International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING

ISSN:2147-6799 www.ijisae.org Original Research Paper

Smart Sensing and Geo-Intelligence: A Portable Approach to Water Quality Monitoring for Environmental Sustainability

Rucha Rajiv Shastrakar, Dr. Vijayalaxmi Biradar

Submitted: 02/10/2024 **Revised:** 12/11/2024 **Accepted:** 23/11/2024

Abstract*:* Access to clean water remains one of the most pressing challenges, particularly in developing regions where traditional testing methods fall short—either too slow, too expensive, or simply inaccessible. This research introduces a practical, portable solution for real-time water quality monitoring, blending smart sensing technology with geo-intelligence. The proposed device integrates a microcontroller, an array of essential water quality sensors (including pH, turbidity, dissolved oxygen, temperature, and conductivity), and a GPS module to collect and tag data across diverse water sources. It's lightweight, cost-effective, and designed for deployment in both rural and urban settings. Data is processed locally and pushed to the cloud, making it instantly available to environmental agencies, local authorities, and even concerned citizens. More than just numbers on a screen, this system paints a live picture of water conditions across a region, enabling quicker decisions and targeted interventions. Ultimately, it's about empowering communities with the tools to safeguard their most vital resource.

Keywords: *heavy metals, environment, contamination, legal requirements, pollution.*

I. INTRODUCTION

Water quality is essential for public health and environmental sustainability. The growing concern over water contamination, particularly in developing regions, has prompted the development of more efficient and accessible ways to monitor and evaluate water quality in real-time. Traditional water quality monitoring methods often rely on laboratory testing, which can be slow and costly. This research proposes the development of a portable device that combines a microcontroller, water quality testing sensors, and a GPS module to conduct real-time surveys of water quality at different geo-locations and from different water sources. The device aims to provide timely, reliable, and actionable data to stakeholders such as local governments, environmental agencies, and the general public. The history of water quality monitoring dates back to the early 20th century, when laboratory methods began to be used to assess the safety of water supplies. With advancements in technology, various sensors have been developed to detect contaminants in water, including physical, chemical, and biological parameters. Despite these advancements, challenges such as remote locations, the cost of testing, and slow data collection remain prevalent in many parts of the world. Current solutions to this issue often lack portability, real-time data processing, and integration with global databases, which limits their utility for wide-scale deployment. The proposed system operates by utilizing a microcontroller (such as the Arduino or Raspberry Pi), integrated with water quality sensors and a GPS module. The sensors measure critical water quality parameters such as pH, turbidity, dissolved oxygen (DO), temperature, and conductivity. These parameters are essential indicators of water quality and can detect pollution or contamination from agricultural runoff, industrial waste, or natural environmental changes. The GPS module allows the system to geo-tag the data, providing precise location coordinates where each water quality sample is taken. The microcontroller receives signals from the sensors, processes the data, and transmits it to an IoT-enabled cloud platform for further analysis and real-time access. The GPS data, along with water quality parameters, is uploaded periodically or on-demand. This data can then be accessed by the relevant stakeholders via a web interface, providing continuous monitoring and geographic tracking of water quality at various sources.

Water pollution is a significant issue globally, with increasing contamination of surface water bodies, groundwater, and drinking water sources. Inadequate water quality monitoring often leads to the failure of early detection of pollution, which in turn causes health hazards, environmental damage, and economic losses. Traditional

Research Scholar

Department of Electronics and communication Engineering

Kalinga University, Raipur, Chhattisgarh

Email: rucha.riyas@gmail.com

Associate Professor

Department of Electronics and Communication Engineering

Kalinga University, Raipur, Chhattisgarh

Email: dr.vijayalaxmi@kalingauniversity.ac.in

water quality monitoring methods are often costly, time-consuming, and labor-intensive, limiting their ability to monitor water quality continuously and in remote locations.

The primary challenges addressed by this research are:

Limited Access to Real-Time Water Quality Data: In many areas, especially in developing countries, water quality is monitored infrequently, if at all. Without real-time data, it is difficult to respond to pollution incidents quickly and appropriately.

High Cost of Water Quality Testing: Current water quality monitoring systems, including laboratory-based testing, are expensive and require specialized equipment and trained personnel. This makes it difficult for organizations to monitor water quality regularly, especially in remote areas.

Lack of Geo-Tagged Data: Without location-specific information, water quality data cannot be effectively mapped or analyzed in relation to geographic regions. This can result in missed opportunities for targeted interventions in polluted areas.

