

IoT-Enabled Real-Time Drinking Water Quality Monitoring System for Smart Cities

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Abstract— The quality of drinking water in the city plays a vital role, as it directly impacts human health. According to ASSOCHAM CSR, approximately 1.5 million people die each year worldwide due to waterborne infections. Global risk rankings from the World Economic Forum place the drinking water crisis at the top. We observe that the condition of water in public areas, such as government offices, railway stations, and individual houses where drinking water is provided, is not up to par. Therefore, to address this issue, we need to ensure the supply of clean and pure drinking water, which requires real-time water quality monitoring. Continuous quality monitoring is necessary to guarantee a safe supply of drinking water. In this paper, we have developed a prototype design for real-time monitoring of the water quality at different junctions of the pipeline in the city. Several sensors make up the system, which can measure the physicochemical parameters of water quality. These parameters are used to detect pH values, total dissolved solids, and suspended particles in water. The quality of water is compared with the reference value set. The measured values from the sensors are being processed by the core controller. The entire sensor data is shown on the display unit and is displayed via the ESP32 microcontroller and IoT. The user gets a message of the findings indicating that the system can successfully process, transmit, and display the readings of physicochemical parameters. This system's installation in the water guarantees the supply of high-quality water to the people of the city.

Keywords—pH sensor, IoT, water quality, smart city, TDS.

I. INTRODUCTION

Public health and well-being depend on access to clean and safe drinking water. But conventional techniques for monitoring water quality are often manual and labor-intensive, and they lack real-time data capabilities. The incorporation of the Internet of Things (IoT) into systems for monitoring water quality provides a quick and contemporary answer to this difficulty. This paper aims to create an IoT-based key. The system is designed to continuously monitor water quality metrics such as pH level, turbidity, temperature, total dissolved solids (TDS), and electrical conductivity. Real-time data is collected by sensors placed in the water supply pipe

and sent to a central processing unit using microcontrollers such as Arduino or Node MCU. The gathered data is displayed on a digital interface such as an LCD or online dashboard and may also be sent to cloud systems for remote access and analysis. Users can set up alerts and messages to warn them if water quality falls below safe levels, therefore ensuring quick intervention. This system improves transparency, efficiency, and reliability in water quality monitoring by using IoT technology, hence making it very appropriate for usage in homes, communities, schools, and municipal water supplies. Despite the numerous advances of this century, there is still no clean drinking water due to worldwide pollution, global warming, and various other issues. Real-time monitoring of the quality of water is becoming more difficult due to factors including rising populations, limited water resources, and global warming. Better approaches must therefore be developed to track the parameters of water quality in real time. As per the reports published by the WHO, billions of people around the world are still suffering from poor access to water, sanitation, and hygiene. Some 2.2 billion people around the world do not have safe drinking water services. The report reveals that 1.8 billion people have gained access to basic drinking water services since 2000, but there are vast inequalities in their accessibility, availability, and quality. It is estimated that 1 in 10 people (785 million) still lack basic services, including the 144 million who drink untreated surface water (UNICEF). The data shows that 8 in 10 people living in rural areas lacked access to these services, and in one in four countries with estimates for different wealth groups, coverage of basic services among the richest was at least twice as high as among the poorest (WHO).

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In recent years, the water quality monitoring system has improved due to the emergence of IoT-enabled systems, which are more effective than conventional approaches for real-time applications. To address these limitations, IoT platforms are combined with advanced sensing and predictive methods. A review of advances in machine learning (ML) with IoT for water quality monitoring, an IoT-based smart water quality monitoring system using Arduino microcontrollers and cloud platforms is used to analyze the quality of water [1]. The water quality parameters, such as pH, turbidity, temperature, and conductivity, are monitored in real-time using multiple water samples. The results validated the feasibility of a cost-effective and efficient IoT model suitable for large-scale deployment [2]. The researchers designed an IoT real-time potable water monitoring and prediction model that is based on cloud computing architecture. The system incorporated sensors for pH, dissolved oxygen (DO), temperature, and total dissolved solids (TDS), with data transmitted using IoT (NB-IoT). A feature of this work was the integration of machine learning classifiers, including decision trees, random forests, and gradient boosting, for predicting water potability. The experimental results decision tree models outperformed other classifiers in terms of accuracy and the potential of combining IoT and ML for predictive water quality assessment. Additionally, real-time alerts were delivered via mobile notifications, making the system highly practical for urban and municipal water monitoring [3]. The system incorporates real-time monitoring capabilities, which facilitate the early detection of water quality anomalies. This functionality enables prompt intervention measures, thereby contributing to the protection of public health and the effective management of water resources.

