A DUAL-CHANNEL,INTERFERENCE-FREE BACTERIA-BASED BIOSENSOR FOR HIGHLY-SENSITIVE WATER QUALITY MONITORING

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ABSTRACT

Monitoring water quality is essential to safeguarding ecosystems and public health from pollution brought on by urbanization, agricultural runoff, and industrial effluents. A dual-channel, bacterial-based biosensor that overcomes interference and limited sensitivity in conventional techniques is presented in this work. Using an STM32 microcontroller and cutting-edge biosensor technology, the system processes data from colour, turbidity, and pH sensors before sending it to the Blynk IoT platform for real-time monitoring. Through the detection of minute metabolic alterations, the bacteria-based biosensor provides remarkable sensitivity. The Random Forest method uses its robustness against overfitting to detect contamination patterns in sensor data analysis, ensuring reliability. This dual-channel method increases the precision of identifying pollutants such as chemical runoff and industrial dyes. The approach has a lot of promise for proactive intervention and sustainable management of water resources.

Keywords: Water quality monitoring, Bacteria-based biosensor, Turbidity sensor, Contamination detection, Sustainable water management.

I.INTRODUCTION

By detecting impurities on-site and in real-time, bacteria-based biosensors transform water quality monitoring and get around the drawbacks of conventional techniques. The system thoroughly assesses the physical and chemical characteristics of water by integrating pH, turbidity, and colour sensors. With the help of the flexible a 32-bit microcontroller, it can be remotely monitored through the Blynk IoT platform and shown locally on a plasma, allowing for constant supervision from any place. By ensuring prompt identification and action, this innovation reduces the hazards connected with contaminated water. By utilizing bacteria's innate sensitivity to contaminants, the biosensor's biotechnological method provides improved detection capabilities over traditional sensors. It encourages improved water management, environmental preservation, and public health and may be scaled for deployment from individual water sources to municipal systems. This system offers a useful analysis by fusing sensor technologies with IoT capabilities.

1.1 WATER QUALITY MONITORING

In order to determine the safety and health of water sources, a thorough evaluation of several physical, chemical, and biological factors is part of the water quality monitoring process. To guarantee adherence to environmental and health regulations, important indicators like pH levels, turbidity, dissolved oxygen, and the presence of pollutants are usually assessed during this process. Water quality monitoring uses these measures to evaluate the integrity of the entire water environment and identify possible sources of pollution. This procedure is essential for separating clean water from tainted sources and allows for focused interventions to deal with particular problems with water quality. Because it promotes ecosystem health, prevents environmental deterioration, and guarantees the supply of clean water for industrial and human usage, early and precise monitoring is crucial.

1.2 BACTERIA-BASED BIOSENSORS

For researchers to find patterns suggestive of water quality indicators, the creation of bacteria-based biosensors entails a careful evaluation of microbial responses to certain environmental conditions. In order to identify contaminants including heavy metals, poisons, and organic pollutants, the biosensor assesses the metabolic activity, enzymatic processes, and fluorescence or luminescence of bacteria. Bacteria-based biosensors can reliably detect water pollution while differentiating it from normal fluctuations in water quality by closely examining these biological reactions. This method provides a sustainable and economical solution by enabling real-time and extremely sensitive monitoring. In order to ensure the safety and purity of water for the environment and public health, early detection using these biosensors is essential for prompt response.

1.3 MULTI-CHANNEL SENSOR SYSTEMS

With the aim to provide a thorough analysis of the target environment, multi-channel sensor systems integrate several sensors to monitor various characteristics at the same time. Real-time, multidimensional evaluation is made possible by these systems' ability to record data from multiple channels, including pH, turbidity, and colour intensity. By using multiple sensor inputs, multi-channel systems improve accuracy and dependability, lowering the chance of mistakes caused by single-sensor limits or environmental interference. These systems are especially useful for applications like water quality monitoring because of their capacity to integrate and correlate data from several sources, which allows them to identify intricate patterns and minute changes. Multi-channel sensor technology must be adopted and optimized early on in order to handle complex environmental issues and improve system performance.