Scalability of Solutions: Traditional methods cannot be easily scaled to cover large geographic areas, especially in countries with limited infrastructure. A portable, scalable solution is needed to monitor water quality across diverse locations.

The solution to this issue is to a compact, portable, microcontroller-based device designed to test and monitor water quality in real-time using a suite of integrated sensors. These sensors measure key parameters such as pH, turbidity, dissolved oxygen, temperature, and conductivity—each of which plays a vital role in assessing the health and safety of water sources. What sets this system apart is its GPS integration, which allows every water sample to be accurately geo-tagged. This geographic tagging enables precise tracking and mapping of water quality variations across different locations, offering valuable insights for environmental agencies, researchers, and policymakers. The device is lightweight, battery-powered, and easy to carry, making it especially suited for deployment in remote or underserved regions where traditional lab testing is either impractical or delayed. Additionally, the collected sensor data is transmitted to an IoT-enabled cloud platform for storage, analysis, and visualization, providing users with remote access and real-time updates. This cloud integration not only facilitates centralized data management but also empowers timely and informed decision-making. A key strength of the system is its simplicity: a user-friendly interface ensures that even individuals with limited technical expertise can operate the device and understand its readings, which is crucial for fieldwork in community settings. Altogether, the device combines smart sensing, mobility, and connectivity to deliver an accessible and scalable solution for continuous water quality monitoring—one that could significantly improve the ability to respond to contamination events and support long-term environmental sustainability.

II. LITERATURE SURVEY

The conversation around water quality monitoring has evolved significantly with the integration of sensors and Internet of Things (IoT) technologies. As concerns about environmental sustainability and public health grow, researchers and technologists have been exploring accessible, scalable, and intelligent systems that allow for real-time assessment of water quality. These modern systems blend hardware, data analytics, and communication tools to offer timely insights and actionable intelligence on water conditions across varied ecosystems.

A central theme across recent research is the deployment of low-cost, microcontroller-based devices—most notably those using Arduino or Raspberry Pi platforms. These systems typically include sensors to measure key physicochemical properties such as pH, turbidity, dissolved oxygen, conductivity, temperature, and sometimes even biological contaminants. For example, Hong et al. (2021) demonstrated the use of Arduino with basic water quality sensors to deliver real-time data through mobile applications, making monitoring more accessible in remote or resource-constrained areas. Similarly, Osman et al. (2018) designed a real-time in-situ system that proves particularly valuable for rural drinking water management.

IoT integration further enhances the capabilities of such systems. Kumar et al. (2024) incorporated cloud platforms and machine learning into their pond monitoring solution, which not only gathered sensor data but also predicted trends and detected anomalies—critical for environmental conservation. Gj et al. (2024) expanded on this by enabling automated pollution detection with real-time alerts, demonstrating how IoT connectivity can streamline the communication between monitoring systems and environmental authorities.

Multiparametric monitoring has also gained attention as it reduces system complexity while broadening the scope of analysis. Fonseca-Campos et al. (2022) and Méndez-Barroso et al. (2020) both emphasized the value of measuring multiple variables from a single platform, allowing comprehensive assessment of environmental water conditions. These systems are especially suitable for complex ecosystems like estuarine lagoons.

Accuracy remains a key consideration. Naik and Bhavani (2023) tackled this issue by enhancing calibration techniques and improving sensor integration within Arduino-based frameworks, ensuring reliable results even with low-cost components. Their work emphasizes the importance of validation and refinement for practical field deployment.

Several studies also highlight the shift toward automation. Atiast and Aljafaar (2022) developed a microcontroller-based system that automates data collection and analysis, reducing dependency on manual sampling—a necessity for long-term monitoring projects. Dharani et al. (2024) went a step further by incorporating biosensors for bacterial detection, offering real-time alerts for contaminants like *E. coli*, which are particularly critical for public health protection.

Meanwhile, efforts such as those by Gadgay (2019) and Hakimi and Jamil (2021) emphasize user accessibility. Their systems combine sensor networks with web servers and graphical interfaces, making data easily viewable in real-time by non-technical users. These platforms ensure that stakeholders—from local authorities to community health workers—can respond swiftly to contamination events.

