The system must be verified to confirm that everything is operating correctly and providing accurate and timely data [18].

In conclusion, the system design and simulation for an IoT based automated solution for water quality monitoring involves sensor selection, communication protocols, networking, data storage, and simulation. The design must provide real-time monitoring and analysis, generate alerts and reports, and be scalable to accommodate future expansion. The system's performance must be tested through simulation, and any issues must be identified and addressed before implementation.

#### V. HARDWARE DEVELOPMENT AND TESTING

The hardware development and testing phase involves assembling and evaluating sensors like pH, turbidity, temperature, and TDS, along with communication modules. Each component is tested individually and collectively to ensure accurate data collection and seamless integration with the IoT platform. This enables real-time monitoring and reliable water quality assessment. The following is an overview of the hardware development and testing process:



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Fig. 4. Circuit Diagram of Proposed System (Proteus)

**Ph Sensor:** The pH sensor is essential for measuring water acidity or alkalinity, determined by hydrogen ion concentration. Naturally occurring water has a pH near 7, while the safe range for drinking water is 6.5 to 9.5. The pH scale spans from 0 (high acidity) to 14 (strong alkalinity), with each unit change representing a tenfold shift in hydrogen ion concentration. Measurement relies on electrode sensitivity, where potential values correlate with ion concentration. Since temperature affects electrical potential, integrating a temperature sensor ensures accurate pH readings by compensating for voltage variations [19].

**Turbidity sensor:** Turbidity sensors measure water cloudiness by detecting light scattering caused by suspended particles. They consist of a light source and a detector, where the detector converts scattered light into an electrical signal for turbidity readings. These sensors provide accurate, continuous data, making them effective for monitoring water quality changes. They help detect pollution events and assess water treatment efficiency. Their real-time monitoring capability is essential for maintaining and improving water quality standards [20].

**Temperature sensor:** A temperature sensor measures temperature by converting it into an electrical signal. Made from two different metals, it generates voltage or resistance in response to temperature changes. This occurs as temperature variations cause a shift in voltage across the sensor's diode terminals. An increase in temperature leads to a corresponding rise in voltage. This mechanism enables precise temperature measurement [21].

**TDS meter:** A Total Dissolved Solids (TDS) meter measures the concentration of dissolved solids in water by assessing its conductivity. Since ionized solids like salts and minerals increase conductivity, the meter infers TDS levels from this measurement. It provides a quick and efficient way to determine water purity. Higher conductivity indicates a greater concentration of dissolved substances. This makes TDS meters essential for water quality monitoring [22].

**Lithium-ion battery Charger:** Lithium-ion batteries display their charge level as a percentage, with voltage ranging from 3.6V (empty) to 4.2V (full). A simple circuit can monitor the charge level of an 18650 lithium-ion battery using LED indicators. The red LED lights up at 3.75V (25% charge), yellow at 3.90V (50%), green at 4.05V (75%), and blue at 4.20V (100% charge). Connecting the circuit to the battery terminals and pressing SW1 allows real-time voltage monitoring. LEDs illuminate sequentially based on voltage, providing a clear visual representation of the battery's charge status [23].

**Bipolar Stepper Motors:** A bipolar stepper motor is a two-phase motor with a single winding per phase, using a fourwire configuration. It consists of a stator (stationary part) and a rotor (rotating component). These motors require a reversible current in each winding to function, typically controlled by an H-bridge circuit. Bipolar stepper motors offer higher torque and efficiency compared to unipolar motors. They are widely used in precision applications like robotics and CNC machines [24].

**Buck Module:** A step-down DC-DC converter, or buck converter, reduces input voltage to a lower, stable output voltage while maintaining efficient power delivery. It regulates output current, making it essential for applications requiring a lower voltage from a higher source. The converter operates using a switching mechanism with an inductor, capacitor, and transistor to optimize energy transfer. Its high efficiency makes it ideal for battery-powered devices and power regulation in electronics[25].