Owing to its scalable architecture, the system holds significant potential for large-scale deployment across both urban and rural environments. [4] proposes an Internet of Things (IoT) system designed to monitor and control the water level in containers using ultrasonic sensors. Ultrasonic sensors operate by emitting high-

frequency sound waves toward the surface of the water and measuring the time it takes for the echo to return. This time-of-flight data is then used to calculate the distance between the sensor and the water surface, thereby enabling accurate estimation of the water level [5]. The system for monitoring water quality in the aquaculture industry aims to enhance the development of intelligent, informative, and smart monitoring solutions. By integrating Internet of Things (IoT) technology, the system enables real-time collection and analysis of critical water quality parameters. This system leverages the capabilities of the Ali Cloud IoT platform, allowing for seamless control and management of the monitoring devices deployed in the aquaculture environment. Through this integration, water quality data is continuously gathered, enabling operators to access up-to-date information about various water quality metrics such as temperature, pH, dissolved oxygen, and contaminants. The system not only provides valuable insights into the water conditions but also facilitates automated responses to deviations, thus improving the overall management and sustainability of aquaculture operations [6]. This paper investigates the correlation between various water quality parameters and their impact on the health of Indian Major Carp (IMC) in aquaculture systems with a particular emphasis on disease development. The study focuses on several key water quality parameters that are crucial for maintaining a healthy aquatic environment and preventing adverse health outcomes in fish. These parameters include dissolved oxygen (DO), temperature, total dissolved solids (TDS), pH, salinity, conductivity, ammonia, hydrogen sulfide, nitrites, nitrates, phosphorus, chlorine, total suspended solids (TSS), and carbon dioxide (CO₂) [7].

II. METHODOLOGY

The proposed methodology is the development of an intelligent water quality monitoring system with integration with IoT technology and the analysis of real-time data from various sensors. The key factors of the system are Total Dissolved Solids (TDS), pH, and turbidity, which all have a direct effect on the

quality of the water. There are three main steps in the overall methodology: getting the data, sending it, and analyzing it. A sensor is an electronic device that detects and measures physical parameters and converts them into corresponding electrical signals for analysis or control purposes. These physical parameters may include temperature, humidity, atmospheric pressure, motion, and various other environmental or physiological variables [6]. Sensors are integral components in a wide range of applications across multiple domains, including industrial automation, medical diagnostics, automotive engineering, and household technologies. For instance, they are employed to monitor engine temperature in vehicles, measure blood oxygen saturation in healthcare settings, regulate indoor climate conditions in smart home systems, and detect human presence for security and surveillance. The widespread integration of sensor technologies has significantly enhanced the functionality, efficiency, and intelligence of modern electronic systems. Monitoring water quality is not only limited to humans, but it also affects the health of aquatic animals like fish [7].

A. TDS Sensor

The Total Dissolved Solids (TDS) sensor is an analytical device designed to measure the concentration of dissolved solid substances present in water or other liquid samples. These substances include both organic and inorganic compounds, such as minerals, salts, and metals, which are fully dissolved in the solution. The TDS value serves as an important indicator of water quality, with higher readings signifying elevated concentrations of dissolved materials, often leading to decreased water clarity. Conversely, lower TDS values are indicative of pure and transparent water. TDS measurements are essential in a range of applications, including potable water assessment, environmental monitoring, and industrial water treatment processes. The normal TDS value of

drinking water should be in the range of (50-150 PPM).

B. Ph Sensor

A pH sensor is an analytical device used to determine the hydrogen ion activity in aqueous solutions, thereby measuring the acidity or alkalinity of the liquid. The sensor typically comprises two electrodes -one constructed from bronze and the other from silver, with a diameter differential of approximately 1.2 cm. The operating principle of the sensor is based on the electrochemical potential generated at the interface between two liquids with differing ionic concentrations. This potential difference arises due to the unequal distribution of hydrogen ions within the solution. Specifically, the glass electrode responds selectively to hydrogen ion activity, while the calomel electrode serves as a stable reference. The voltage generated between these two electrodes is directly correlated with the pH of the solution. The normal pH range of human life requires a pH level of about 6.0–8.5, which is the acceptable value for consumption [4]