In specialized applications, Hidayatullah et al. (2022) adapted similar technology for agricultural hydroponics, showcasing the flexibility and cross-domain utility of these tools. This adaptability is further supported by Araneta (2022), who highlighted the portability and field-readiness of Arduino-based systems, and Lakshmanan et al. (2020), who provided a comparative analysis of various platforms, confirming Arduino's balance between functionality and affordability.

Taken together, these studies confirm that IoT-enabled water quality monitoring systems are not only viable but necessary in the modern context. They offer a sustainable, data-driven approach to environmental and public health management, bridging the gap between high-end laboratory testing and real-world field applications. As these systems continue to evolve—through the integration of machine learning, advanced analytics, and broader sensor arrays—the potential for proactive and preventive water management becomes increasingly achievable.

III. METHODS AND MATERIALS

The core of the proposed system is the integration of a microcontroller, water quality sensors, and a GPS module, which work together to monitor water quality in real time and provide geo-tagged data. The water quality sensors measure specific parameters that are indicative of water contamination or pollution, and these values are then processed by the microcontroller. The microcontroller sends the data to a cloud-based server for analysis, storage, and visualization, enabling remote monitoring of water sources.

Water Quality Sensors

Each water quality parameter (e.g., pH, turbidity, dissolved oxygen, etc.) requires a different type of sensor, each with its own working principle. The sensors selected for the system must be capable of operating in the field without frequent calibration or maintenance.

- **pH Sensor**: The pH of water is a measure of its acidity or alkalinity, and it significantly affects the solubility of nutrients and pollutants. A pH sensor typically uses a glass electrode or an ion-sensitive field-effect transistor (ISFET) to measure hydrogen ion concentration in water. The output is a voltage proportional to the pH value.
- **Turbidity Sensor**: Turbidity refers to the cloudiness of water caused by suspended solids such as dirt, silt, and microorganisms. Turbidity sensors work based on the scattering of light. A laser or LED light source is directed through the water sample, and a photodetector measures the amount of light scattered by the particles.
- **Dissolved Oxygen (DO) Sensor**: Dissolved oxygen is essential for aquatic life. A DO sensor works by detecting the partial pressure of oxygen in water. There are various types of DO sensors, but electrochemical sensors (such as Clark-type electrodes) are commonly used. These sensors measure the oxygen concentration through a redox reaction.
- **Temperature Sensor**: The temperature of water influences the solubility of gases and the rate of chemical reactions. Temperature sensors, often thermistors or thermocouples, measure the temperature by detecting changes in electrical resistance.
- **Conductivity Sensor**: Conductivity sensors measure the ability of water to conduct electricity, which is influenced by the concentration of dissolved ions, such as salts and metals. These sensors work by passing a small electrical current through the water and measuring the resulting voltage drop.

Microcontroller

The microcontroller serves as the brain of the system, interfacing with the sensors, processing the raw data, and sending it to the cloud. A low-cost microcontroller such as the Arduino or Raspberry Pi is ideal for this application due to its flexibility, ease of use, and extensive support from the maker community. The microcontroller reads the analog signals from the sensors, converts them into digital data, and processes this information to determine the water quality parameters.

GPS Module

A GPS module is used to collect geographic coordinates (latitude, longitude) where each water sample is taken. This ensures that each data point is geo-tagged, allowing for mapping of water quality across different locations. The GPS module communicates with the microcontroller to synchronize location data with sensor measurements.

Data Transmission to Cloud

Once the data is processed by the microcontroller, it is transmitted to a cloud-based server via a communication module (such as Wi-Fi or cellular network). This allows for real-time monitoring of water quality. The cloud platform stores the data and provides a dashboard for visualization, enabling stakeholders to view water quality trends over time and take action if necessary.

IV. PROPOSED SYSTEM

Municipal water supply companies are responsible for the distribution of drinking and usable water across various regions, typically using traditional methods. Throughout this process, both laboratory and field tests often reveal challenges related to water quality and quantity management. Issues such as water leaks, inadequate distribution, and the terrain height can impact water delivery, but another crucial factor is the materials used in water transportation. The pipes and materials involved in the system may also have an effect on the water quality. Additionally, wells or open wells, which are often relied upon as a dependable water source after basic purification, also require careful management.