1.4 IoT PLATFORM

Data collection, analysis, and sharing in real time are made possible by the IoT platform, which provides a strong framework for smoothly integrating and managing linked devices. The platform ensures effective data flow across the system by facilitating the connecting of sensors, microcontrollers, and communication modules during installation. To improve decision-making and operational efficiency, important features including automated alarms, continuous logging, and remote monitoring are used. The IoT platform enables users to visualize and comprehend data patterns through a single interface, promoting proactive reactions to environmental changes or system anomalies. Early IoT platform adoption and proper use enable researchers and industries to successfully address problems, spur innovation, and enhance system performance.

II. LITERATURE REVIEW

In this system, Belkin, S., Smirnov, S., [1] et al. suggested that paper explores the cutting-edge field of bacterial whole-cell biosensors as sophisticated instruments for environmental monitoring, with an emphasis on their use in the evaluation of water quality. Bacterial biosensors use the biological reactions that bacteria naturally produce to identify pollutants with remarkable specificity and sensitivity. These biosensors, in contrast to conventional methods, offer real-time monitoring capabilities, which makes them perfect for field applications and facilitating quick reactions to environmental dangers. The authors emphasize developments in biosensor technology, such as the smooth fusion of cutting-edge analytical tools with biotechnology. A wide range of contaminants, including pathogenic microorganisms and dangerous chemical poisons, have been detected because to this collaboration. The versatility of bacterial biosensors, which makes them a scalable and adaptable choice for a range of environmental circumstances, is also covered in the research.

Important issues are carefully considered, including sensor stability, interference from intricate environmental matrices, and deployment in a variety of scenarios. The authors offer ways to improve these biosensors' accuracy, dependability, and robustness. This thorough study highlights how bacterial biosensors can overcome the drawbacks of conventional water monitoring techniques, opening the door to better public health outcomes and sustainable environmental management.

Kumar[[2] et al. gives importance of pH and turbidity as crucial markers in water quality monitoring is emphasized by this study. Aquatic ecosystems and the water's suitability for human consumption are directly impacted by pH values, which indicate how acidic or alkaline the water is. Deviations from typical pH levels might signal contamination events like chemical spills, according to Kumar et al. (2020), highlighting the need to integrate pH sensors into real-time monitoring systems. By enabling timely detection and reaction, these sensors protect the environment and public health. Conversely, turbidity gauges the clarity of water by determining the amount of organic matter, suspended particles, and microbiological pollutants present.

Li [3] et al., increased turbidity is a crucial metric for determining the safety of water since it frequently indicates the presence of dangerous contaminants or microbes. Turbidity monitoring aids in detecting hazards that could impair the usage of water, such as sedimentation or bacterial infection. When combined, pH and turbidity sensors provide a strong and comprehensive method for evaluating the quality of water, improving the capacity to efficiently monitor, manage, and safeguard water resources for the sake of the environment and public health.

Singh [4] et al analyse the growing use of colour sensors in water quality monitoring is examined in this research, with a focus on their special capacity to identify discoloration as an indicator of contamination. Colour sensors pay attention to visible changes in water, as opposed to more conventional characteristics like pH and turbidity. These changes may be a sign of biological processes like algae blooms, chemical runoff, or contamination from industrial colours. He showed that, especially in areas affected by industrial discharges, even minute colour changes in water could work as an early warning system for detecting chemical or biological contaminants. The incorporation of colour sensors into water quality monitoring systems improves the capacity to detect pollutants that traditional techniques might miss.

Utilizing colour sensors' high sensitivity and accuracy gives monitoring systems an effective and adaptable tool to enhance conventional techniques. This strategy ensures a proactive approach to resolving environmental and public health issues while fortifying the broader framework for protecting water resources.

Ahmed [5] et al. proposed in this system. By improving data collection, processing, and real-time responsiveness, the Internet of Things (IoT) is transforming water quality monitoring systems, as this study explores. It concentrate on the STM32 microcontroller, a potent and popular Internet of Things platform, for effective data transmission and processing. The STM32 enables seamless access to cloud platforms, enabling continuous data logging and remote monitoring. One major benefit of IoT-based systems is their ability to provide real-time notifications, which allows for prompt action in response to contamination issues. Platforms like Blynk allow users to remotely monitor critical water quality variables like pH, turbidity, and colour through intuitive visualizations. This real-time capability ensures quick responses, minimizing potential risks to water safety and public health. The study emphasizes how IoT-enabled monitoring systems are accessible and scalable, which makes them perfect for overseeing large water networks where manual monitoring would be ineffective. These systems provide a proactive approach to water quality management by integrating IoT technology, guaranteeing safer and cleaner water resources for the preservation of the environment and public health.