C. Turbidity Sensor

A turbidity sensor is an optical measurement device employed to quantify the degree of cloudiness or haziness in water, a property that is often imperceptible to the human eye [9]. The sensor functions by analyzing the scattering of light caused by suspended particulate matter within the water. Turbidity is typically expressed as the ratio of reflected light to incident light, providing an indirect assessment of the concentration of suspended solids. Under controlled conditions, the intensity of the reflected light is directly proportional to the concentration of these particles [10]. As such, turbidity sensors are widely used in environmental monitoring, water treatment, and various industrial processes to evaluate and ensure water quality.

III. SYSTEM ARCHITECTURE

The system architecture of the proposed real-time water quality monitoring setup is shown in Fig. 1. It illustrates the integration of various sensors, such as the pH sensor, turbidity sensor, and TDS sensor, with the ESP32 microcontroller. The ESP32 collects sensor data at regular intervals, processes the readings, and transmits the decision or analysis result to the Blynk Cloud via Wi-Fi. This enables remote monitoring and visualization through the Blynk mobile application. Architecture ensures seamless communication between the hardware layer and the cloud-based IoT platform, making real-time data access and alerts possible for end-users.

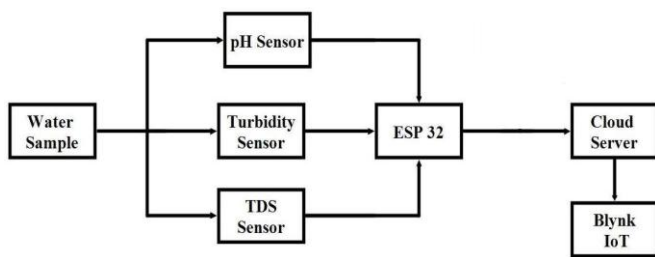


Fig. 1. System Architecture of Proposed Design

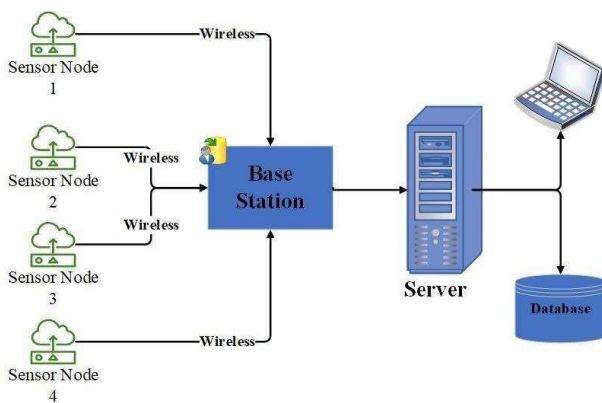


Fig. 2. Wireless Sensor Node Communication and Data Flow

Wireless sensor node communication and data flow in the proposed system (Fig. 2), data from four sensor nodes—each equipped with water quality sensors (e.g., pH, turbidity, TDS, and temperature) is transmitted wirelessly to a central base station.

These sensor nodes use ESP32 microcontrollers with built-in Wi-Fi modules. At the base station, the received data is aggregated and processed. The system compares the measured values against predefined water quality thresholds. Once the data is analyzed. It is sent to a cloud server for remote access and logging. If any value exceeds safety limits, a notification or SMS alert is automatically generated and sent to the registered users via the communication gateway (e.g., GSM or internet-based alert system). Additionally, the processed results are displayed on a monitoring dashboard (via web or mobile app), providing real-time feedback to users or authorities. Water quality is evaluated using numerous essential factors, including pH, conductivity, and turbidity. The pH level denotes the acidity or basicity of water; pure water possesses a neutral pH of 7, with readings below 7 classified as acidic and those over 7 as alkaline. The pH of drinking water often ranges from 6 to 8.5. Electrical conductivity denotes the capacity of water to transmit an electric current, contingent upon the quantity of dissolved minerals and ions, including calcium, sodium, sulfate, nitrate, and chloride. Elevated conductivity levels often signify an increased concentration of these dissolved compounds. A vital measurement is turbidity, which quantifies the concentration of suspended particles that diminishes water clarity. Elevated turbidity indicates a higher concentration of visible particles and may imply contamination or microbial presence, rendering it a dependable indication of water quality. The rest of this paper is organized as follows: Section II examines pertinent literature; Section III delineates the proposed system and its components; Section IV details the circuit schematic and operational principles; Section V showcases results and analyzes their implications; and Section VI concludes the paper with recommendations for future research.