To optimize this process and leverage technology, IoT (Internet of Everything) can be employed to monitor the full scope of water distribution, including both quality and quantity. Achieving this requires extensive research, fieldwork, and data analysis. This study aims to integrate various water quality testing sensors, electronically controlled valves, and quantity measurement tools, all linked through IoE technology, to enhance the efficiency of the water distribution system. The research will contribute to the broader goals of smart city initiatives by analyzing the water distribution supply chain. The study will proceed through several key stages: the design and development of a remotely monitored quality sensor, the collection of water sample data from various locations, mapping and understanding different drinking water sources using GIS technology, and proposing improvements to the current water distribution process. Additionally, this work will include the development of a cloud-based system to monitor municipal pipeline statistics and assess the impact of different pipeline materials on the quality of the water being delivered.

The potable water supply chain involves the movement of water from multiple sources to its end destination, requiring various stages of processing, storage, and transportation through reservoirs, storage tanks, and transport tankers. Water quality must be checked at each stage, as the water changes contact points and locations along the way. Ensuring the quality of water cannot be a task left for periodic checks alone; it must be continuously monitored during the distribution process. While water quality testing can be done manually at multiple locations, this method can be challenging and prone to errors due to human intervention. Water quality cannot be compromised, making the security of the water supply chain a major concern for governments. One proposal is to implement in-pipe water quality testing systems in all water transport pipes, which would continuously monitor the quality of water in real-time. This system could issue alerts in case of significant anomalies, ensuring immediate action can be taken. Such systems would need to be implemented at various locations along the distribution network, including at each storage or release point.

Further, water quality testing should be carried out each time water is delivered to consumers, as they generally assume that the responsible authorities are ensuring the water's safety. It is not only the water quality that needs constant monitoring but also the sensors and electronic components involved in the testing process. Given that these devices can be affected by environmental factors, regular calibration and accuracy checks are essential to maintaining reliable readings.

Figure 1.0 presents the proposed system overview where complete process flow including data gathering notification analysis and further action plan can be seen.

The core of the proposed system is the integration of a microcontroller, water quality sensors, and a GPS module, which work together to monitor water quality in real time and provide geo-tagged data. The water quality sensors measure specific parameters that are indicative of water contamination or pollution, and these values are then processed by the microcontroller. The microcontroller sends the data to a cloud-based server for analysis, storage, and visualization, enabling remote monitoring of water sources.