Priya [6] et al. proposed in this system The advantages of biosensor-based systems over conventional techniques for water quality monitoring are examined in this research. Conventional methods frequently entail gathering water samples, delivering them to labs, and conducting in-depth analyses—a procedure that is expensive and time-consuming. According to biosensor-based systems have a number of benefits, such as real-time, on-site monitoring capabilities that do away with the delays that come with traditional testing techniques. Faster reaction times to any hazards are made possible by biosensors' great sensitivity and ability to identify even the smallest changes in water quality parameters. These devices provide a dynamic and thorough evaluation of water quality by continuously monitoring the water's characteristics. Their functionality is further improved by their interaction with Internet of Things (IoT) technologies, which enables early pollution detection and remote monitoring. By taking a proactive stance, contamination can be stopped from spreading, lowering hazards to the environment and human health. The study emphasizes how biosensor-based systems are more scalable and efficient, which makes them perfect for a variety of uses, ranging from huge municipal systems to individual water sources. They are a game-changing option for contemporary water quality management because of their capacity to integrate sensitivity, speed, and connectivity.

III.EXISTING SYSTEM

Conventional techniques including chemical testing, physical parameter measurement, and microbial analysis are the mainstays of current water quality monitoring systems, and they have significant drawbacks. Complex environmental matrices frequently interact with these systems, decreasing their accuracy and dependability. Furthermore, until contaminants reach critical proportions, their sensitivity is frequently insufficient to detect modest quantities of contaminants, such as industrial colours or minute microbiological alterations. Additionally, traditional methods mostly rely on laboratory analysis and periodic sampling, which delays the discovery of contamination and prompt intervention. Even while IoT technologies are incorporated into some systems, their integration is frequently lacking, which restricts the ability to monitor remotely and continuously log data. Furthermore, a lot of current systems concentrate on single-parameter detection, which is insufficient in situations where many pollutants need to be monitored simultaneously. For efficient water quality assessment, these drawbacks highlight the need for a cutting-edge solution such as a dual-channel, bacteria-based biosensor that provides high sensitivity, real-time monitoring free of interference, and thorough IoT connectivity.

IV.METHODOLOGY

A. SENSOR SELECTION AND CALIBRATION

The proposed strategy combines many sensor technologies, microcontroller features, and remote monitoring systems to create a bacteria-based biosensor for water quality monitoring. First, the hydrogen-ion concentration of water will be measured using the pH sensor, which will provide a voltage according to the pH level. To ensure accuracy, a turbidity sensor calibrated against the National Technical University standards will measure the clarity of the water. Furthermore, a colour sensor will be selected to identify variations in water colour; coloured water samples will be used for calibration in order to create a reference point for comparisons. Certain bacteria will be chosen for the biosensor integration based on their capacity to provide measurable signals in reaction to pollutants. This choice is essential since the sensors built into the system need to be able to quickly identify the bacterial reactions.

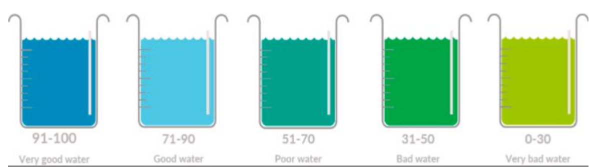

Fig 1. Variations of contaminant water -pH level

Turbidity is a crucial metric in water quality monitoring since it quantifies the amount of suspended particles, including silt, algae, and organic matter, to determine how clear the water is. By housing dangerous microbes or decreasing the effectiveness of disinfection procedures, high turbidity levels can be a sign of contamination that affects aquatic ecosystems and human health. Turbidity sensors, which provide precise and real-time readings, are crucial instruments for determining the clarity of water. Light is emitted into the water sample, and the amount of light scattered by particles is measured by the sensor. Turbidity levels, which are commonly measured in Nephelometric Turbidity Units (NTU), are correlated with the intensity of the dispersed light. This non-invasive technique guarantees prompt and accurate evaluations across a range of water situations, such as natural bodies such as rivers and lakes, industrial effluents, and sources of drinking water.