The flowchart in Fig.3 begins with the initialization of the system, where the required hardware components, such as the ESP32 microcontroller and water quality sensors, are identified. Water samples are then collected from different locations to be tested, and the appropriate sensor is selected based on the parameter to be measured, such as pH,

turbidity, or TDS. A program is developed and uploaded to ESP32 to handle data acquisition and processing, after which the selected sensor is interfaced with the ESP32 for proper operation. The microcontroller is configured to establish a wireless connection with the server node, enabling data transfer and centralized monitoring. Sensor readings are continuously monitored through the interface and transmitted to the server node for analysis. The processed results are then displayed on an LCD screen, providing real-time feedback on water quality parameters.

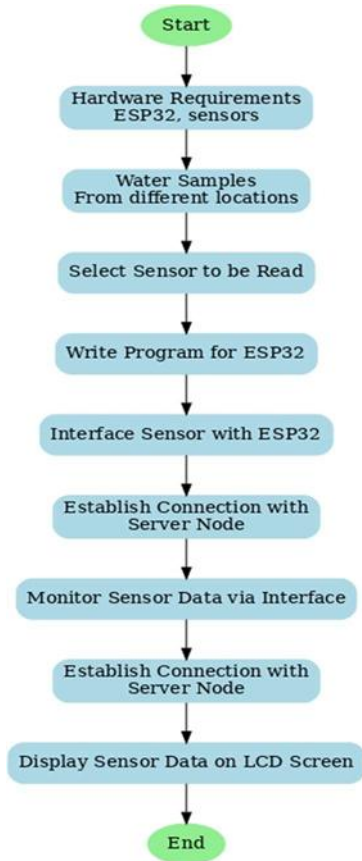


Fig. 3. Process Flow Diagram

IV. EXPERIMENTAL SETUP

In the experimental setup (Fig.4), a pH sensor, a turbidity sensor, and a TDS (Total Dissolved Solids) sensor were interfaced with an ESP32 microcontroller. In place of ESP32, Raspberry Pi is also used [10]. The ESP32 was programmed to periodically acquire sensor readings at fixed real-time intervals. Multiple water samples of varying quality were collected and evaluated to evaluate the performance and accuracy of the sensing system.

For each sample, the ESP32 collected data from the connected sensors and compared the measured values against predefined standard threshold values based on water quality norms. Based on the comparison, ESP32 decided regarding the water quality status (e.g., safe or unsafe) and transmitted the result to a display system for real-time visualization and monitoring.

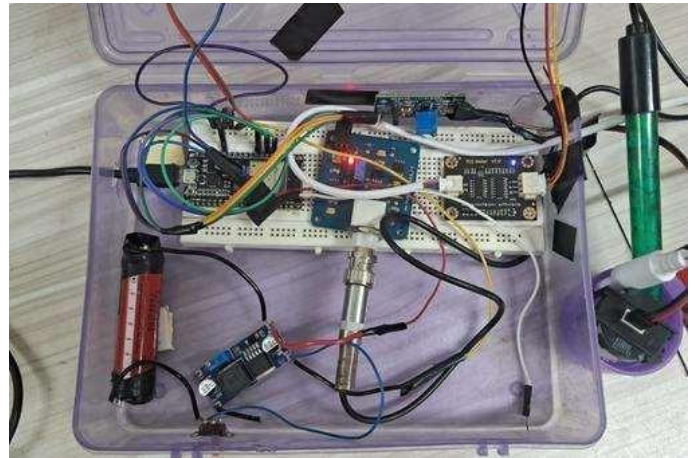


Fig.4. Experimental Setup

V. RESULTS AND DISCUSSION

A. pH Value Graph

The data presented in the graphs A, B, and C show the variations in pH values over time at different sensor nodes. Graph A (Fig.5) of pH value shows significant fluctuations in pH values from 7.60 to 8.10 between 10:10 AM and 10:30 AM (taking approx. 40 datasets). The pH has irregular peaks and drops, dynamic chemical reactions, or environmental changes impacting the system. A sharp spike towards the end of the measurement period indicates an abrupt change in the system's behavior. Graph B (Fig.6) of pH value shows significant fluctuation- actions in pH values from 6.40 to 7.40 between 11:05 AM and 11:30 AM (taking approx. 40 datasets). The pH has irregular peaks and drops, dynamic chemical reactions, or environmental changes impacting the system. A sharp fall towards the end of the measurement period indicates an abrupt change in the system's behavior. Graph C (Fig.7) of pH value shows significant fluctuation in pH values from 8.20 to 8.50 between 11:35 AM and 11:30 AM (taking