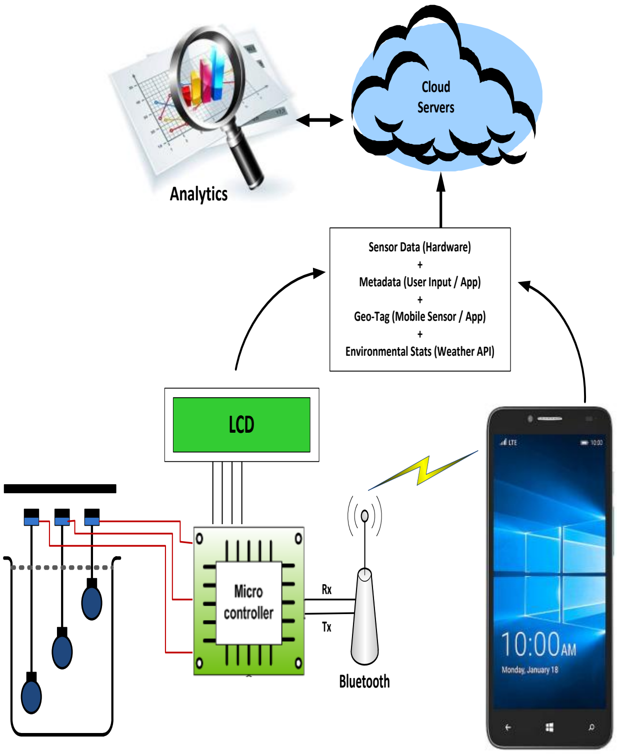

Figure 1.0: System Workflow

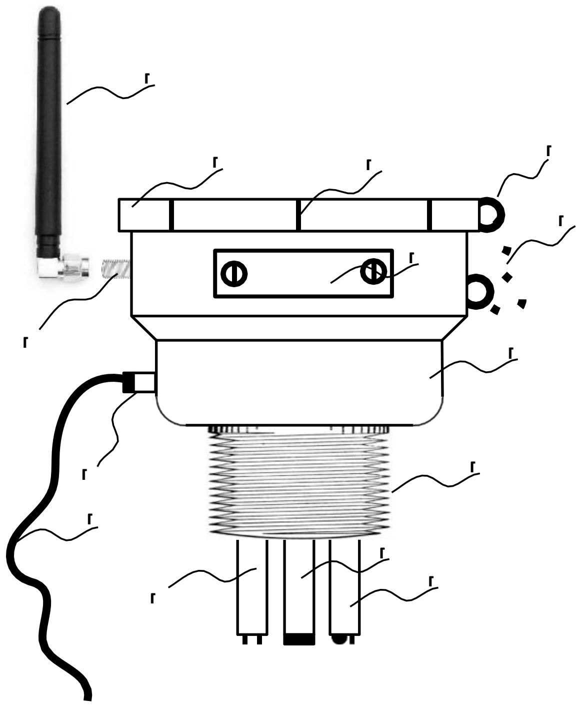

Figure 2. Design layout of proposed system / model (Side View)

[100] The primary enclosure, or the main body of the product, serves as the protective housing that contains all internal components and the electronics required for the system's operation. This robust structure is designed to ensure durability and environmental protection for the internal modules. [101] The model incorporates metal threads which allow it to be securely coupled with a T-type junction block of pipes. These junctions, of a compatible size, use threaded connections to provide a firm and leak-resistant attachment, which is particularly important in utility or plumbing environments. [101] Furthermore, the operational part of the device includes a display section that must remain water resistant. To achieve this, a transparent lid is used to cover the display, and this lid is screwed on in a threaded manner to ensure a tight, protective seal against moisture ingress.

[103] For ease of handling, the upper lid features embossed grip patterns. These textured grips are carefully designed to help users securely grasp and lift the lid without slipping, especially in wet or field conditions. [104] A small slot is included on the upper lid, aligned with the body portion of the product, which allows a nylon thread or chain to be inserted and attached. This mechanism ensures the lid remains tethered to the main unit when opened, preventing it from getting misplaced. [105] The top cover, therefore, comes equipped with either a nylon thread or a metal chain to serve this purpose effectively.

[106] Additionally, the product may include an optional maintenance lid. This secondary access point allows service personnel to open a smaller section of the enclosure for inspecting or repairing internal circuitry without dismantling the entire unit. [107] To power the electronic components, an external wire connector is provided. This connector is specially designed with a water-resistant seal to protect the system from environmental exposure. [108] The external power wire connects to this sealed port, ensuring a reliable and safe energy supply under various conditions.

[109] Communication capability is enhanced through the use of a GSM module. A threaded SM (SubMiniature) connector is integrated into the design for this purpose, allowing an external GSM antenna to be securely attached. [110] This external GSM network antenna ensures robust signal reception, especially in remote or outdoor deployment scenarios, thus supporting continuous wireless communication for the device's telemetry or remote control functions.

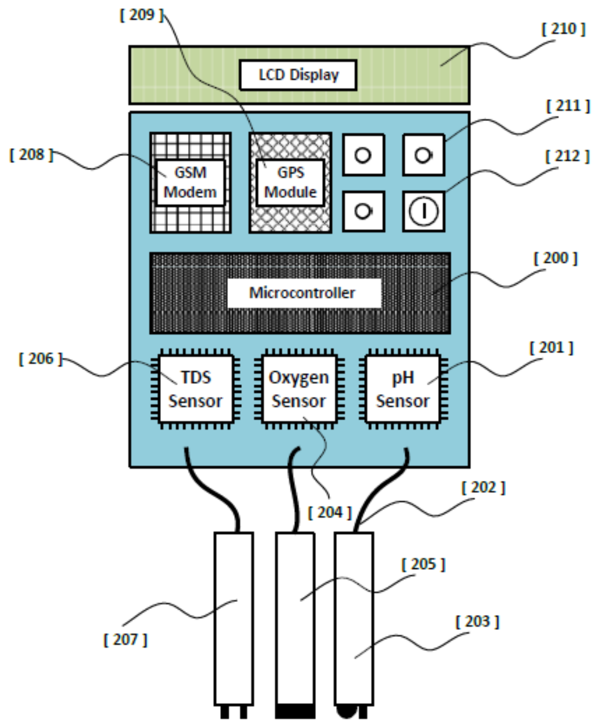

Figure 3. Internal electronics blocks of proposed system / model

[200] At the heart of the system lies the primary microcontroller, often referred to as the logic processor. This crucial component orchestrates all internal operations, managing the flow of data between sensors, processing units, and communication modules. It executes the embedded software responsible for interpreting sensor inputs, controlling outputs, and maintaining overall product logic. [201] To support specific water quality measurements, individual integrated circuits (ICs) are employed for each type of sensor. For instance, the IC dedicated to pH sensor processing ensures accurate interpretation of the analog signals received from the probe. [202] These signals are transmitted through high-quality, multi-core copper cables, which are selected for their excellent conductivity and reliable data transmission, even in challenging environmental conditions.