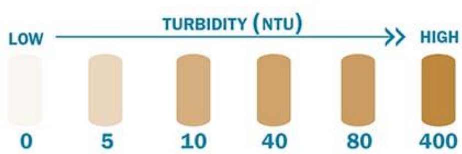

Fig 2 . Detection of Turbidity Level in contaminant water

The colour sensor is essential for identifying colour changes in the water, which frequently signal chemical runoff, algal blooms, or industrial dye contamination. Water colour changes can indicate the presence of contaminants that could be harmful to aquatic ecosystems and human health. The RGB (Red, Green, Blue) components of the water sample are analysed by the sensor, which then compares the values found to predetermined criteria. Baseline calibration is a crucial step in ensuring precise and trustworthy results. This entails creating a number of coloured water samples that resemble common pollutants and have known quantities. By setting thresholds for clean water and different levels of pollution, these samples are utilized to build a reference database.

B. BACTERIA SELECTION FOR BIOSENSOR INTEGRATION

A key step in creating a biosensor for water quality monitoring is choosing the right bacterial strains. The bacteria's sensitivity to certain pollutants, quick reaction time, and capacity to produce observable signals—like fluorescence, luminescence, or modifications in metabolic byproducts—are among the selection factors. The chosen strains need to be resilient, able to endure changes in their surroundings, and show regular reactions to pollutants within predetermined concentration ranges. The bacterial strain affects the signal generating mechanism. When exposed to contaminants, some emit detectable visual signals (like bioluminescence), while others change the turbidity or pH of the surrounding environment. The sensors in the system record and measure these signals. The biosensor guarantees accurate water quality detection by combining the capabilities of pH, turbidity, and colour sensors with bacterial reactions.

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C.MICROCONTROLLER INTREGRATION

The water quality monitoring system's central component, the STM32 microcontroller, controls the collection, processing, and communication of sensor data. It is perfect for real-time Internet of Things applications because of its dual-core architecture and integrated Wi-Fi. The STM32's Analog and digital pins are used to interface with sensors, including colour, turbidity, and pH sensors. Digital sensors interact via Arduino while Analog signals are processed by the onboard ADC (Analog-to-Digital Converter).

D. DATA VISUALIZATION AND REMOTE MONITORING

Two essential elements of the suggested biosensor system are data display and remote monitoring. The STM32 microcontroller is interfaced with an LCD screen to enable on-device monitoring. The pH, turbidity, and colour sensors' real-time data are shown on this screen, giving users instant feedback on the water quality at the monitoring location. Field workers can easily grasp the user-friendly interface .The Blynk IoT platform is included into the system to facilitate wireless connection between the STM32 and the cloud for IoT-based remote monitoring. The platform is set up to safely store sensor data in the Blynk cloud and send it over Wi-Fi. The Blynk app features an intuitive dashboard that graphically displays both historical trends and real-time data. Additionally, when readings diverge from predetermined safety criteria, it instantly notifies users.

F. ADVANCED DATA PROCESSING

By merging data from several sensors, sensor fusion algorithms significantly improve the precision and dependability of water quality evaluations. The system's three sensors—colour, turbidity, and pH—all offer useful but different data. However, because of noise, sensor drift, or environmental changes, depending solely on individual sensor readings may result in inaccurate results. By combining various data streams, sensor fusion enables the system to more efficiently detect anomalies and cross-validate data.

A sharp rise in turbidity, for instance, could be a symptom of contamination; however, when combined with a drop in pH and a noticeable colour shift, this information can be used to confirm the presence of certain contaminants and minimize false positives. To effectively combine sensor outputs, fusion algorithms like weighted averaging, Kalman filters, or machine learning models might be used.

F. MODEL EVALUATION

To ascertain how well the trained Random Forest model performs, the Model Evaluation module is essential. This module evaluates the model's performance in dyslexia classification using a number of metrics, including as accuracy, precision, recall, and F1-score. Additionally, classification results are visualized using confusion matrices, which highlight areas where the model performs well and those that need development. In addition to confirming the model's clinical applicability, this thorough evaluation process guides continuous improvements and modifications, ensuring that the system is a reliable resource for early intervention and support for dyslexic individuals.