approx. 50 datasets). The pH has irregular peaks and drops, dynamic chemical reactions, or environmental changes impact the system. A sharp fall towards the end is an indication of abrupt change in the system's behaviour.

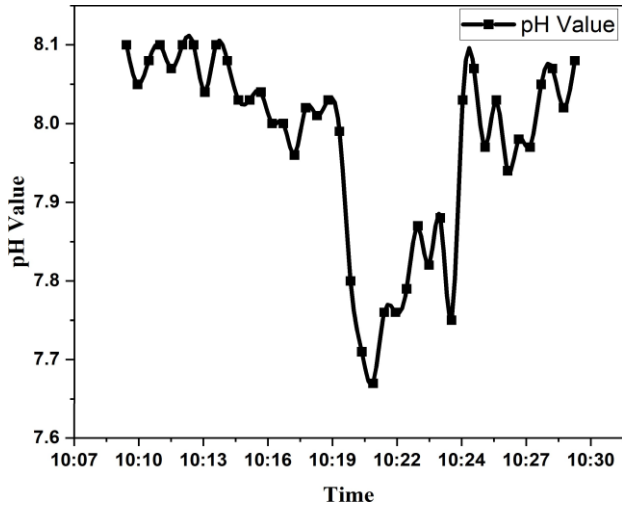


Fig. 5. pH values at sensor Node A

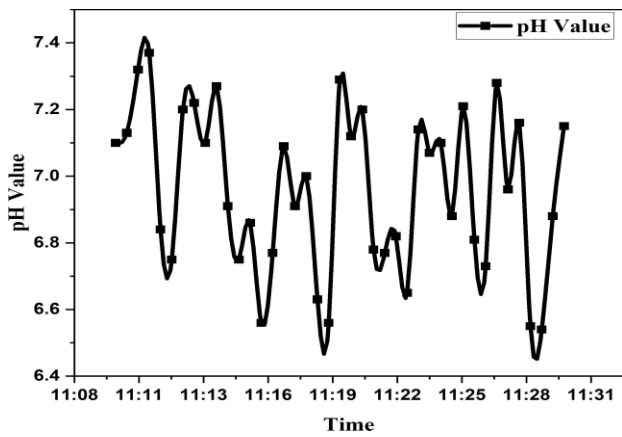


Fig. 6. pH values at sensor Node B

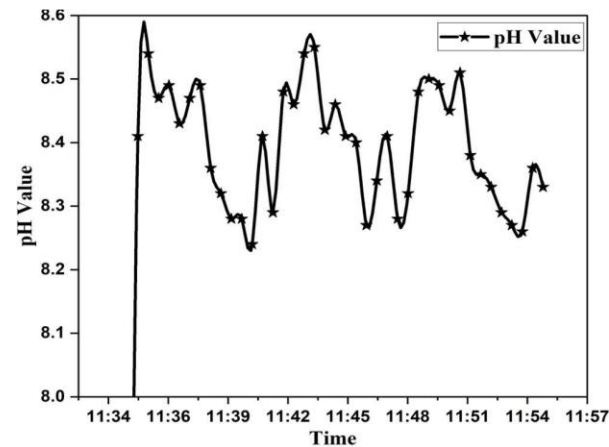


Fig. 7. pH values at sensor Node C

B. TDS Value Graph

TDS (Total Dissolved Solids) values over time for three different sensor nodes. The TDS graph A (Fig.8) for sensor node A has stable readings from 10:10 AM to 10:30 AM, fluctuating between 160 and 200 TDS units. A sharp spike at 10:12 AM, where the TDS falls over 100, is a significant event or disturbance in the system that affects the total dissolved solids.