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#### VI. EXPERIMENTAL RESULTS

An IoT-based water quality monitoring system was developed to enable real-time assessment of key water quality parameters. The system comprises a sensor module, a microcontroller, and a cloud-based server. The sensor module measures pH, temperature, and turbidity, while the microcontroller processes the data and transmits it to the cloud via Wi-Fi. The collected data is then displayed in graphical form on a dashboard for real-time analysis. Laboratory tests using water samples of varying quality confirmed the system's accuracy in measuring these parameters. Unlike traditional methods, which are costly and require manual intervention, this IoT-based approach offers a cost-effective and automated solution for continuous water quality monitoring. Its scalability makes it suitable for both small- and large-scale applications, and its ability to function in remote areas ensures broader access to water quality data. Additionally, the system aids in early detection of water quality issues and evaluates the efficiency of water treatment processes, ensuring that water remains within safe parameters. This real-time monitoring capability helps prevent contamination and enhances water safety. Overall, the IoT-based system provides an efficient, scalable, and easily deployable solution for water quality monitoring, improving public health and environmental management. Figures below demonstrate the real-life implementation of the project, with Figure 7d displaying pH readings on a laptop.



Fig. 5. Hardware development and Testing

The mathematical analysis is shown here accordingly, the waterQship system's methodology relies on the use of equations to calculate water quality parameters. For example, dissolved oxygen can be calculated using the following equation:

$$DO = K \times [(V2 - V1)/t]$$

Where DO is dissolved oxygen, K is a constant, V1 is the initial volume of the sample, V2 is the final volume of the sample, and t is the time taken to reach V2.

The waterQship uses different sensors to collect water quality data, which is transmitted to a control station onshore for analysis. The sensors measure various parameters, including: Temperature (T): Measured using a temperature sensor. pH (pH): Measured using a pH sensor. Turbidity (Tu): Measured using a turbidity sensor.Dissolved Oxygen (DO): Measured using a dissolved oxygen sensor.



Fig. 6. Hardware development and Testing

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Fig. 7. Temperature graph

Conductivity (Cond): Measured using a conductivity sensor. The equations used to calculate the water quality parameters are: Temperature (T): T = Vout \* 100

Where Vout is the voltage output from the temperature sensor. pH(pH): pH = -log[H+]

Where H+ is the hydrogen ion concentration. Turbidity (Tu): Tu = (Vout / Vs) \* K

Where Vout is the voltage output from the turbidity sensor, Vs is the voltage output from the reference sensor, and K is a calibration constant.

Dissolved Oxygen (DO): DO = (Vout – Vblank) / Slope

Where Vout is the voltage output from the dissolved oxygen sensor, Vblank is the voltage output from a blank sample, and Slope is a calibration constant.

Conductivity (Cond): Cond = K \* Vout

Where K is a calibration constant, and Vout is the voltage output from the conductivity sensor.



Fig. 8. PH Sensor graph

#### VII. CONCLUSION

Aquaponics is a sustainable system that combines Recirculating Aquaculture Systems (RAS) with hydroponics, integrating fish farming and plant cultivation in a mutually beneficial environment. In this system, water from the fish tank circulates through multiple stages: it undergoes filtration to remove waste, passes through plant grow beds for nutrient absorption, and returns to the fish tank. The filtration process includes a mechanical filter to eliminate solid waste and a biofilter that fosters bacteria responsible for nitrification—converting toxic ammonia into nitrate. This



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nitrate, along with other essential nutrients, is then absorbed by plants, effectively cleansing the water before recirculation.

An automated water quality management system in aquaponics significantly enhances system efficiency and productivity. Continuous monitoring minimizes human intervention, ensuring more stable operations. Moreover, platforms like Blynk facilitate data analysis, optimizing both water circulation and energy usage for uninterrupted flow. This project aims to develop an automated system capable of accurately measuring nutrient levels, further promoting sustainability and efficiency within aquaponic farming.

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