[203] The pH sensing system includes a specially designed detection probe, which interfaces directly with the corresponding IC. This probe is tailored to respond quickly and accurately to changes in hydrogen ion concentration in the water. [204] Similarly, a separate IC is used to handle data from the dissolved oxygen sensor, allowing real-time evaluation of oxygen levels in the sample. [205] This oxygen sensor is equipped with a custom-built probe engineered for precise and stable measurements, which is vital for environmental monitoring and aquatic ecosystem health. [206] Another dedicated IC manages data from the Total Dissolved Solids (TDS) sensor, which provides insight into the concentration of ions and substances present in the water. [207] The TDS sensor also features a custom-designed probe that enhances sensitivity and durability in varied water conditions.

[208] For communication purposes, the system incorporates a GSM modem module. This component enables wireless data transmission to a cloud server over a cellular network, facilitating real-time monitoring and remote access to data. [209] Complementing this is a GPS module that accurately determines the geographic coordinates of each deployed node. This geolocation data is essential for tracking the position of units, creating virtual pipeline maps, and correlating water quality readings with specific locations for more effective environmental management. [210] An integrated LCD display is also part of the interface, allowing users to view sensor values and system information directly on the device. This local visualization is especially helpful for on-site troubleshooting and configuration.

[211] Additionally, an LED indicator is included to provide immediate visual feedback regarding the status of the communication modules or overall system operation. This LED helps users understand whether the device is functioning correctly or if any faults are present. [212] Finally, a power switch is built into the design to enable simple power control, allowing the user to turn the system on or off or reset it when necessary. This control switch enhances usability, especially in field deployments where quick and reliable access to power management is critical.

V. RESULTS AND DATA ANALYSIS

To evaluate the performance of the proposed water quality monitoring system, tests were conducted across five different water bodies, including urban tap water, river water, agricultural runoff, a pond, and industrial discharge. The following key parameters were measured using the developed system: pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Turbidity, and Temperature. Each sample was geo-tagged and transmitted in real time to the cloud for remote analysis and visualization. Table 1.0 section presents real-time water quality measurements recorded at various locations using the developed monitoring device. Each data point includes key parameters such as pH, dissolved oxygen, TDS, turbidity, temperature, and precise GPS coordinates, offering a comprehensive snapshot of water conditions across different environments. This dataset forms the basis for analysis, validation, and future trend mapping.

Table 1.0: Sample Data Collected from Field Test

Sample ID	Location Type	Latitude	Longitude	pH	DO (mg/L)	TDS (ppm)	Turbidity (NTU)	Temp (°C)	GPS Timestamp
WQ001	Urban Tap Water	21.1458	79.0882	7.2	6.8	310	1.1	26.5	2025-06-15 09:32:20
WQ002	River (Nag River)	21.1523	79.1035	6.5	5.2	489	9.4	28.1	2025-06-15 10:01:12
WQ003	Agricultural Runoff	21.1607	79.1199	6.9	4.9	745	14.2	30.3	2025-06-15 11:45:30
WQ004	Local Pond	21.1720	79.1324	7.5	4.0	690	22.3	31.7	2025-06-15 12:10:15
WQ005	Industrial Discharge	21.1874	79.1511	5.4	2.7	1190	45.7	35.6	2025-06-15 13:55:42