The TDS graph B (Fig.9) for sensor node B has relatively stable readings from 11:10 AM to 11:25 AM, fluctuating between 150 and 170 TDS units. A sharp spike at 11:25 AM, where the TDS reaches over 200, is a significant event or disturbance in the system that affects the total dissolved solids. The graph (C), Fig. 10, for sensor node C shows a stable pattern with fluctuations around 240 TDS units, but there are notable drops and increases. At 11:37 AM, there is a sharp drop followed by a rapid recovery, indicating an unusual event or shift in the system. Despite these changes, the values stabilize again towards the end of the period. These changes show that TDS values can vary a lot, due to outside influences like reactions, system problems, or changes in how things are run. Further investigation is required to understand the causes of these fluctuations and their potential impact on the system's overall behavior.

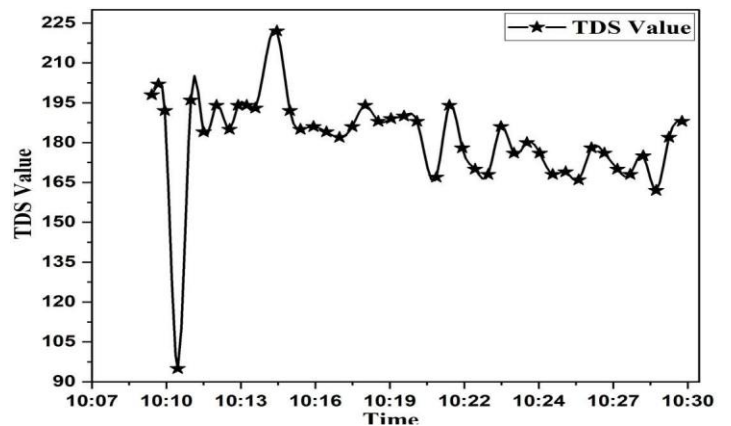


Fig. 8. TDS Values at Sensor Node A

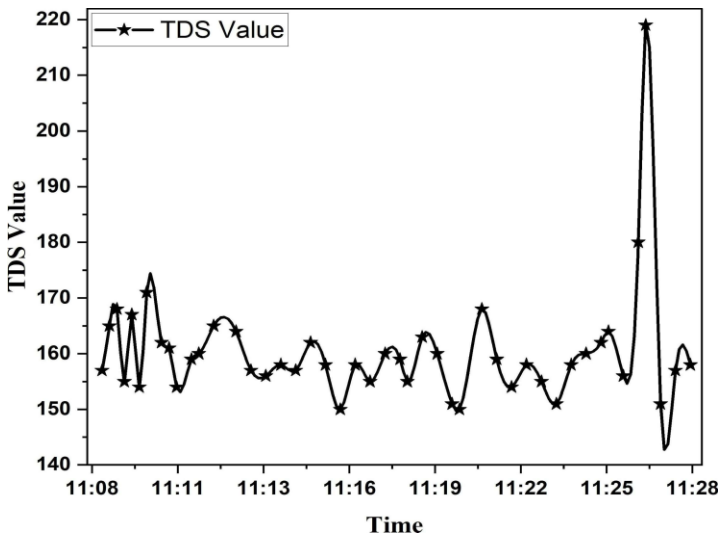


Fig. 9. TDS Values at Sensor Node B

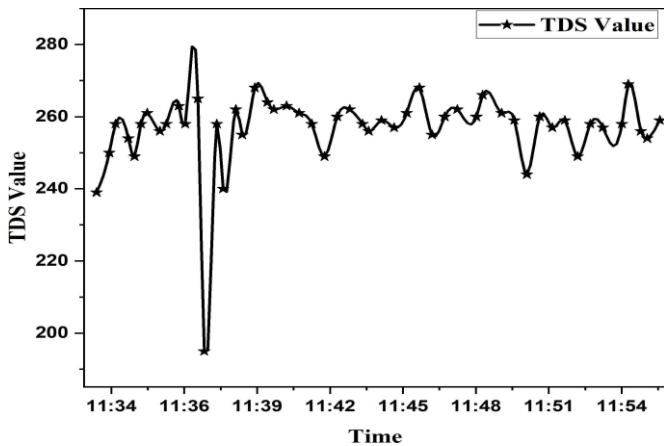


Fig. 10. TDS values at Sensor Node C

C. Turbidity Sample Graph

During the interval from 10:10 AM to 10:30 AM, turbidity levels recorded at sensor node A (Fig. 11) exhibited significant fluctuations, ranging from 50 NTU to 240 NTU. This elevated and variable turbidity profile is indicative of a high concentration of suspended solids, suggesting a substantial decline in water quality and potential impairment of physicochemical stability within the monitored system. Node B (Fig. 12) shows a secondary turbidity measurement from Sensor Node B, highlighting short-term variations. The