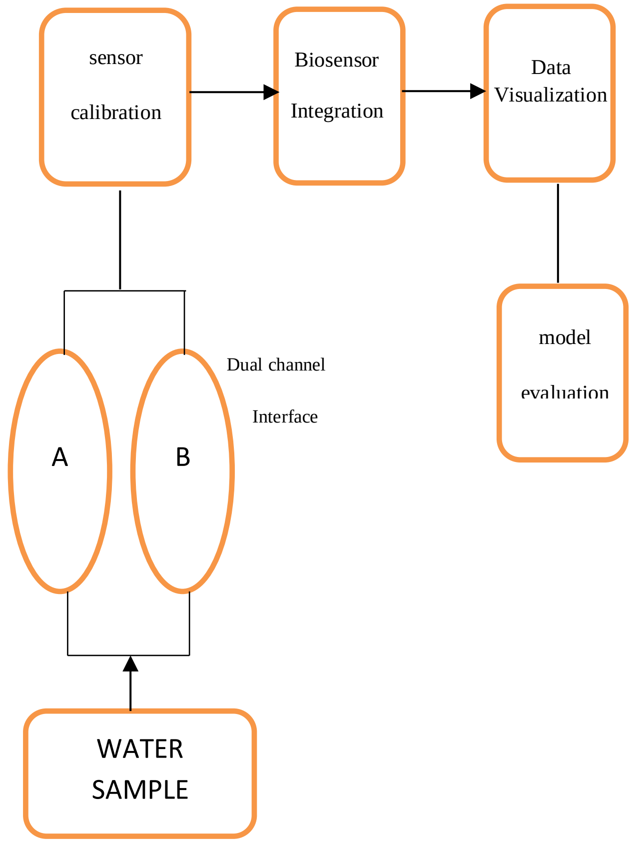

Fig 3. SYSTEM FLOW DIAGRAM

V.PROPOSED SYSTEM

Advanced sensor technologies, microcontroller operations, and remote monitoring capabilities are all integrated into the suggested bacteria-based biosensor system for water quality monitoring. Important parts include a colour sensor that uses dyed sample baselines to detect changes in water colour, a turbidity sensor that measures water clarity (calibrated in NTU), and a pH sensor that measures hydrogen-ion concentration. In order to ensure quick and accurate reactions, biosensor integration entails choosing bacterial strains that may provide detectable signals when pollutants are present.

As the central processing unit, the STM32 microcontroller connects Analog and digital sensors and uses the appropriate libraries to ensure smooth operation. It creates alarm thresholds for departures from safe water standards by processing data on pH, turbidity, and colour. For real-time feedback, sensor data is shown on an interfaced LCD. The Blynk IoT platform makes remote monitoring possible by enabling cloud-based dashboards for timely warnings and Wi-Fi communication. The accuracy and dependability of the system will be guaranteed by extensive testing and calibration using a variety of water samples. The system will use the STM32's power-saving modes for continuous monitoring when it is placed in high-risk water bodies after it has been verified. To maintain performance, routine calibration and maintenance will be carried out, including component replacement.

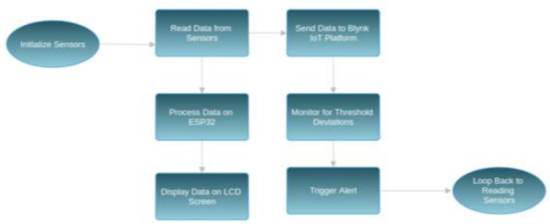

Fig 4. Block diagram of proposed system

To ensure accurate signals for changes in water quality, research on bacterial strains will concentrate on their sensitivity and response periods to particular contaminants. The accuracy of the assessment will be improved by integrating data from the pH, turbidity, and colour sensors using sensor fusion algorithms. Environmental monitoring criteria, such as those established by the EPA or municipal authorities, will be followed by the system.

This biosensor system, which combines bacterial biosensors, sensor fusion technology, and Internet of Things-based remote accessibility for enhanced environmental safety, is designed for accuracy and efficiency and offers a comprehensive approach to real-time water quality monitoring.

• **Entropy and Information Gain:**

Another metric for evaluating the dataset's uncertainty in decision trees is **Entropy** . It is employed to assess how effectively a split lowers data uncertainty.

Formula for Parent Entropy Calculation:

Before a decision is taken, the parent entropy shows how unsure the entire system is. According to the biosensor, this might have to do with the differences between bacterial response signals in contaminated and uncontaminated conditions or variations in water quality indicators (such as pH, turbidity, and colour sensor readings).

Entropy parent=−i=1∑cPilog2Pi

where PiP_iPi is the probability of each water quality state (e.g., safe, unsafe).