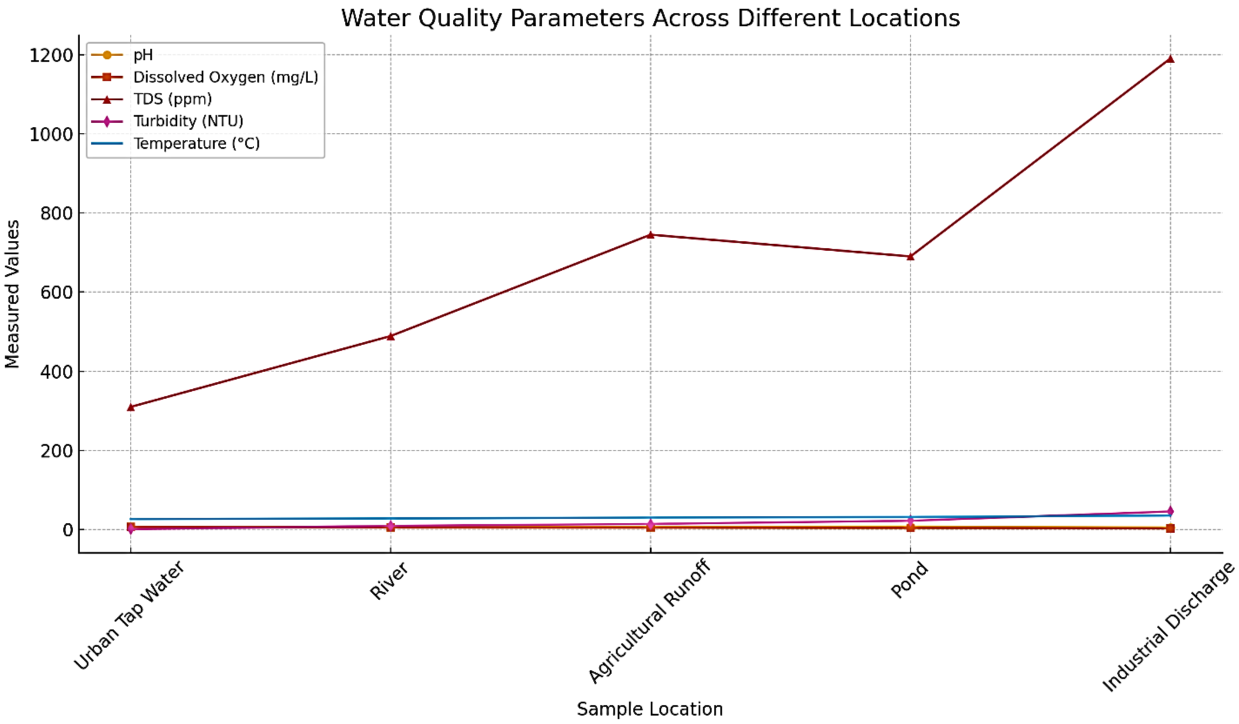

Figure 4.0: Graphical Presentation of Sample Data collected

Figure 4.0 is a graph that visualizes the water quality parameters (pH, DO, TDS, Turbidity, and Temperature) collected from various field test locations. Each line represents a different parameter, highlighting how water quality varies across different environments. Let me know if you'd like separate graphs for each parameter or a bar chart version.

VI. CONCLUSION

This research presents the successful design and implementation of a portable, sensor-integrated, IoT-enabled water quality monitoring system equipped with GPS and GSM modules for real-time, location-based environmental data collection. By combining low-cost microcontrollers with multiparametric sensing capabilities, the system offers an effective and scalable alternative to conventional water testing methods, which are often time-consuming, labor-intensive, and location-constrained. The system's ability to transmit live data to a cloud platform enables remote monitoring, immediate decision-making, and long-term environmental trend analysis — all of which are critical for sustainable water resource management.

The practical implications of this system are far-reaching. It empowers local authorities, environmental agencies, and community organizations to continuously monitor water quality at various sources, detect pollution early, and respond promptly to contamination events. In remote or underserved areas where laboratory access is limited, this system can serve as a vital tool to ensure water safety and public health. The inclusion of GPS geotagging further enhances its utility by enabling spatial mapping and tracking of contamination patterns across geographic regions.

Looking ahead, this technology holds significant potential for future enhancements. Integration with machine learning algorithms could enable predictive analytics, anomaly detection, and automated water quality grading. Incorporating solar power or low-power networking technologies (e.g., LoRaWAN) could improve energy efficiency and enable broader deployment in rural or disaster-prone regions. Additionally, expanding the sensor suite to detect heavy metals, microbial contaminants, or chemical residues would extend its applications in industrial, agricultural, and municipal domains.

In essence, this system lays a strong foundation for smart environmental monitoring infrastructure. As water quality continues to be a global concern, innovations like this will play a pivotal role in ensuring transparency, accessibility, and accountability in water management for years to come.

VII. REFERNCES

(1) Hong, W., Shamsuddin, N., Abas, E., Apong, R., Masri, Z., Suhaimi, H., Gödeke, S., & Noh, M. (2021). Water Quality Monitoring with Arduino Based Sensors. Environments. https://doi.org/10.3390/ENVIRONMENTS8010006.