turbidity values begin near 0 NTU and steadily rise to above 80 NTU. Minor fluctuations observed along the curve may result from transient environmental factors such as microbubbles or minor sensor perturbations. These deviations remain within acceptable limits and reflect the sensor’s responsiveness to fine-scale environmental changes. During the interval from 11:30 AM to 12:00 PM, turbidity readings at sensor node C (Fig. 13) ranged between 250 NTU and 360 NTU. These values exceed the permissible limits for potable water, as defined by standard regulatory frameworks, and reflect a high concentration of colloidal and suspended particulate matter. Such conditions indicate acute deterioration in water quality, rendering it non-compliant with drinking water standards and posing potential health hazards due to microbial and physicochemical contamination.

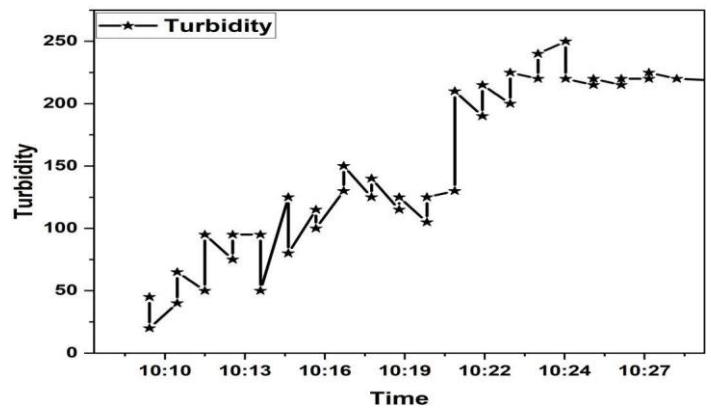
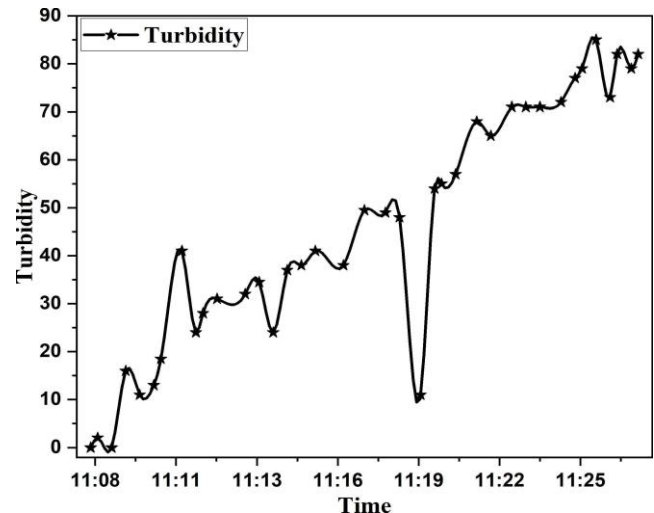


Fig. 11. Turbidity values at Sensor Node A



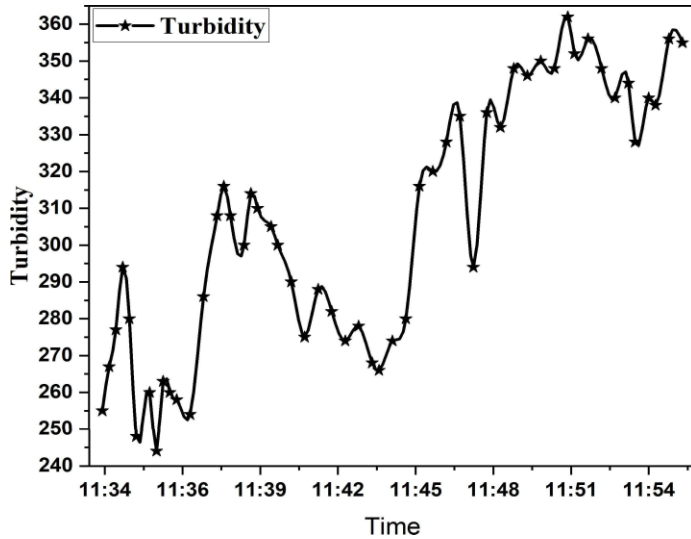


Fig. 12. Turbidity values at Sensor Node B

Fig. 13. Turbidity values at Sensor Node C

D. Interpretation and Comparison

In Table 1, the average values of pH, TDS, and Turbidity are taken from the sensor nodes connected. It illustrates that stable pH across time with fluctuations in TDS and turbidity, indicating varying water quality. Sensor node B value emerges the cleanest with the lowest turbidity and TDS, optimal for consumption, whereas the place where sensor C is connected has poor quality of water.