Formula for split on channels(Dual Sensors):

IG=Entropy parent−k=1∑m∣N∣∣Nk∣×Entropy(Nk)

where ∣Nk∣/∣N∣|N_k|/|N|∣Nk∣/∣N∣ is the proportion of data points in subset NkN_kNk.

• **Out-of-Bag (OOB) Error Estimation:**

Out-of-bag (OOB) samples are used by Random Forest to estimate the model's error. Every tree is trained using a bootstrap sample, and the accuracy of the model is evaluated using the OOB data—the data points that were not in the bootstrap sample.

Formula for OOB Error:

OOB Error = Number of incorrect predictions on OOB samplesTotal number of OOB samplesOOB \ Error = \frac{\text{Number of incorrect predictions on OOB samples}}{\text{Total numberofOOBsamples}} OOB Error = Total number of OOB samplesNumber of incorrect predictions on OOB samples

V. RESULT ANALYSIS

A greeting screen stating "Bacteria Detection" and "Using Bio Sensor" is displayed when the display first boots up. Following a brief pause, it transitions to showing the intensity value obtained from a sensor and the Analog readings are used to calculate the intensity value that is shown on the LCD. Two sensors attached to pins 34 and 35 of the STM32 provide Analog values to the software. In order to determine the pH value—which is crucial for comprehending the quality of water—the data are first converted to voltage. The formula is used to get the pH value. Meaningful interpretation of sensor data is made possible by the intensity calculation, which is based on the Analog reading and scaled to a percentage of the maximum voltage (in this case, 4095 equals 3.3V). Given its impact on aquatic life and the solubility of contaminants and nutrients, pH monitoring is crucial for evaluating the quality of water. It can help with real-time monitoring if pH levels can be dynamically displayed. Using an LCD is a good option for instant on-site monitoring, enabling users to view important parameters without requiring further equipment. To guarantee accuracy in pH readings, the system might need to be calibrated, particularly when using several sensor types. Including data logging capabilities would improve system performance and enable users to monitor changes over time. With the integration of IoT platforms (such as Blynk), alarms for significant changes in water quality could be sent via real-time remote monitoring.

ALGORITHM	**ACCURACY**
EXISTING	85
PROPOSED	90

Fig 4.COMPARISON TABLE

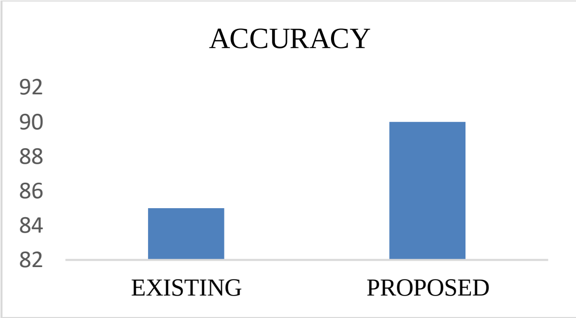

Figure 5. COMPARISON GRAPH

VI. CONCUSION

By combining a bacteria-based biosensor with more conventional sensors like pH, turbidity, and color sensors, this study effectively creates a novel, extremely sensitive water quality monitoring device. The system uses an STM32 microcontroller to process real-time data from various sensors, send the data to the Blynk IoT platform for remote monitoring, and show the results on an LCD screen. This dual strategy offers a complete solution for ongoing, automated tracking by guaranteeing that users may remotely and on-site monitor vital water quality metrics. The system's capacity to identify variations from safe water standards enables prompt notifications, facilitating prompt remedial measures to avert possible health risks. This system's high scalability due to IoT connectivity enables its deployment in a variety of situations, including natural water bodies, industrial settings, and urban water sources. By providing a practical, affordable solution that improves environmental preservation and public health protection, this initiative tackles major issues in water safety management. Its capacity for ongoing monitoring guarantees that contamination events—whether brought on by industrial pollutants, chemical runoff, or toxic algal blooms—are identified early, reducing hazards to ecosystems and people.

VII. FUTURE WORK

The system's capabilities may be further expanded by upcoming upgrades. Predictive analysis using artificial intelligence (AI) would enhance the system's preventative capabilities by enabling it to foresee contamination episodes based on trends in prior data. Even more precise data would be obtained by increasing the sensitivity of both conventional and biosensors, especially when it comes to identifying low-level pollutants. All things considered, this project makes a substantial contribution to the development of water quality monitoring technologies by providing a strong, expandable, and intelligent platform that aids in public health and sustainable water management.

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