(2) Kumar, J., Gupta, R., Sharma, S., Chakrabarti, T., Chakrabarti, P., & Margala, M. (2024). IoT-Enabled Advanced Water Quality Monitoring System for Pond Management and Environmental Conservation. IEEE Access, 12, 58156-58167. https://doi.org/10.1109/ACCESS.2024.3391807.

(3) Fonseca-Campos, J., Reyes-Ramírez, I., Guzmán-Vargas, L., Fonseca-Ruiz, L., Mendoza-Pérez, J., & Rodriguez-Espinosa, P. (2022). Multiparametric System for Measuring Physicochemical Variables Associated to Water Quality Based on the Arduino Platform. IEEE Access, 10, 69700-69713. https://doi.org/10.1109/ACCESS.2022.3187422.

(4) Naik, B., & Bhavani, N. (2023). Accuracy Enhancement of Real-Time Novel Water Quality Monitoring System using Arduino in Comparison with Microcontroller based System. 2023 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI),. https://doi.org/10.1109/ACCAI58221.2023.10201238.

(5) Nayak, P., Reddy, C., & Adla, D. (2020). Applications of Raspberry Pi and Arduino to Monitor Water Quality Using Fuzzy Logic. Intelligent Computing in Engineering. https://doi.org/10.1007/978-981-15-2780-7_17.

(6) Osman, S., Mohamed, M., Suliman, A., & Mohammed, A. (2018). Design and Implementation of a Low-Cost Real-Time In-Situ Drinking Water Quality Monitoring System Using Arduino. 2018 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE), 1-7. https://doi.org/10.1109/ICCCEEE.2018.8515886.

(7) Atiast, A., & Aljafaar, K. (2022). Automation system for monitoring the quality of water sources to maintain their sustainability using microcontroller. 2022 International Conference on Electrical, Computer and Energy Technologies (ICECET), 1-4. https://doi.org/10.1109/ICECET55527.2022.9873422.

(8) Gj, P., T, S., P, V., Muzammil, S., & Karthikeya, N. (2024). Smart Water Pollution Management: IoT for Automatic Detection and Prevention. International Journal of Advanced Research in Science, Communication and Technology. https://doi.org/10.48175/ijarsct-18484.

(9) Dharani, N., Nithisha, E., Kavya, E., Nazeer, T., Shanmukha, K., & SaiKumar, N. (2024). Real Time Monitoring System for Bacterial Contamination in Drinking Water using Embedded Technology. 2024 2nd International Conference on Sustainable Computing and Smart Systems (ICSCSS), 280-287. https://doi.org/10.1109/ICSCSS60660.2024.10625233.

(10) Hakimi, I., & Jamil, Z. (2021). Development of Water Quality Monitoring Device Using Arduino UNO. IOP Conference Series: Materials Science and Engineering, 1144. https://doi.org/10.1088/1757-899X/1144/1/012064.

(11) Méndez-Barroso, L., Rivas-Márquez, J., Sosa-Tinoco, I., & Robles-Morua, A. (2020). Design and implementation of a low-cost multiparameter probe to evaluate the temporal variations of water quality conditions on an estuarine lagoon system. Environmental Monitoring and Assessment, 192. https://doi.org/10.1007/s10661-020-08677-5.

(12) Gadgay, B. (2019). Arduino UNO based Water Quality Monitoring and Reporting over Web Server. International Journal for Research in Applied Science and Engineering Technology. https://doi.org/10.22214/ijraset.2019.10070.

(13) Araneta, A. (2022). Design of an Arduino-Based Water Quality Monitoring System. International Journal of Computer Science and Mobile Computing. https://doi.org/10.47760/ijcsmc.2022.v11i03.017.

(14) Lakshmanan, L., Jesudoss, A., Sivasangari, A., Maran, S., & Theresa, M. (2020). Analysis of the Water Quality Monitoring System. 2020 International Conference on Communication and Signal Processing (ICCSP), 1032-1035. https://doi.org/10.1109/ICCSP48568.2020.9182256.

(15) Hidayatullah, M., Sofyan, S., Topan, P., Andriani, T., & Nurhairunnisah, N. (2022). Monitoring System of Water Quality on Hydroponic Planting Media using Total Dissolved Solid (TDS) Sensor Based Arduino Uno R3. JURNAL ILMU FISIKA | UNIVERSITAS ANDALAS. https://doi.org/10.25077/jif.14.2.108-115.2022.