TABLE 1
Water quality parameters from Different Sensors

Sample	pH	TDS (ppm)	Turbidity (NTU)
Sensor Node A	7.92	181.4	143
Sensor Node B	7.17	151.2	44.6
Sensor Node C	8.44	255.9	298.7

VI. CONCLUSION

Sixth The Internet of Things (IoT) system for monitoring water quality offers a promising way to manage the urgent need for ongoing water resource management and monitoring. The system uses advances in data analytics, sensor technology, and

connectivity to detect changes in water quality in real time and to take measures to protect the environment and public health. We have effectively shown throughout that our method of delivering real-time insights into water quality parameters is both feasible and effective. But the adventure does not stop here. The system can be expanded and improved in many ways to satisfy changing stakeholder demands and challenges. Prospects include the ability to integrate with other IoT platforms and devices and expand the parameters to accommodate more sensors. To establish data-sharing networks or open-source platforms where data on water quality is gathered from various sources. In summary, our system for monitoring water quality using the Internet of Things (IoT) is a big step toward realizing our common objective of making sure that both the current and future generations have access to clean and safe water.

REFERENCES

- [1] I. Essamlali, H. Nhaila, and M. El Khaili, "Advances in machine learning and IoT for water quality monitoring: A comprehensive review," *Heliyon*, vol. 10, no. 6, p. e27920, Mar. 2024.
- [2] V. Lakshmikantha, A. Hiriyannagowda, A. Manjunath, A. Patted, J. Basavaiah, and A. A. Anthony, "IoT based smart water quality monitoring system," *Global Transitions Proceedings*, vol. 2, no. 2, pp. 181– 186, Nov. 2021
- [3] Wiryasaputra, Rita, Chin-Yin Huang, Yu-Ju Lin, and Chao-Tung Yang. 2024." An IoT Real-Time Potable Water Quality Monitoring and Pre- diction Model Based on Cloud Computing Architecture" *Sensors* 24, no. 4: 1180.
- [4] G. N. Satya Sai, R. Sudheer, K. S. Manikanta, S. G. Arjula, B. N. Rao and D. V. Sai Maneeswar Mutyala, "IoT based Water Quality Monitoring System," *2021 IEEE 9th Region 10 Humanitarian Technology Conference (R10-HTC)*, Bangalore, India, 2021, pp. 01-06,
- [5] S. Sachio, A. Noertjahyana, and R. Lim: Proc.3rd Technology Innovation Management and Engineering Science Int. Conf. (2018) 1–5. <https://doi.org/10.1109/TIMES-iCON.2018.8621630>
- [6] K. Hu, H. Fu, M. Yang, J. Jia and Y. Jiang, "Research on the Application of a Water Quality Monitoring System in Aquaculture Based on IoT Technology," *2023 4th International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering (ICBAIE)*, Hangzhou, China, 2023, pp.

- 298-308,
- [7] S. M. A. Yamin, S. Sk, S. SK, A. Ali, and C. Ghorai, "IoT Sensor-Based Monitoring of Fish Diseases in Aquaculture: A Review," 2024 IEEE International Conference on Intelligent Signal Processing and Effective Communication Technologies (INSPECT), Gwalior, India, 2024, pp. 1- 6.
 - [8] N. Vijayakumar and R. Ramya, "The real time monitoring of water quality in IoT environment," 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS), Coimbatore, India, 2015, pp. 1-5.
 - [9] A. Lestari and A. Zafia, "Implementation of Internet-based Water Quality Monitoring System," LEDGER, 2022.
 - [10] R. A. Wadu, Y. S. B. Ada, and I. U. Panggalo, "Design of Automatic Water Circulation System in Freshwater Fish Aquarium Based on Water Turbidity," J. Ilm. FLASH, vol. 3, no. 1, pp. 1–10, 2017.